



create™

Student Study Guide/Solutions Manual
to accompany Organic Chemistry, Fourth Edition

University of Pretoria



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Chapter 1 Structure and Bonding

Chapter Review

Important facts

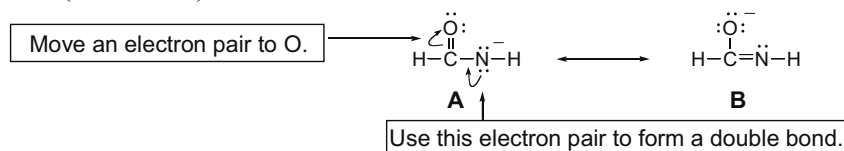
- **The general rule of bonding:** Atoms strive to attain a complete outer shell of valence electrons (Section 1.2). H “wants” 2 electrons. Second-row elements “want” 8 electrons.

			nonbonded electron pair			
	—H	—C— 	—N— 	—O— 	—X: 	X = F, Cl, Br, I
Usual number of bonds in neutral atoms →	1	4	3	2	1	
Number of nonbonded electron pairs →	0	0	1	2	3	
The sum (# of bonds + # of lone pairs) = 4 for all elements except H.						

- **Formal charge (FC)** is the difference between the number of valence electrons on an atom and the number of electrons it “owns” (Section 1.3C). See Sample Problem 1.3 for a stepwise example.

Definition:	formal charge	=	number of valence electrons	–	number of electrons an atom “owns”
Examples:	$\begin{array}{c} \\ -C- \\ \end{array}$ • C shares 8 electrons. • C “owns” 4 electrons. • FC = 0		$\begin{array}{c} + \\ -C- \\ \end{array}$ • C shares 6 electrons. • C “owns” 3 electrons. • FC = +1		$\begin{array}{c} \\ -C: \\ \end{array}$ • C shares 6 electrons. • C has 2 unshared electrons. • C “owns” 5 electrons. • FC = –1

- **Curved arrow notation** shows the movement of an electron pair. The tail of the arrow always begins at an electron pair, either in a bond or a lone pair. The head points to where the electron pair “moves” (Section 1.6).

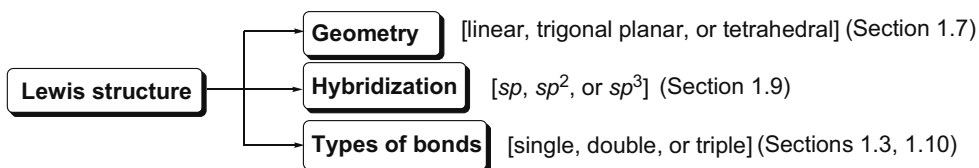


- **Electrostatic potential plots** are color-coded maps of electron density, indicating electron rich (red) and electron deficient (blue) regions (Section 1.12).

Chapter 1–2

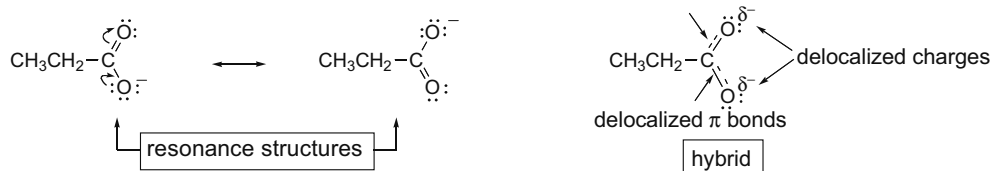
The importance of Lewis structures (Sections 1.3–1.5)

A properly drawn Lewis structure shows the number of bonds and lone pairs present around each atom in a molecule. In a valid Lewis structure, each H has two electrons, and each second-row element has no more than eight. This is the first step needed to determine many properties of a molecule.

**Resonance (Section 1.6)**

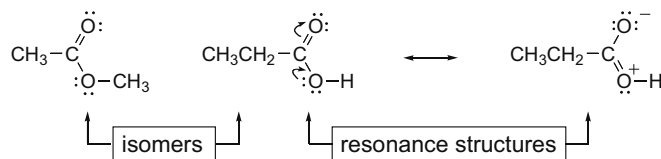
The basic principles:

- Resonance occurs when a compound cannot be represented by a single Lewis structure.
- Two resonance structures differ *only* in the position of nonbonded electrons and π bonds.
- The resonance hybrid is the only accurate representation for a resonance-stabilized compound. A hybrid is more stable than any single resonance structure because electron density is delocalized.



The difference between resonance structures and isomers:

- Two **isomers** differ in the arrangement of *both* atoms and electrons.
- **Resonance structures** differ *only* in the *arrangement of electrons*.

**Geometry and hybridization**

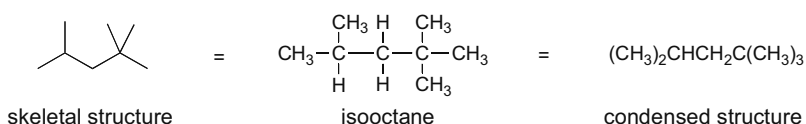
The number of groups around an atom determines both its geometry (Section 1.7) and hybridization (Section 1.9).

Number of groups	Geometry	Bond angle ($^{\circ}$)	Hybridization	Examples
2	linear	180	sp	BeH_2 , $\text{HC}\equiv\text{CH}$
3	trigonal planar	120	sp^2	BF_3 , $\text{CH}_2=\text{CH}_2$
4	tetrahedral	109.5	sp^3	CH_4 , NH_3 , H_2O

Structure and Bonding 1–3

Drawing organic molecules (Section 1.8)

- Shorthand methods are used to abbreviate the structure of organic molecules.



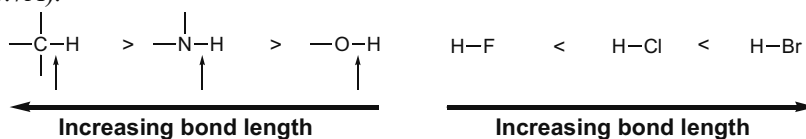
- A carbon bonded to four atoms is tetrahedral in shape. The best way to represent a tetrahedron is to draw two bonds in the plane, one in front, and one behind.

Four equivalent drawings for CH₄

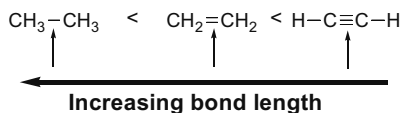
Each drawing has two solid lines, one wedge, and one dashed line.

Bond length

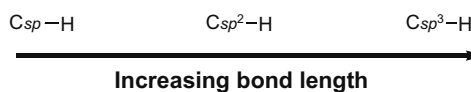
- Bond length decreases across a row and increases down a column of the periodic table (Section 1.7A).



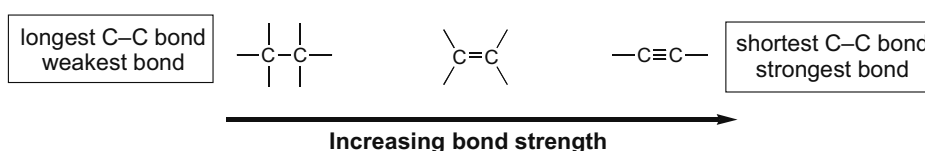
- Bond length decreases as the number of electrons between two nuclei increases (Section 1.11A).



- Bond length increases as the percent *s*-character decreases (Section 1.11B).

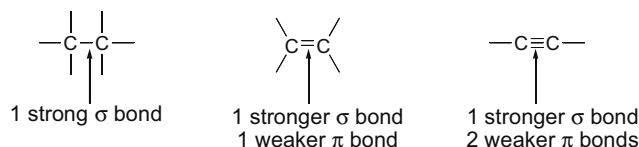


- Bond length and bond strength are inversely related. Shorter bonds are stronger bonds (Section 1.11).



Chapter 1–4

- Sigma (σ) bonds are generally stronger than π bonds (Section 1.10).

**Electronegativity and polarity (Sections 1.12, 1.13)**

- Electronegativity increases from left to right across a row and decreases down a column of the periodic table.
- A polar bond results when two atoms of different electronegativity are bonded together. Whenever C or H is bonded to N, O, or any halogen, the bond is polar.
- A polar molecule has either one polar bond, or two or more bond dipoles that reinforce.

Drawing Lewis structures: A shortcut

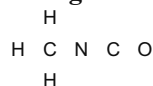
Chapter 1 devotes a great deal of time to drawing valid Lewis structures. For molecules with many bonds, it may take quite awhile to find acceptable Lewis structures by using trial-and-error to place electrons. Fortunately, a shortcut can be used to figure out how many bonds are present in a molecule.

Shortcut on drawing Lewis structures—Determining the number of bonds:

- [1] Count up the number of valence electrons.
- [2] Calculate how many electrons are needed if there are no bonds between atoms and every atom has a filled shell of valence electrons; that is, hydrogen gets two electrons, and second-row elements get eight.
- [3] Subtract the number obtained in Step [1] from the sum obtained in Step [2]. **This difference tells how many electrons must be shared** to give every H two electrons and every second-row element eight. Since there are two electrons per bond, dividing this difference by two tells how many bonds are needed.

To draw the Lewis structure:

- [1] Arrange the atoms as usual.
- [2] Count up the number of valence electrons.
- [3] Use the shortcut to determine how many bonds are present.
- [4] Draw in the two-electron bonds to all the H's first. Then, draw the remaining bonds between other atoms making sure that no second-row element gets more than eight electrons and that you use the total number of bonds determined previously.
- [5] Finally, place unshared electron pairs on all atoms that do not have an octet of electrons, and calculate formal charge. You should have now used all the valence electrons determined in the first step.

Example: Draw all valid Lewis structures for CH₃NCO using the shortcut procedure.**[1] Arrange the atoms.**

- In this case the arrangement of atoms is implied by the way the structure is drawn.

[2] Count up the number of valence electrons.

3H's	x	1 electron per H	=	3 electrons
2C's	x	4 electrons per C	=	8 electrons
1N	x	5 electrons per N	=	5 electrons
1O	x	6 electrons per O	=	+ 6 electrons
				22 electrons total

[3] Use the shortcut to figure out how many bonds are needed.

- Number of electrons needed if there were no bonds:

$$\begin{array}{rcl} 3 \text{ H's} & \times & 2 \text{ electrons per H} = 6 \text{ electrons} \\ 4 \text{ second-row elements} & \times & 8 \text{ electrons per element} = + 32 \text{ electrons} \\ \hline & & \mathbf{38 \text{ electrons needed if there were no bonds}} \end{array}$$

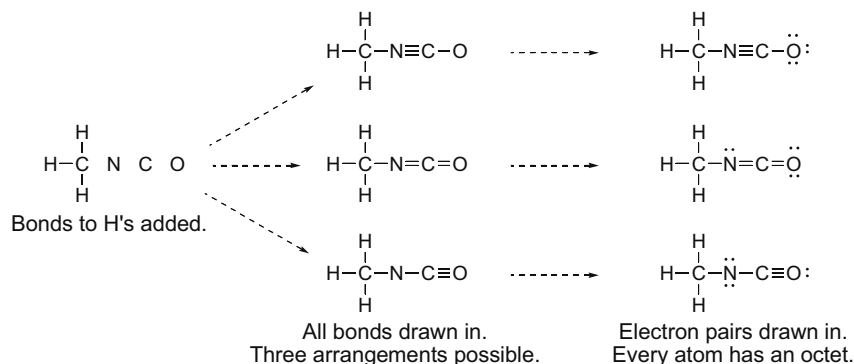
- Number of electrons that must be shared:

$$\begin{array}{r} 38 \text{ electrons} \\ - 22 \text{ electrons} \\ \hline \mathbf{16 \text{ electrons must be shared}} \end{array}$$

- Since every bond takes two electrons, $16/2 = 8$ **bonds are needed.**

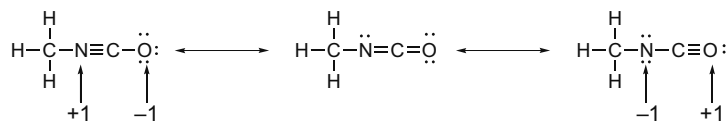
[4] Draw all possible Lewis structures.

- Draw the bonds to the H's first (three bonds). Then add five more bonds. Arrange them between the C's, N, and O, making sure that no atom gets more than eight electrons. There are three possible arrangements of bonds; that is, there are three resonance structures.
- Add additional electron pairs to give each atom an octet and check that all 22 electrons are used.



Chapter 1–6

- Calculate the formal charge on each atom.

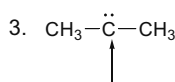
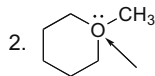
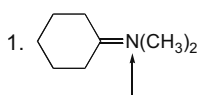


- You can evaluate the Lewis structures you have drawn. The middle structure is the best resonance structure, since it has no charged atoms.

Note: This method works for compounds that contain second-row elements in which every element gets an octet of electrons. It does NOT necessarily work for compounds with an atom that does not have an octet (such as BF_3), or compounds that have elements located in the third row and later in the periodic table.

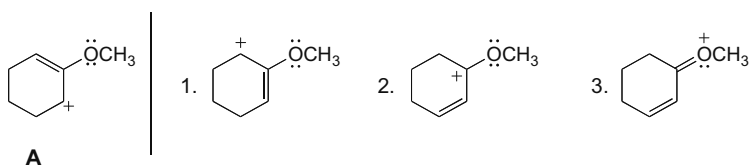
Practice Test on Chapter Review

1. a. Which compound(s) contain a labeled atom with a +1 formal charge? All lone pairs of electrons have been drawn in.



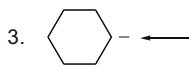
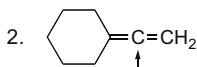
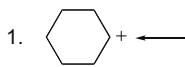
4. Both (1) and (2) have labeled atoms with a +1 charge.
5. Compounds (1), (2), and (3) all contain labeled atoms with a +1 formal charge.

- b. Which of the following compounds is a valid resonance structure for A?



4. Both (1) and (2) are valid resonance structures for A.
5. Cations (1), (2), and (3) are all valid resonance structures for A.

- c. Which species contains a labeled carbon atom that is sp^2 hybridized?

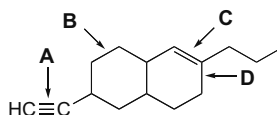


4. Both (1) and (2) contain labeled sp^2 hybridized atoms.
5. Species (1), (2), and (3) all contain labeled sp^2 hybridized carbon atoms.

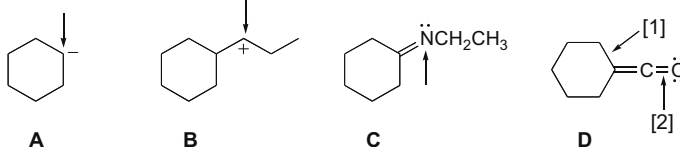
d. Which of the following compounds has a net dipole?

1. $\text{CH}_3\text{CH}_2\text{NHCH}_2\text{CH}_3$
2. $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$
3. $\text{FCH}_2\text{CH}_2\text{CH}_2\text{F}$
4. Compounds (1) and (2) both have net dipoles.
5. Compounds (1), (2), and (3) all have net dipoles.

2. Rank the labeled bonds in order of increasing bond length. Label the shortest bond as **1**, the longest bond as **4**, and the bonds of intermediate length as **2** and **3**.



3. Answer the following questions about compounds A–D.

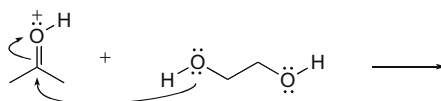


- What is the hybridization of the labeled atom in **A**?
- What is the molecular shape around the labeled atom in **B**?
- In what type of orbital does the lone pair in **C** reside?
- What orbitals are used to form bond [1] in **D**?
- Which orbitals are used to form the carbon–oxygen double bond [2] in **D**?

4. Draw an acceptable Lewis structure for CH_3NO_3 . Assume that the atoms are arranged as drawn.

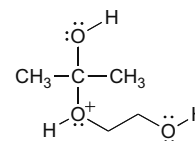


5. Follow the curved arrows and draw the product with all the needed charges and lone pairs.



Answers to Practice Test

1. a. 4 2. **A** – 1 3. a. sp^3 4. One possibility: 5.
- b. 1 **B** – 4 b. trigonal planar
- c. 1 **C** – 2 c. sp^2
- d. 5 **D** – 3 d. Csp^3-Csp^2
- e. $Csp-Osp^2$,
 $Cp-Op$
- $$\begin{array}{c} \text{H} & & \text{:}\ddot{\text{O}}\text{:}^- \\ | & & // \\ \text{H}-\text{C}-\ddot{\text{O}} & - & \text{N}^+=\ddot{\text{O}}\text{:} \\ | & & \\ \text{H} & & \end{array}$$



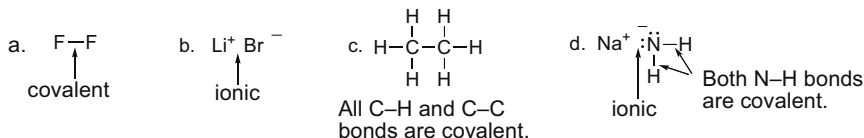
Chapter 1–8

Answers to Problems

- 1.1 The **mass number** is the number of protons and neutrons. The **atomic number** is the number of protons and is the same for all isotopes.

	Nitrogen-14	Nitrogen-13
a. number of protons = atomic number for N = 7	7	7
b. number of neutrons = mass number – atomic number	7	6
c. number of electrons = number of protons	7	7
d. The group number is the same for all isotopes.	5A	5A

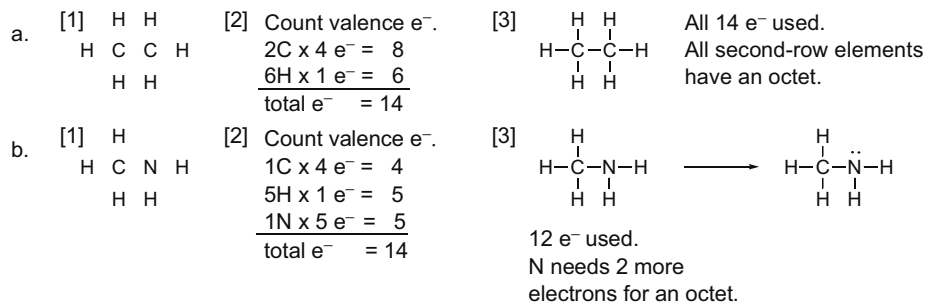
- 1.2 **Ionic bonds** form when an element on the far left side of the periodic table transfers an electron to an element on the far right side of the periodic table. **Covalent bonds** result when two atoms *share* electrons.



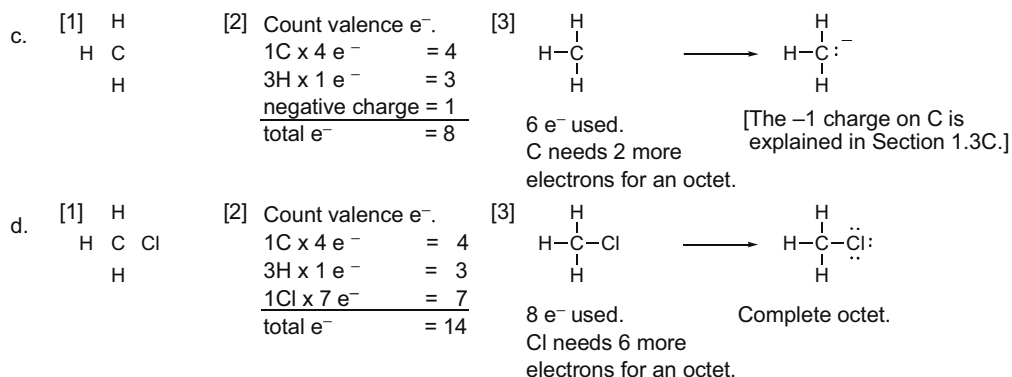
- 1.3 Atoms with one, two, three, or four valence electrons form one, two, three, or four bonds, respectively. Atoms with five or more valence electrons form $[8 - (\text{number of valence electrons})]$ bonds.

- a. O $8 - 6 \text{ valence } e^- = 2 \text{ bonds}$ c. Br $8 - 7 \text{ valence } e^- = 1 \text{ bond}$
b. Al $3 \text{ valence } e^- = 3 \text{ bonds}$ d. Si $4 \text{ valence } e^- = 4 \text{ bonds}$

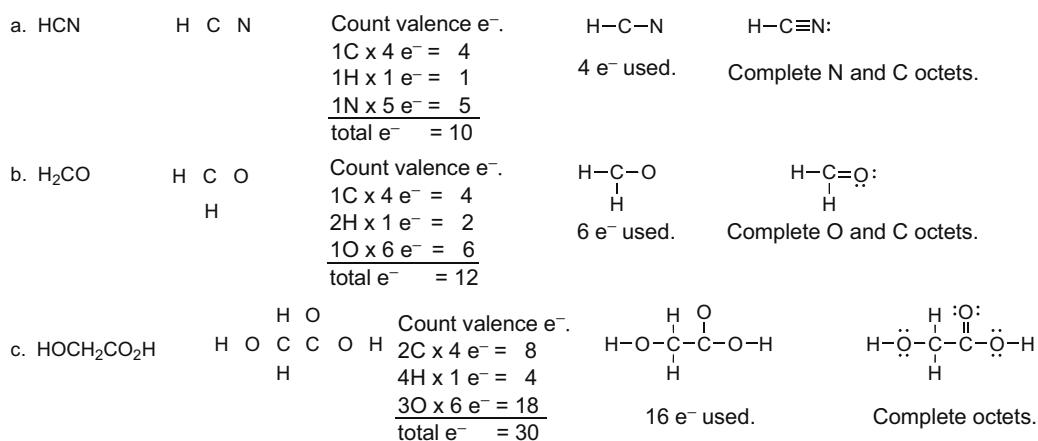
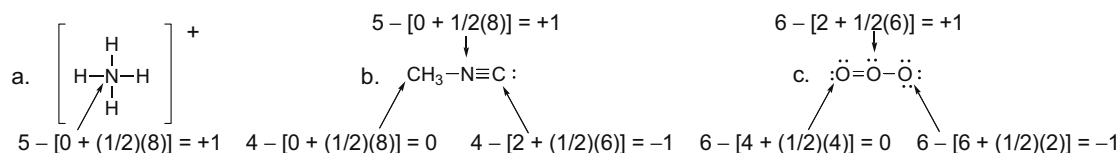
- 1.4 [1] Arrange the atoms with the H's on the periphery.
[2] Count the valence electrons.
[3] Arrange the electrons around the atoms. Give the H's 2 electrons first, and then fill the octets of the other atoms.
[4] Assign formal charges (Section 1.3C).



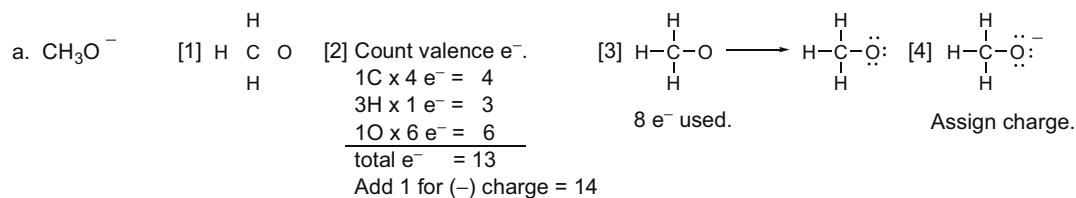
Structure and Bonding 1-9



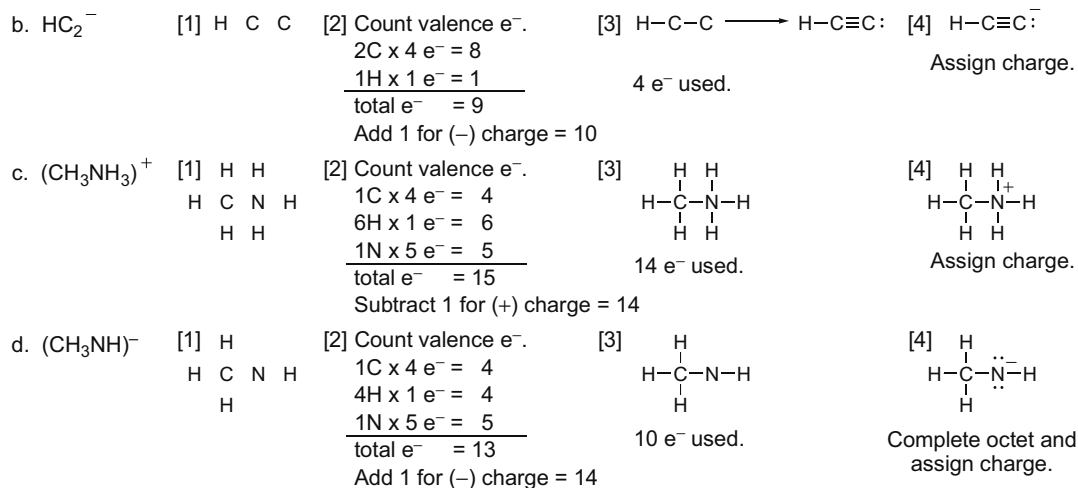
1.5 Follow the directions from Answer 1.4.

1.6 Formal charge (FC) = number of valence electrons – [number of unshared electrons + $(1/2)$ (number of shared electrons)]

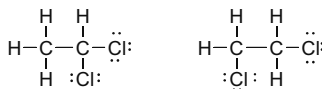
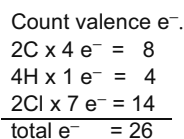
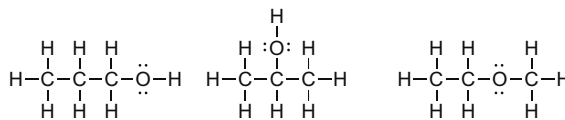
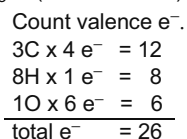
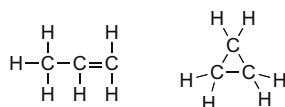
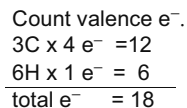
1.7



Chapter 1–10

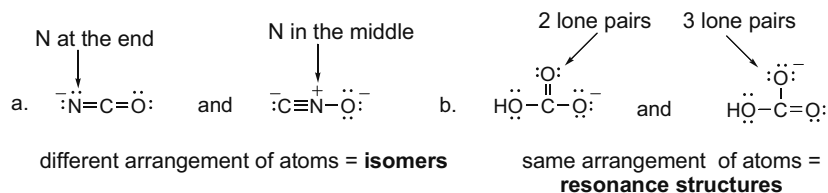


1.8

a. $\text{C}_2\text{H}_4\text{Cl}_2$ (two isomers)b. $\text{C}_3\text{H}_8\text{O}$ (three isomers)c. C_3H_6 (two isomers)

1.9 Two different definitions:

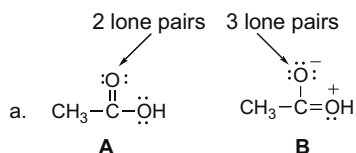
- **Isomers** have the same molecular formula and a *different* arrangement of atoms.
- **Resonance structures** have the same molecular formula and the *same* arrangement of atoms.



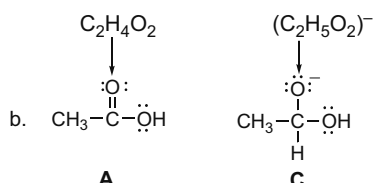
Structure and Bonding 1-11

1.10 Isomers have the same molecular formula and a *different* arrangement of atoms.

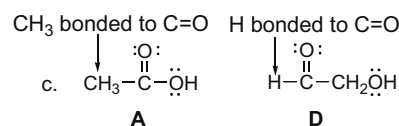
Resonance structures have the same molecular formula and the *same* arrangement of atoms.



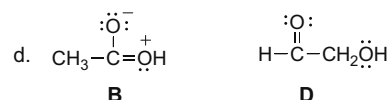
same arrangement of atoms =
resonance structures



different molecular formulas = **neither**

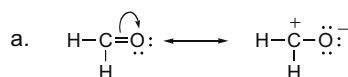


different arrangement of atoms = **isomers**

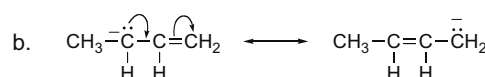


different arrangement of atoms = **isomers**

1.11 Curved arrow notation shows the movement of an electron pair. The tail begins at an electron pair (a bond or a lone pair) and the head points to where the electron pair moves.

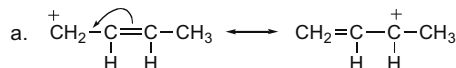


The net charge is the same
in both resonance structures.

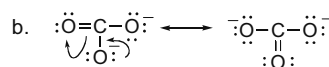


The net charge is the same
in both resonance structures.

1.12 Compare the resonance structures to see what electrons have “moved.” Use one curved arrow to show the movement of each electron pair.

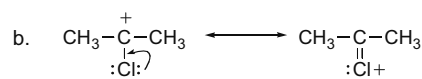
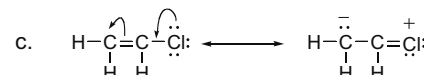
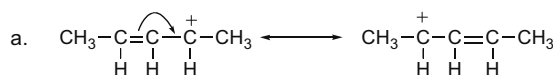


One electron pair moves:
one curved arrow.



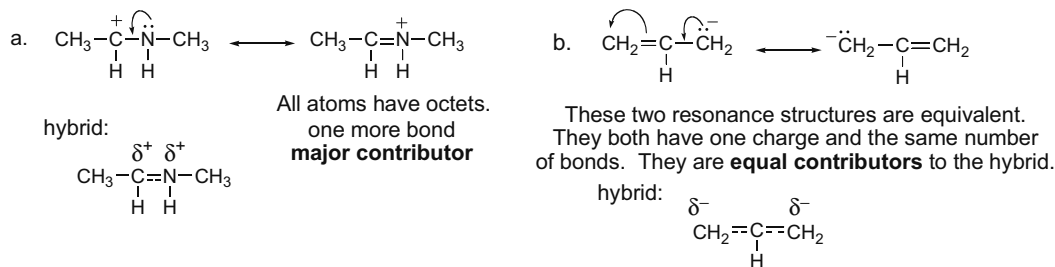
Two electron pairs move:
two curved arrows.

1.13 To draw another resonance structure, move electrons only in multiple bonds and lone pairs and keep the number of unpaired electrons constant.

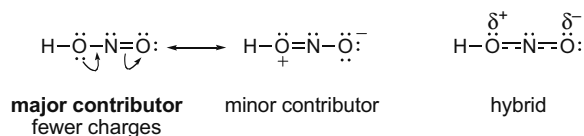


Chapter 1–12

1.14 A “better” resonance structure is one that has more bonds and fewer charges. The better structure is the major contributor and all others are minor contributors. To draw the resonance hybrid, use dashed lines for bonds that are in only one resonance structure, and use partial charges when the charge is on different atoms in the resonance structures.



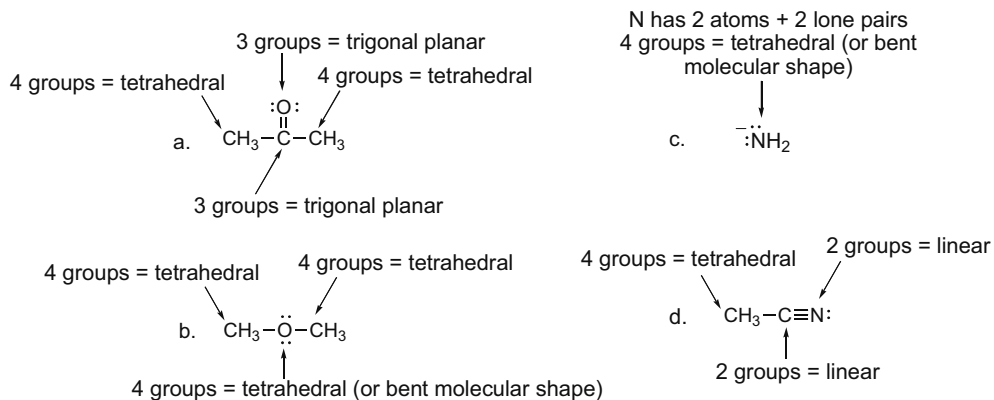
1.15 Draw a second resonance structure for nitrous acid.



1.16 All representations have a carbon with two bonds in the plane of the page, one in front of the page (solid wedge) and one behind the page (dashed line). Four possibilities:

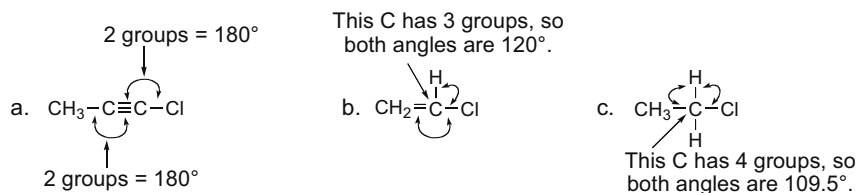


1.17 To predict the geometry around an atom, **count the number of groups (atoms + lone pairs)**, making sure to draw in any needed lone pairs or hydrogens: 2 groups = linear, 3 groups = trigonal planar, 4 groups = tetrahedral.

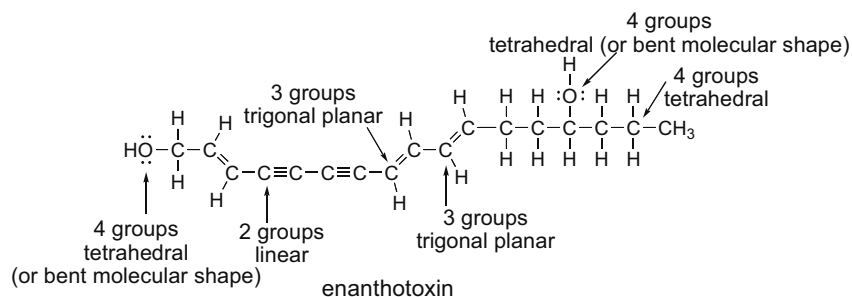


Structure and Bonding 1-13

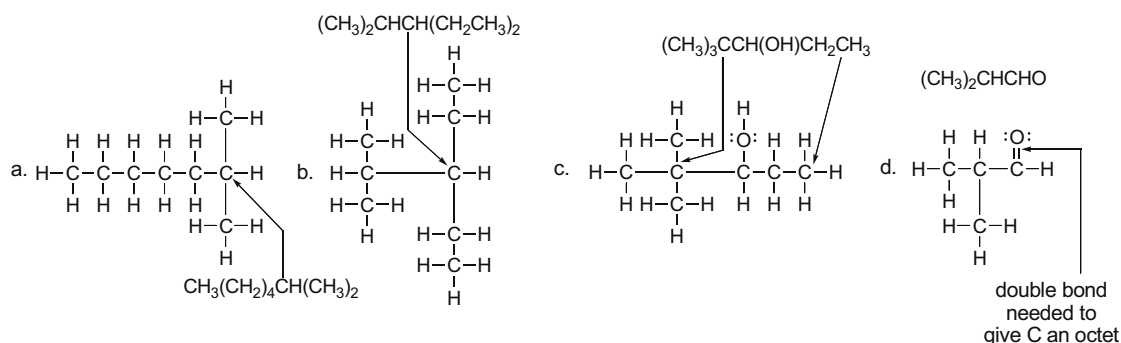
- 1.18** To predict the bond angle around an atom, **count the number of groups (atoms + lone pairs)**, making sure to draw in any needed lone pairs or hydrogens: 2 groups = 180° , 3 groups = 120° , 4 groups = 109.5° .



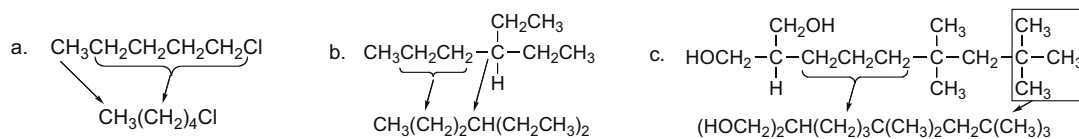
- 1.19** To predict the geometry around an atom, use the rules in Answer 1.17.



- 1.20** Reading from left to right, draw the molecule as a Lewis structure. Always check that carbon has four bonds and all heteroatoms have an octet by adding any needed lone pairs.

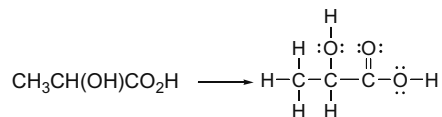
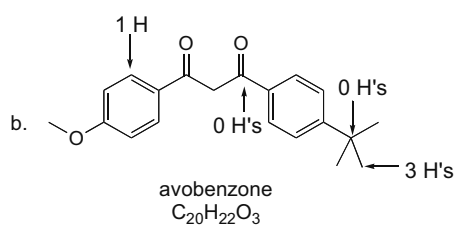
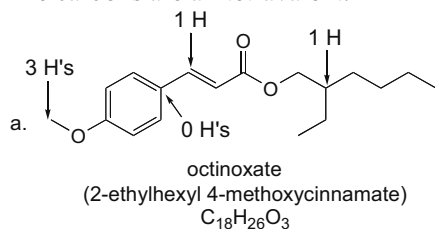
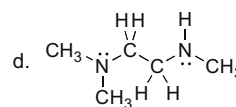
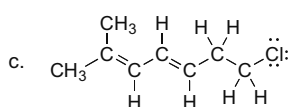
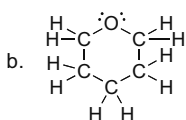
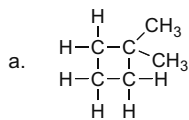
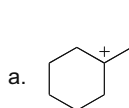


- 1.21** Simplify each condensed structure using parentheses.

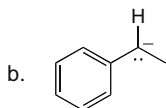


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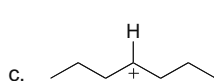
1.22 Draw the Lewis structure of lactic acid.

1.23 In shorthand or skeletal drawings, **all line junctions or ends of lines represent carbon atoms.** The carbons are all tetravalent.1.24 In shorthand or skeletal drawings, **all line junctions or ends of lines represent carbon atoms.** Convert by writing in all carbons, and then adding hydrogen atoms to make the carbons tetravalent.1.25 A charge on a carbon atom takes the place of one hydrogen atom. **A negatively charged C has one lone pair, and a positively charged C has none.**

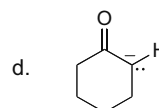
positive charge
no lone pairs
no H's needed



negative charge
one lone pair
one H needed

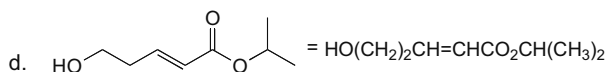
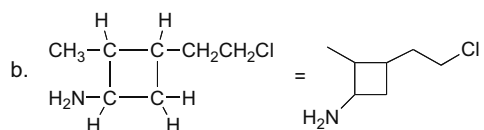
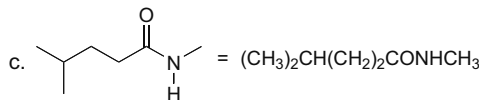
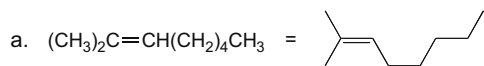


positive charge
no lone pairs
one H needed



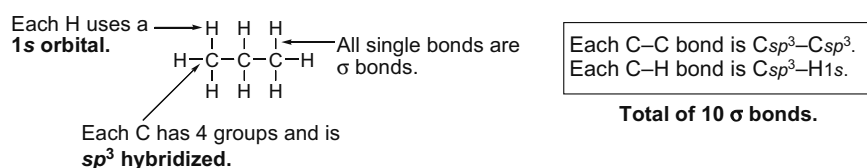
negative charge
one lone pair
one H needed

1.26 Draw each indicated structure. Recall that in the skeletal drawings, a carbon atom is located at the intersection of any two lines and at the end of any line.



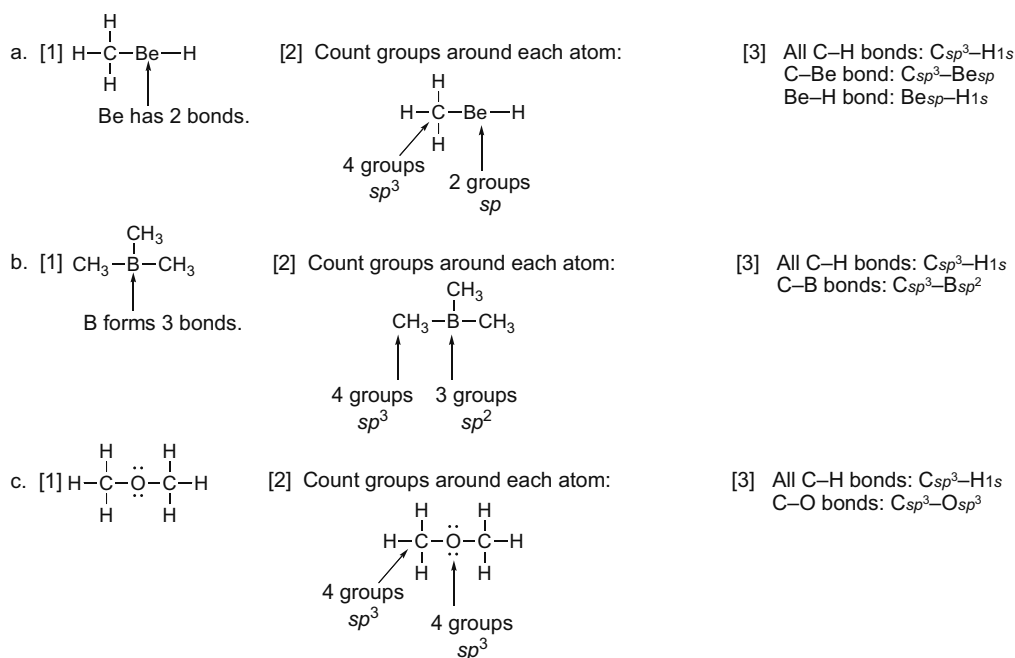
Structure and Bonding 1–15

- 1.27** To determine the orbitals used in bonding, **count the number of groups** (atoms + lone pairs):
 4 groups = sp^3 , 3 groups = sp^2 , 2 groups = sp , H atom = $1s$ (no hybridization).
 All covalent single bonds are σ , and all double bonds contain one σ and one π bond.

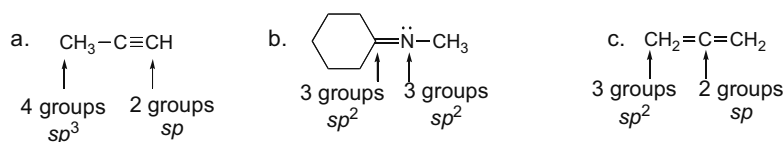


- 1.28** [1] Draw a valid Lewis structure for each molecule.
 [2] **Count the number of groups** around each atom: 4 groups = sp^3 , 3 groups = sp^2 , 2 groups = sp , H atom = $1s$ (no hybridization).

Note: Be and B (Groups 2A and 3A) do not have enough valence e^- to form an octet, **and do not form an octet in neutral molecules.**



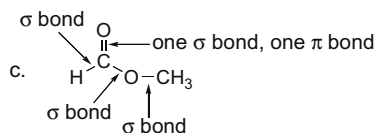
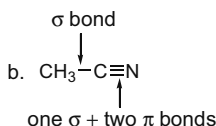
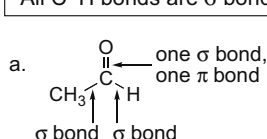
- 1.29** To determine the hybridization, **count the number of groups** around each atom: 4 groups = sp^3 , 3 groups = sp^2 , 2 groups = sp , H atom = $1s$ (no hybridization).



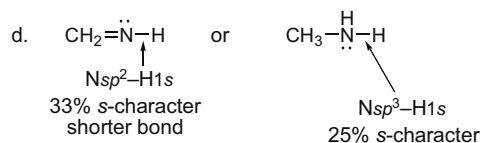
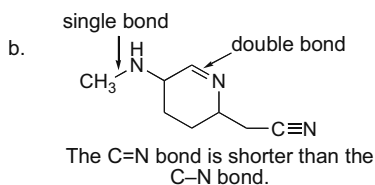
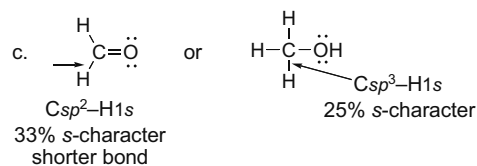
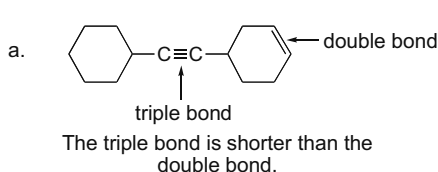
Chapter 1–16

1.30 All single bonds are σ . Multiple bonds contain one σ bond, and all others are π bonds.

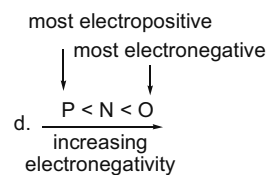
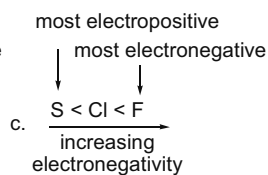
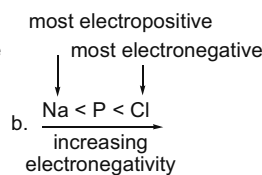
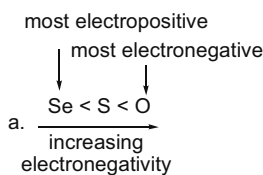
All C–H bonds are σ bonds.



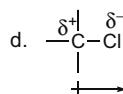
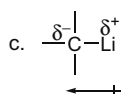
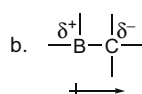
1.31 Single bonds are weaker and longer than double bonds, which are weaker and longer than triple bonds. Increasing percent *s*-character increases bond strength and decreases bond length.



1.32 Electronegativity increases from left to right across a row of the periodic table and decreases down a column. Look at the relative position of the atoms to determine their relative electronegativity.

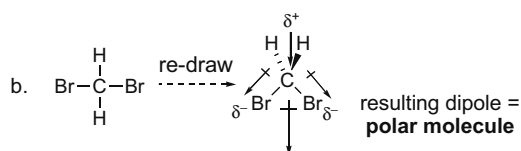
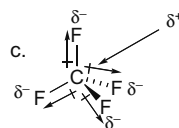
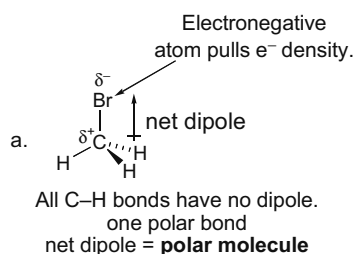


1.33 Dipoles result from unequal sharing of electrons in covalent bonds. More electronegative atoms “pull” electron density towards them, making a dipole. **Dipole arrows point towards the atom of higher electron density.**

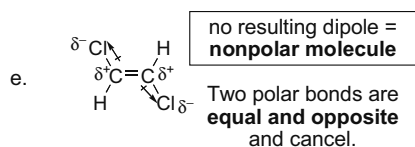
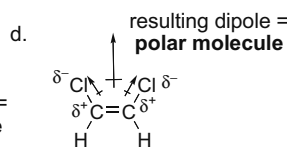


1.34 Polar molecules result from a net dipole. To determine polarity, draw the molecule in three dimensions around any polar bonds, draw in the dipoles, and look to see whether the dipoles cancel or reinforce.

Structure and Bonding 1-17

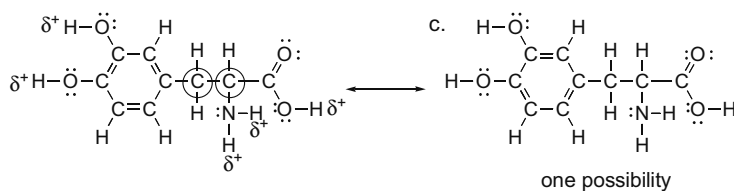


Note: You must draw the molecule in three dimensions to observe the net dipole. In the Lewis structure, it appears the dipoles would cancel out, when in fact they add to make a polar molecule.



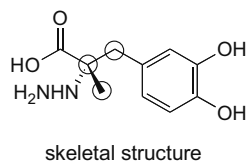
1.35

- a. The two circled C's are sp^3 hybridized.
b. All the C-H bonds are nonpolar. All H's bonded to O and N bear a partial positive charge (δ^+).

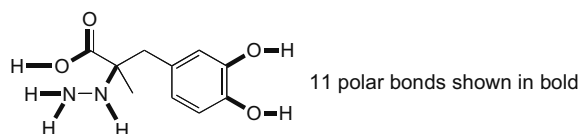


1.36

a.

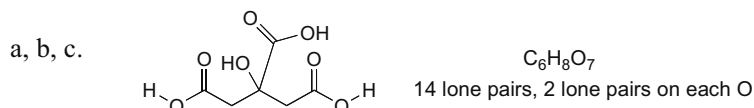


- b. Circled carbons are sp^3 hybridized. All others are sp^2 hybridized.
c. Each N is surrounded by three atoms and a lone pair, making it sp^3 hybridized and trigonal pyramidal in molecular shape.
d.



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1.37

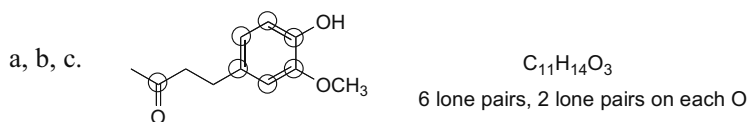


d. Each C that is part of a C=O is sp^2 hybridized, so there are three sp^2 C's.

e. Orbitals:

- [1] C=O, Csp^2-Osp^2 and $Cp-Op$
- [2] C-C, Csp^3-Csp^2
- [3] O-H, Osp^3-H1s
- [4] C-O, Csp^3-Osp^3

1.38



d. The sp^2 hybridized C's (seven) are labeled with circles.

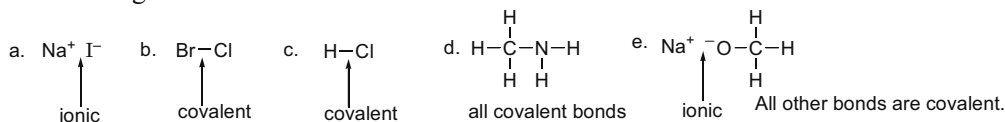
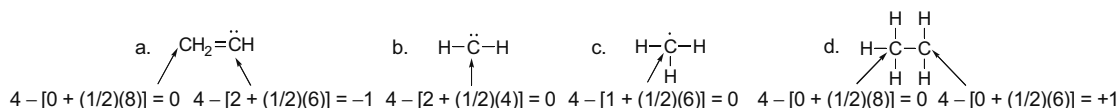
e. Orbitals:

- [1] C-C, Csp^3-Csp^2
- [2] C-C, Csp^3-Csp^3
- [3] C-H, Csp^3-H1s
- [4] C-H, Csp^2-H1s

1.39 Use the definitions in Answer 1.1.

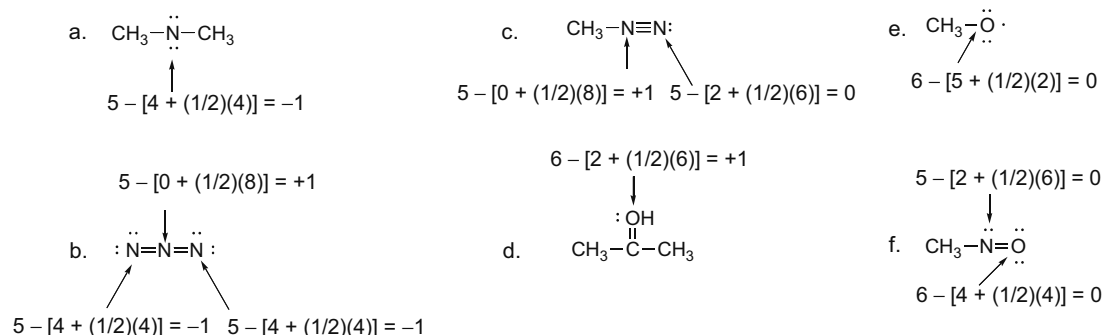
	Iodine-123	Iodine-131
a. number of protons = atomic number for I = 53	53	53
b. number of neutrons = mass number – atomic number	70	78
c. number of electrons = number of protons	53	53
d. The group number is the same for all isotopes.	7A	7A

1.40 Use bonding rules in Answer 1.2.

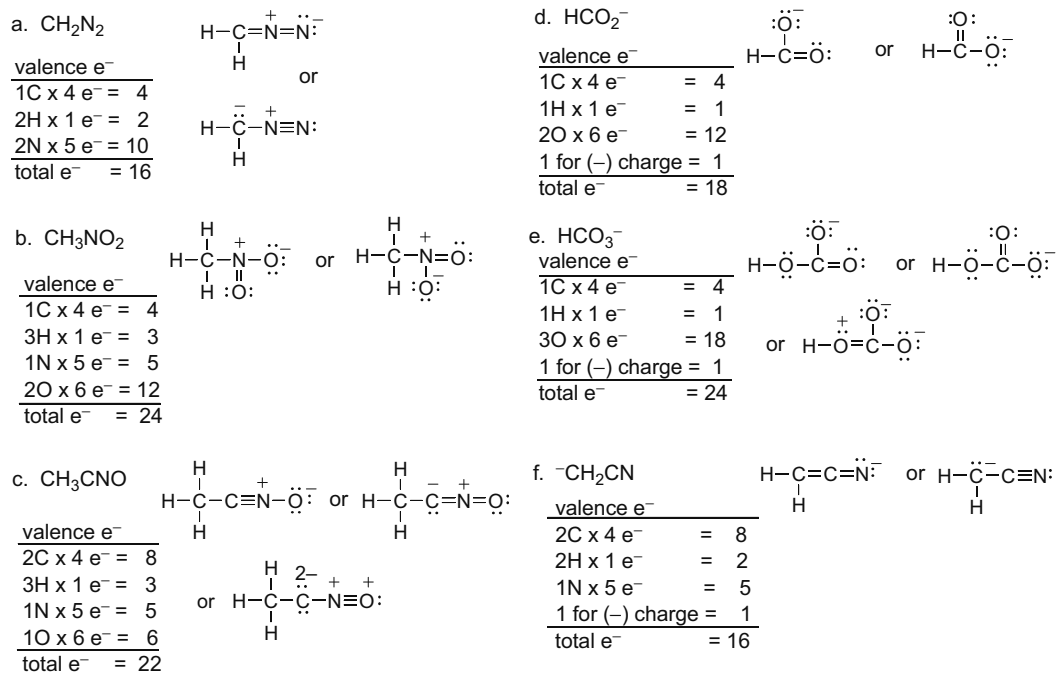
1.41 Formal charge (FC) = number of valence electrons – [number of unshared electrons + $(\frac{1}{2})(\text{number of shared electrons})$]. C is in group 4A.

Structure and Bonding 1-19

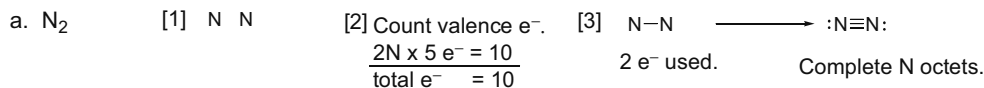
1.42 Formal charge (FC) = number of valence electrons – [number of unshared electrons + $(\frac{1}{2})(\text{number of shared electrons})$]. N is in group 5A and O is in group 6A.



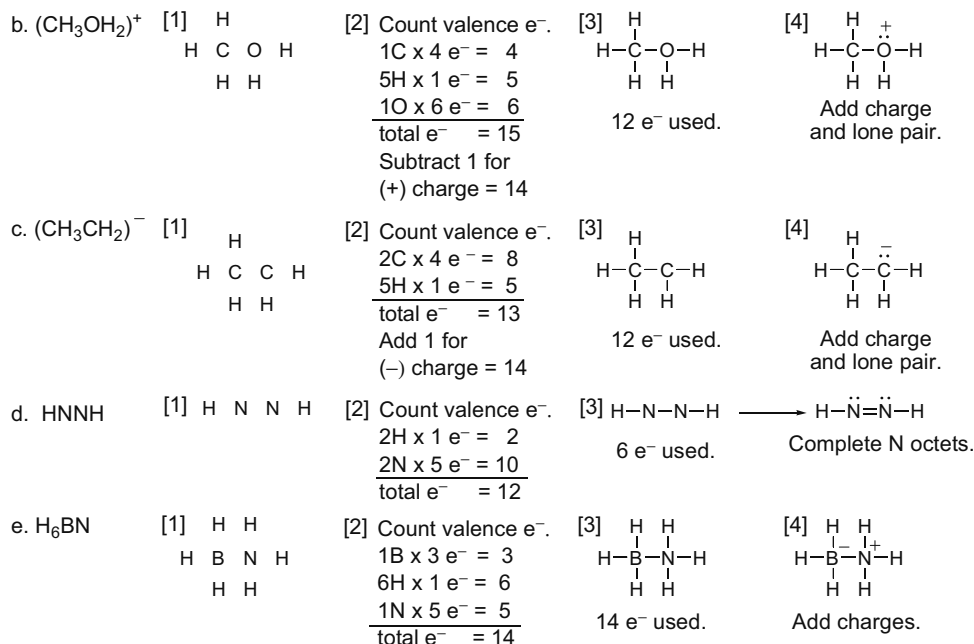
1.43 Follow the steps in Answer 1.4 to draw Lewis structures.



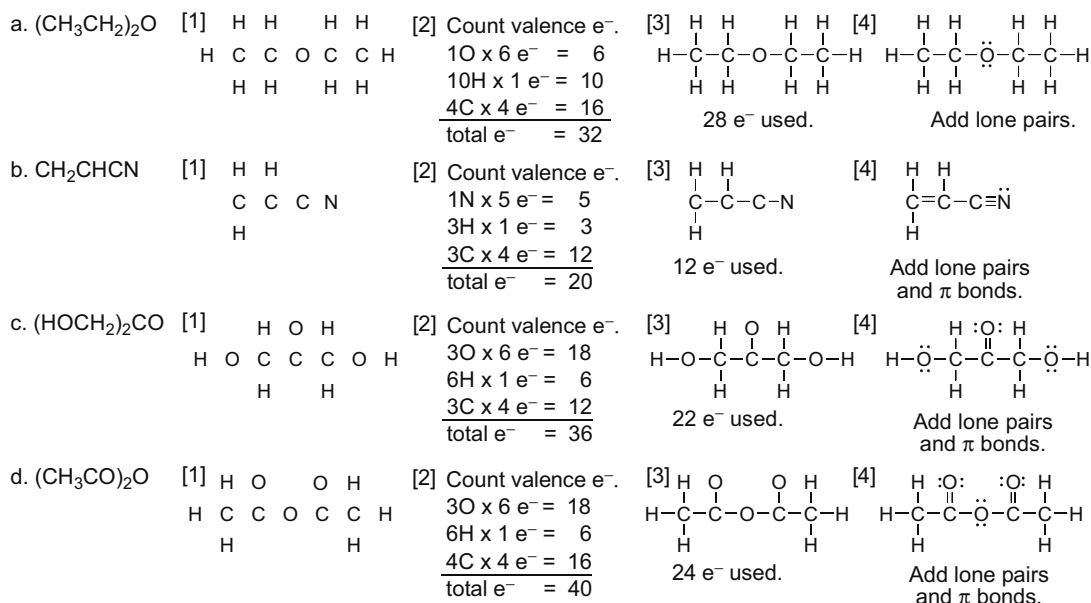
1.44 Follow the steps in Answer 1.4 to draw Lewis structures.



Chapter 1–20



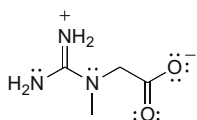
1.45 Follow the steps in Answer 1.4 to draw Lewis structures.



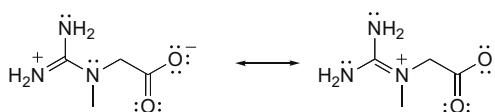
Structure and Bonding 1-21

1.46

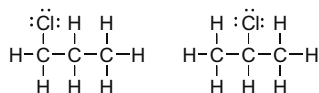
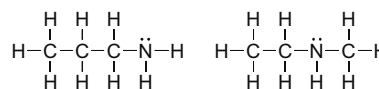
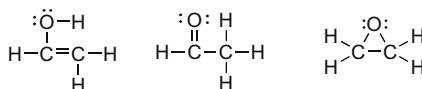
a.



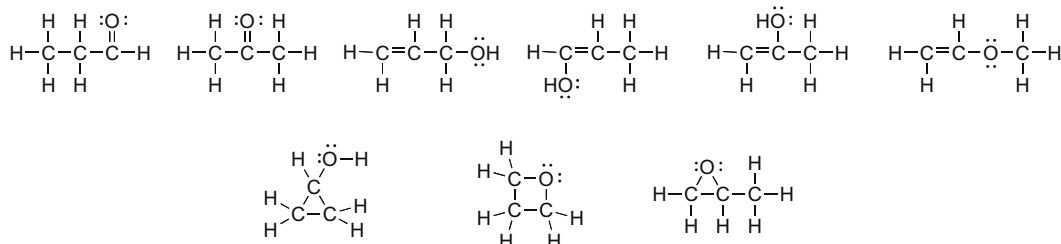
b. Two of the possible resonance structures:



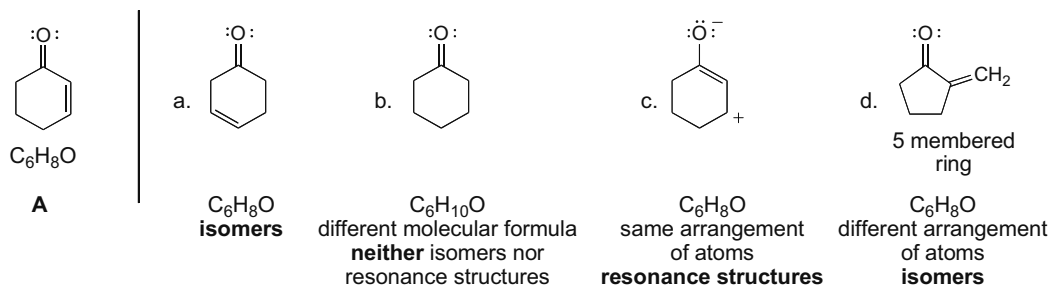
1.47 Isomers must have a different arrangement of atoms.

a. Two isomers of molecular formula C_3H_7Cl c. Four isomers of molecular formula C_3H_9N b. Three isomers of molecular formula C_2H_4O 

1.48

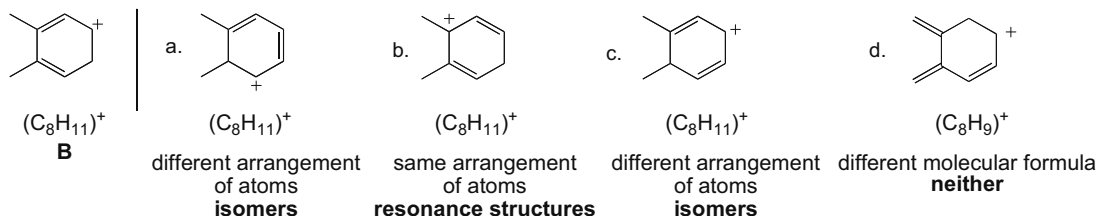
Nine isomers of C_3H_6O :

1.49 Use the definition of isomers and resonance structures in Answer 1.9.

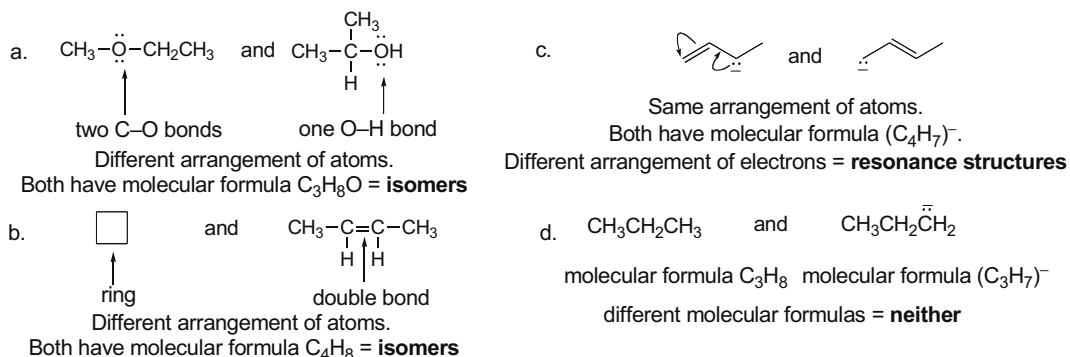


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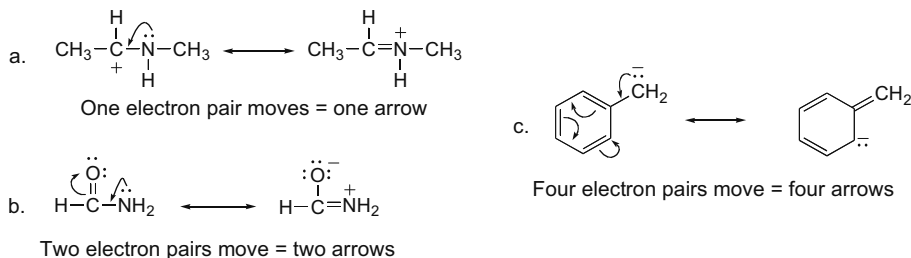
1.50 Use the definitions of isomers and resonance structures in Answer 1.9.



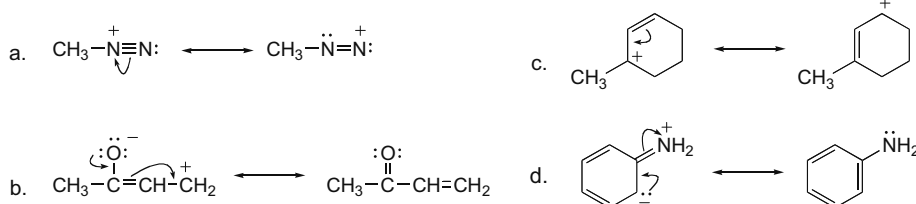
1.51 Use the definitions of isomers and resonance structures in Answer 1.9.



1.52 Compare the resonance structures to see what electrons have “moved.” Use one curved arrow to show the movement of each electron pair.

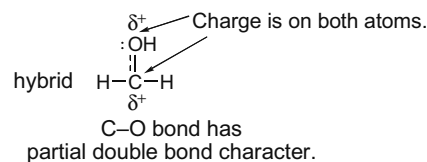
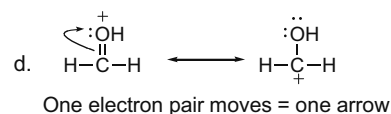
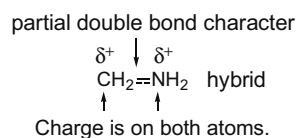
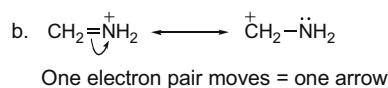
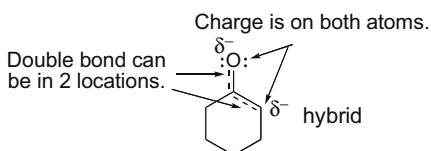
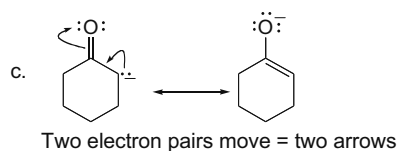
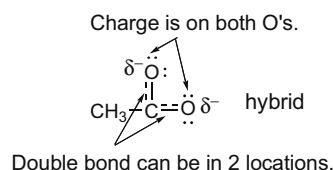
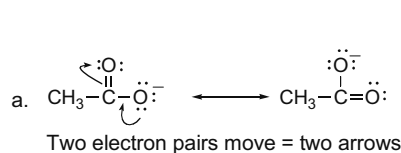


1.53 Curved arrow notation shows the movement of an electron pair. The tail begins at an electron pair (a bond or a lone pair) and the head points to where the electron pair moves.

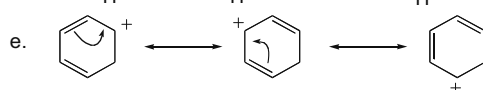
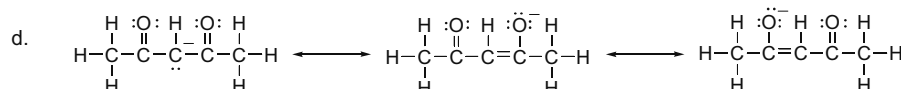
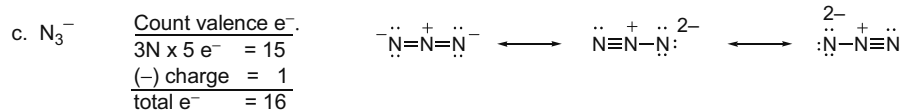
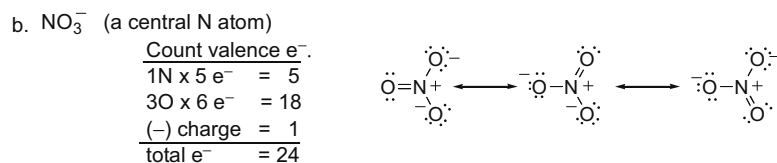
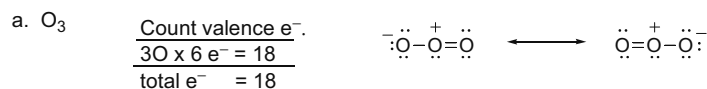


Structure and Bonding 1-23

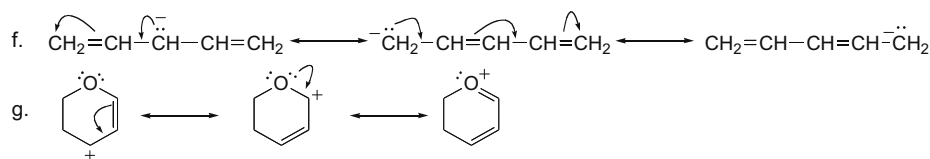
1.54 Use the rules in Answer 1.13.



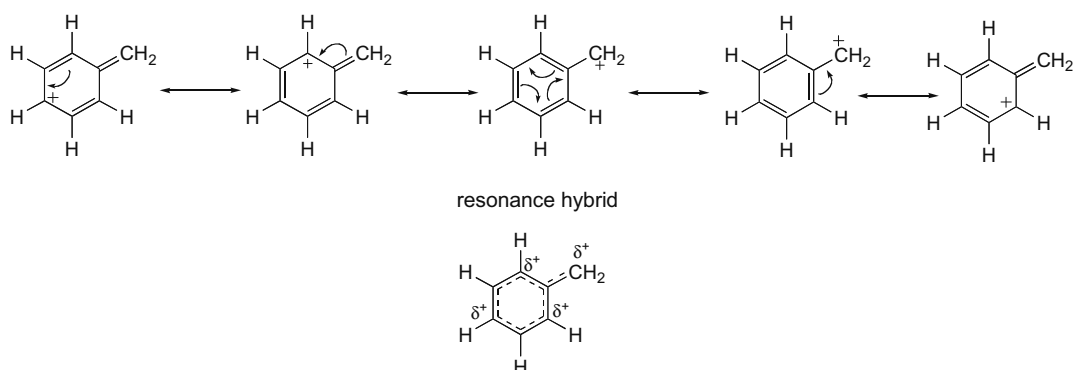
1.55 For the compounds where the arrangement of atoms is not given, first draw a Lewis structure. Then use the rules in Answer 1.13.



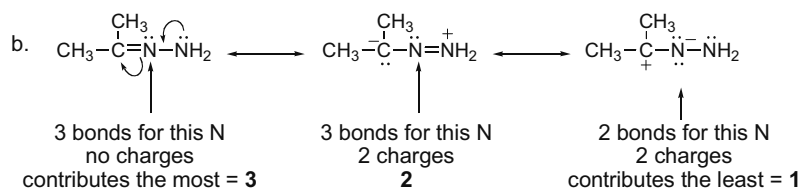
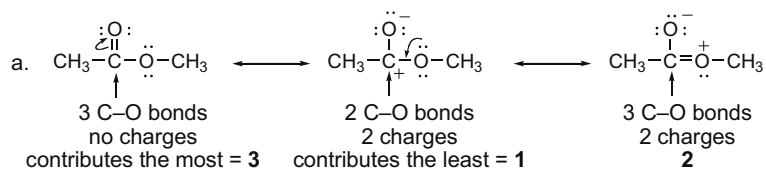
Chapter 1-24



1.56 To draw the **resonance hybrid**, use the rules in Answer 1.14.

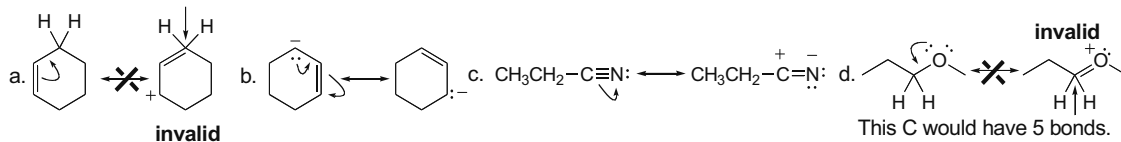


1.57 A **“better” resonance structure is one that has more bonds and fewer charges.** The better structure is the major contributor and all others are minor contributors.



1.58

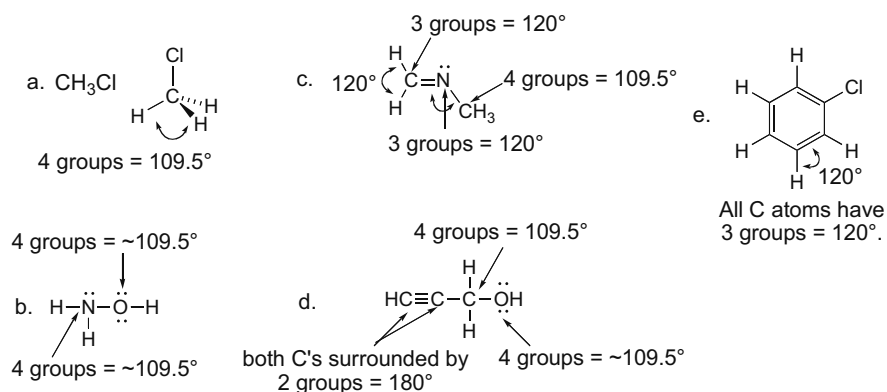
This C would have 5 bonds.



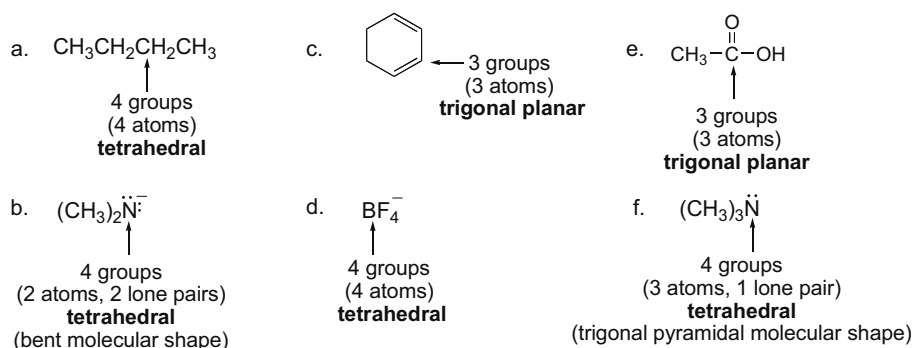
[Note: The pentavalent C's in (a) and (d) bear a (-1) formal charge.]

Structure and Bonding 1–25

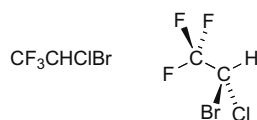
1.59 Use the rules in Answer 1.18.



1.60 To predict the geometry around an atom, use the rules in Answer 1.17.

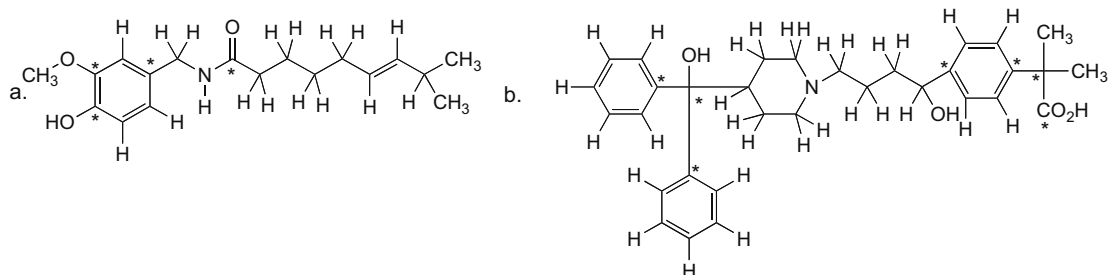


1.61 Each C has two bonds in the plane of the page, one in front of the page (solid wedge) and one behind the page (dashed line).

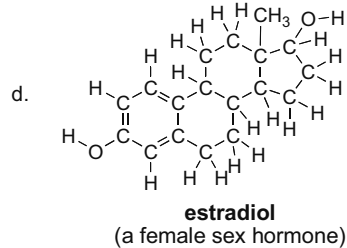
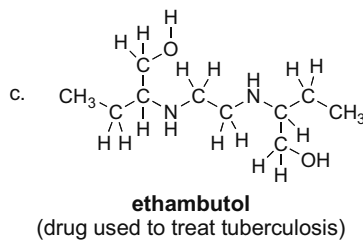
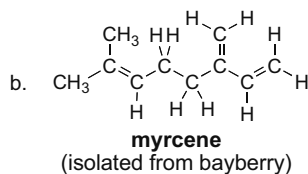
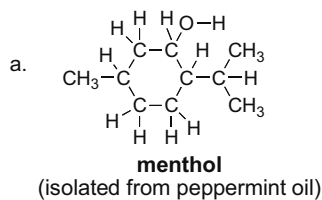


1.62 In shorthand or skeletal drawings, **all line junctions or ends of lines represent carbon atoms**. The C's are all tetravalent. All H's bonded to C's are drawn in the following structures. C's labeled with (*) have no H's bonded to them.

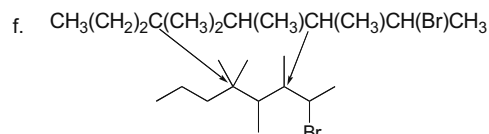
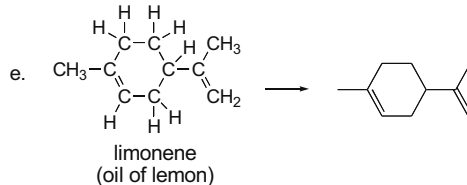
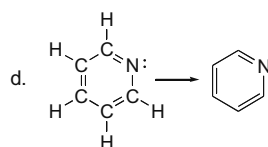
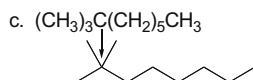
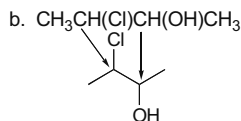
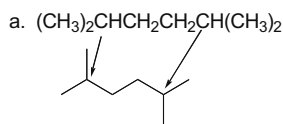
Chapter 1–26



1.63 In shorthand or skeletal drawings, **all line junctions or ends of lines represent carbon atoms.** Convert by writing in all C's, and then adding H's to make the C's tetravalent.

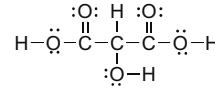
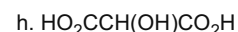
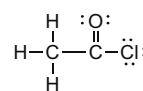
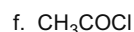
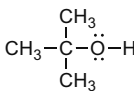
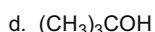
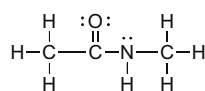
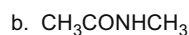
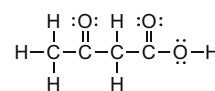
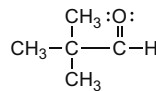
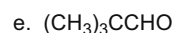
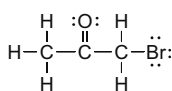
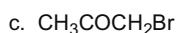
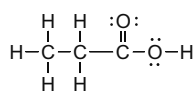


1.64 In skeletal formulas, leave out all C's and H's, except H's bonded to heteroatoms.

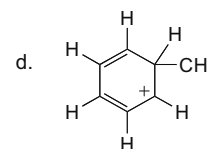
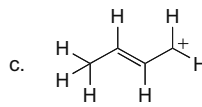
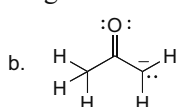
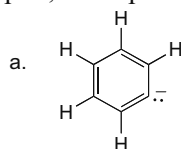


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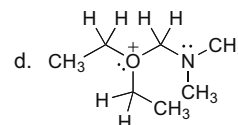
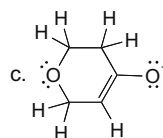
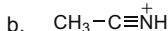
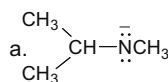
1.65 For Lewis structures, all atoms including H's and all lone pairs must be drawn in.



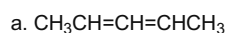
1.66 A charge on a C atom takes the place of one H atom. A negatively charged C has one lone pair, and a positively charged C has none.



1.67



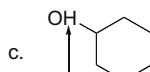
1.68 Examine each structure to determine the error.



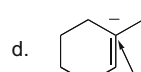
This C has 5 bonds.



This C has 5 bonds.

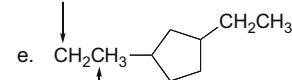


This H has 2 bonds. It should be HO-.



This C has 4 bonds. The negative charge means a lone pair, which gives C 10 electrons.

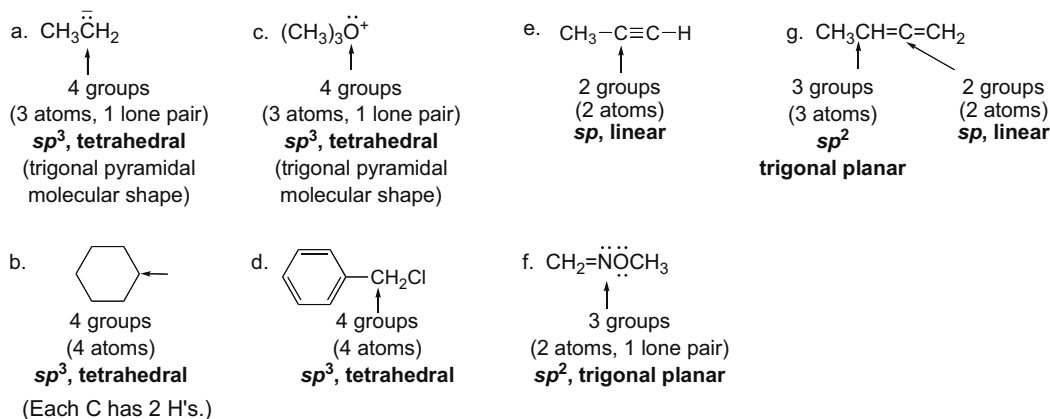
This C has 3 bonds.



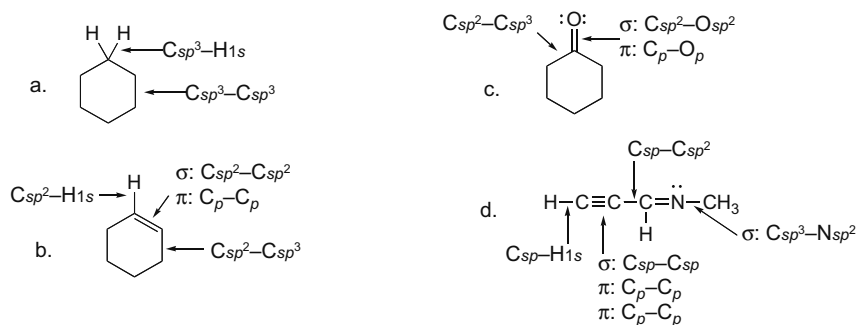
This C has 5 bonds. It should be CH_3CH_2^- .

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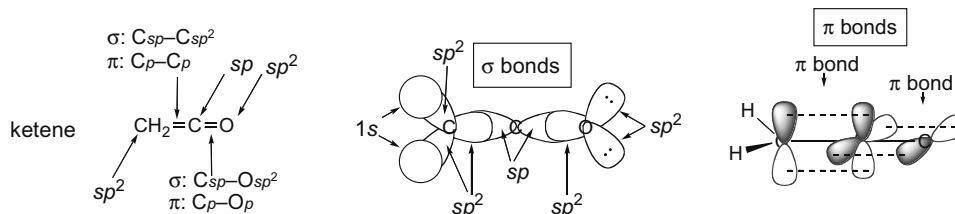
1.69 To determine the hybridization around the labeled atoms, use the procedure in Answer 1.29.



1.70 To determine what orbitals are involved in bonding, use the procedure in Answer 1.27.



1.71



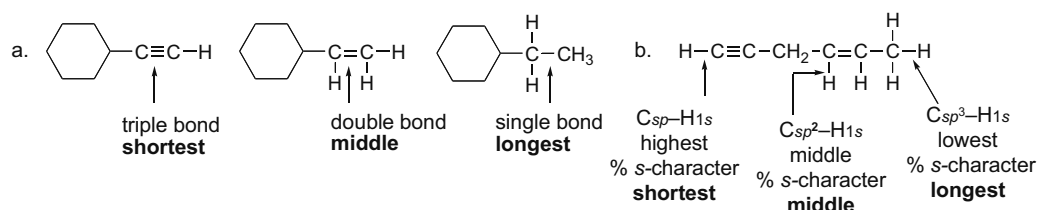
[For clarity, only the large bonding lobes of the hybrid orbitals are drawn.]

1.72

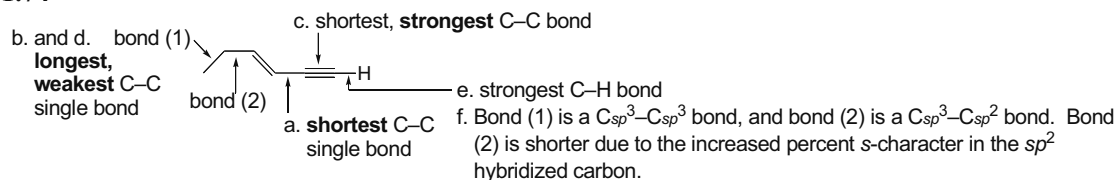


Structure and Bonding 1-29

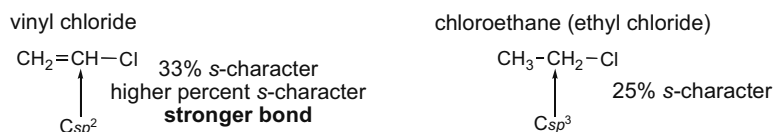
1.73 To determine relative bond length, use the rules in Answer 1.31.



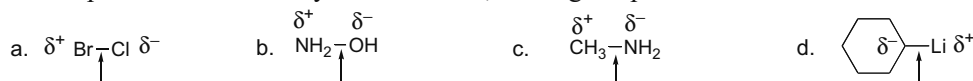
1.74



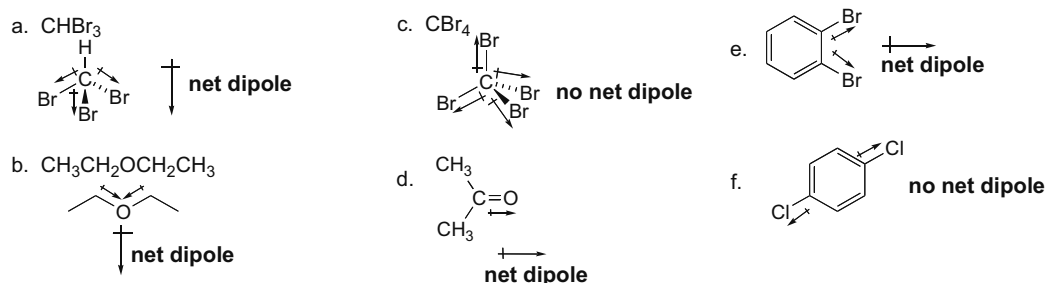
1.75 Percent s-character determines the strength of a bond. The higher percent s-character of an orbital used to form a bond, the stronger the bond.



1.76 Dipoles result from unequal sharing of electrons in covalent bonds. More electronegative atoms "pull" electron density towards them, making a dipole.

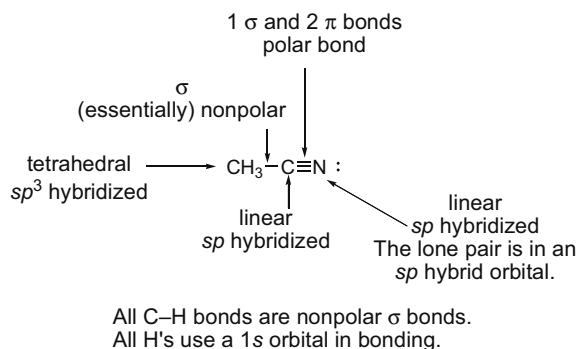


1.77 Use the directions from Answer 1.34.



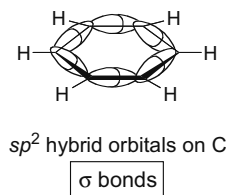
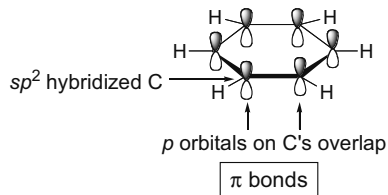
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1.78

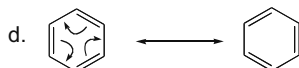


1.79

- a. sp^2
 b. Each C is trigonal planar; the ring is flat, drawn as a hexagon.
 c.

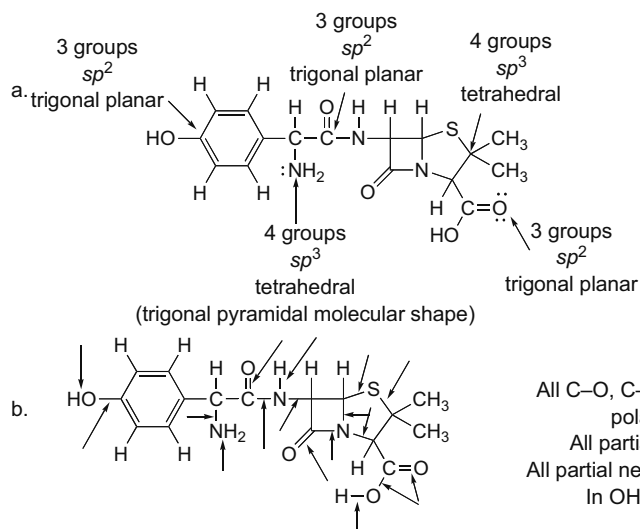


[Only the larger bonding lobe of each orbital is drawn.]



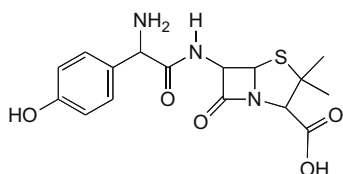
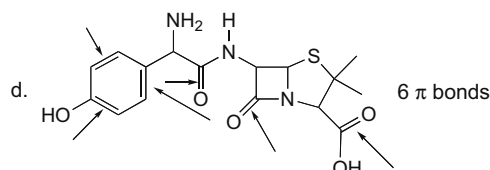
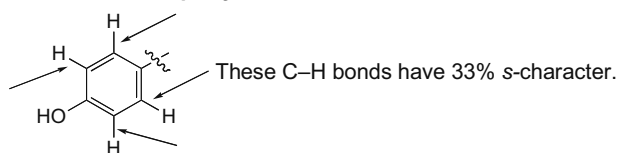
- e. Benzene is stable because of its two resonance structures that contribute equally to the hybrid. [This is only part of the story. We'll learn more about benzene's unusual stability in Chapter 17.]

1.80

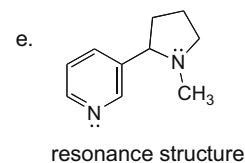
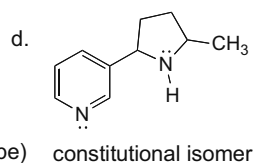
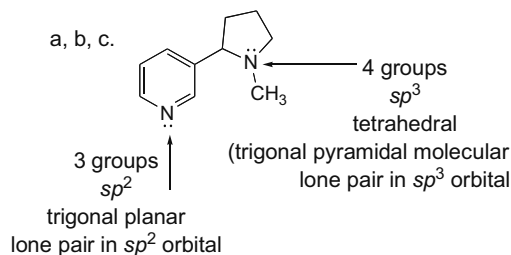


All C–O, C–N, C–S, N–H, and O–H bonds are polar and labeled with arrows.
 All partial positive charges lie on the C.
 All partial negative charges lie on the O, N, or S.
 In OH and NH bonds, H bears a δ^+ .

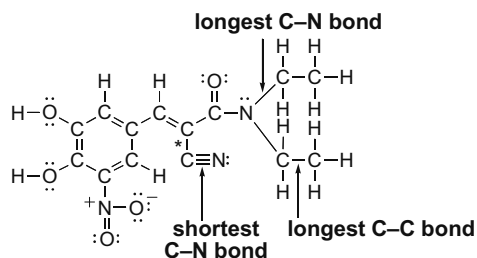
Structure and Bonding 1–31

c. **skeletal structure:**e. **33% s-character = sp^2 hybridized**

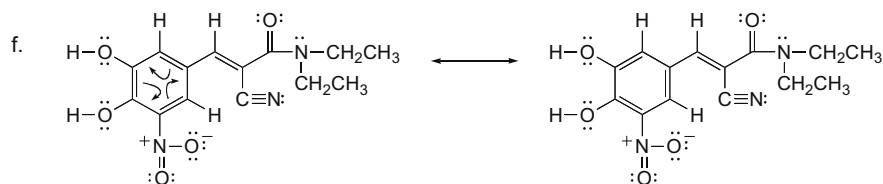
1.81



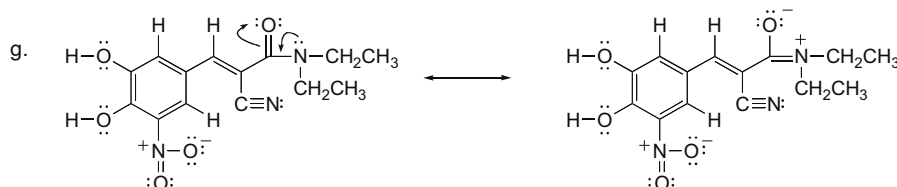
1.82 a.



- The C–C bonds in the CH_2CH_3 groups are the longest because they are formed from sp^3 hybridized C's.
- The shortest C–C bond is labeled with a (*) because it is formed from orbitals with the highest percent s-character ($\text{C}_{sp}-\text{C}_{sp^2}$).
- The longest C–N bond is formed from the sp^3 hybridized C atom bonded to a N atom [labeled in part (a)].
- The shortest C–N bond is the triple bond ($\text{C}\equiv\text{N}$); increasing the number of electrons between atoms decreases bond length.



Chapter 1–32



1.83

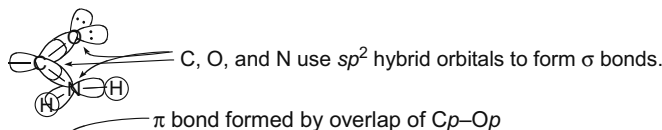
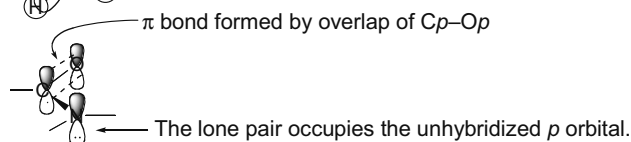
CH_3^+ 3 groups
 sp^2 trigonal planar
plot A

The blue region is evidence of the electron-poor cation.

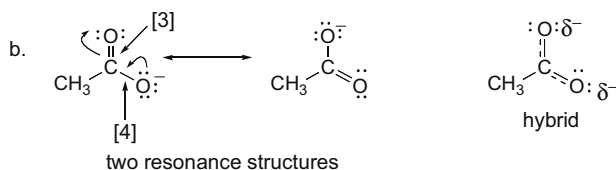
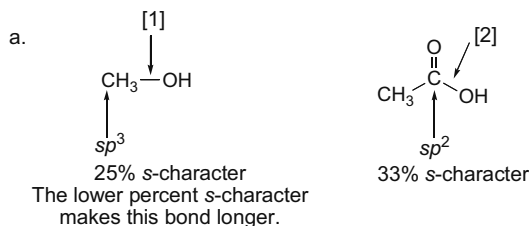
CH_3^- 4 groups
 sp^3 tetrahedral
(The molecular shape is trigonal pyramidal.)
plot B

The red region is evidence of the electron-rich anion.

1.84 If the N atom is sp^2 hybridized, the lone pair occupies a p orbital, which can overlap with the π bond of the adjacent $\text{C}=\text{O}$. This allows electron density to delocalize, which is a stabilizing feature.

 σ bonds in $-\text{CONH}_2$  π bonds in $-\text{CONH}_2$ 

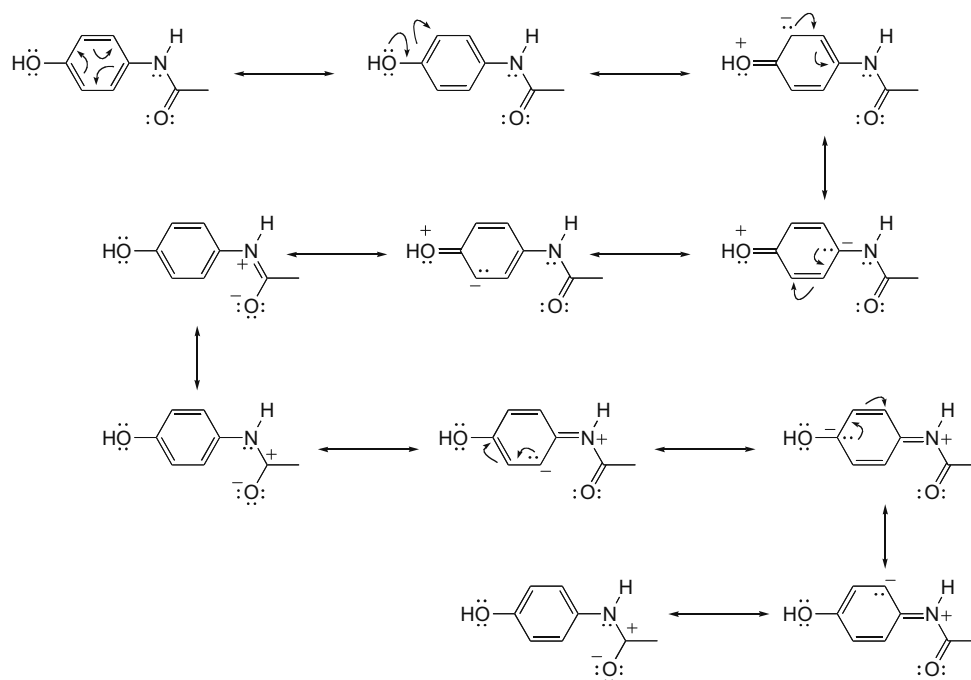
1.85



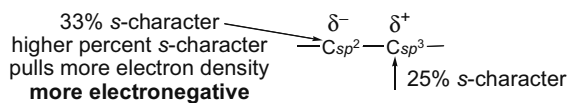
Bonds [3] and [4] are both equivalent in length, because the anion is resonance-stabilized, and the $\text{C}-\text{O}$ bond of the hybrid is a composite of one single bond and one double bond. Both resonance structures contribute equally to the hybrid. Since each $\text{C}-\text{O}$ bond in the hybrid has partial double bond character, it is shorter than the $\text{C}-\text{O}$ single bond labeled [2].

Structure and Bonding 1-33

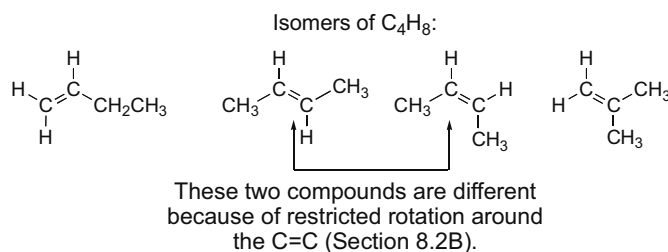
1.86 Ten additional resonance structures are drawn. (There are more possibilities.)



1.87 Polar bonds result from unequal sharing of electrons in covalent bonds. Normally we think of more electronegative atoms “pulling” more of the electron density towards them, making a dipole. In looking at a $C_{sp^2}-C_{sp^3}$ bond, the atom with a higher percent s -character will “pull” more of the electron density towards it, creating a small dipole.

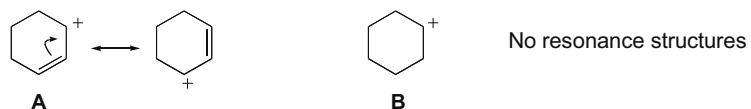
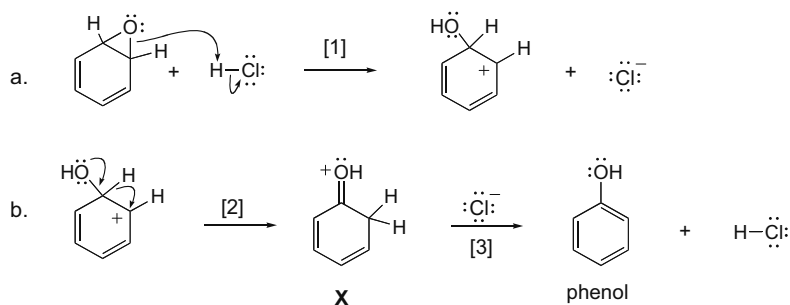


1.88



Chapter 1–34

1.89 Carbocation **A** is more stable than carbocation **B** because resonance distributes the positive charge over two carbons. Delocalizing electron density is stabilizing. **B** has no possibility of resonance delocalization.

**1.90**

Chapter 2 Acids and Bases

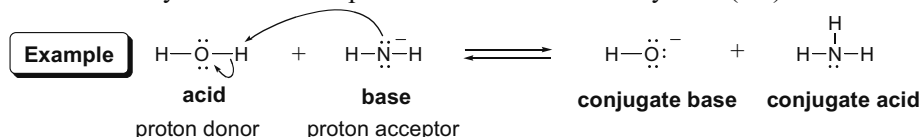
Chapter Review

A comparison of Brønsted–Lowry and Lewis acids and bases

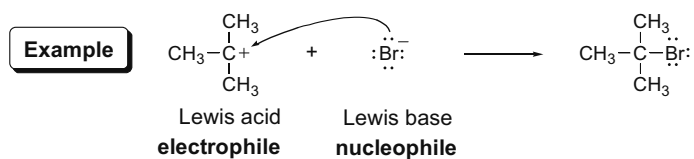
Type	Definition	Structural feature	Examples
Brønsted–Lowry acid (2.1)	proton donor	a proton	HCl, H ₂ SO ₄ , H ₂ O, CH ₃ COOH, TsOH
Brønsted–Lowry base (2.1)	proton acceptor	a lone pair <i>or</i> a π bond	[−] OH, [−] OCH ₃ , H [−] , [−] NH ₂ , CH ₂ =CH ₂
Lewis acid (2.8)	electron pair acceptor	a proton, <i>or</i> an unfilled valence shell, <i>or</i> a partial (+) charge	BF ₃ , AlCl ₃ , HCl, CH ₃ COOH, H ₂ O
Lewis base (2.8)	electron pair donor	a lone pair <i>or</i> a π bond	[−] OH, [−] OCH ₃ , H [−] , [−] NH ₂ , CH ₂ =CH ₂

Acid–base reactions

[1] A Brønsted–Lowry acid donates a proton to a Brønsted–Lowry base (2.2).



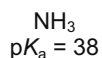
[2] A Lewis base donates an electron pair to a Lewis acid (2.8).



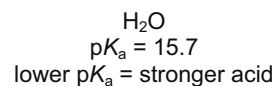
- Electron-rich species react with electron-poor ones.
- Nucleophiles react with electrophiles.

Important facts

- Definition: $\text{p}K_{\text{a}} = -\log K_{\text{a}}$. The lower the $\text{p}K_{\text{a}}$, the stronger the acid (2.3).

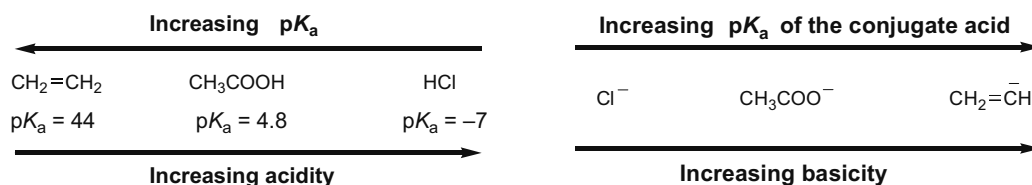


versus

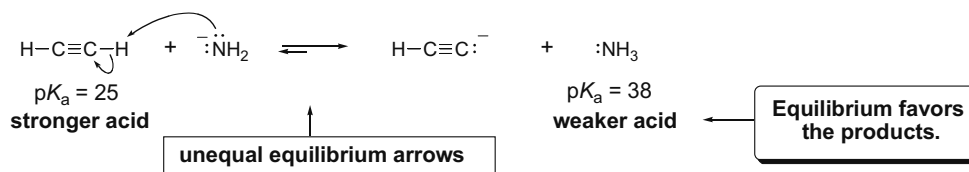


Chapter 2-2

- The stronger the acid, the weaker the conjugate base (2.3).



- In proton transfer reactions, equilibrium favors the weaker acid and the weaker base (2.4).

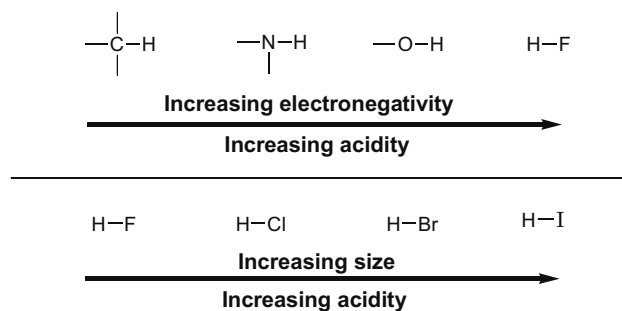


- An acid can be deprotonated by the conjugate base of any acid having a **higher** pK_a (2.4).

Acid	pK_a	Conjugate base
$\text{CH}_3\text{COO}-\text{H}$	4.8	CH_3COO^-
$\text{CH}_3\text{CH}_2\text{O}-\text{H}$	16	$\text{CH}_3\text{CH}_2\text{O}^-$
$\text{HC}\equiv\text{CH}$	25	$\text{HC}\equiv\text{C}^-$
$\text{H}-\text{H}$	35	H^-
higher pK_a than $\text{CH}_3\text{COO}-\text{H}$		These bases can deprotonate $\text{CH}_3\text{COO}-\text{H}$.

Factors that determine acidity (2.5)**[1] Element effects (2.5A)**

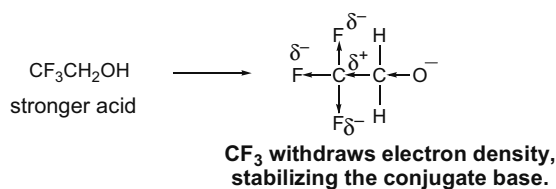
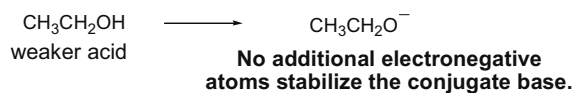
The acidity of $\text{H}-\text{A}$ increases both left to right across a row and down a column of the periodic table.



Acids and Bases 2-3

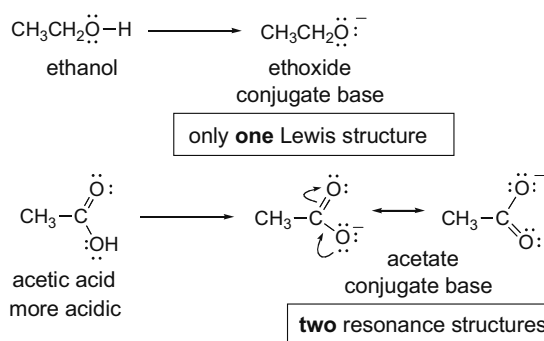
[2] Inductive effects (2.5B)

The acidity of H-A increases with the presence of electron-withdrawing groups in A.



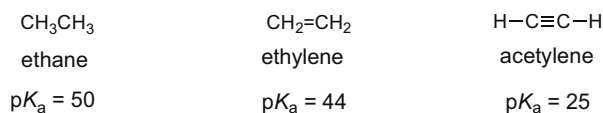
[3] Resonance effects (2.5C)

The acidity of H-A increases when the conjugate base A:⁻ is resonance stabilized.



[4] Hybridization effects (2.5D)

The acidity of H-A increases as the percent s-character of the A:⁻ increases.




 Increasing acidity

Chapter 2-4

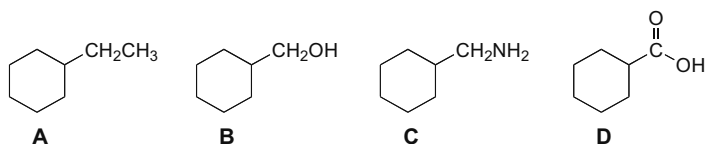
Practice Test on Chapter Review

1. a Given the pK_a data, which of the following bases is strong enough to deprotonate C_6H_5OH ($pK_a = 10$) so that the equilibrium lies to the right?

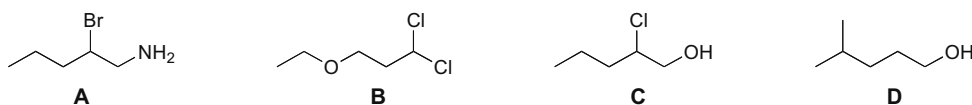
Compound	pK_a	
H_3O^+	-1.7	1. NaOH
NH_4^+	9.4	2. $NaNH_2$
H_2O	15.7	3. NH_3
NH_3	38	4. Compounds (1) and (2) are strong enough to deprotonate C_6H_5OH .
		5. Compounds (1), (2), and (3) are all strong enough to deprotonate C_6H_5OH .

- b. Which of the following statements is true about pK_a , acidity, and basicity?
1. A higher pK_a means the acid is less acidic.
 2. In an acid-base reaction, the equilibrium lies on the side of the acid with the higher pK_a .
 3. A lower pK_a value for the acid means the conjugate base is more basic.
 4. Statements (1) and (2) are both true.
 5. Statements (1), (2), and (3) are all true.
- c. Which of the following species can be Lewis acids?
1. BCl_3
 2. CH_3OH
 3. $(CH_3)_3C^+$
 4. Both (1) and (2) can be Lewis acids.
 5. Species (1), (2), and (3) can all be Lewis acids.

2. Answer the following questions about compounds **A–D**.

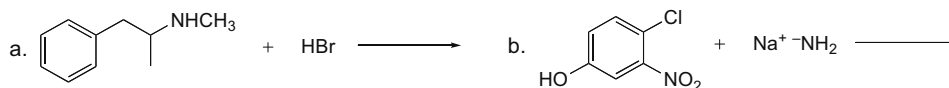


- Which compound is the strongest acid?
 - Which compound forms the strongest conjugate base?
 - The conjugate base of **C** is strong enough to remove a proton on which compound(s) such that the equilibrium favors the products?
3. (a) Which compound is the strongest Brønsted–Lowry acid? (b) Which compound is the weakest Brønsted–Lowry acid?

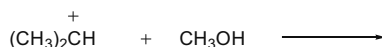


Acids and Bases 2–5

4. Draw all the products formed in the following reactions.



5. Draw the product(s) formed in the following Lewis acid–base reaction.

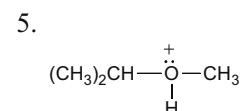
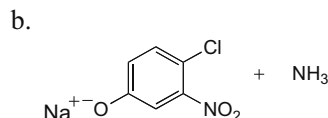
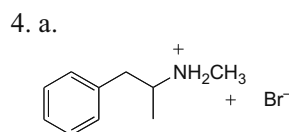


Answers to Practice Test

1. a. 4
b. 4
c. 5

2. a. **D**
b. **A**
c. **B, D**

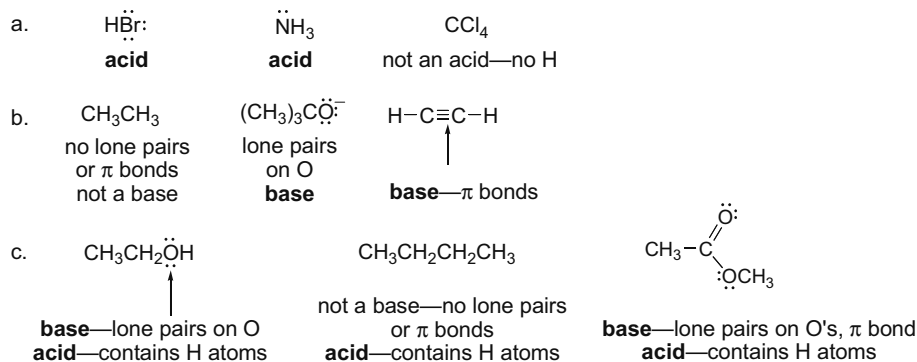
3. a. **C**
b. **B**



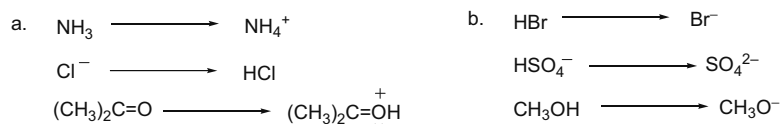
Answers to Problems

2.1 Brønsted–Lowry acids are **proton donors** and must contain a hydrogen atom.

Brønsted–Lowry bases are **proton acceptors** and must have an available electron pair (either a lone pair or a π bond).

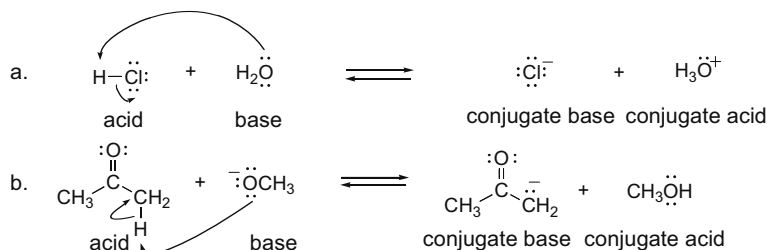


2.2 A Brønsted–Lowry base accepts a proton to form the conjugate acid. A Brønsted–Lowry acid loses a proton to form the conjugate base.



Chapter 2-6

2.3 The Brønsted–Lowry base accepts a proton to form the conjugate acid. The Brønsted–Lowry acid loses a proton to form the conjugate base. Use curved arrows to show the movement of electrons (**NOT protons**). Re-draw the starting materials if necessary to clarify the electron movement.

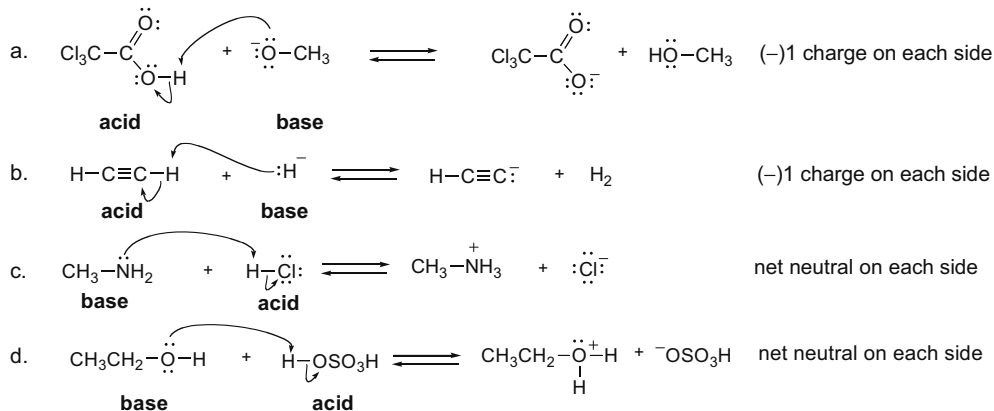


2.4 To draw the products:

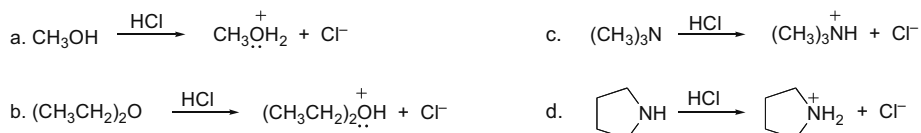
[1] Find the acid and base.

[2] Transfer a proton from the acid to the base.

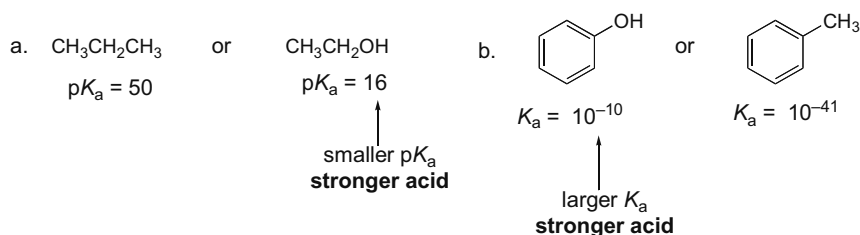
[3] Check that the charges on each side of the arrows are balanced.



2.5 Draw the products in each reaction as in Answer 2.4.

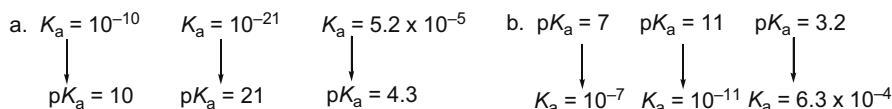


2.6 The smaller the $\text{p}K_a$, the stronger the acid. The larger the K_a , the stronger the acid.

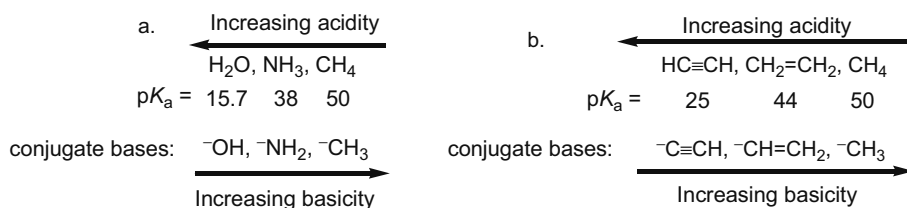


Acids and Bases 2-7

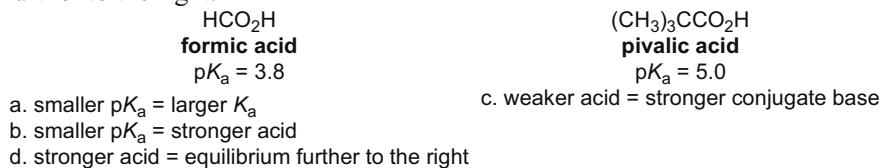
- 2.7 To convert from K_a to pK_a , take $(-)$ the log of the K_a ; $pK_a = -\log K_a$.
To convert pK_a to K_a , take the antilog of $(-)$ the pK_a .



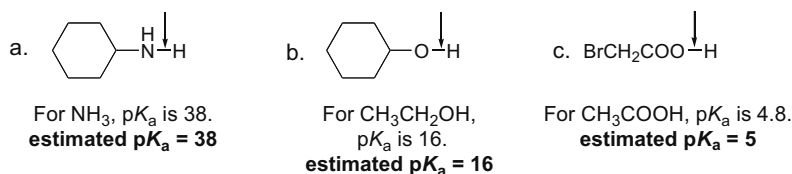
- 2.8 Since **strong acids form weak conjugate bases**, the basicity of conjugate bases increases with increasing pK_a of their acids. Find the pK_a of each acid from Table 2.1 and then rank the acids in order of increasing pK_a . This will also be the order of increasing basicity of their conjugate bases.



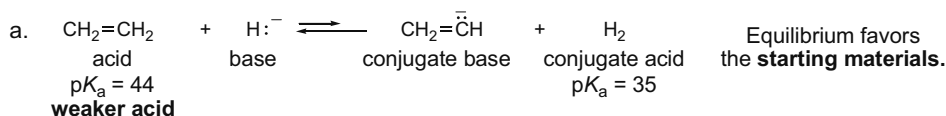
- 2.9 Use the definitions in Answer 2.8 to compare the acids. The smaller the pK_a , the larger the K_a and the stronger the acid. When a stronger acid dissolves in water, the equilibrium lies further to the right.



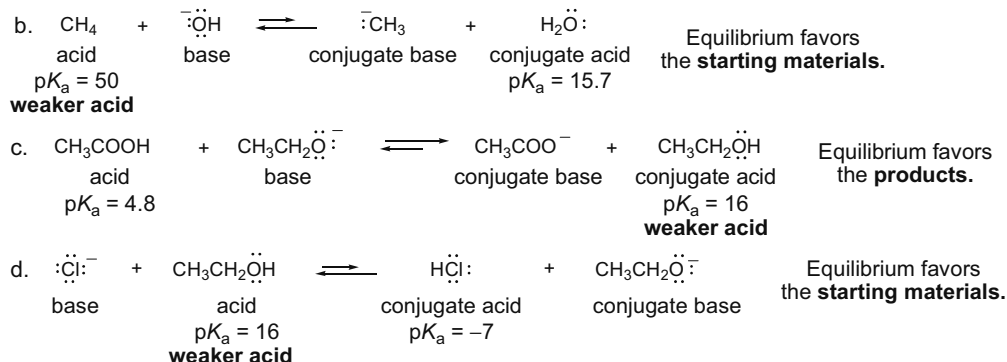
- 2.10 To estimate the pK_a of the indicated bond, find a similar bond in the pK_a table (H bonded to the same atom with the same hybridization).



- 2.11 Label the acid and the base and then transfer a proton from the acid to the base. To determine if the reaction will proceed as written, compare the pK_a of the acid on the left with the conjugate acid on the right. **The equilibrium always favors the formation of the weaker acid and the weaker base.**



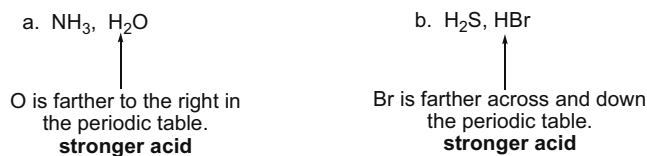
Chapter 2-8



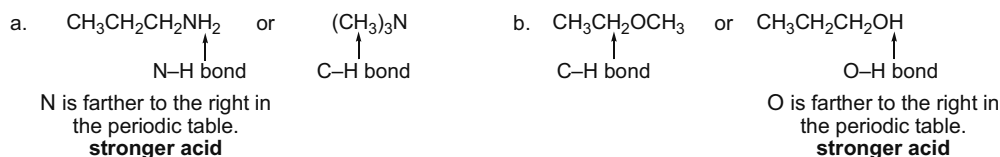
2.12 An acid can be deprotonated by the conjugate base of any acid with a higher pK_a .

CH_3CN $pK_a = 25$ Any base having a conjugate acid with a pK_a higher than 25 can deprotonate this acid.	Base NaH Na ₂ CO ₃ NaOH NaNH ₂ NaHCO ₃	Conjugate acid H ₂ HCO ₃ ⁻ H ₂ O NH ₃ H ₂ CO ₃	pK_a 35 10.2 15.7 38 6.4	Only NaH and NaNH ₂ are strong enough to deprotonate acetonitrile.

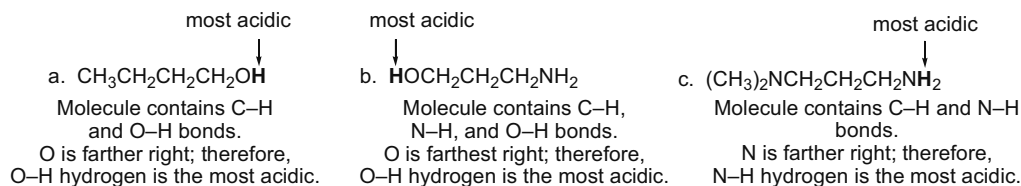
2.13 The acidity of H-Z increases left to right across a row and down a column of the periodic table.



2.14 Compare the most acidic protons in each compound to determine the stronger acid.

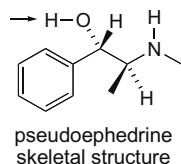


2.15 Look at the element bonded to the acidic H and decide its acidity based on the periodic trends. **Farther to the right and down the periodic table is more acidic.**



Acids and Bases 2-9

- 2.16 The acidity of HA increases left to right across the periodic table. Pseudoephedrine contains C-H, N-H, and O-H bonds. The O-H bond is most acidic.



- 2.17 **More electronegative atoms stabilize the conjugate base, making the acid stronger.**
Compare the electron-withdrawing groups on the acids below to decide which is a stronger acid (**more electronegative groups = more acidic**).

a. ClCH_2COOH or FCH_2COOH
more acidic
F is more electronegative than Cl, making the O-H bond in the acid on the right **more acidic**.

c. CH_3COOH or $\text{O}_2\text{NCH}_2\text{COOH}$
more acidic
 NO_2 is electron withdrawing, making the O-H bond in the acid on the right **more acidic**.

b. $\text{Cl}_2\text{CHCH}_2\text{OH}$ or $\text{Cl}_2\text{CHCH}_2\text{CH}_2\text{OH}$
Cl is closer to the acidic O-H bond. **more acidic**
Cl is farther from the O-H bond.

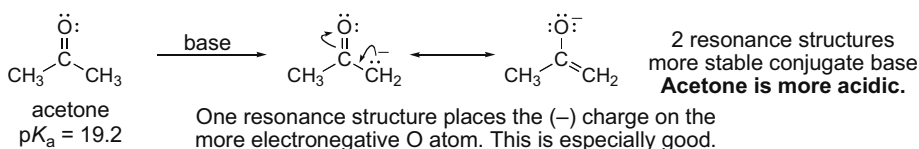
- 2.18 **More electronegative groups stabilize the conjugate base, making the acid stronger.**

$\downarrow$
 $\text{HOCH}_2\text{CO}_2\text{H}$
an α -hydroxy acid
The extra OH group contains an electronegative O, which stabilizes the conjugate base.
stronger acid

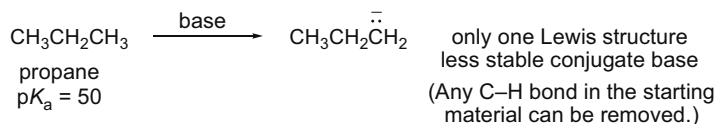
$\text{CH}_3\text{CO}_2\text{H}$
acetic acid

- 2.19 HBr is a stronger acid than HCl because Br is farther down a column of the periodic table, and the larger Br^- anion is more stable than the smaller Cl^- anion. In these acids the H is bonded directly to the halogen. In HOCl and HOBr, the H is bonded to O, and the halogens Cl and Br exert an inductive effect. In this case, the more electronegative Cl stabilizes ^-OCl more than the less electronegative Br stabilizes ^-OBr . Thus, HOCl forms the more stable conjugate base, making it the stronger acid.

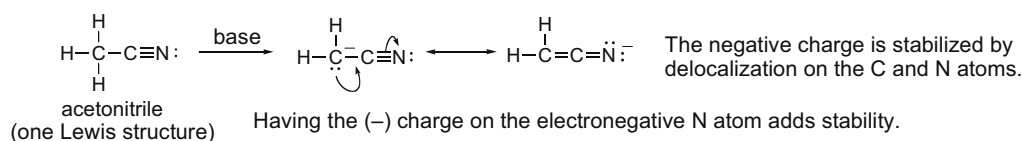
- 2.20 The acidity of an acid increases when the conjugate base is resonance stabilized. Compare the conjugate bases of acetone and propane to explain why acetone is more acidic.



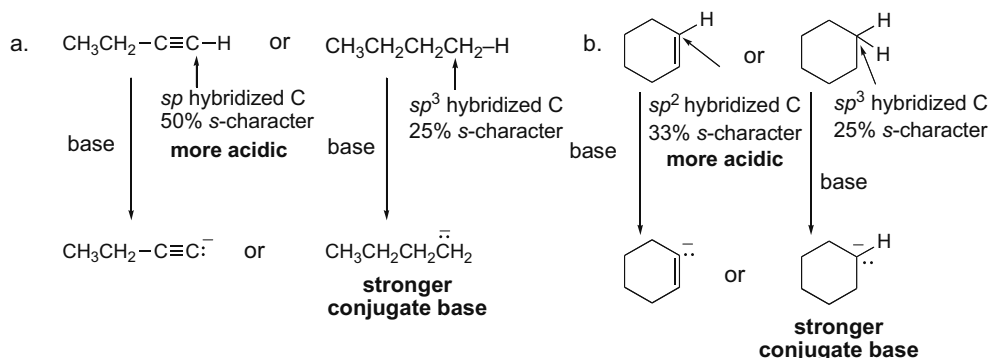
Chapter 2-10



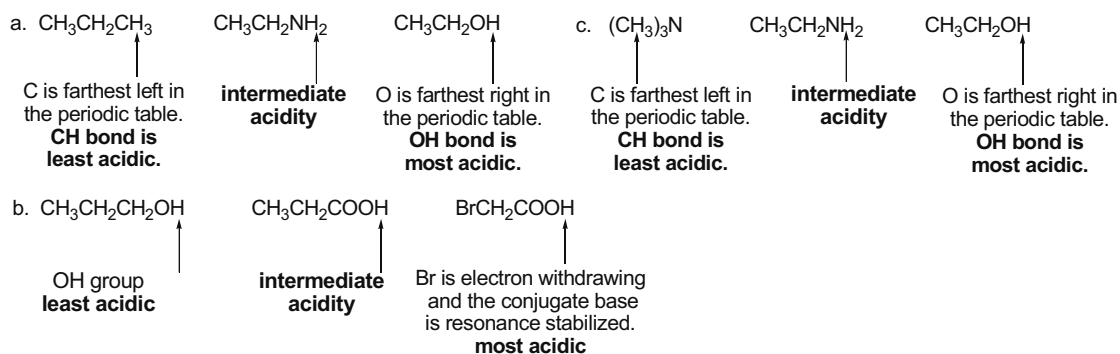
2.21 The acidity of an acid increases when the conjugate base is resonance stabilized. Acetonitrile has a resonance-stabilized conjugate base, which accounts for its acidity.



2.22 Increasing percent s-character makes an acid more acidic. Compare the percent s-character of the carbon atoms in each of the C-H bonds in question. A stronger acid has a weaker conjugate base.

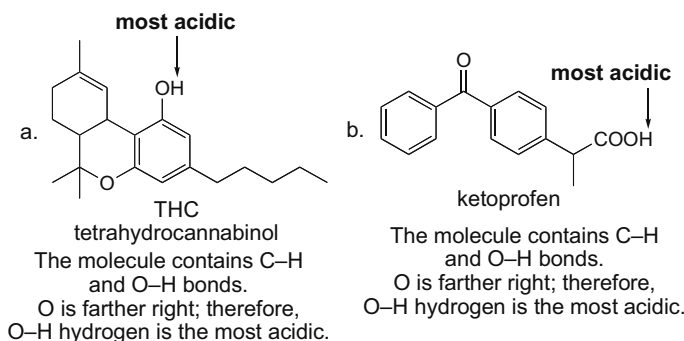


2.23 To compare the acids, first **look for element effects**. Then identify electron-withdrawing groups, resonance, or hybridization differences.

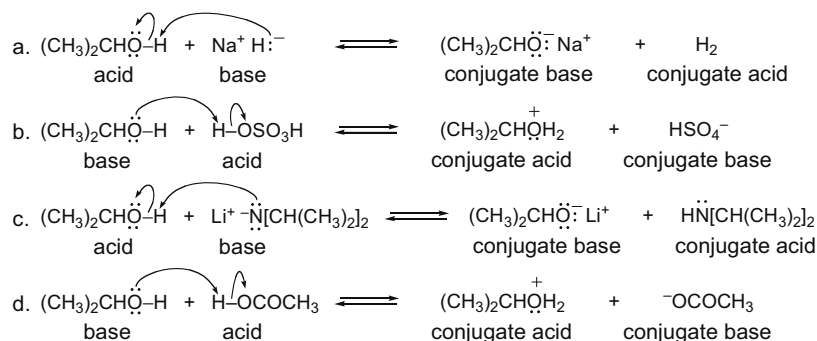


Acids and Bases 2-11

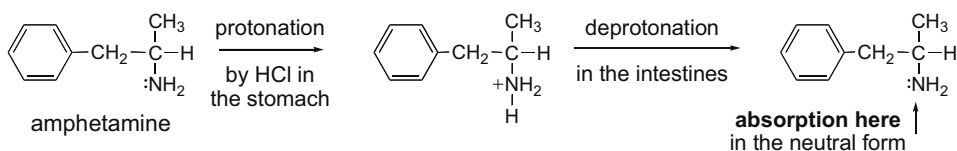
- 2.24** Look at the element bonded to the acidic H and decide its acidity based on the periodic trends. **Farther to the right and down the periodic table is more acidic.**



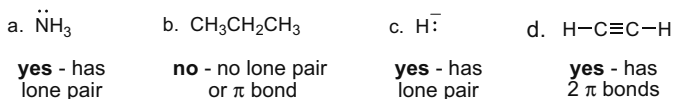
- 2.25** Draw the products of proton transfer from the acid to the base.



- 2.26** To cross a cell membrane, amphetamine must be in its neutral (not ionic) form.



- 2.27** **Lewis bases are electron pair donors:** they contain a lone pair or a π bond.

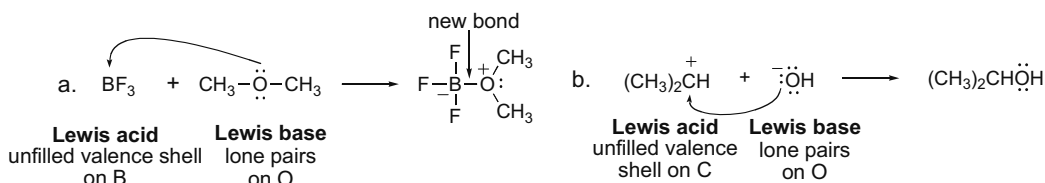


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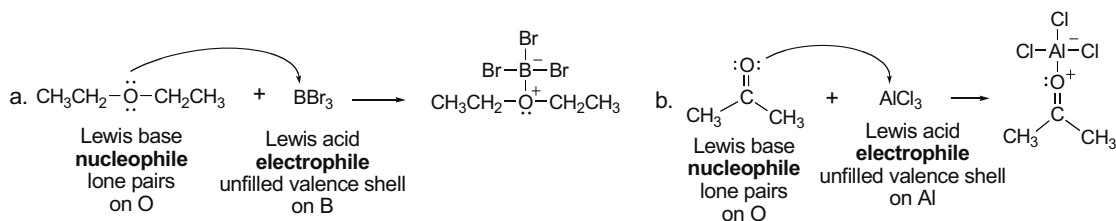
2.28 Lewis acids are electron pair acceptors. Most Lewis acids contain a proton or an unfilled valence shell of electrons.

a. BBr_3	b. $\text{CH}_3\text{CH}_2\text{OH}$	c. $(\text{CH}_3)_3\text{C}^+$	d. Br^-
yes unfilled valence shell on B	yes contains a proton	yes unfilled valence shell on C	no no proton no unfilled valence shell

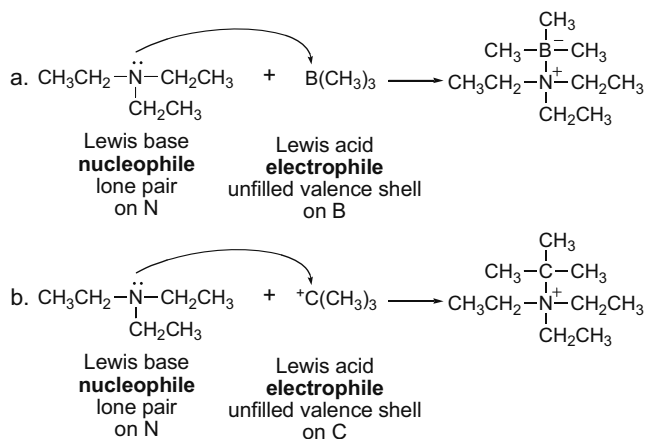
2.29 Label the Lewis acid and Lewis base and then draw the curved arrows.



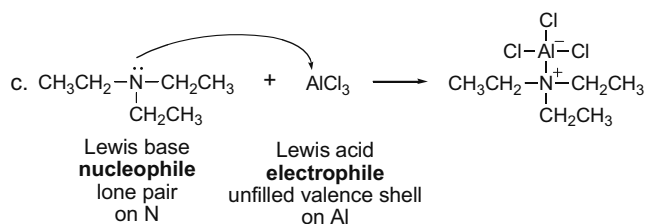
2.30 A Lewis acid is also called an **electrophile**. When a Lewis base reacts with an electrophile other than a proton, it is called a **nucleophile**. Label the electrophile and nucleophile in the starting materials and then draw the products.



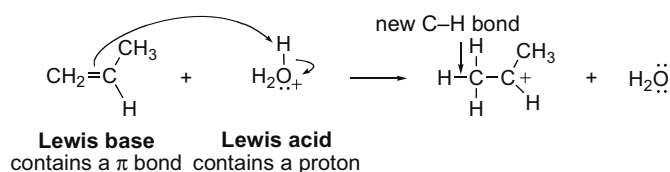
2.31 Draw the product of each reaction by using an electron pair of the Lewis base to form a new bond to the Lewis acid.



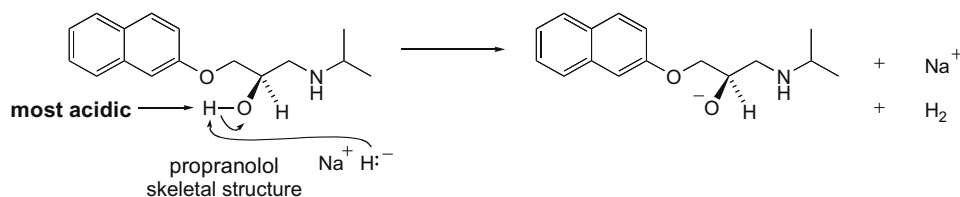
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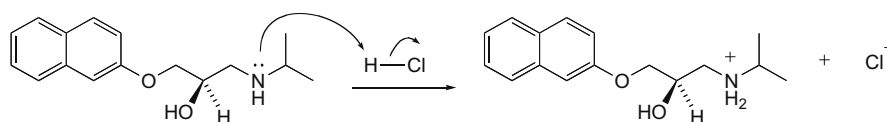
2.32 Curved arrows begin at the Lewis base and point towards the Lewis acid.



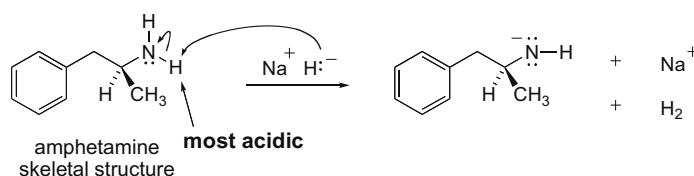
2.33 a, b. Since acidity increases from left to right across a row of the periodic table and propranolol has C-H, N-H, and O-H bonds, the O-H bond is most acidic. NaH is a base and removes the most acidic OH proton.



c, d. Of the atoms with lone pairs (N and O), N is to the left in the periodic table, making it the most basic site. HCl is an acid, which protonates the most basic site.

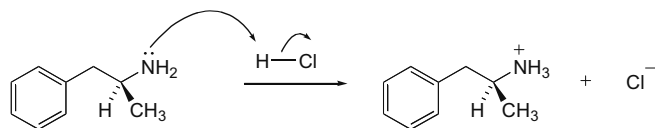


2.34 a, b. Using periodic trends, the N-H bond of amphetamine is most acidic. NaH is a base that removes a proton on N.

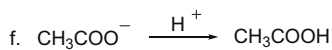
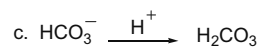
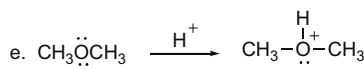
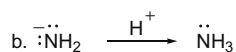
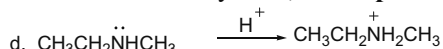
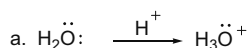


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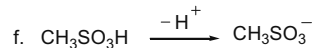
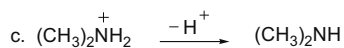
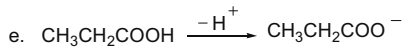
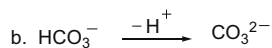
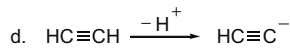
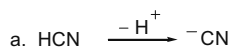
c. HCl protonates the lone pair on N.



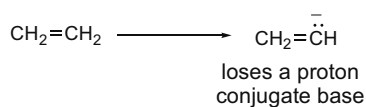
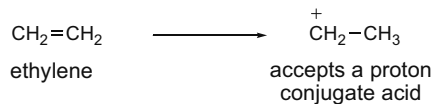
2.35 To draw the conjugate acid of a Brønsted–Lowry base, **add a proton to the base**.



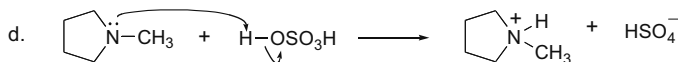
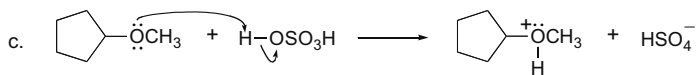
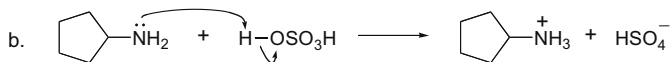
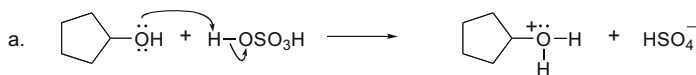
2.36 To draw the conjugate base of a Brønsted–Lowry acid, **remove a proton from the acid**.



2.37 Use the definitions from Answer 2.2.

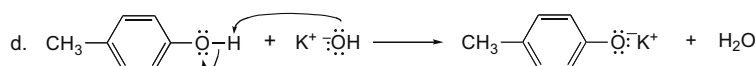
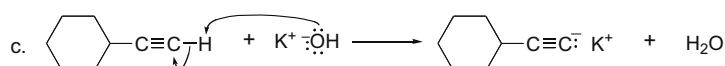
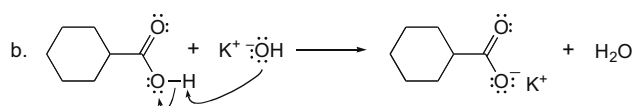
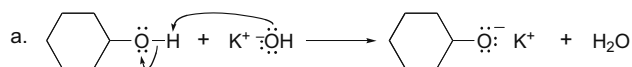


2.38 To draw the products of an acid–base reaction, transfer a proton from the acid (H_2SO_4 in this case) to the base.

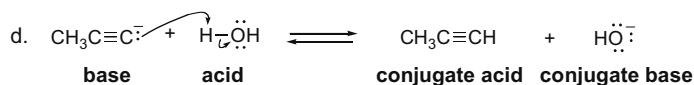
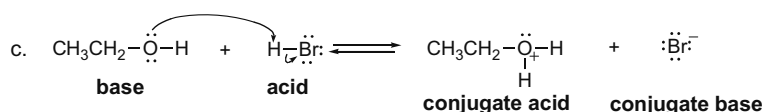
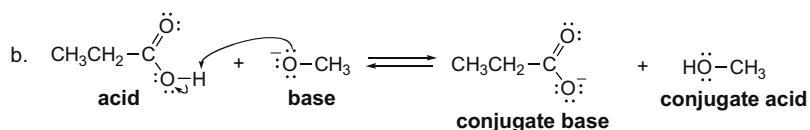
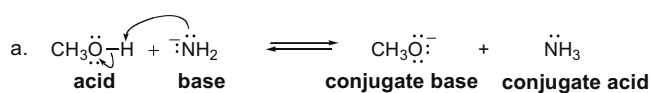


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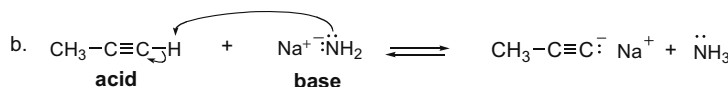
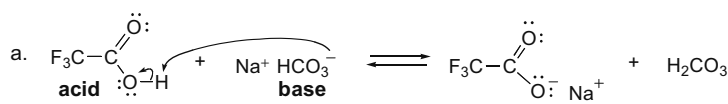
2.39 To draw the products of an acid–base reaction, transfer a proton from the acid to the base (OH in this case).



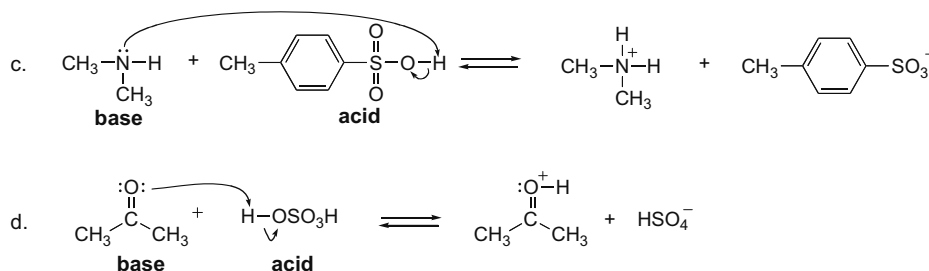
2.40 Label the Brønsted–Lowry acid and Brønsted–Lowry base in the starting materials and transfer a proton from the acid to the base for the products.



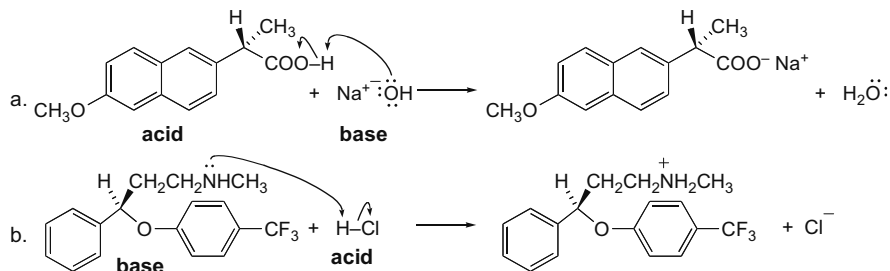
2.41 Label the acid and base in the starting materials and then draw the products of proton transfer from acid to base.



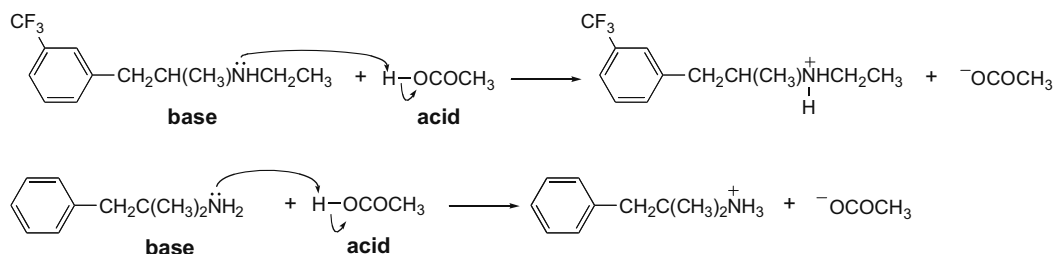
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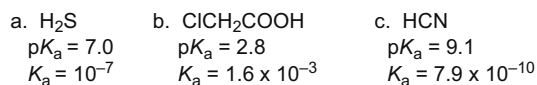
2.42 Draw the products of proton transfer from acid to base.



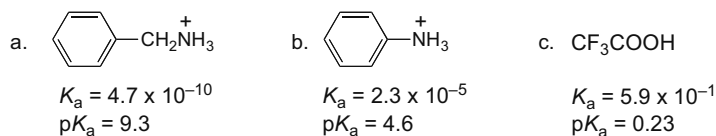
2.43 Draw the products of proton transfer from acid to base.



2.44 To convert pK_a to K_a , take the antilog of $(-)$ the pK_a .



2.45 To convert from K_a to pK_a , take $(-)$ the log of the K_a ; $pK_a = -\log K_a$.



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2.46 An acid can be deprotonated by the conjugate base of any acid with a higher pK_a .

$\text{CH}_3\text{CH}_2\text{CH}_2\text{C}\equiv\text{CH}$
 $pK_a = 25$
 Any base having a conjugate acid with a pK_a higher than 25 can deprotonate this acid.

Base	Conjugate acid	pK_a
H_2O	H_3O^+	-1.7
NaOH	H_2O	15.7
NaNH_2	NH_3	38
NH_3	NH_4^+	9.4
NaH	H_2	35
CH_3Li	CH_4	50

Only NaNH_2 , NaH , and CH_3Li are strong enough to deprotonate the acid.

2.47 ^-OH can deprotonate any acid with a $pK_a < 15.7$.

a. HCOOH

$pK_a = 3.8$
 stronger acid
 deprotonated

b. H_2S

$pK_a = 7.0$
 stronger acid
 deprotonated

c. 

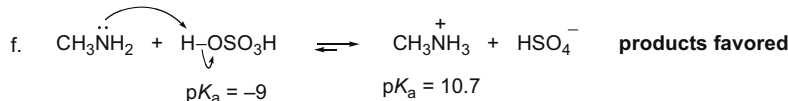
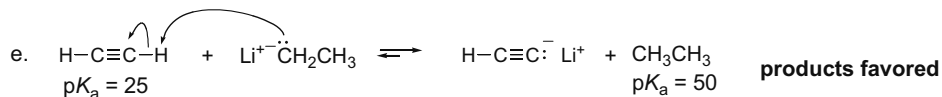
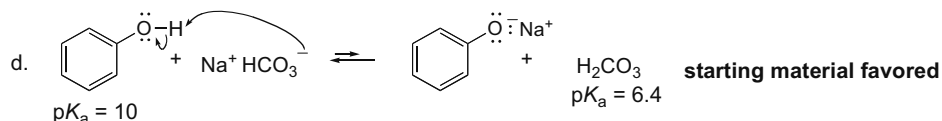
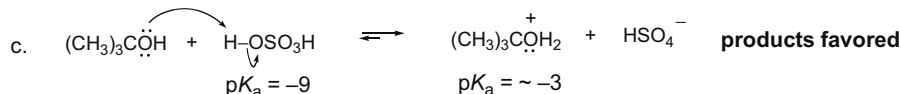
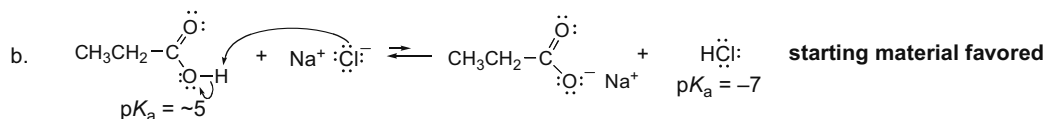
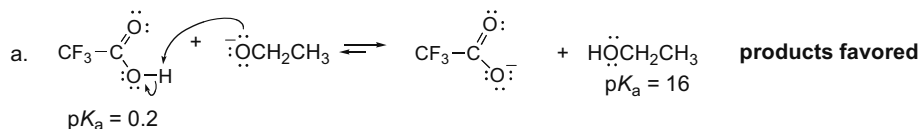
$pK_a = 41$
 weaker acid

d. CH_3NH_2

$pK_a = 40$
 weaker acid

These acids are too weak to be deprotonated by ^-OH .

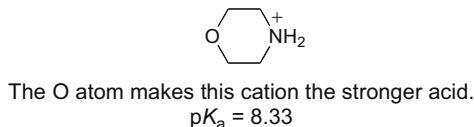
2.48 Draw the products and then compare the pK_a of the acid on the left and the conjugate acid on the right. **The equilibrium lies towards the side having the acid with a higher pK_a (weaker acid).**



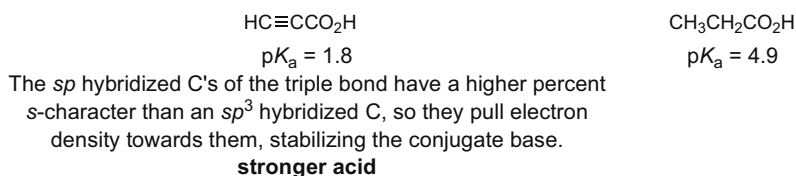
2.49 Compare element effects first and then resonance, hybridization, and electron-withdrawing groups to determine the relative strengths of the acids.

- 2.50** The strongest acid has the weakest conjugate base.

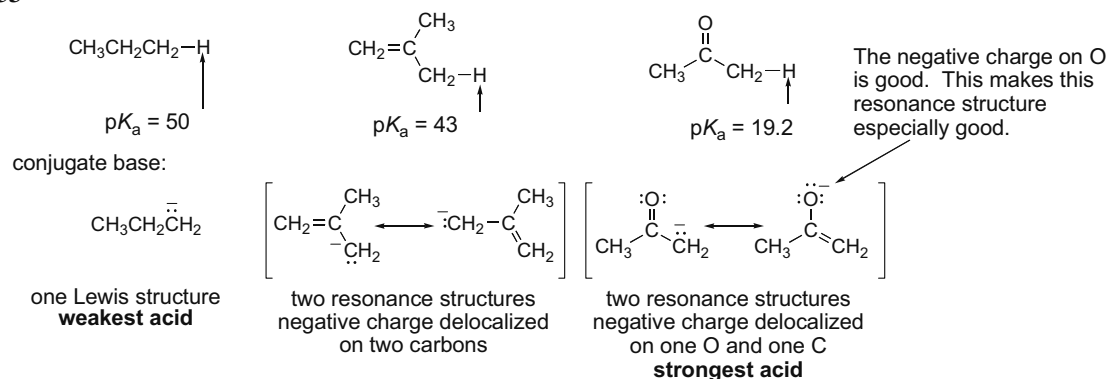
- 2.51 More electronegative atoms stabilize the conjugate base by an electron-withdrawing inductive effect, making the acid stronger.** Thus, an O atom increases the acidity of an acid.



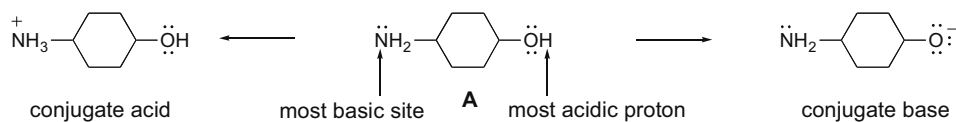
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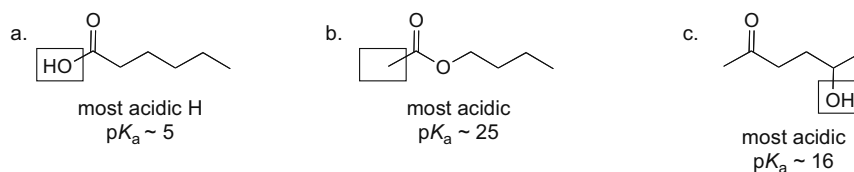
2.53



2.54 To draw the conjugate acid, look for the most basic site and protonate it. To draw the conjugate base, look for the most acidic site and remove a proton.

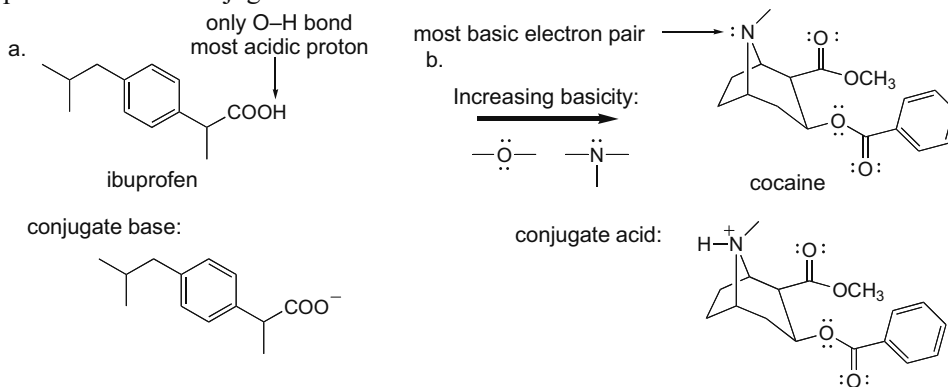


2.55 Estimate the pK_a of **B** as 16. A difference of 10^5 in acidity is a difference of 5 pK_a units.

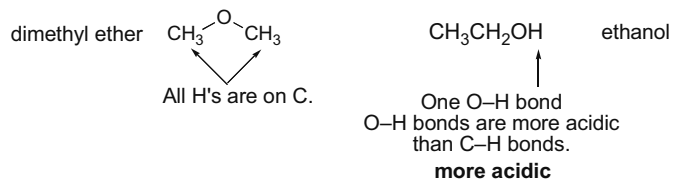


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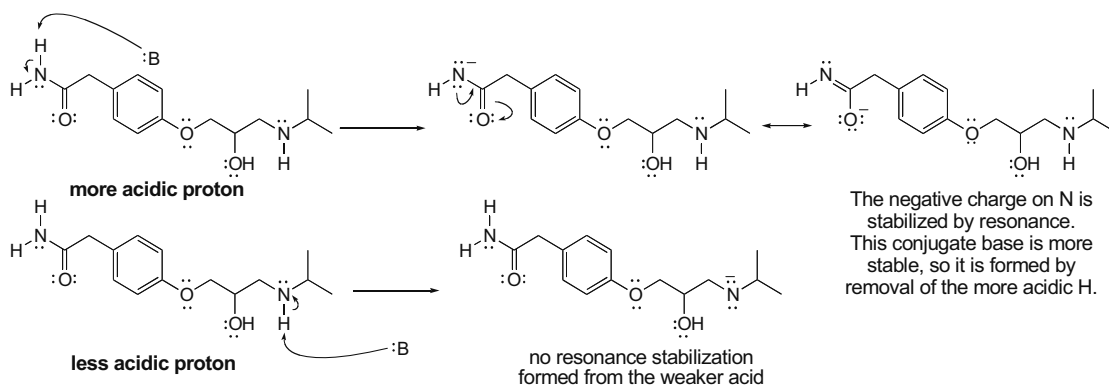
2.56 Remove the most acidic proton to form the conjugate base. Protonate the most basic electron pair to form the conjugate acid.



2.57 Compare the isomers.

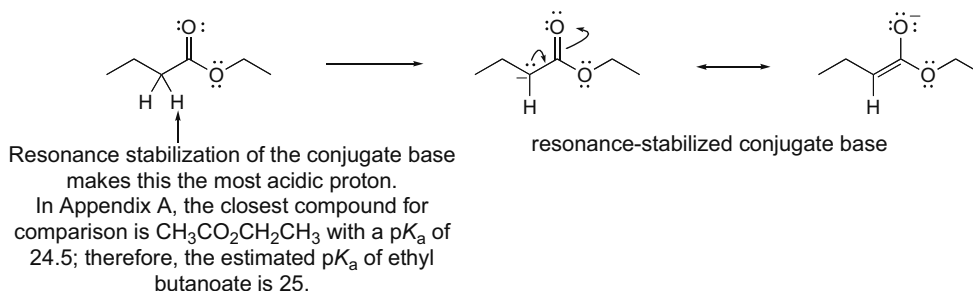


2.58 Compare the Lewis structures of the conjugate bases when each H is removed. The more stable base makes the proton more acidic.

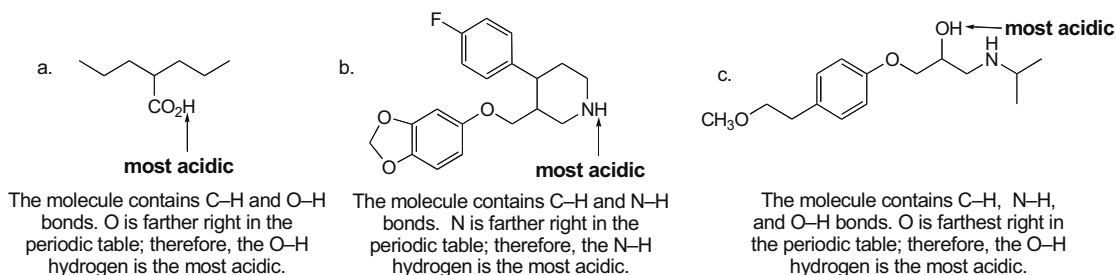


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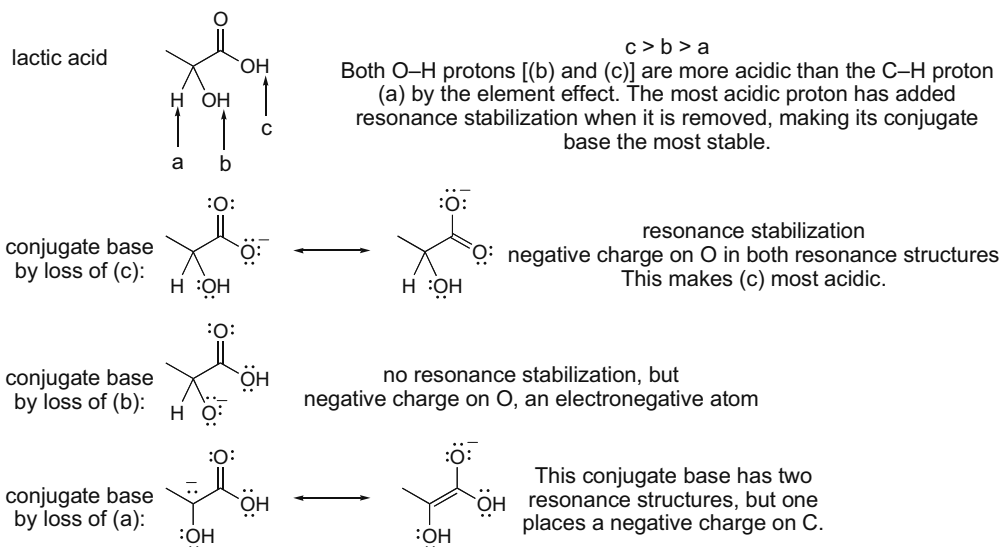
2.59 Draw the conjugate base to determine the most acidic hydrogen.



2.60 Look at the element bonded to the acidic H and decide its acidity based on the periodic trends. **Farther to the right across a row and down a column of the periodic table is more acidic.**

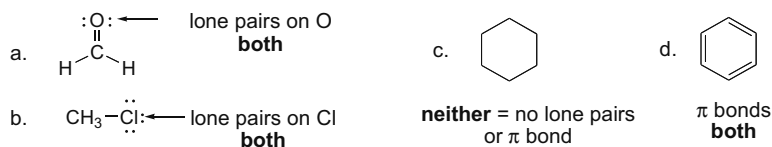


2.61 Use element effects, inductive effects, and resonance to determine which protons are the most acidic. The H's of the CH_3 group are least acidic since they are bonded to an sp^3 hybridized C and the conjugate base formed by their removal is not resonance stabilized.

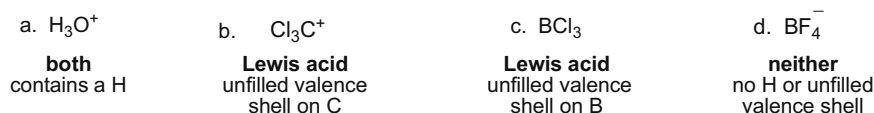


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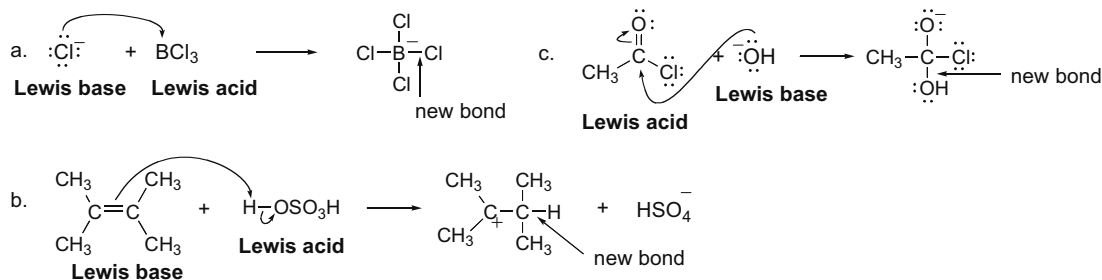
2.62 Lewis bases are electron pair donors: they contain a lone pair or a π bond. **Brønsted–Lowry bases are proton acceptors:** to accept a proton they need a lone pair or a π bond. This means Lewis bases are also Brønsted–Lowry bases.



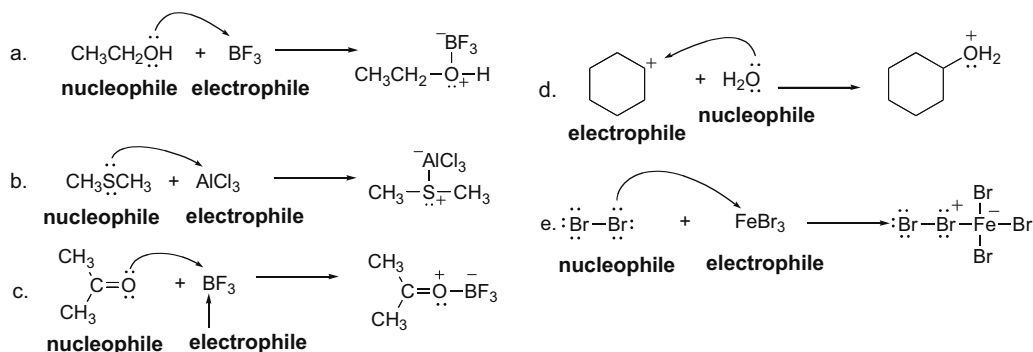
2.63 A Lewis acid is an electron pair acceptor and usually contains a proton or an unfilled valence shell of electrons. A **Brønsted–Lowry acid is a proton donor** and must contain a hydrogen atom. All Brønsted–Lowry acids are Lewis acids, though the reverse may not be true.



2.64 Label the Lewis acid and Lewis base and then draw the products.

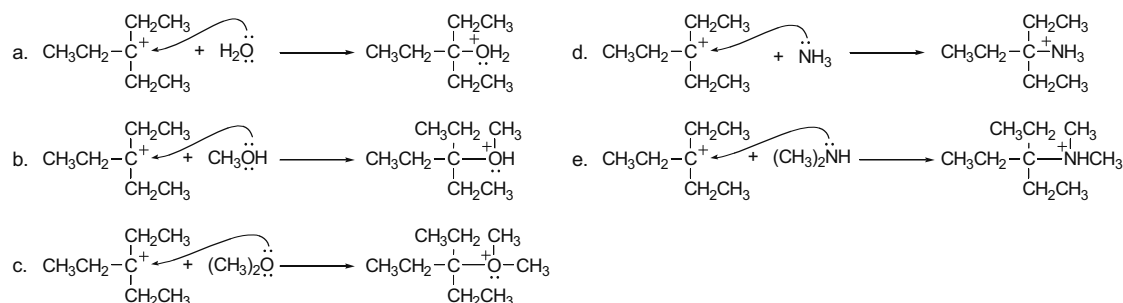


2.65 A Lewis acid is also called an electrophile. When a Lewis base reacts with an electrophile other than a proton, it is called a **nucleophile**. Label the electrophile and nucleophile in the starting materials and then draw the products.

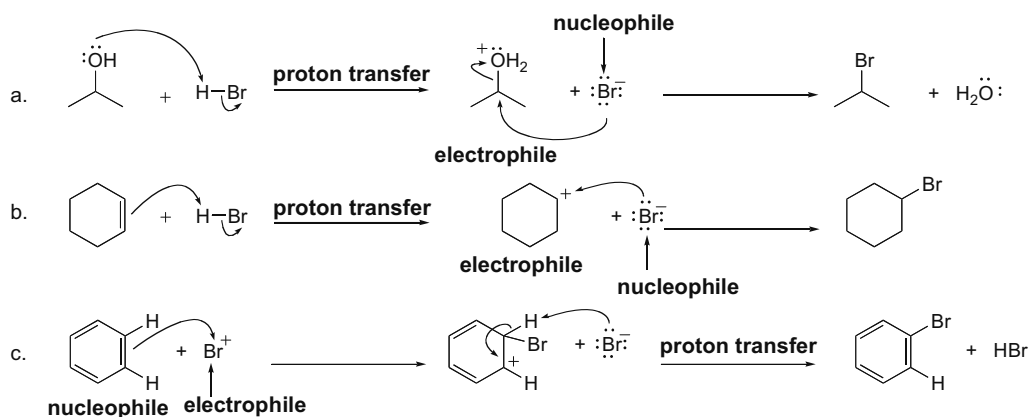
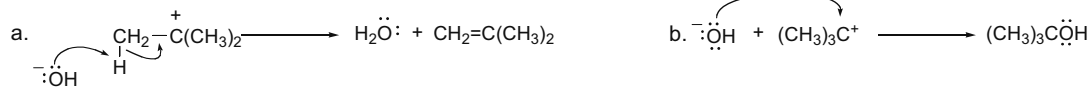


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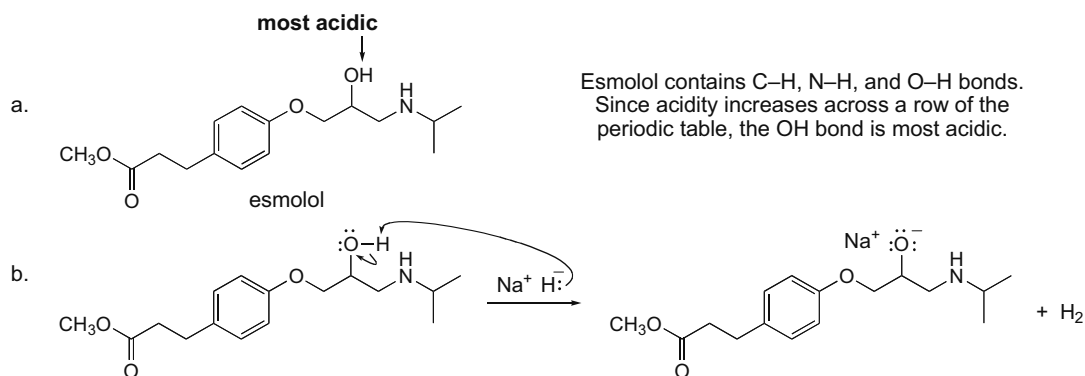
2.66 Draw the product of each reaction.



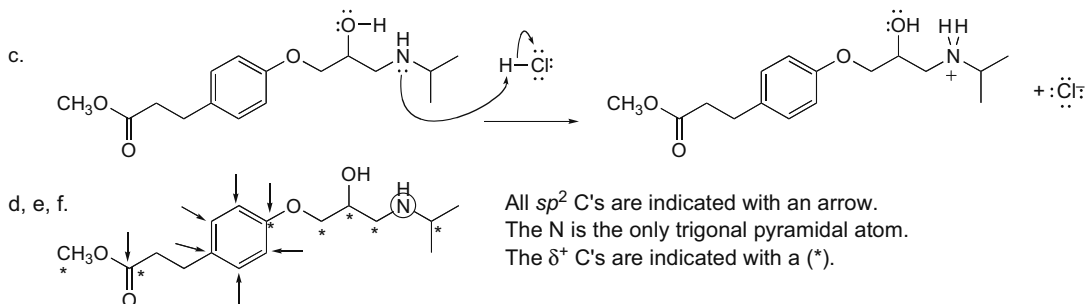
2.67

2.68 Draw the products of each reaction. In part (a), OH^- pulls off a proton and thus acts as a Brønsted-Lowry base. In part (b), OH^- attacks a carbon and thus acts as a Lewis base.

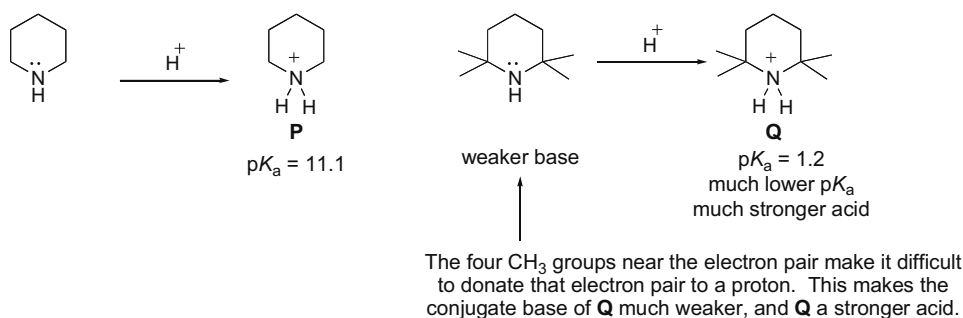
2.69 Answer each question about esmolol.



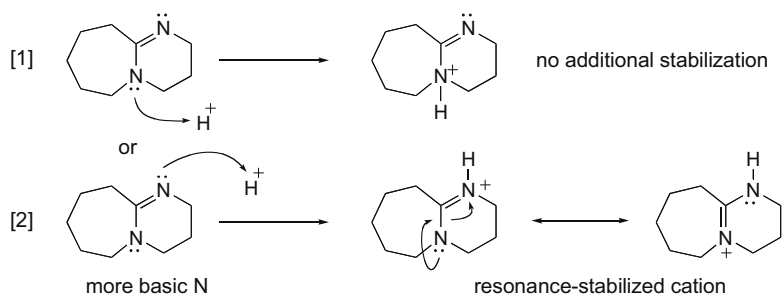
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2.70

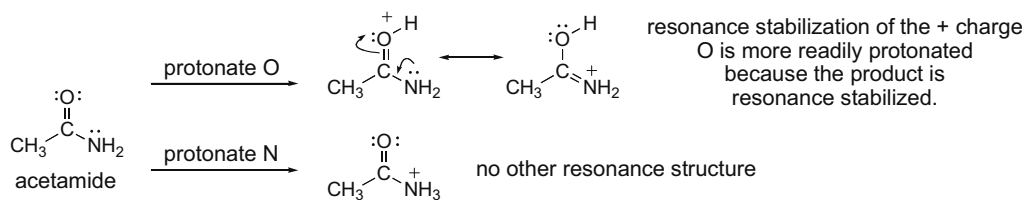


2.71



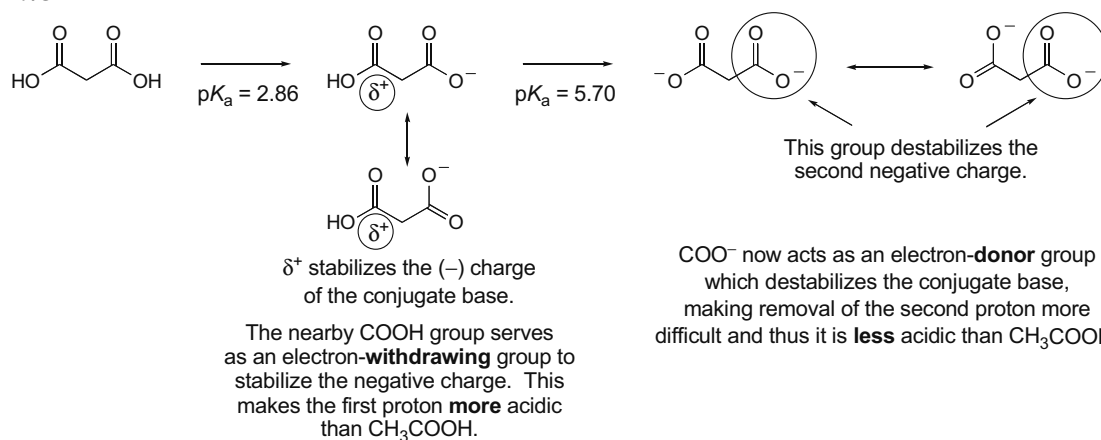
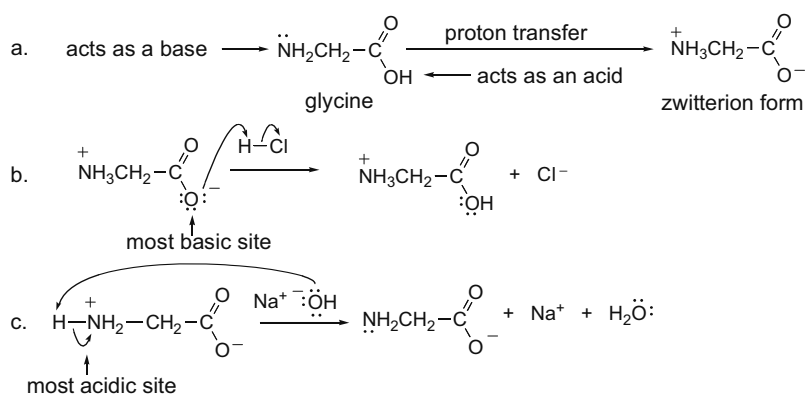
Path [2] is favored because a resonance-stabilized conjugate acid is formed. The N that is part of the $C=N$ is therefore more basic.

2.72 Draw the product of protonation of either O or N and compare the conjugate acids. When acetamide reacts with an acid, the O atom is protonated because it results in a resonance-stabilized conjugate acid.

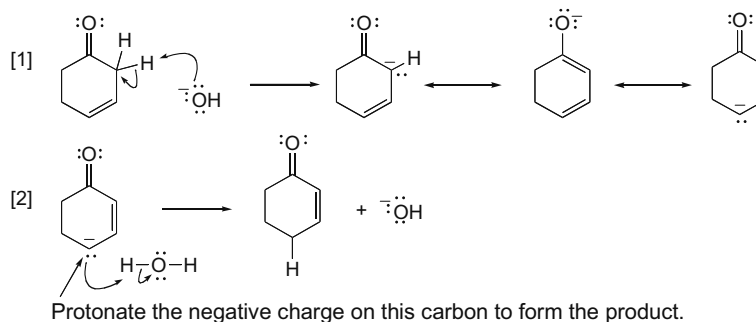


Acids and Bases 2-25

2.73

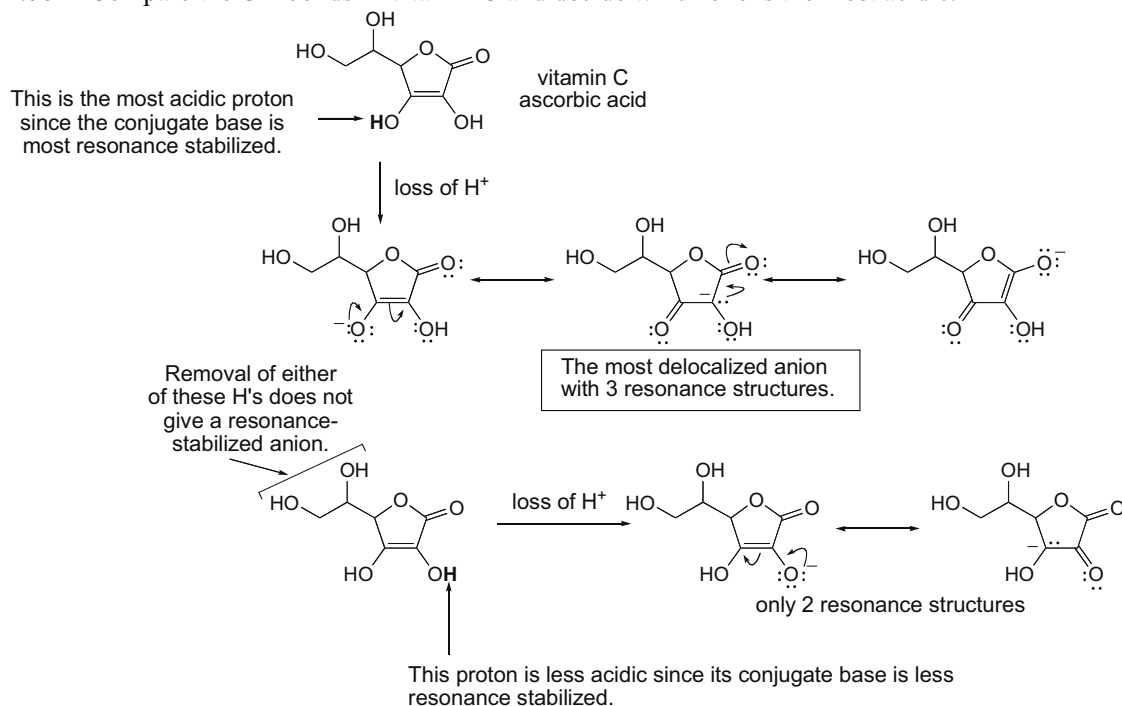
2.74 The COOH group of glycine gives up a proton to the basic NH_2 group to form the zwitterion.

2.75 Use curved arrows to show how the reaction occurs.

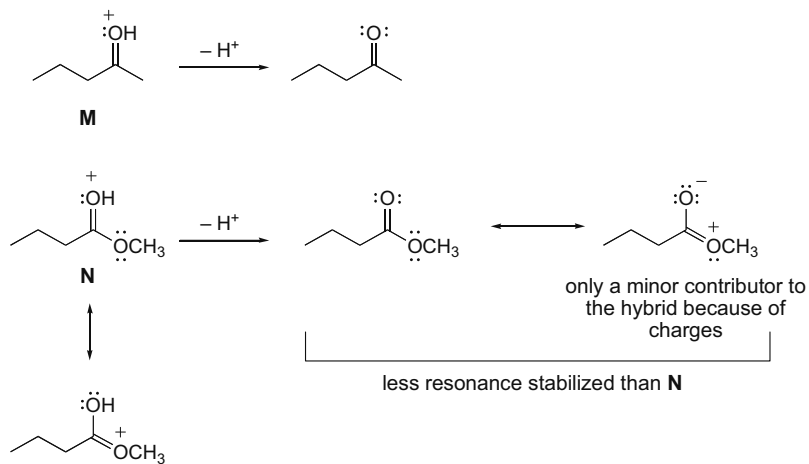


Chapter 2-26

2.76 Compare the OH bonds in vitamin C and decide which one is the most acidic.



2.77



N has two resonance structures with the same number of bonds and charges, so both contribute approximately equally to the hybrid. This makes **N** more resonance stabilized than its conjugate base, and less willing to give up a proton than **M**, which has no similar resonance stabilization. Thus **M** is a stronger acid than **N**. (Resonance structures that break the $\text{C}=\text{O}$ bond are not drawn in this solution, since they are possible for each compound.)

Introduction to Organic Molecules and Functional Groups 3–1

Chapter 3 Introduction to Organic Molecules and Functional Groups

Chapter Review

Types of intermolecular forces (3.3)

	Type of force	Cause	Examples
	van der Waals (VDW)	Due to the interaction of temporary dipoles • Larger surface area, stronger forces • Larger, more polarizable atoms, stronger forces	All organic compounds
	dipole–dipole (DD)	Due to the interaction of permanent dipoles	(CH ₃) ₂ C=O, H ₂ O
	hydrogen bonding (HB or H-bonding)	Due to the electrostatic interaction of a H atom in an O–H, N–H, or H–F bond with another N, O, or F atom.	H ₂ O
	ion–ion	Due to the interaction of two ions	NaCl, LiF

Physical properties

Property	Observation												
Boiling point (3.4A)	For compounds of comparable molecular weight, the stronger the forces the higher the bp.<table><tr><td>$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$</td><td>$\text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}$</td><td>$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$</td></tr><tr><td>VDW</td><td>VDW, DD</td><td>VDW, DD, HB</td></tr><tr><td>MW = 72</td><td>MW = 72</td><td>MW = 74</td></tr><tr><td>bp = 36 °C</td><td>bp = 76 °C</td><td>bp = 118 °C</td></tr></table> Increasing strength of intermolecular forces Increasing boiling point	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}$	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$	VDW	VDW, DD	VDW, DD, HB	MW = 72	MW = 72	MW = 74	bp = 36 °C	bp = 76 °C	bp = 118 °C
	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}$	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$										
	VDW	VDW, DD	VDW, DD, HB										
	MW = 72	MW = 72	MW = 74										
	bp = 36 °C	bp = 76 °C	bp = 118 °C										
For compounds with similar functional groups, the larger the surface area, the higher the bp.<table><tr><td>$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$</td><td>$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$</td></tr><tr><td>bp = 0 °C</td><td>bp = 36 °C</td></tr></table> Increasing surface area Increasing boiling point	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$	bp = 0 °C	bp = 36 °C									
$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$												
bp = 0 °C	bp = 36 °C												
For compounds with similar functional groups, the more polarizable the atoms, the higher the bp.<table><tr><td>CH_3F</td><td>CH_3I</td></tr><tr><td>bp = -78 °C</td><td>bp = 42 °C</td></tr></table> Increasing polarizability Increasing boiling point	CH_3F	CH_3I	bp = -78 °C	bp = 42 °C									
CH_3F	CH_3I												
bp = -78 °C	bp = 42 °C												

Chapter 3-2

Property	Observation							
Melting point (3.4B)	- For compounds of comparable molecular weight, the stronger the forces the higher the mp. <table><tr><td>$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$ VDW MW = 72 mp = -130°C</td><td>$\text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}$ VDW, DD MW = 72 mp = -96°C</td><td>$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$ VDW, DD, HB MW = 74 mp = -90°C</td></tr></table> $\xrightarrow{\hspace{10em}}$ Increasing strength of intermolecular forces Increasing melting point - For compounds with similar functional groups, the more symmetrical the compound, the higher the mp. <table><tr><td>$\text{CH}_3\text{CH}_2\text{CH}(\text{CH}_3)_2$ mp = -160°C</td><td>$(\text{CH}_3)_4\text{C}$ mp = -17°C</td></tr></table> $\xrightarrow{\hspace{10em}}$ Increasing symmetry Increasing melting point	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$ VDW MW = 72 mp = -130°C	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}$ VDW, DD MW = 72 mp = -96°C	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$ VDW, DD, HB MW = 74 mp = -90°C	$\text{CH}_3\text{CH}_2\text{CH}(\text{CH}_3)_2$ mp = -160°C	$(\text{CH}_3)_4\text{C}$ mp = -17°C		
	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$ VDW MW = 72 mp = -130°C	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}$ VDW, DD MW = 72 mp = -96°C	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$ VDW, DD, HB MW = 74 mp = -90°C					
	$\text{CH}_3\text{CH}_2\text{CH}(\text{CH}_3)_2$ mp = -160°C	$(\text{CH}_3)_4\text{C}$ mp = -17°C						
Solubility (3.4C)	Types of water-soluble compounds: - Ionic compounds - Organic compounds having ≤ 5 C's, and an O or N atom for hydrogen bonding (for a compound with one functional group). Types of compounds soluble in organic solvents: - Organic compounds regardless of size or functional group. - Examples: <table><tr><td>$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$ butane</td><td>$\xrightarrow{\text{CCl}_4}$ soluble</td><td rowspan="2">$\text{CH}_3\text{C}(=\text{O})\text{CH}_3$ acetone</td><td>$\xrightarrow{\text{CCl}_4}$ soluble</td></tr><tr><td></td><td>$\xrightarrow{\text{H}_2\text{O}}$ insoluble</td><td>$\xrightarrow{\text{H}_2\text{O}}$ soluble</td></tr></table>	$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$ butane	$\xrightarrow{\text{CCl}_4}$ soluble	$\text{CH}_3\text{C}(=\text{O})\text{CH}_3$ acetone	$\xrightarrow{\text{CCl}_4}$ soluble		$\xrightarrow{\text{H}_2\text{O}}$ insoluble	$\xrightarrow{\text{H}_2\text{O}}$ soluble
$\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$ butane	$\xrightarrow{\text{CCl}_4}$ soluble	$\text{CH}_3\text{C}(=\text{O})\text{CH}_3$ acetone	$\xrightarrow{\text{CCl}_4}$ soluble					
	$\xrightarrow{\text{H}_2\text{O}}$ insoluble		$\xrightarrow{\text{H}_2\text{O}}$ soluble					
	Key: VDW = van der Waals, DD = dipole–dipole, HB = hydrogen bonding MW = molecular weight							

Reactivity (3.8)

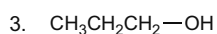
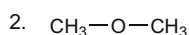
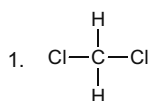
- Nucleophiles react with electrophiles.**
- Electronegative heteroatoms create electrophilic carbon atoms, which tend to react with nucleophiles.
- Lone pairs and π bonds are nucleophilic sites that tend to react with electrophiles.



Introduction to Organic Molecules and Functional Groups 3–3

Practice Test on Chapter Review

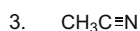
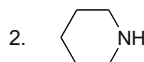
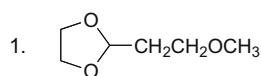
1.a. Which of the following compounds exhibits dipole–dipole interactions?



4. Compounds (1) and (2) both exhibit dipole–dipole interactions.

5. Compounds (1), (2), and (3) all exhibit dipole–dipole interactions.

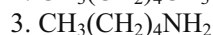
b. Which of the following compounds can hydrogen bond to both another molecule like itself and to water?



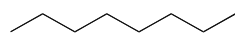
4. Compounds (1) and (2) can each hydrogen bond to another molecule like itself and water.

5. Each of the three compounds, (1), (2), and (3), can hydrogen bond to another molecule like itself and to water.

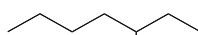
c. Which of the following compounds has the highest boiling point?



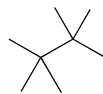
d. Which statement(s) is (are) true about the following compounds?



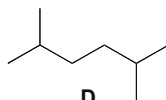
A



C



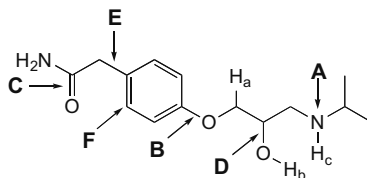
B



D

1. The boiling point of **A** is higher than the boiling point of **B**.
2. The melting point of **B** is higher than the melting point of **C**.
3. The boiling point of **A** is higher than the boiling point of **D**.
4. Statements (1) and (2) are both true.
5. Statements (1), (2), and (3) are all true.

2. Consider the anti-hypertensive agent atenolol drawn below.



Chapter 3–4

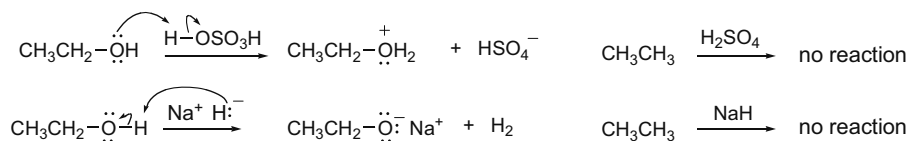
- What is the hybridization of the N atom labeled with **A**?
- What is the shape around the C atom labeled with **F**?
- What orbitals are used to form the bond labeled with **E**?
- Which bond (**B**, **C**, or **D**) is the longest bond?
- Would you predict atenolol to be soluble in water?
- Which of the labeled H atoms (H_a , H_b , or H_c) is most acidic?

Answers to Practice Test

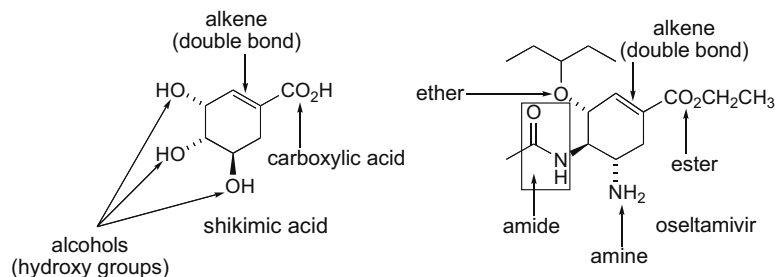
- 5
 - 2
 - 3
 - 5
- sp^3
 - trigonal planar
 - $C_{sp^2}-C_{sp^3}$
 - D**
 - yes
 - H_b

Answers to Problems

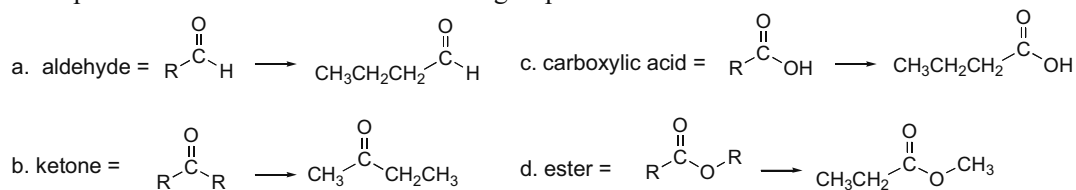
3.1



3.2 Identify the functional groups based on Tables 3.1, 3.2, and 3.3.

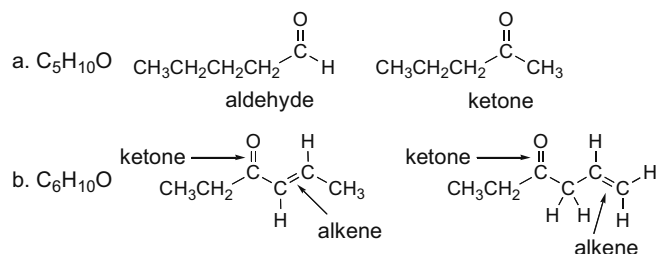


3.3 One possible structure for each functional group:



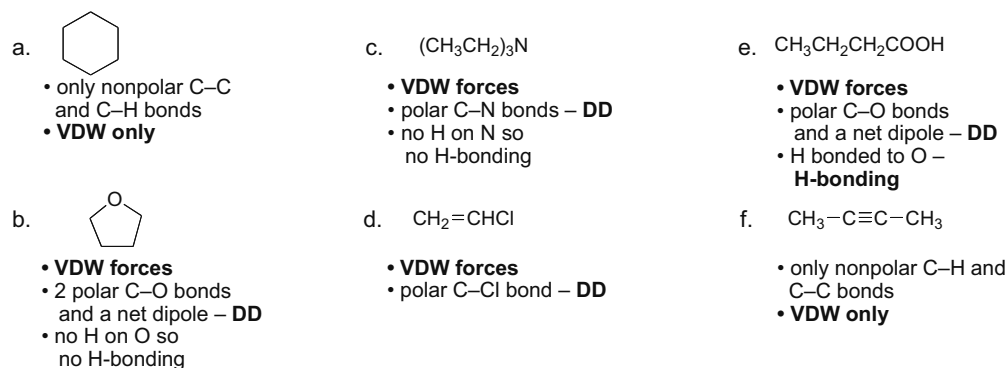
Introduction to Organic Molecules and Functional Groups 3–5

3.4 One possible structure for each description:



3.5 Summary of forces:

- **All compounds exhibit van der Waals forces (VDW).**
- **Polar molecules have dipole–dipole forces (DD).**
- **Hydrogen bonding (H-bonding)** can occur only when a **H** is bonded to an **O, N, or F**.



3.6 One principle governs boiling point:

- **Stronger intermolecular forces = higher bp.**

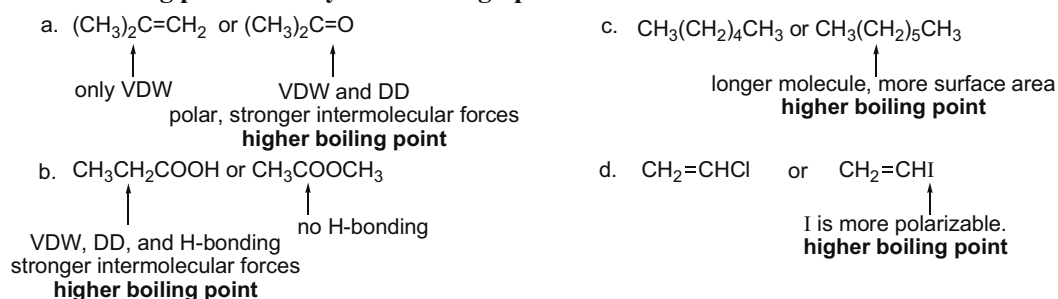
Increasing intermolecular forces: van der Waals < dipole–dipole < hydrogen bonding

Two factors affect the strength of van der Waals forces, and thus affect bp:

- **Increasing surface area = increasing bp.**

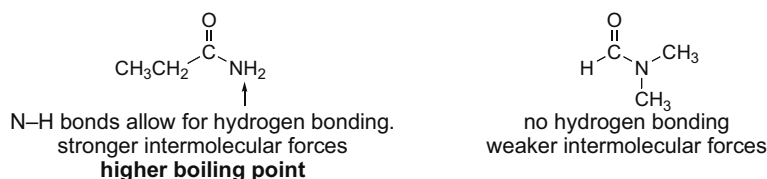
Longer molecules have a larger surface area. Any branching decreases the surface area of a molecule.

- **Increasing polarizability = increasing bp.**

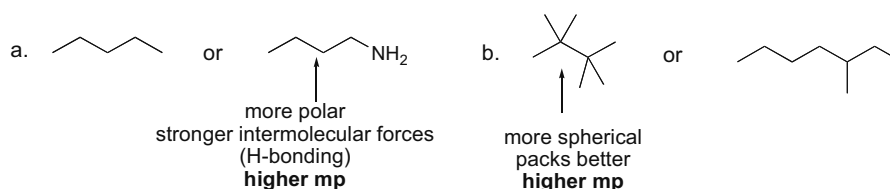


Chapter 3–6

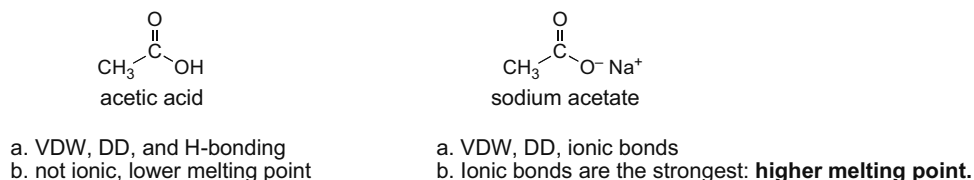
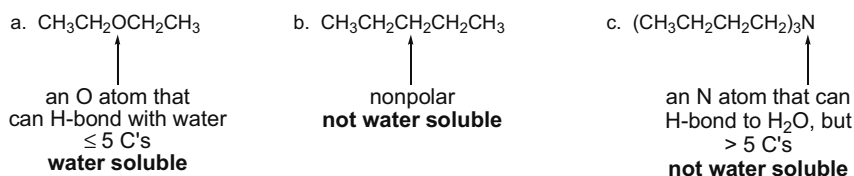
3.7 Increasing intermolecular forces: van der Waals < dipole–dipole < hydrogen bonding



3.8

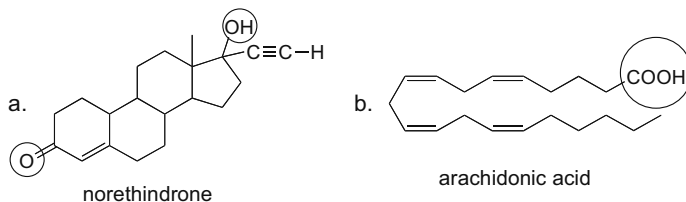


3.9 Compare the intermolecular forces to explain why sodium acetate has a higher melting point than acetic acid.

3.10 A compound is water soluble if it is ionic or if it has an O or N atom and ≤ 5 C's.

3.11 Hydrophobic portions will primarily be hydrocarbon chains. Hydrophilic portions will be polar.

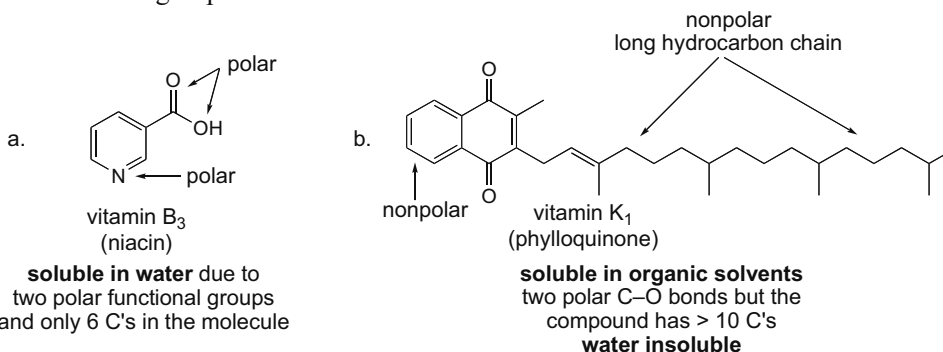
Circled regions are **hydrophilic** because they are polar.
All other regions are **hydrophobic** since they have only C and H.



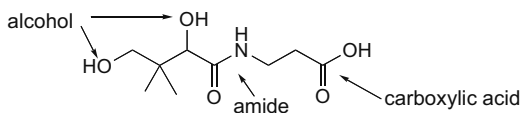
Introduction to Organic Molecules and Functional Groups 3–7

3.12 Like dissolves like.

- To be **soluble in water**, a molecule must be ionic, or have a polar functional group capable of H-bonding for every 5 C's.
- Organic compounds are generally **soluble in organic solvents** regardless of size or functional group.

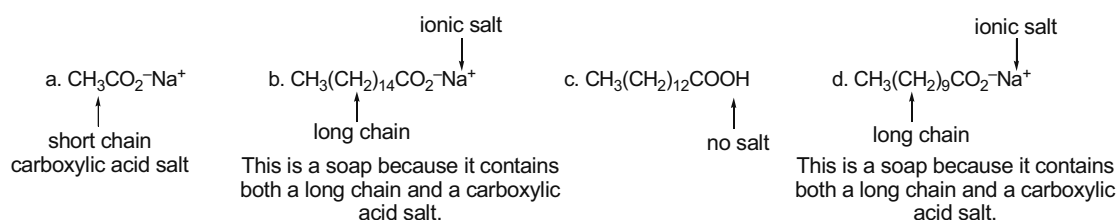


3.13 a.

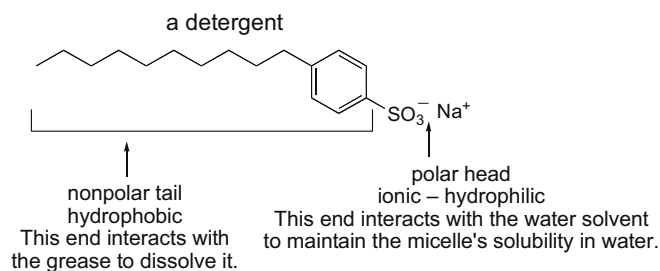


- b. The amide, carboxylic acid, and both alcohols can all hydrogen bond with water.
- c. Since pantoic acid has only nine carbons with four functional groups that can hydrogen bond, pantoic acid is a water-soluble vitamin.

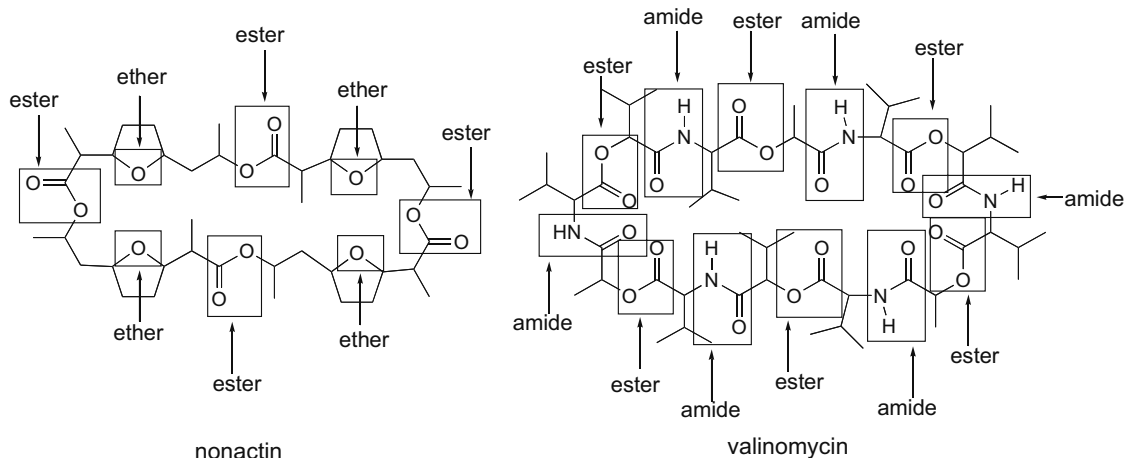
3.14 A soap contains both a long hydrocarbon chain and a carboxylic acid salt.

3.15 Detergents have a polar head consisting of oppositely charged ions, and a nonpolar tail consisting of C–C and C–H bonds, just like soaps do. Detergents clean by having the **hydrophobic ends of molecules surround grease**, while the **hydrophilic portion of the molecule interacts with the polar solvent** (usually water).

Chapter 3–8

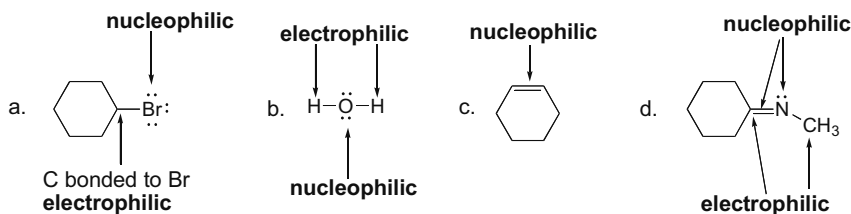


3.16



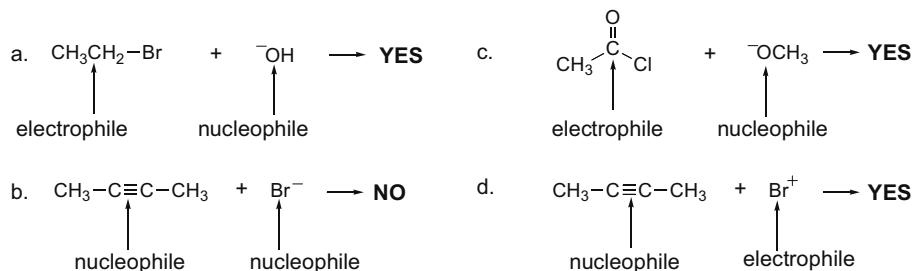
3.17 Because the interior of a cell membrane is nonpolar, aspirin crosses a cell membrane as a neutral carboxylic acid, by the general rule “Like dissolves like.”

3.18 Electronegative heteroatoms like N, O, or X make a carbon atom an *electrophile*.
 A lone pair on a heteroatom makes it basic and nucleophilic.
 Pi (π) bonds create *nucleophilic* sites and are more easily broken than σ bonds.

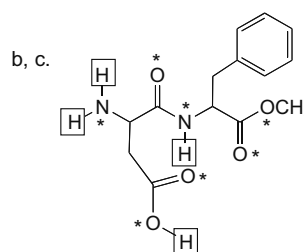
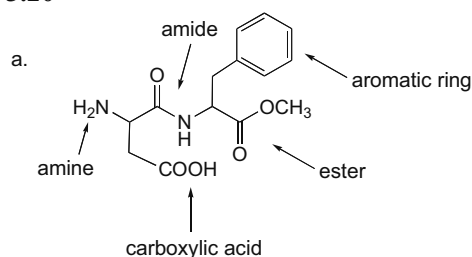


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3.19 Electrophiles and nucleophiles react with each other.

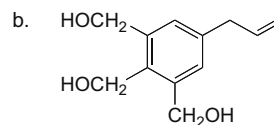
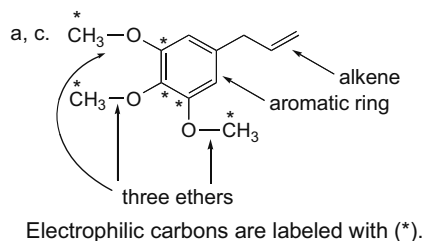


3.20



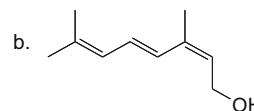
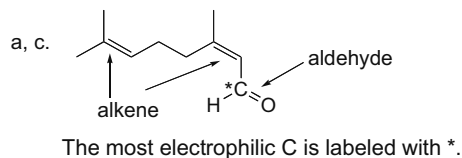
H's that are boxed in can hydrogen bond to O of H_2O .
 Atoms labeled with (*) can hydrogen bond to H of H_2O .

3.21



Three OH's allow for H-bonding.
 Stronger intermolecular forces mean
 a higher bp and mp.

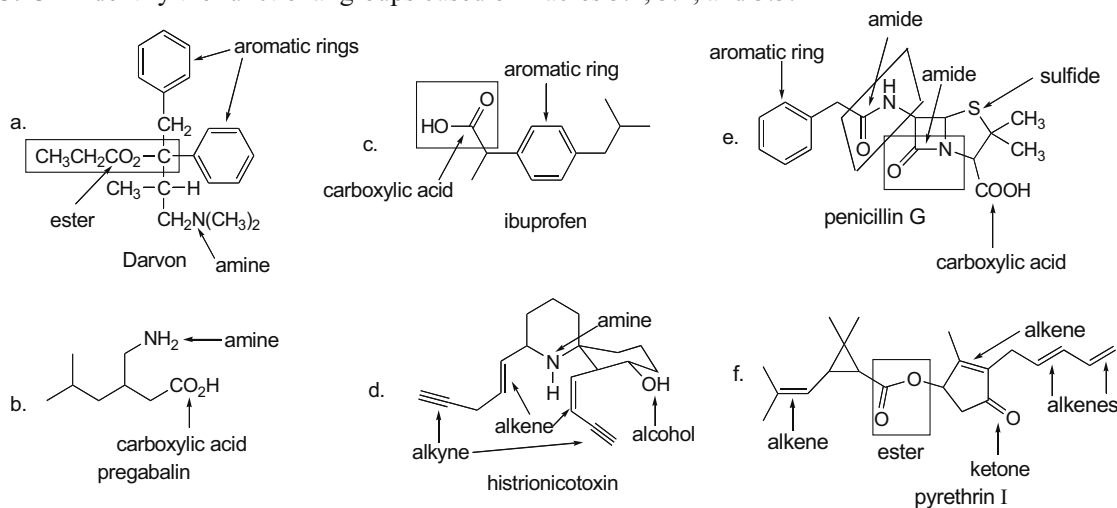
3.22



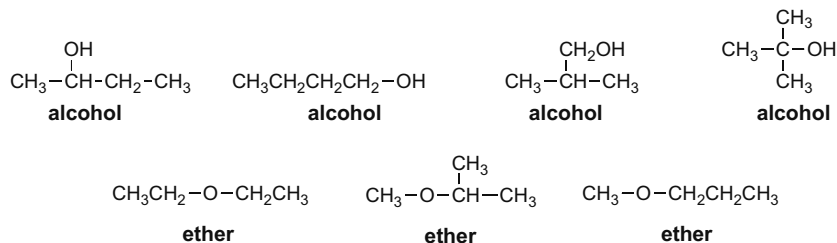
This isomer has an OH, more opportunities
 for H-bonding (through both O and H
 atoms), and so probably more H_2O soluble.

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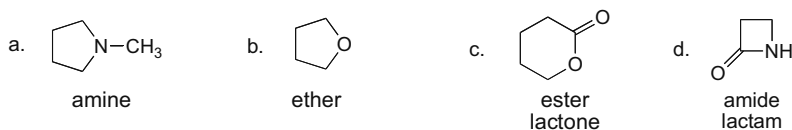
3.23 Identify the functional groups based on Tables 3.1, 3.2, and 3.3.



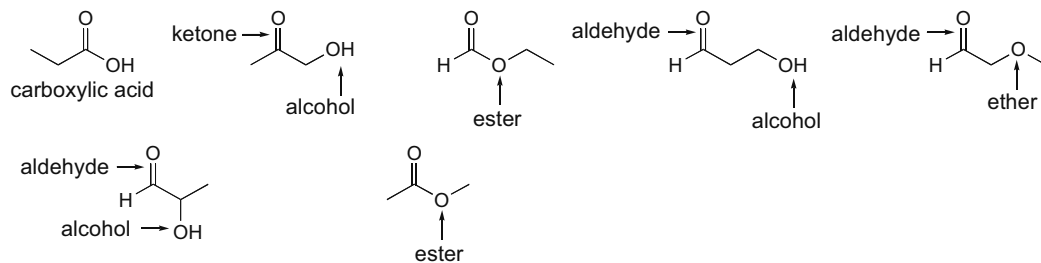
3.24



3.25 A cyclic ester is called a lactone. A cyclic amide is called a lactam.

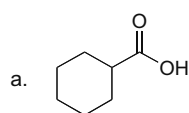


3.26 Draw the constitutional isomers and identify the functional groups.

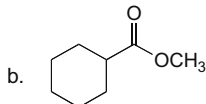


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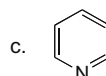
3.27 Use the rules from Answer 3.5.



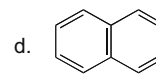
VDW
dipole-dipole
H-bonding (O-H bond)



VDW
dipole-dipole
no H-bonding (no O-H bond)



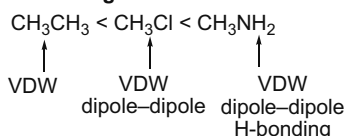
VDW
dipole-dipole
no H-bonding (no N-H bond)



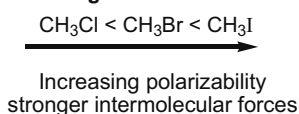
VDW
no dipole-dipole
(nonpolar C-C, C-H bonds)
no H-bonding (no O, N, F)

3.28 Increasing intermolecular forces: van der Waals < dipole-dipole < H-bonding

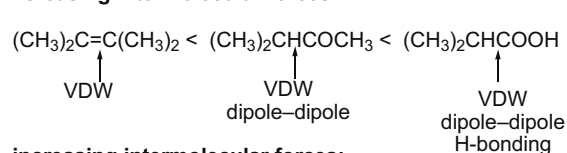
a. increasing intermolecular forces:



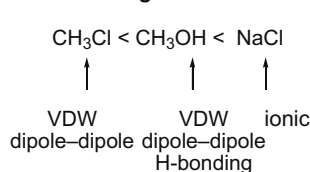
b. increasing intermolecular forces:



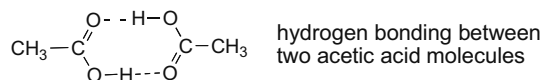
c. increasing intermolecular forces:



d. increasing intermolecular forces:

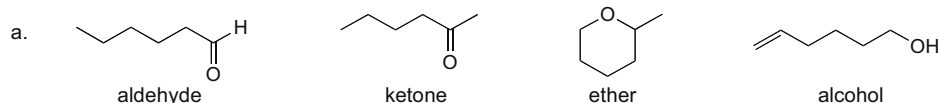


3.29



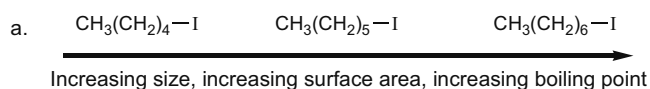
3.30 A = VDW forces; B = H-bonding; C = ion-ion interactions; D = H-bonding; E = H-bonding; F = VDW forces.

3.31

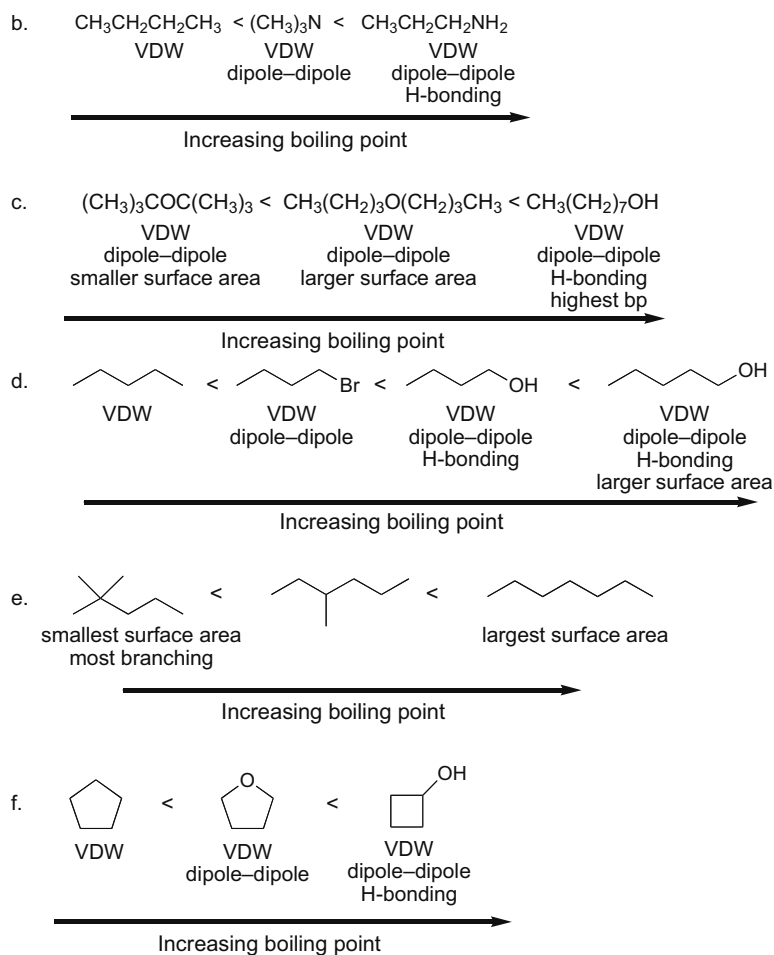


b. The alcohol is the highest boiling since it is the only isomer that can hydrogen bond with another molecule like itself.

3.32 Use the principles from Answer 3.6.

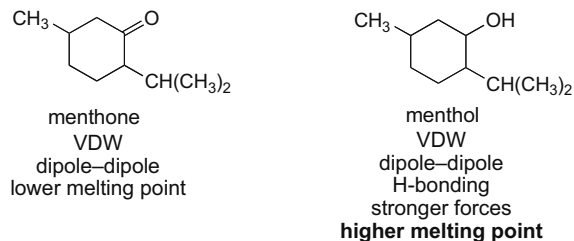


Chapter 3–12

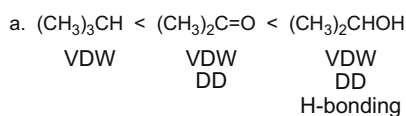


3.33 In $\text{CH}_3\text{CH}_2\text{NHCH}_3$, there is a N–H bond so the molecules exhibit intermolecular hydrogen bonding, whereas in $(\text{CH}_3)_3\text{N}$ the N is bonded only to C, so there is no hydrogen bonding. The hydrogen bonding in $\text{CH}_3\text{CH}_2\text{NHCH}_3$ makes it have much **stronger intermolecular forces** than $(\text{CH}_3)_3\text{N}$. As intermolecular forces increase, the boiling point of a molecule of the same molecular weight increases.

3.34 Stronger forces, higher mp.



Introduction to Organic Molecules and Functional Groups 3-13

3.35 Stronger forces, higher mp. More symmetrical compounds, higher mp.

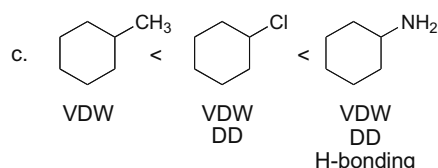
Increasing intermolecular forces

 Increasing melting point



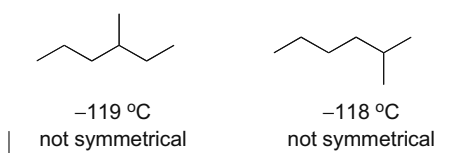
Increasing polarizability

 Increasing melting point

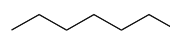


Increasing intermolecular forces

 Increasing melting point

3.36

In both compounds the CH_3 group dangling from the chain makes packing in the solid difficult, so the mp is low.



-91 °C
 symmetrical
 higher mp

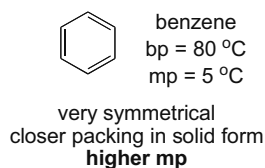
This molecule can pack somewhat better since it has no CH_3 group dangling from the chain, so the mp is somewhat higher. It also has the most surface area and this increases VDW forces compared to the first two compounds.



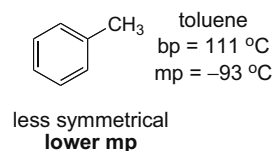
-25 °C
 most spherical
 highest mp

This compound packs the best since it is the most spherical in shape, increasing its mp.

3.37 Boiling point is determined solely by the strength of the intermolecular forces. Since benzene has a smaller size, it has less surface area and weaker VDW interactions and therefore a lower boiling point than toluene. The increased melting point for benzene can be explained by symmetry: benzene is much more symmetrical than toluene. More symmetrical molecules can pack more tightly together, increasing their melting point. Symmetry has no effect on boiling point.



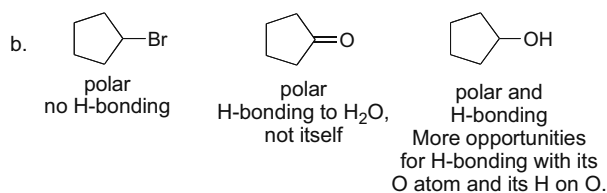
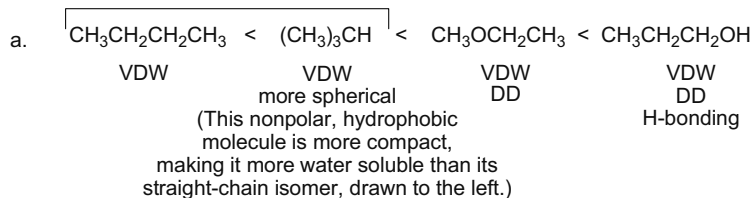
and



Chapter 3–14

3.38 Increasing polarity = increasing water solubility.

Neither compound is very H₂O soluble.



3.39 Look for two things:

- To H-bond to another molecule like itself, the molecule must contain a **H bonded to O, N, or F**.
- To H-bond with water, a molecule needs **only to contain an O, N, or F**.

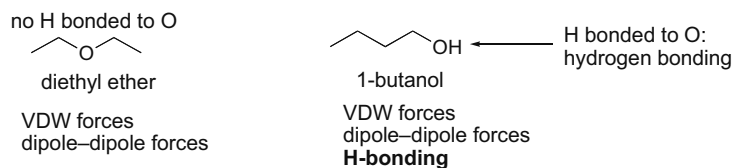
Each of these molecules can H-bond to another molecule like itself. Both compounds have N–H bonds.

b. CH₃NH₂, e. CH₃CH₂CH₂CONH₂

These molecules can H-bond with water. All of these molecules have an O or N atom.

b. CH₃NH₂, c. CH₃OCH₃, d. (CH₃CH₂)₃N,
e. CH₃CH₂CH₂CONH₂, g. CH₃SOCH₃,
h. CH₃CH₂COOCH₃

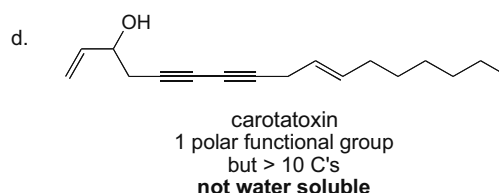
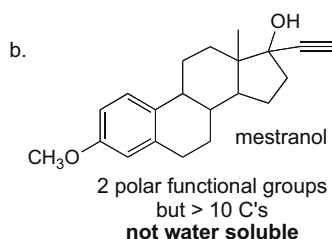
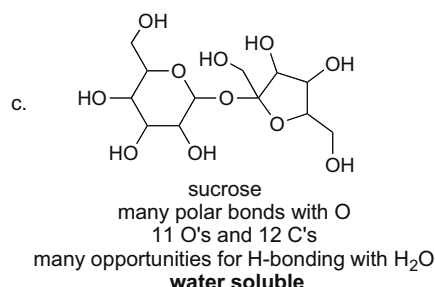
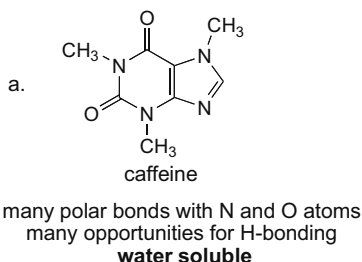
3.40 Draw the molecules in question and look at the intermolecular forces involved.



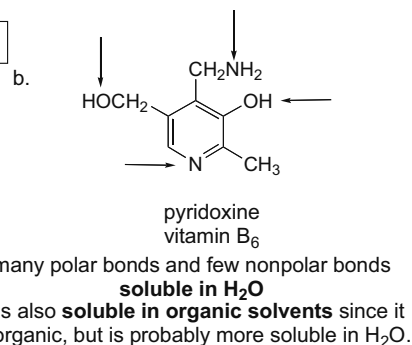
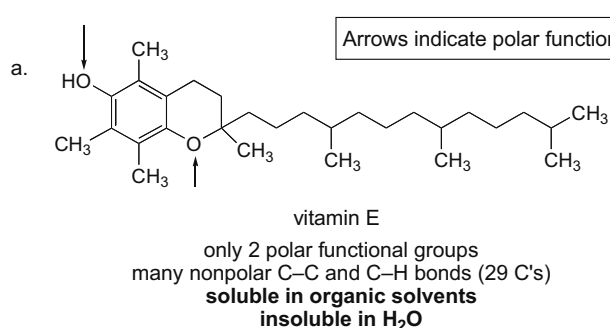
- Both have ≤ 5 C's and an electronegative O atom, so they can H-bond to water, making them soluble in water.
- Only 1-butanol can H-bond to another molecule like itself, and this increases its boiling point.

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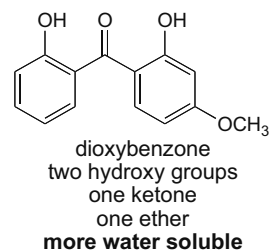
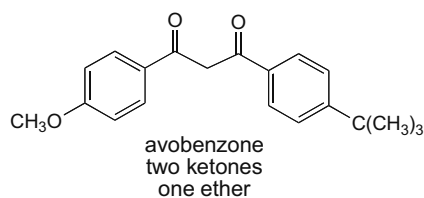
3.41 Use the solubility rule from Answer 3.12.



3.42 Water solubility is determined by polarity. Polar molecules are soluble in water, while nonpolar molecules are soluble in organic solvents.

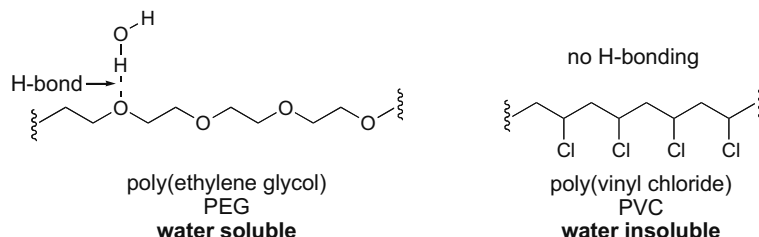


3.43 Compare the functional groups in the two components of sunscreen. Dioxybenzone will most likely be washed off in water because it contains two hydroxy groups and is more water soluble.

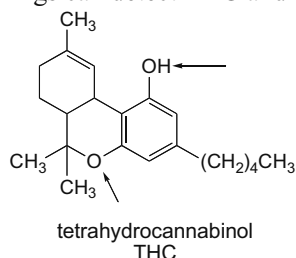


Chapter 3–16

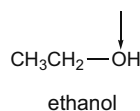
- 3.44** Because of the O atoms, PEG is capable of hydrogen bonding with water, which makes PEG water soluble and suitable for a product like shampoo. PVC cannot hydrogen bond to water, so PVC is water insoluble, even though it has many polar bonds. Since PVC is water insoluble, it can be used to transport and hold water.



- 3.45** Molecules that dissolve in water are readily excreted from the body in urine, whereas less polar molecules that dissolve in organic solvents are soluble in fatty tissue and are retained for longer periods. Compare the solubility properties of THC and ethanol to determine why drug screenings can detect THC and not ethanol weeks after introduction to the body.



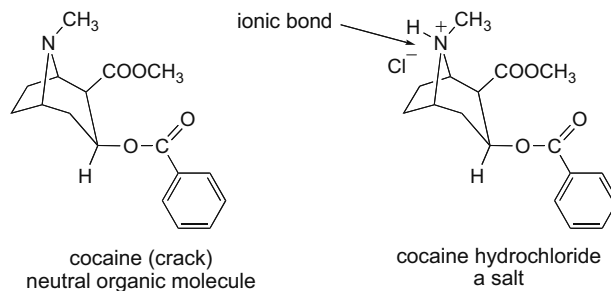
THC has relatively few polar bonds compared to the number of nonpolar bonds, making it **soluble in organic solvents** and therefore **soluble in fatty tissue**.



Ethanol has 1 O atom and only 2 C's, making it **soluble in water**.

Due to their solubilities, **THC is retained much longer in the fatty tissue of the body**, being slowly excreted over many weeks, while ethanol is excreted rapidly in urine after ingestion.

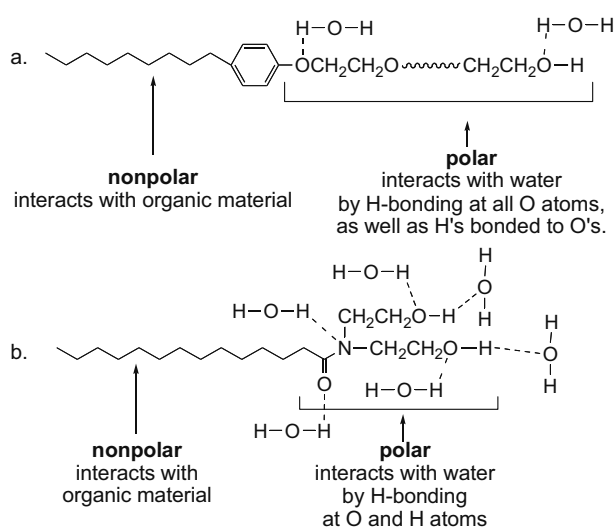
- 3.46** Compare the intermolecular forces of crack and cocaine hydrochloride. Stronger intermolecular forces increase both the boiling point and the water solubility.



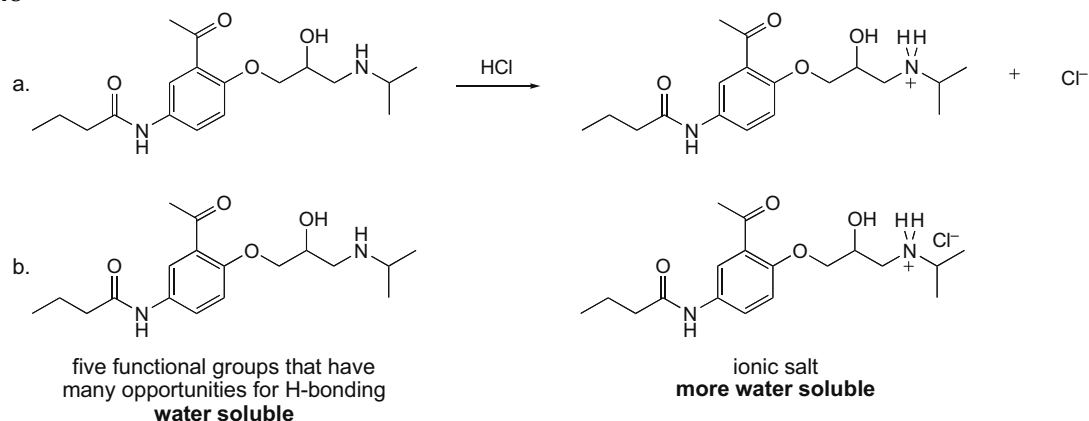
Introduction to Organic Molecules and Functional Groups 3–17

The molecules are identical except for the ionic bond in cocaine hydrochloride. Ionic forces are extremely strong forces, and therefore the cocaine hydrochloride salt has a much **higher boiling point and is more water soluble**. Since the salt is highly water soluble, it can be injected directly into the bloodstream, where it dissolves. Crack is smoked because it can dissolve in the organic tissues of the nasal passages and lungs.

- 3.47 A laundry detergent must have both a highly polar end of the molecule and a nonpolar end of the molecule. The polar end will interact with water, while the nonpolar end surrounds the grease or other organic material.



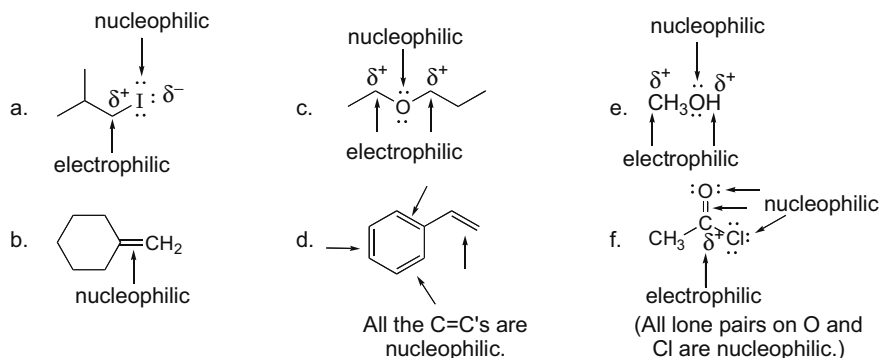
3.48



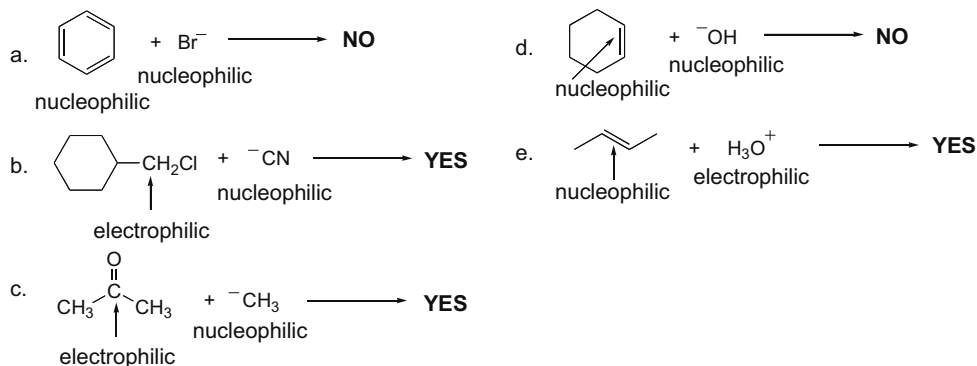
- c. Since the hydrochloride salt is ionic and therefore more water soluble, it is more readily transported in the bloodstream.

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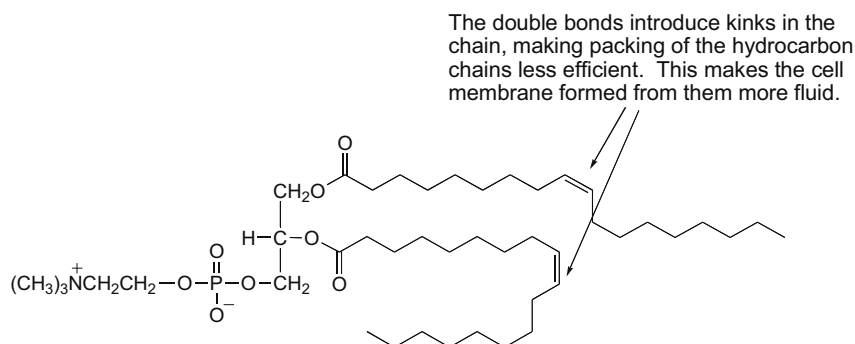
3.49 Use the rules from Answer 3.18.



3.50

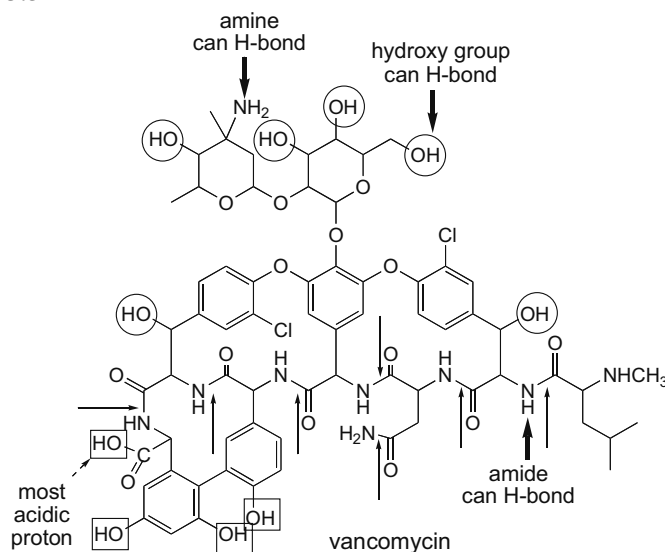


3.51 More rigid cell membranes have phospholipids with *fewer* C=C's. Each C=C introduces a bend in the molecule, making the phospholipids pack less tightly. Phospholipids without C=C's can pack very tightly, making the membrane less fluid, and more rigid.



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3.52

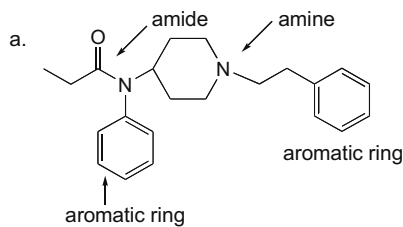


- Seven amide groups [regular (unbolded) arrows]
- OH groups bonded to sp^3 C's are circled. OH groups bonded to sp^2 C's have a square.
- Despite its size, vancomycin is water soluble because it contains many polar groups and many N and O atoms that can H-bond to H_2O .
- The most acidic proton is labeled (COOH group).
- Four functional groups capable of H-bonding are ROH, RCOOH, amides, and amines.

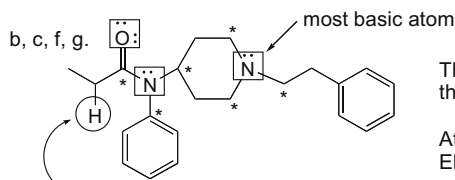
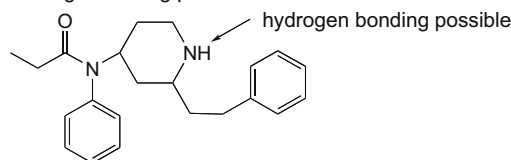
3.53 Because the O atom in tetrahydrofuran is in a ring, the C atoms bonded to it are kept away from the lone pairs on O. This allows the O atom to more readily hydrogen bond with water, thus increasing its solubility in water.



3.54



e. An isomer that can hydrogen bond should have a higher boiling point.



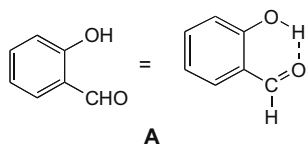
The N atom of the amide is less basic because the lone pair is part of resonance with the $C=O$.

Atoms that can hydrogen bond to H_2O are boxed in. Electrophilic carbons are labeled with (*).

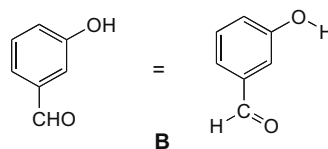
- d. Fentanyl exhibits van der Waals and dipole–dipole interactions but no hydrogen bonding, since there is no H bonded to O or N.

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3.55



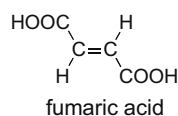
The OH and CHO groups are close enough that they can intramolecularly H-bond to each other. Since the two polar functional groups are involved in intramolecular H-bonding, they are less available for H-bonding to H_2O . This makes **A** less H_2O soluble than **B**, whose two functional groups are both available for H-bonding to the H_2O solvent.



The OH and the CHO are too far apart to intramolecularly H-bond to each other, leaving more opportunity to H-bond with solvent.

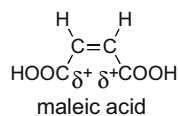
3.56

a. melting point

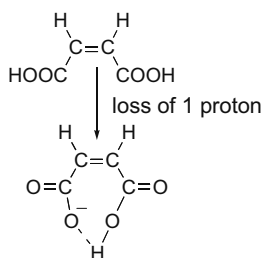


Fumaric acid has its two larger COOH groups on opposite ends of the molecule, and in this way it can pack better in a lattice than maleic acid, giving it a **higher mp**.

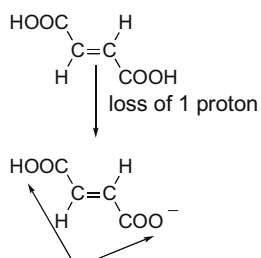
b. solubility



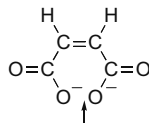
Maleic acid is more polar, giving it greater **H_2O solubility**. The bond dipoles in fumaric acid cancel.

c. removal of the first proton ($\text{p}K_{a1}$)

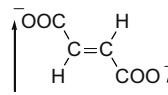
In maleic acid, intramolecular H-bonding stabilizes the conjugate base after one H is removed, making maleic acid more acidic than fumaric acid.



Intramolecular H-bonding is not possible here.

d. removal of the second proton ($\text{p}K_{a2}$)

Now the dianion is held in close proximity in maleic acid, and this destabilizes the conjugate base. Thus, removing the second H in maleic acid is harder, making it a weaker acid than fumaric acid for removal of the second proton.



The two negative charges are much farther apart. This makes the dianion from fumaric acid more stable and thus $\text{p}K_{a2}$ is lower for fumaric acid than maleic acid.

Chapter 4 Alkanes

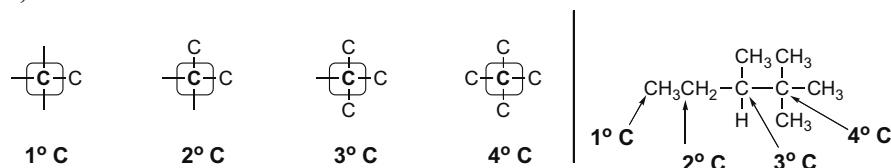
Chapter Review

General facts about alkanes (4.1-4.3)

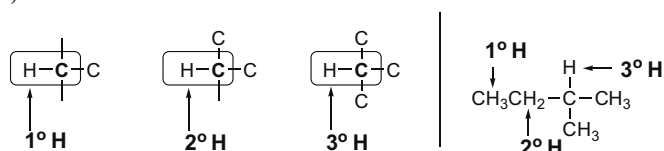
- Alkanes are composed of **tetrahedral, sp^3** hybridized C's.
- There are two types of alkanes: acyclic alkanes having molecular formula C_nH_{2n+2} , and cycloalkanes having molecular formula C_nH_{2n} .
- Alkanes have only **nonpolar C-C and C-H bonds** and no functional group so they undergo few reactions.
- Alkanes are named with the suffix **-ane**.

Classifying C's and H's (4.1A)

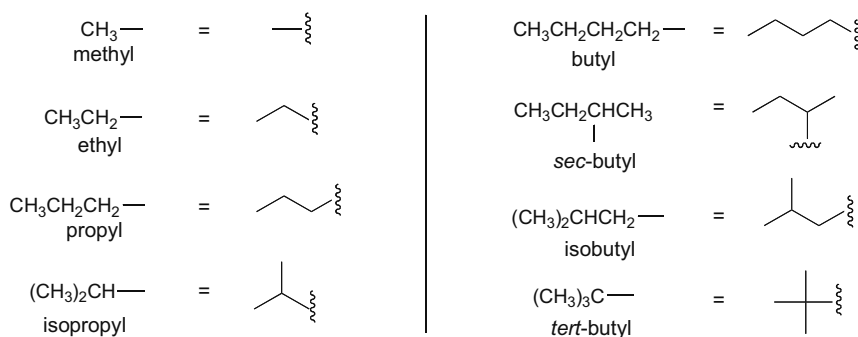
- Carbon atoms are classified by the number of C's bonded to them; a **1° C is bonded to one other C**, and so forth.



- Hydrogen atoms are classified by the type of carbon atom to which they are bonded; a **1° H is bonded to a 1° C**, and so forth.



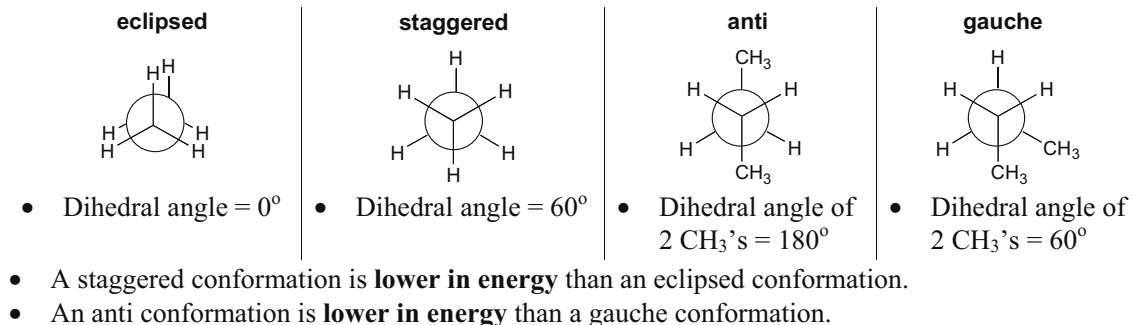
Names of alkyl groups (4.4A)



Chapter 4-2

Conformations in acyclic alkanes (4.9, 4.10)

- Alkane conformations can be classified as **staggered**, **eclipsed**, **anti**, or **gauche** depending on the relative orientation of the groups on adjacent carbons.

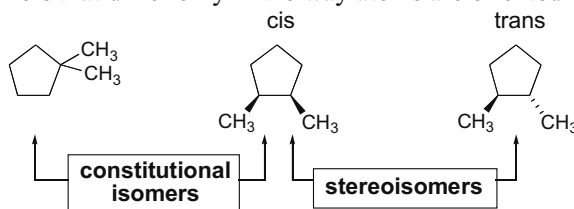


Types of strain

- Torsional strain**—an increase in energy due to eclipsing interactions (4.9).
- Steric strain**—an increase in energy when atoms are forced too close to each other (4.10).
- Angle strain**—an increase in energy when tetrahedral bond angles deviate from 109.5° (4.11).

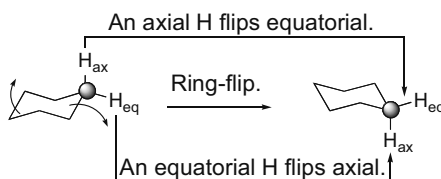
Two types of isomers

- [1] **Constitutional isomers**—isomers that differ in the way the atoms are connected to each other (4.1A).
 [2] **Stereoisomers**—isomers that differ only in the way atoms are oriented in space (4.13B).



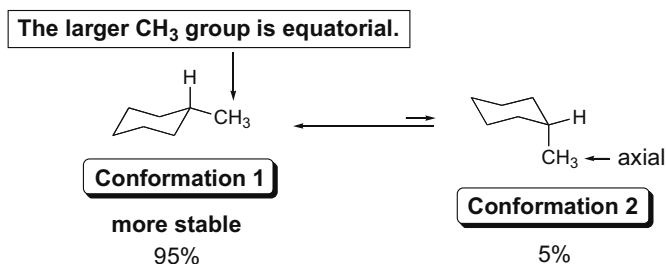
Conformations in cyclohexane (4.12, 4.13)

- Cyclohexane exists as **two chair conformations** in rapid equilibrium at room temperature.
- Each carbon atom on a cyclohexane ring has **one axial** and **one equatorial hydrogen**. Ring-flipping converts axial H's to equatorial H's, and vice versa.

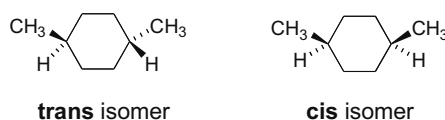


Alkanes 4-3

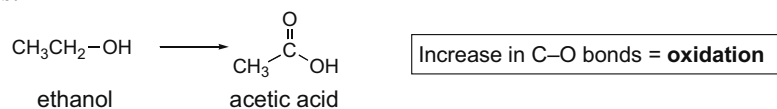
- In substituted cyclohexanes, groups larger than hydrogen are more stable in the **more roomy equatorial position**.



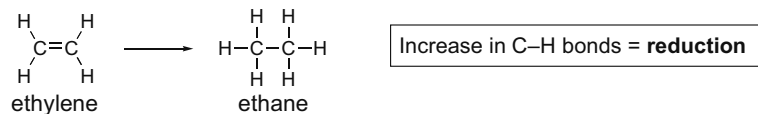
- Disubstituted cyclohexanes with substituents on different atoms exist as two possible stereoisomers.
 - The **cis** isomer has two groups on the **same side** of the ring, either both up or both down.
 - The **trans** isomer has two groups on **opposite sides** of the ring, one up and one down.

**Oxidation–reduction reactions (4.14)**

- Oxidation** results in an **increase in the number of C–Z bonds** or a **decrease in the number of C–H bonds**.



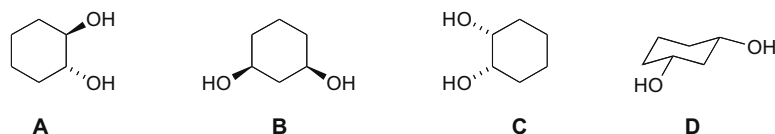
- Reduction** results in a **decrease in the number of C–Z bonds** or an **increase in the number of C–H bonds**.



Chapter 4-4

Practice Test on Chapter Review

1. a. Which statement is true about compounds A–D below?

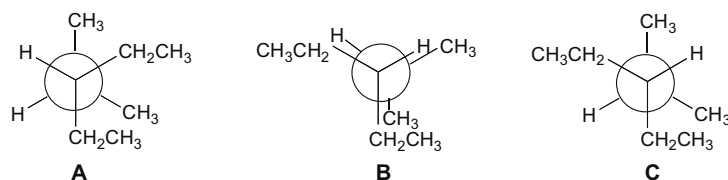


1. A and C are stereoisomers.
2. B and D are identical.
3. A and B are stereoisomers.
4. Statements (1) and (2) are both true.
5. Statements (1), (2), and (3) are all true.

b. Which of the following statements is true about *cis*-1-isopropyl-2-methylcyclohexane?

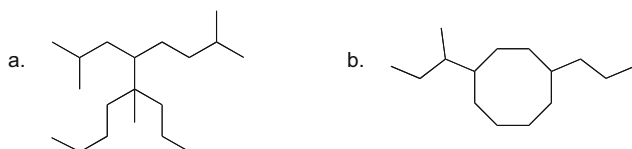
1. The more stable conformation has the isopropyl group in the equatorial position and the methyl group in the axial position.
2. The more stable conformation has both the methyl and isopropyl groups in the equatorial position.
3. *cis*-1-Isopropyl-2-methylcyclohexane is a meso compound.
4. Statements (1) and (2) are true.
5. Statements (1), (2), and (3) are all true.

c. Rank the following conformations in order of *increasing energy*.

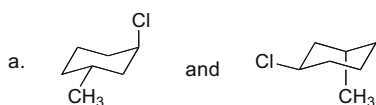


1. C < B < A
2. C < A < B
3. A < C < B
4. B < A < C
5. A < B < C

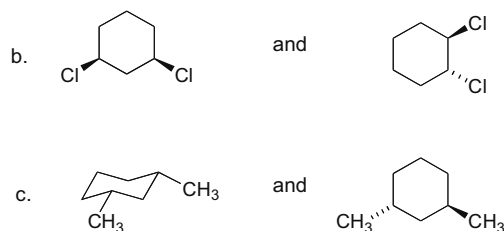
2. Give the IUPAC name for each of the following compounds.



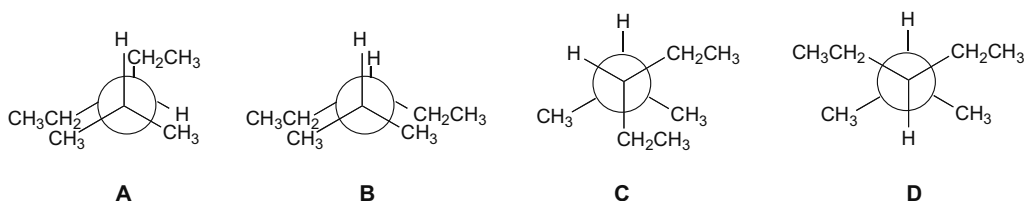
3. How are the molecules in each pair related? Are they constitutional isomers, stereoisomers, identical, or not isomers?



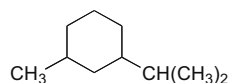
Alkanes 4–5



4. Rank the following conformations in order of increasing energy. Label the conformation of lowest energy as **1**, the highest energy as **4**, and the conformations of intermediate energy as **2** and **3**.



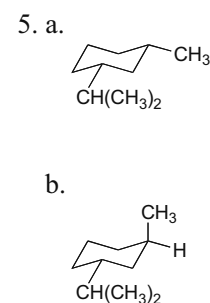
5. Consider the following disubstituted cyclohexane drawn below:



- Draw the more stable chair conformation for the cis isomer.
- Draw the more stable chair conformation for the trans isomer.

Answers to Practice Test

1. a. 4	2. a. 5-isobutyl-2,6-dimethyl-6-propyldecane	3. a. identical	4. A –3 B –4 C –2 D –1
b. 1	b. 1- <i>sec</i> -butyl-4-propylcyclooctane	b. constitutional isomers	
c. 2		c. stereoisomers	



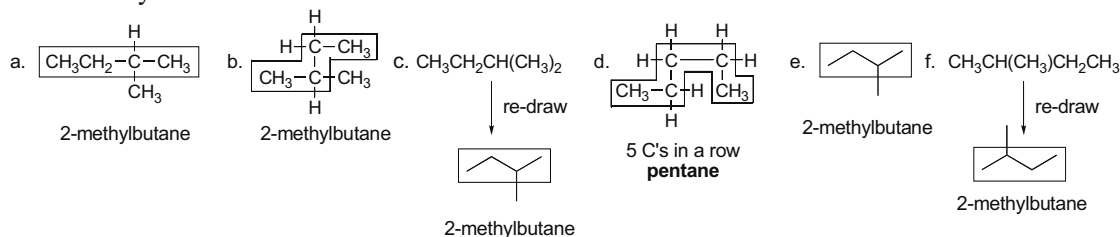
Chapter 4–6

Answers to Problems

4.1 The general molecular formula for an acyclic alkane is C_nH_{2n+2} .

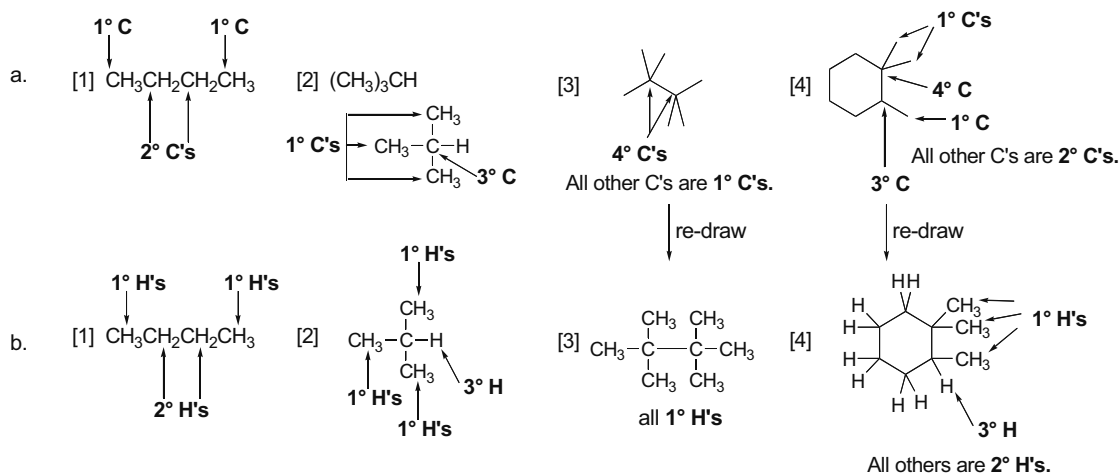
Number of C atoms = n	$2n + 2$	Number of H atoms
23	$2(23) + 2 =$	48
25	$2(25) + 2 =$	52
27	$2(27) + 2 =$	56

4.2 2-Methylbutane has 4 C's in a row with a 1 C branch.



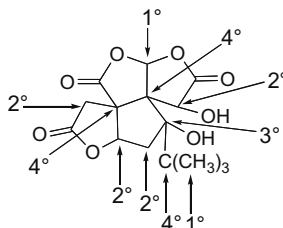
4.3 To classify a carbon atom as 1° , 2° , 3° , or 4° **determine how many carbon atoms it is bonded to** (1° C = bonded to **one** other C, 2° C = bonded to **two** other C's, 3° C = bonded to **three** other C's, 4° C = bonded to **four** other C's). Re-draw if necessary to see each carbon clearly.

To classify a hydrogen atom as 1° , 2° , or 3° , **determine if it is bonded to a 1° , 2° , or 3° C** (a 1° H is bonded to a 1° C; a 2° H is bonded to a 2° C; a 3° H is bonded to a 3° C).
 Re-draw if necessary.



Alkanes 4–7

4.4 Use the definition of 1°, 2°, 3°, or 4° carbon atoms from Answer 4.3.



4.5 Constitutional isomers differ in the way the atoms are connected to each other. To draw all the constitutional isomers:

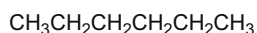
[1] Draw all of the C's in a long chain.

[2] Take off one C and use it as a substituent. (Don't add it to the end carbon: this re-makes the long chain.)

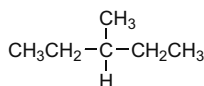
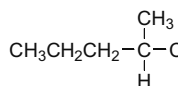
[3] Take off two C's and use these as substituents, etc.

Five constitutional isomers of molecular formula C_6H_{14} :

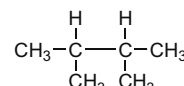
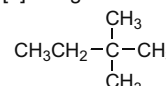
[1] long chain



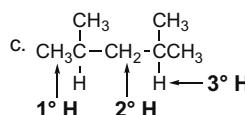
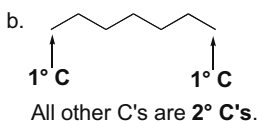
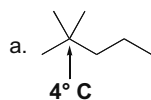
[2] with one C as a substituent



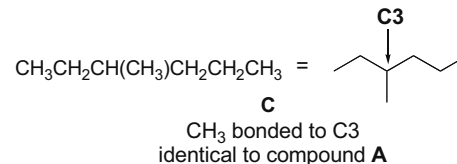
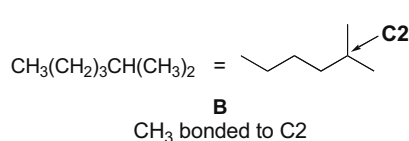
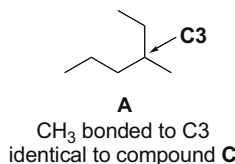
[3] using two C's as substituents



4.6 Draw each alkane to satisfy the requirements.

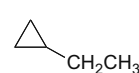
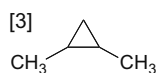
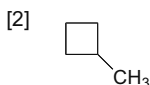
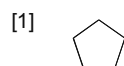


4.7 Draw each compound as a skeletal structure to compare the compounds.



4.8 Use the steps from Answer 4.5 to draw the constitutional isomers.

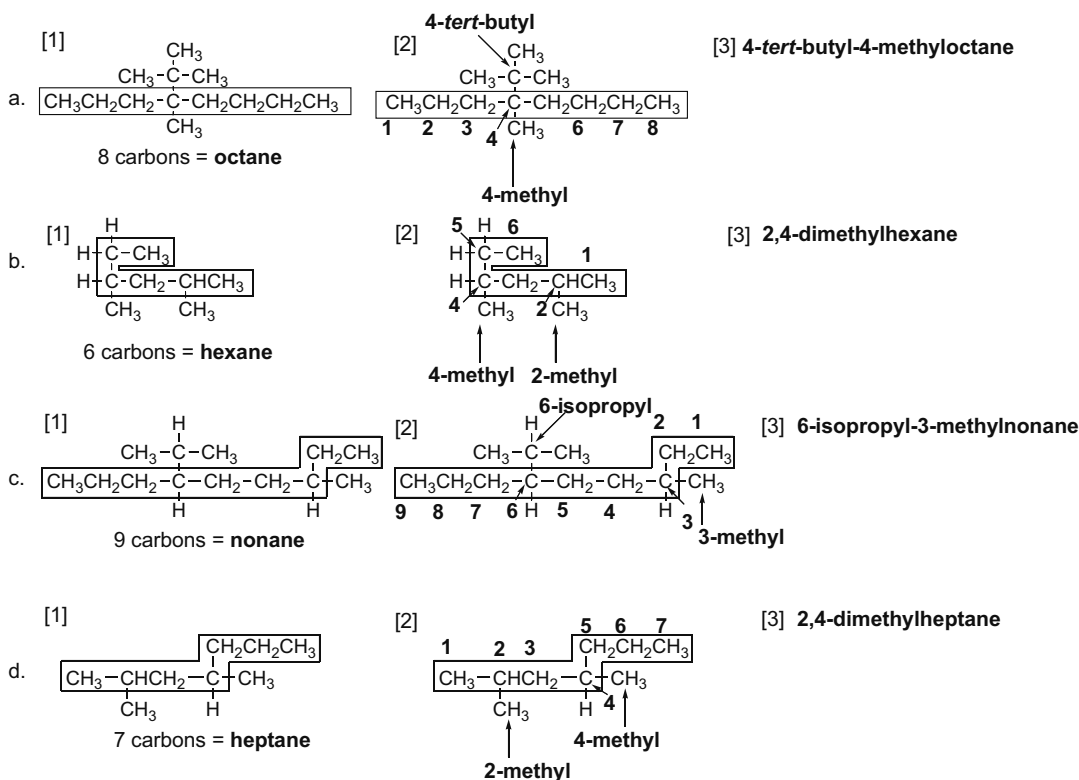
Five constitutional isomers of molecular formula C_5H_{10} having one ring:



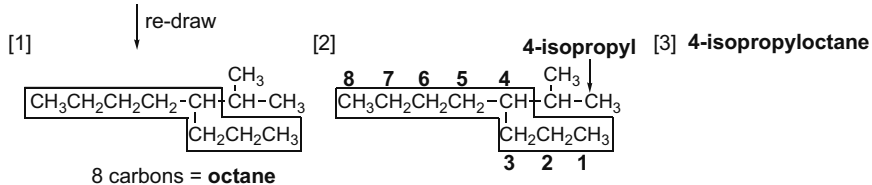
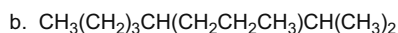
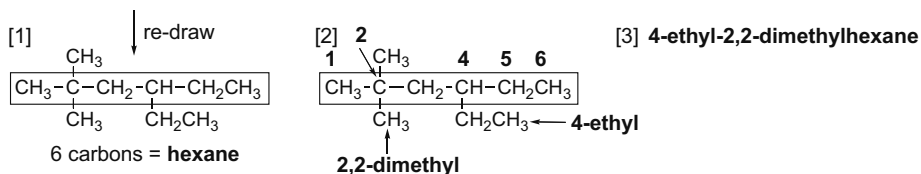
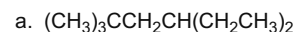
Chapter 4-8

4.9 Follow these steps to name an alkane:

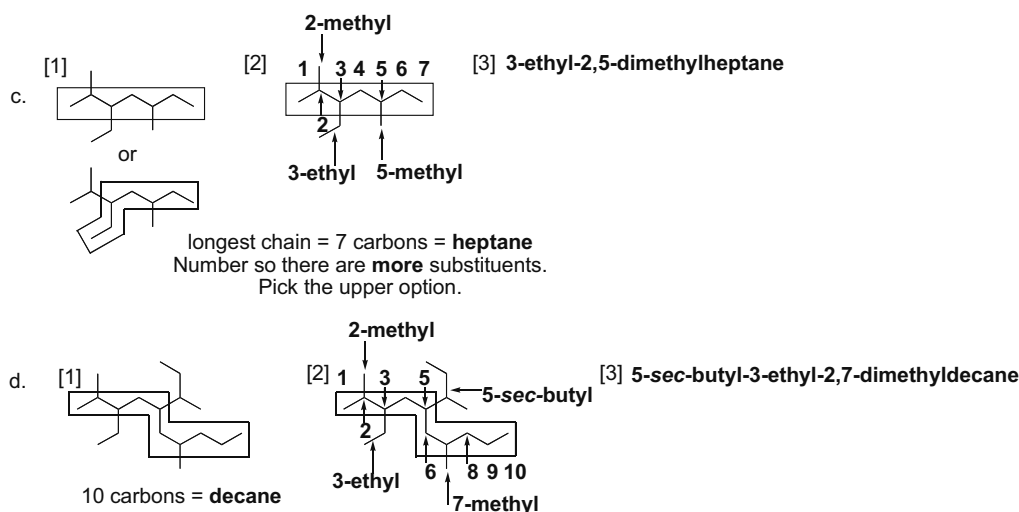
- [1] **Name the parent chain** by finding the longest C chain.
- [2] **Number the chain** so that the first substituent gets the lower number. Then **name and number all substituents**, giving like substituents a prefix (di, tri, etc.).
- [3] **Combine all parts**, alphabetizing the substituents, ignoring all prefixes except *iso*.



4.10 Use the steps in Answer 4.9 to name each alkane.

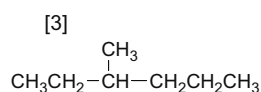
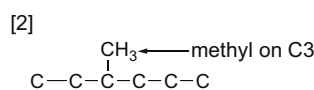
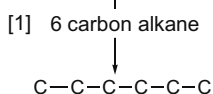


Alkanes 4–9

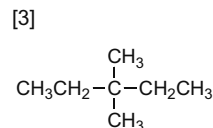
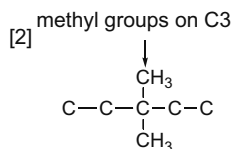
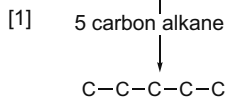
**4.11 To work backwards from a name to a structure:**

- [1] Find the parent name and draw that number of C's. Use the suffix to identify the functional group (**-ane = alkane**).
- [2] Arbitrarily number the C's in the chain. Add the substituents to the appropriate C's.
- [3] Re-draw with H's to make C's have four bonds.

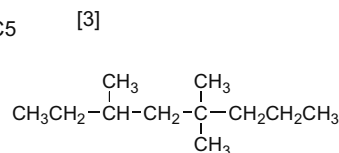
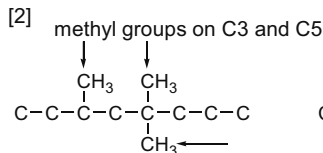
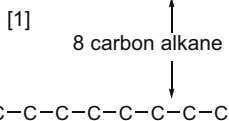
a. 3-methylhexane



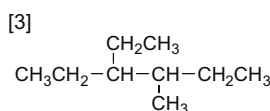
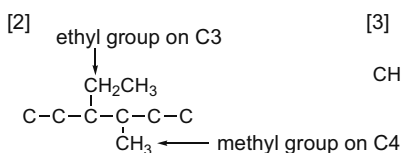
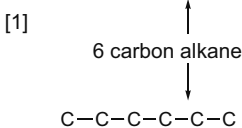
b. 3,3-dimethylpentane



c. 3,5,5-trimethyloctane

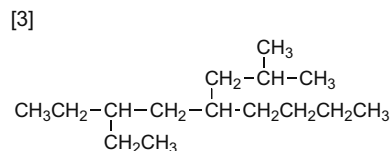
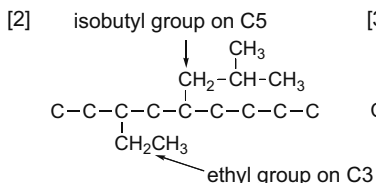
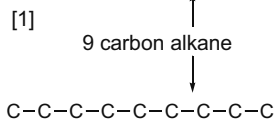


d. 3-ethyl-4-methylhexane

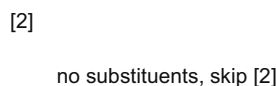
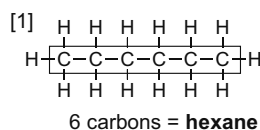
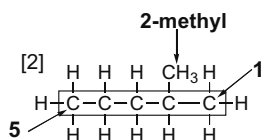
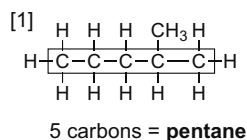
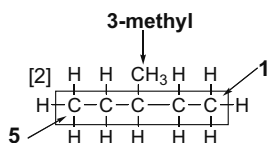
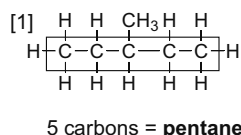
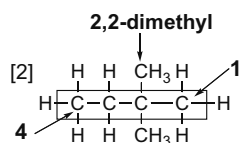
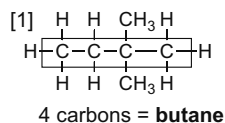
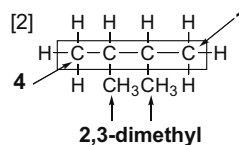
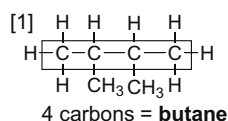


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e. 3-ethyl-5-isobutylnonane



4.12 Use the steps in Answer 4.9 to name each alkane.

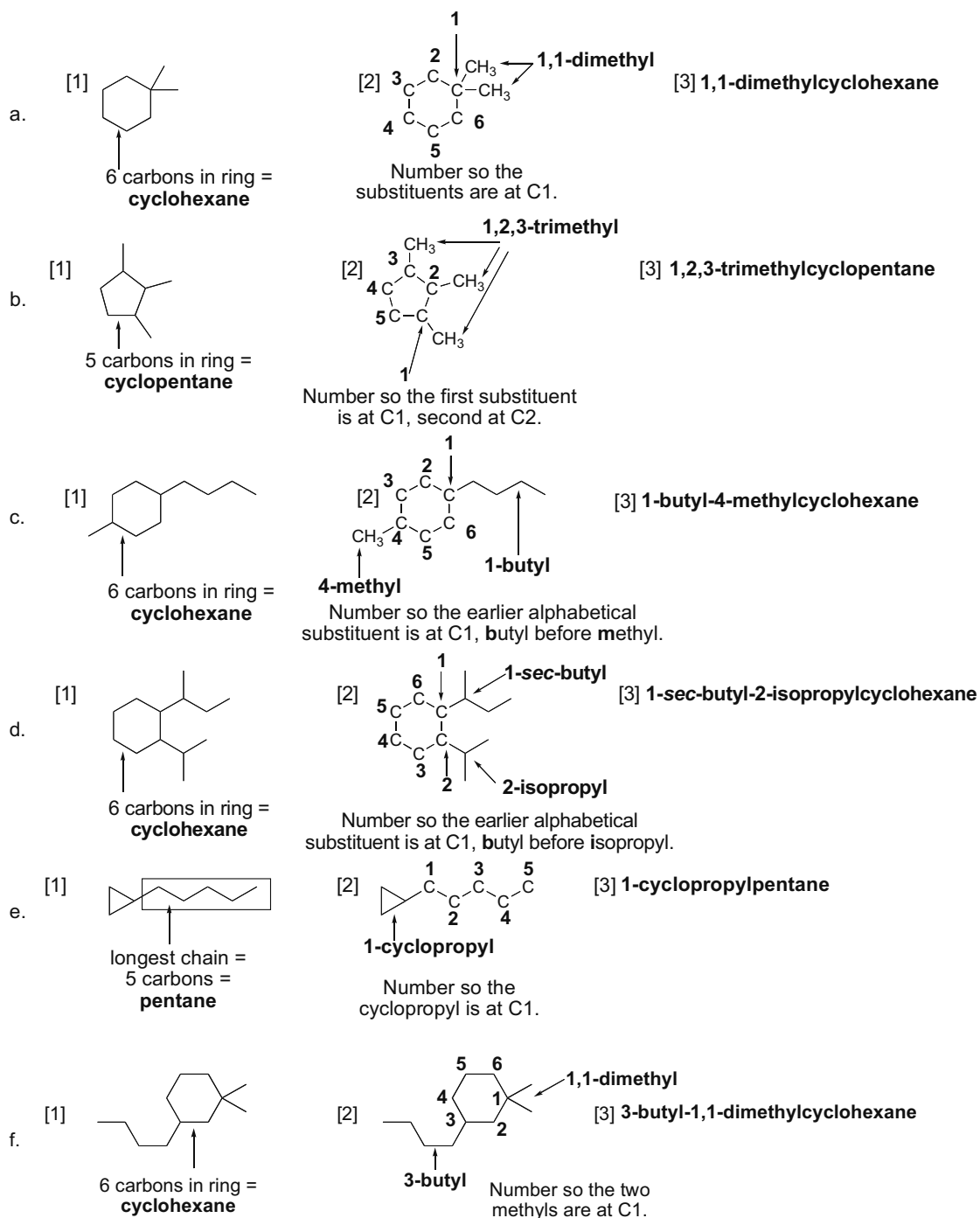
[3] **hexane**[3] **2-methylpentane**[3] **3-methylpentane**[3] **2,2-dimethylbutane**[3] **2,3-dimethylbutane**

4.13 Follow these steps to name a cycloalkane:

[1] **Name the parent cycloalkane** by counting the C's in the ring and adding cyclo-[2] **Numbering:**[2a] **Number around the ring** beginning at a substituent and giving the second substituent the lower number.[2b] **Number to assign the lower number to the substituents alphabetically.**[2c] **Name and number all substituents**, giving like substituents a prefix (di, tri, etc.).[3] **Combine all parts**, alphabetizing the substituents, ignoring all prefixes except *iso*.

(Remember: If a carbon chain has more C's than the ring, the chain is the parent, and the ring is a substituent.)

Alkanes 4-11

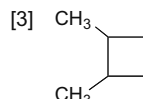
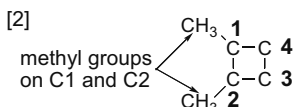


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4.14 To draw the structures, use the steps in Answer 4.11.

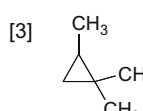
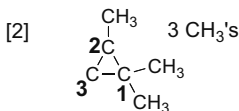
a. 1,2-dimethylcyclobutane

[1] 4 carbon cycloalkane



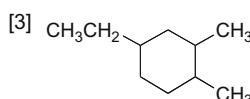
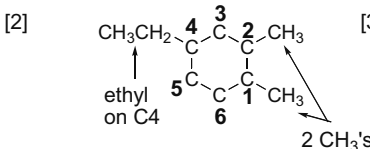
b. 1,1,2-trimethylcyclopropane

[1] 3 carbon cycloalkane



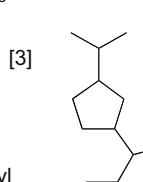
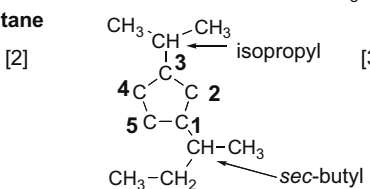
c. 4-ethyl-1,2-dimethylcyclohexane

[1] 6 carbon cycloalkane



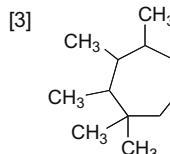
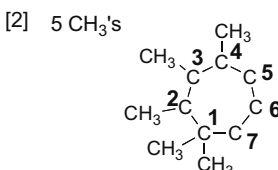
d. 1-sec-butyl-3-isopropylcyclopentane

[1] 5 carbon cycloalkane



e. 1,1,2,3,4-pentamethylcycloheptane

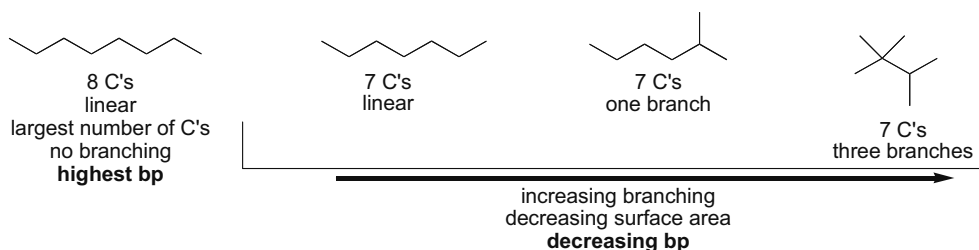
[1] 7 carbon cycloalkane



4.15 Compare the number of C's and surface area to determine relative boiling points. Rules:

[1] Increasing number of C's = increasing boiling point.

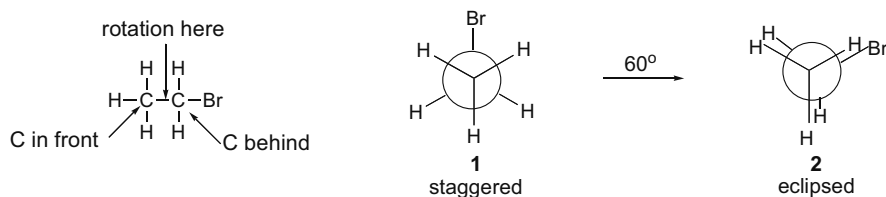
[2] Increasing surface area = increasing boiling point (branching decreases surface area).



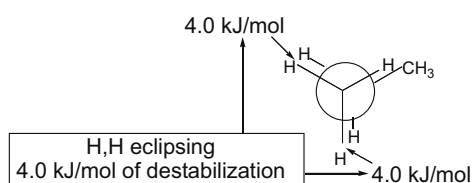
Increasing boiling point: $(\text{CH}_3)_3\text{CCH}(\text{CH}_3)_2 < \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}(\text{CH}_3)_2 < \text{CH}_3(\text{CH}_2)_5\text{CH}_3 < \text{CH}_3(\text{CH}_2)_6\text{CH}_3$

4.16 To draw a Newman projection, visualize the carbons as one in front and one in back of each other. The C–C bond is not drawn. There is only one staggered and one eclipsed conformation.

Alkanes 4-13



4.17

To calculate H,CH₃ destabilization:

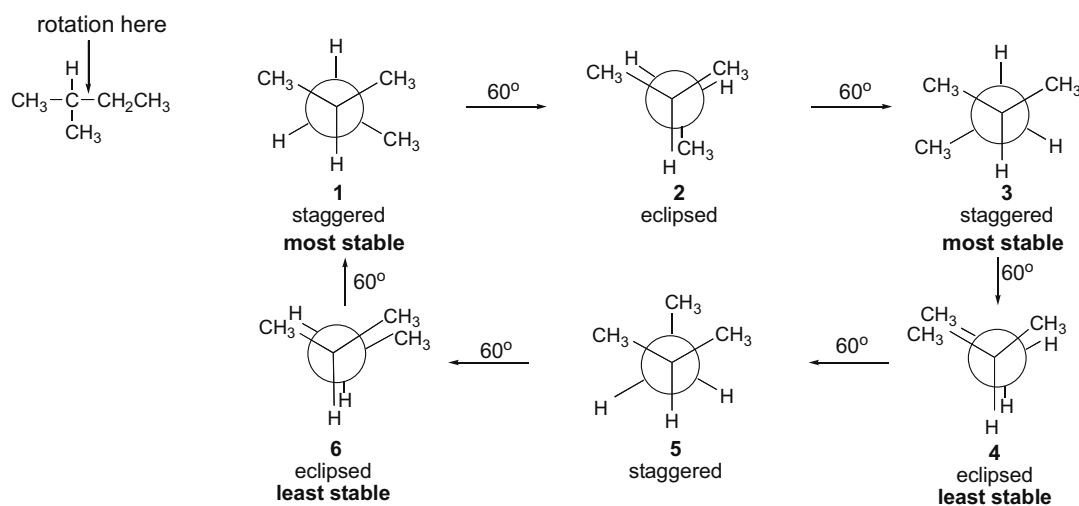
14 kJ/mol (total) –
8.0 kJ/mol for 2 H,H eclipsing interactions
= **6 kJ/mol** for one H,CH₃ eclipsing interaction

4.18 To determine the energy of conformations keep two things in mind:

[1] Staggered conformations are more stable than eclipsed conformations.

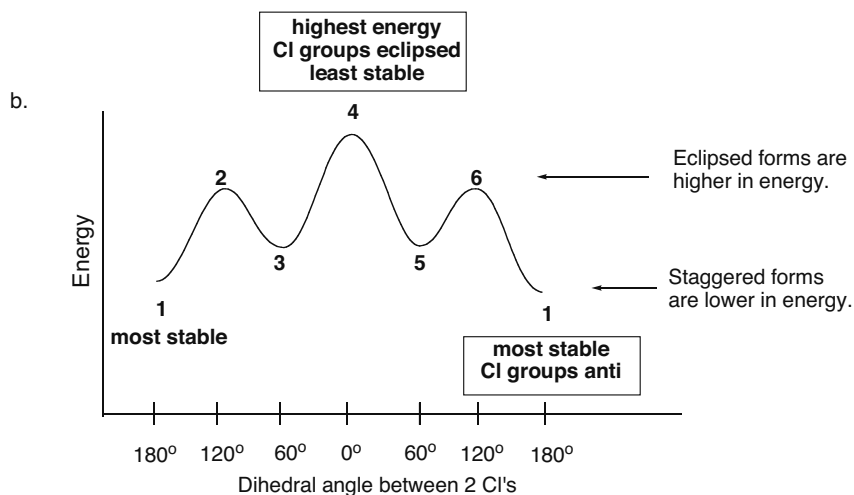
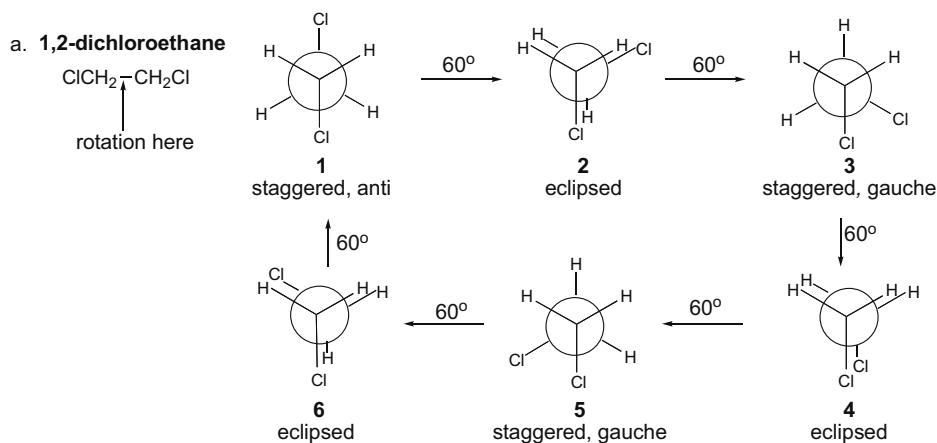
[2] Minimize steric interactions: keep large groups away from each other.

The highest energy conformation is the eclipsed conformation in which the two largest groups are eclipsed. The lowest energy conformation is the staggered conformation in which the two largest groups are anti.

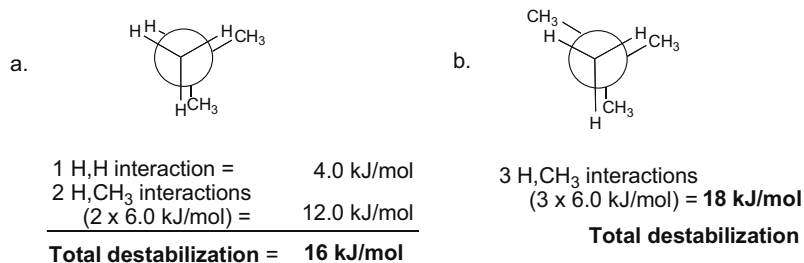


Chapter 4–14

4.19 To determine the most and least stable conformations, use the rules from Answer 4.18.

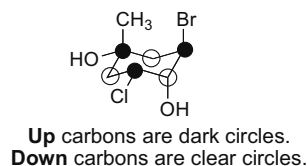
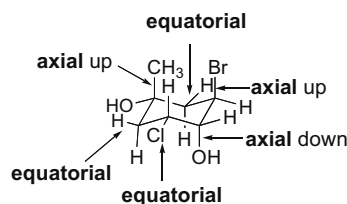


4.20 Add the energy increase for each eclipsing interaction to determine the destabilization.



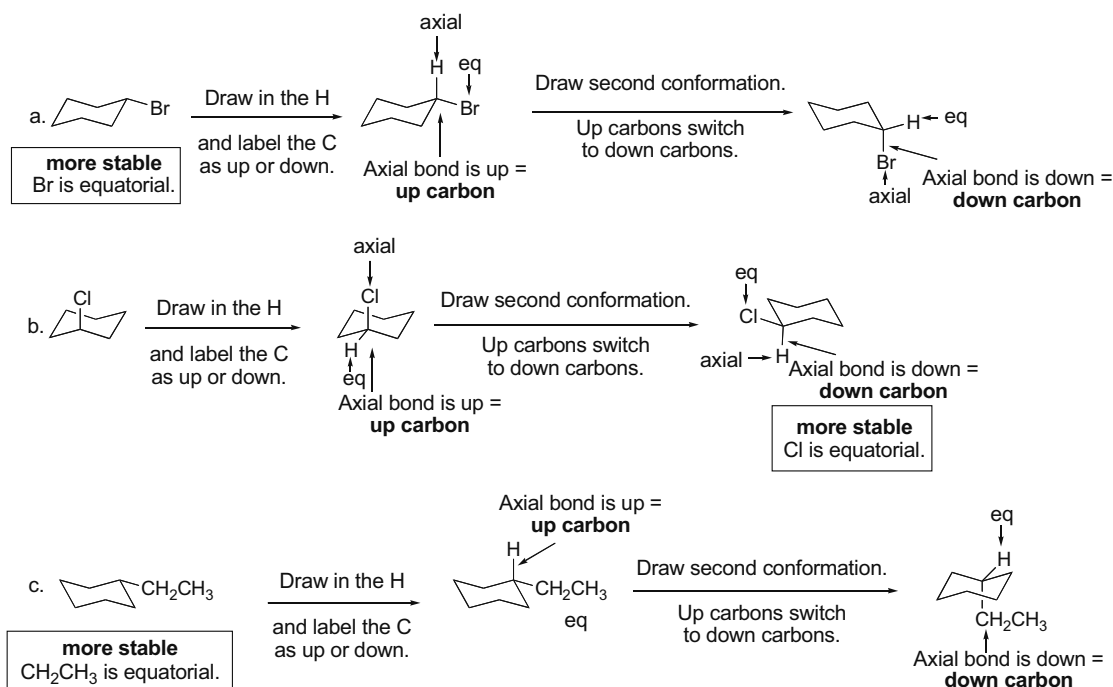
4.21 Two points:

- Axial bonds point up or down, while equatorial bonds point out.
- An *up* carbon has an axial *up* bond, and a *down* carbon has an axial *down* bond.



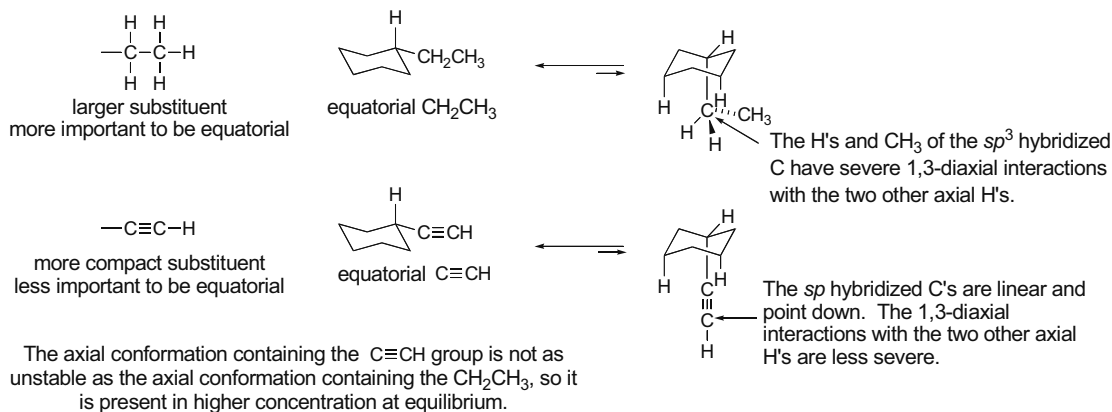
4.22 Draw the second chair conformation by flipping the ring.

- The *up* carbons become *down* carbons, and the axial bonds become equatorial bonds.
- Axial bonds become equatorial, but *up* bonds stay *up*; that is, an axial *up* bond becomes an equatorial *up* bond.
- The conformation with **larger groups equatorial** is the **more stable** conformation and is present in higher concentration at equilibrium.

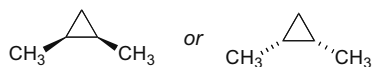


4.23 Larger axial substituents create unfavorable diaxial interactions, whereas equatorial groups have more room and are favored.

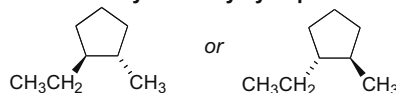
Chapter 4–16



4.24 Wedges represent “up” groups in front of the page, and dashes are “down” groups in back of the page. Cis groups are on the same side of the ring, and trans groups are on opposite sides of the ring.

a. **cis-1,2-dimethylcyclopropane**

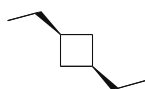
cis = same side of the ring
both groups on wedges or
both on dashes

b. **trans-1-ethyl-2-methylcyclopentane**

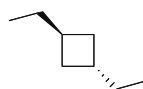
trans = opposite sides of the ring
one group on a wedge,
one group on a dash

4.25 Cis and trans isomers are stereoisomers.

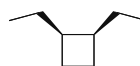
cis-1,3-diethylcyclobutane



cis = same side of the ring
both groups on wedges or
both on dashes

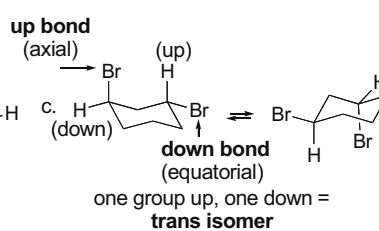
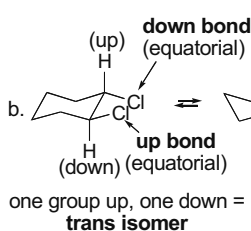
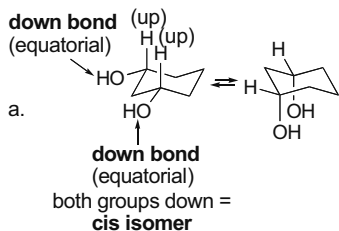
a. **trans-1,3-diethylcyclobutane**

trans = opposite sides of the ring
one group on a wedge,
one group on a dash

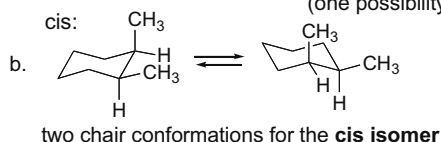
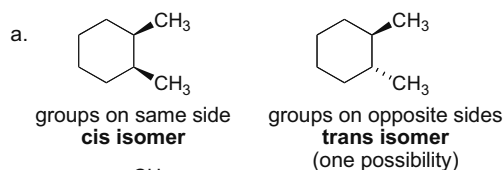
b. **cis-1,2-diethylcyclobutane**

constitutional isomer
different arrangement of atoms

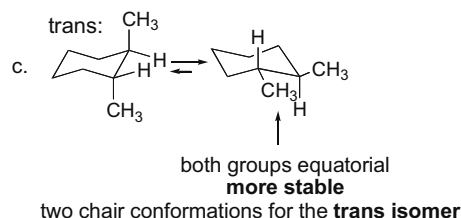
4.26 To classify a compound as a cis or trans isomer, **classify each non-hydrogen group as up or down. Groups on the same side = cis isomer; groups on opposite sides = trans isomer.**



4.27

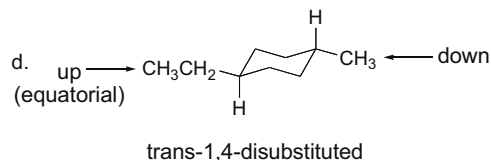
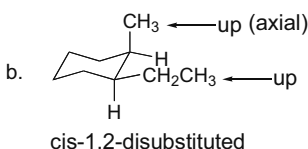
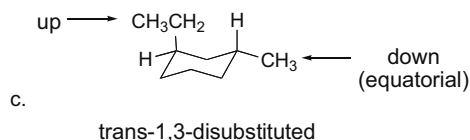
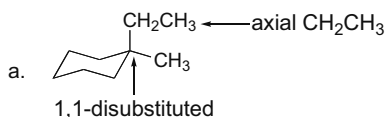


Same stability since they both have one equatorial, one axial CH_3 group.



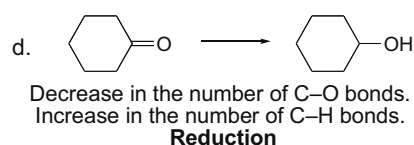
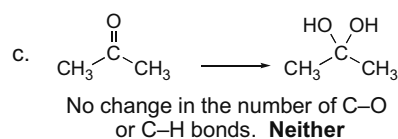
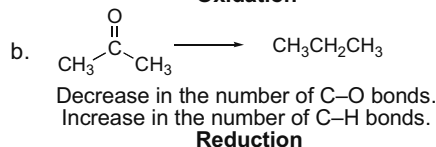
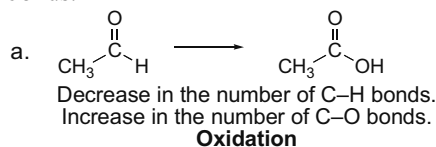
d. The **trans isomer is more stable** because it can have both methyl groups in the more roomy **equatorial** position.

4.28

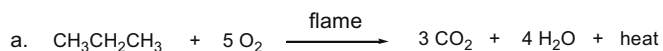


4.29 **Oxidation** results in an *increase* in the number of C-Z bonds, or a *decrease* in the number of C-H bonds.

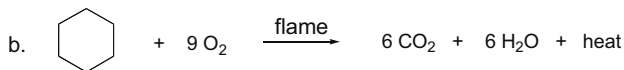
Reduction results in a *decrease* in the number of C-Z bonds, or an *increase* in the number of C-H bonds.



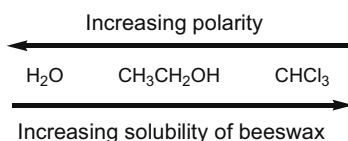
4.30 The products of a combustion reaction of a hydrocarbon are always the same: **CO_2 and H_2O** .



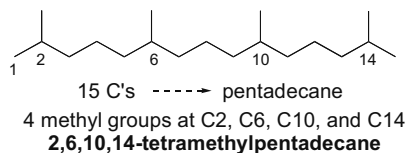
Chapter 4–18



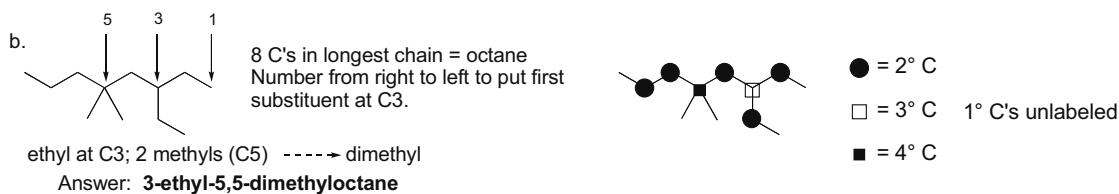
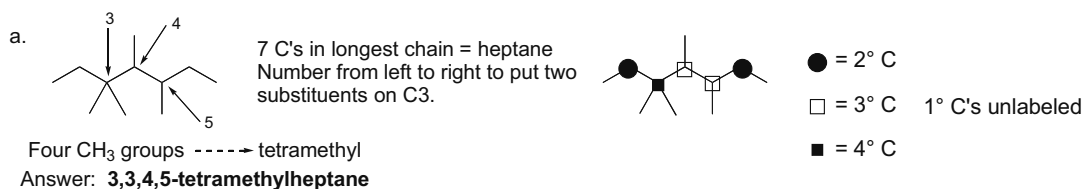
- 4.31 “Like dissolves like.” Beeswax is a lipid, so it will be more soluble in nonpolar solvents. H₂O is very polar, ethanol is slightly less polar, and chloroform is least polar. Beeswax is most soluble in the least polar solvent.



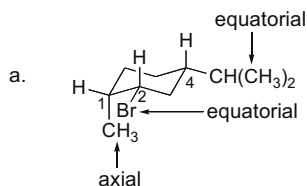
- 4.32 Re-draw the model as a skeletal structure. The longest chain has 15 C's, making it a derivative of pentadecane. Numbering from either direction gives the same numbers.



- 4.33 Re-draw each alkane as a skeletal structure, and use the steps in Answer 4.9 to name each compound. Use the definitions in Answer 4.3 to classify C's.



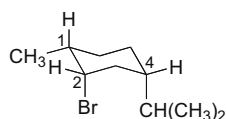
- 4.34 Re-draw the ball-and-stick model as a chair form.



Alkanes 4-19

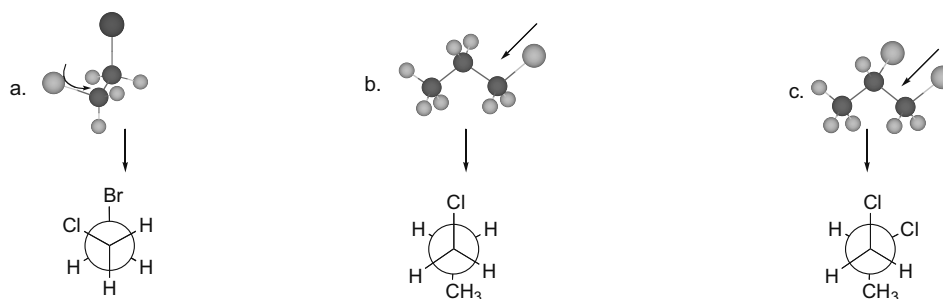
- b. CH_3 on C1 and Br on C2 are both down, making them cis.
 c. Br on C2 and $\text{CH}(\text{CH}_3)_2$ on C4 are both down, making them cis.

d. Second chair form:

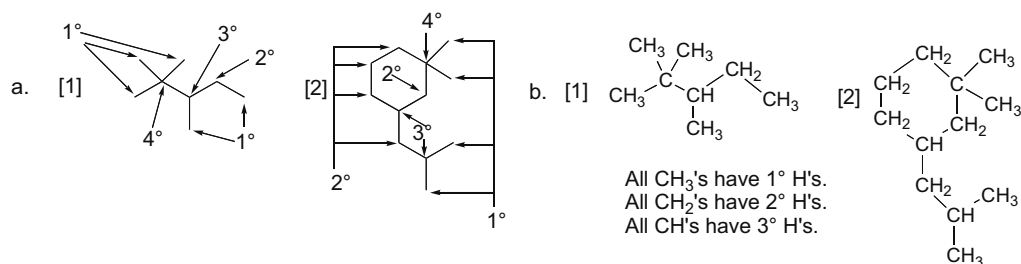


This chair form is less stable because two groups [Br and $\text{CH}(\text{CH}_3)_2$] are in the more crowded axial position.

4.35

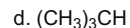
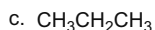
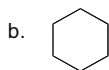
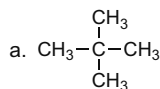


4.36 Use the rules from Answer 4.3.



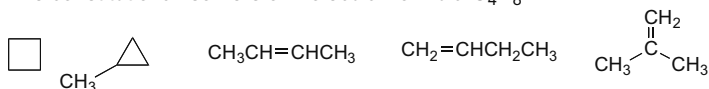
4.37

One possibility:

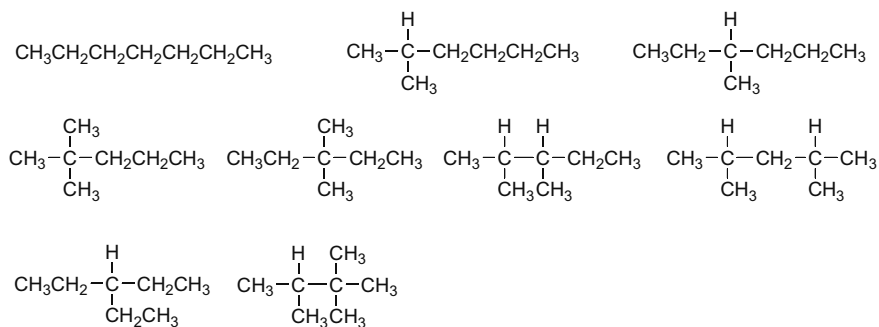
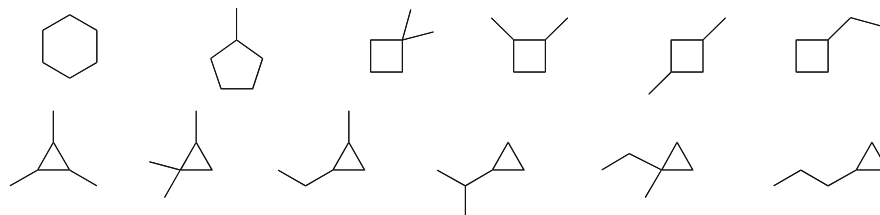


4.38

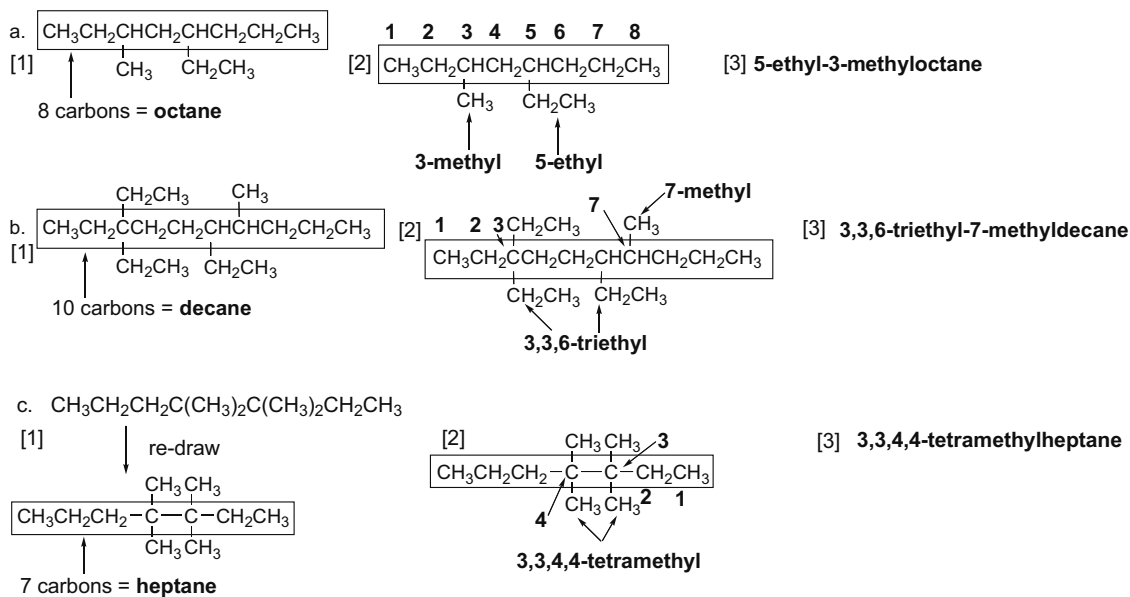
a. Five constitutional isomers of molecular formula C_4H_8 :



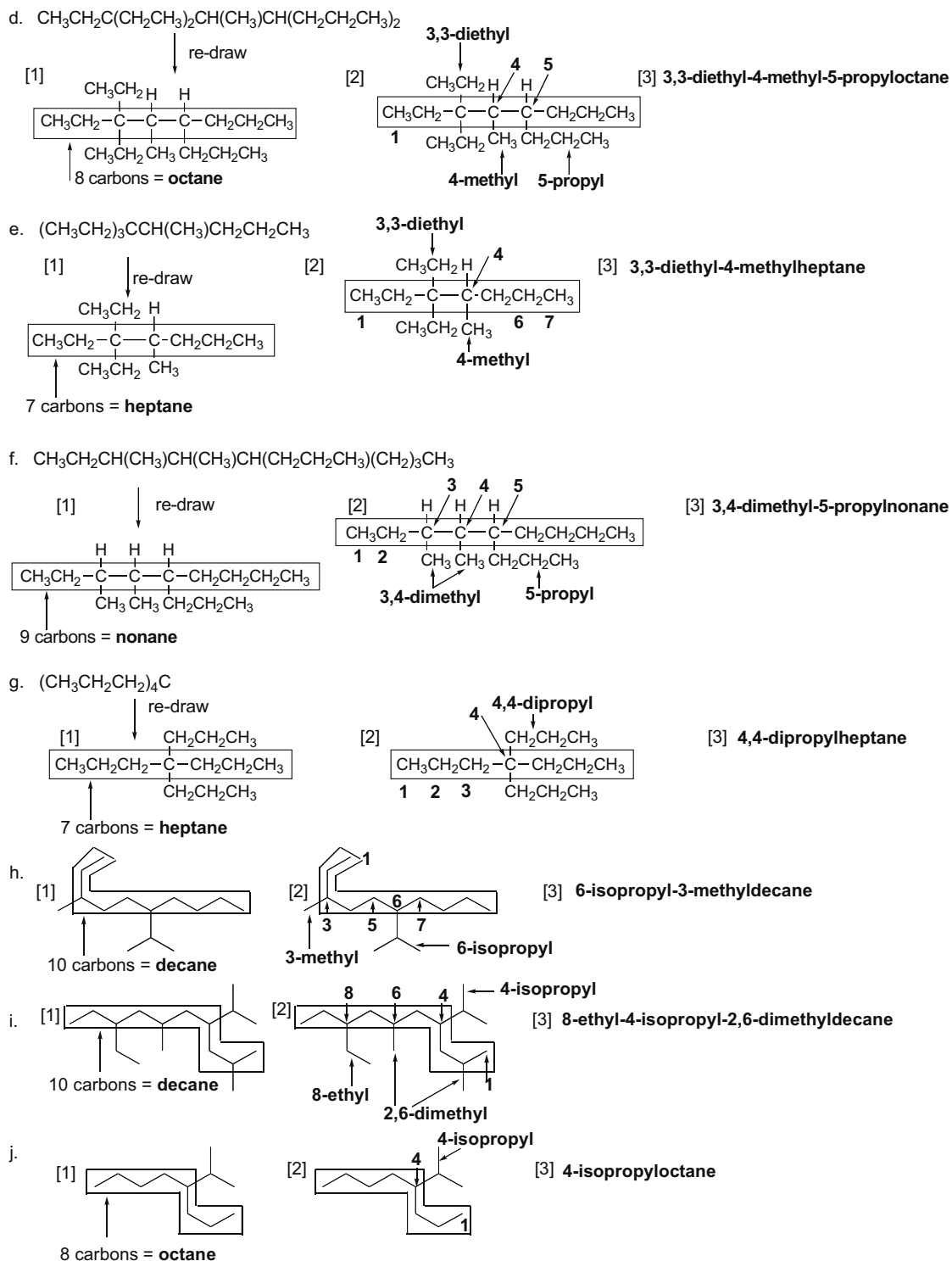
Chapter 4–20

b. Nine constitutional isomers of molecular formula C_7H_{16} :c. Twelve constitutional isomers of molecular formula C_6H_{12} containing one ring:

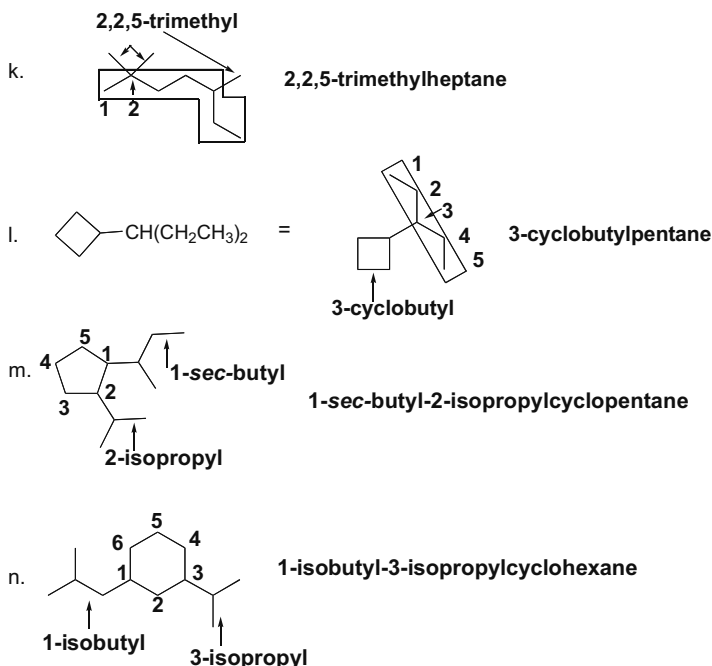
4.39 Use the steps in Answers 4.9 and 4.13 to name the alkanes.



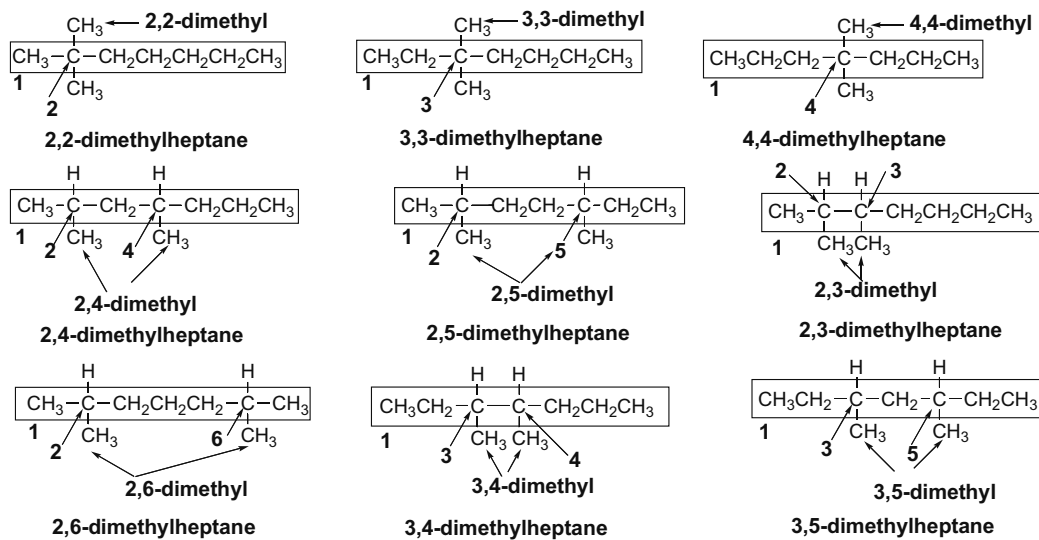
Alkanes 4-21



Chapter 4-22

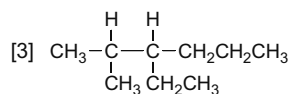
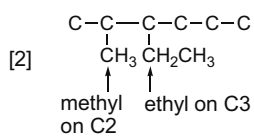
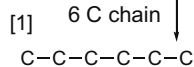


4.40



4.41 Use the steps in Answer 4.11 to draw the structures.

a. 3-ethyl-2-methylhexane



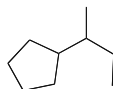
Alkanes 4-23

b. *sec*-butylcyclopentane

[1] 5 C ring

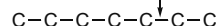


[2]

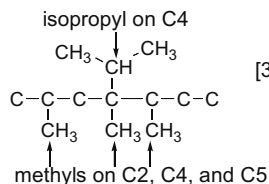


c. 4-isopropyl-2,4,5-trimethylheptane

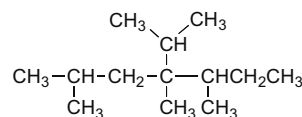
[1] 7 C chain



[2]

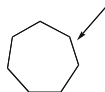


[3]

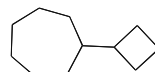


d. cyclobutylcycloheptane

[1] 7 C cycloalkane

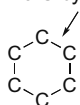


[2]

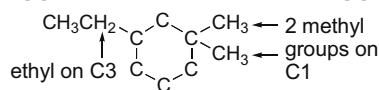


e. 3-ethyl-1,1-dimethylcyclohexane

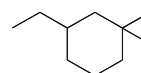
[1] 6 C cycloalkane



[2]

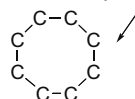


[3]



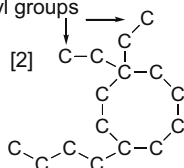
f. 4-butyl-1,1-diethylcyclooctane

[1] 8 C cycloalkane

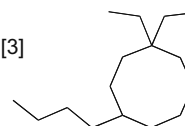


2 ethyl groups

[2]

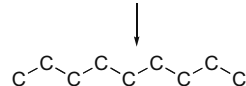


[3]

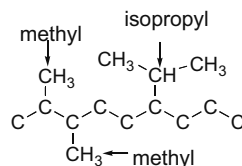


g. 6-isopropyl-2,3-dimethylnonane

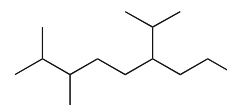
[1] 9 C alkane



[2]

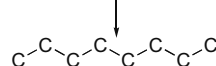


[3]

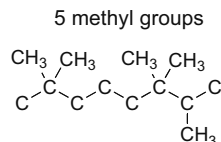


h. 2,2,6,6,7-pentamethyloctane

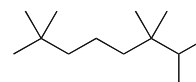
[1] 8 C alkane



[2]



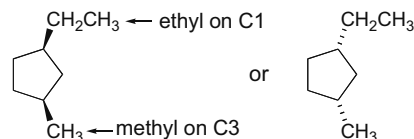
[3]

i. *cis*-1-ethyl-3-methylcyclopentane

[1] 5 C ring



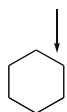
[2]



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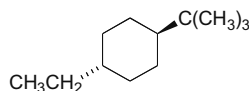
j. *trans*-1-*tert*-butyl-4-ethylcyclohexane

[1]

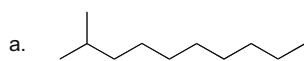


6 C ring

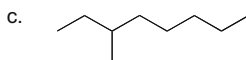
[2]



4.42 Undecane has 11 C's in an unbranched long chain, with molecular formula $C_{11}H_{24}$. A compound that is not an isomer must have a different molecular formula. Only (c) has a different molecular formula.



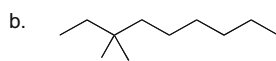
2-methyldecane
 $C_{11}H_{24}$
isomer



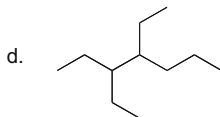
3-ethyloctane
 $C_{10}H_{22}$
not an isomer



2,2,3,3,4,4-hexamethylpentane
 $C_{11}H_{24}$
isomer



3,3-dimethylnonane
 $C_{11}H_{24}$
isomer

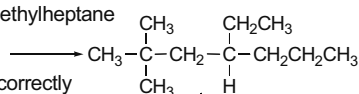


3,4-diethylheptane
 $C_{11}H_{24}$
isomer

4.43 Draw the compounds.

a. 2,2-dimethyl-4-ethylheptane

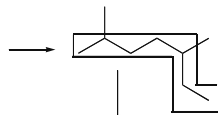
alphabetized incorrectly
ethyl before methyl



4-ethyl-2,2-dimethylheptane

b. 5-ethyl-2-methylhexane

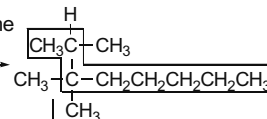
Longest chain was not
chosen = **heptane**



2,5-dimethylheptane

c. 2-methyl-2-isopropylheptane

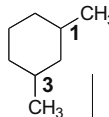
Longest chain was not
chosen = **octane**



2,3,3-trimethyloctane

d. 1,5-dimethylcyclohexane

Numbered incorrectly.
Re-number so methyls
are at C1 and C3.

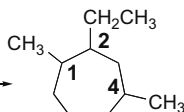


1,3-dimethylcyclohexane

Alkanes 4-25

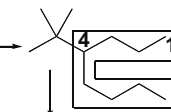
e. 1-ethyl-2,6-dimethylcycloheptane

Numbered incorrectly.
Re-number so methyls
are at C1 and C4.

**2-ethyl-1,4-dimethylcycloheptane**

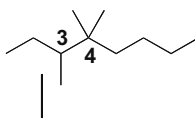
g. 3-butyl-2,2-dimethylhexane

Longest chain not
chosen = **octane**

**4-tert-butyl-octane**

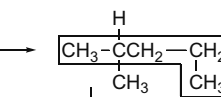
f. 5,5,6-trimethyloctane

Numbered incorrectly.
Re-number so methyls
are at C3 and C4.

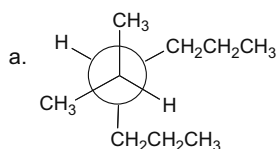
**3,4,4-trimethyloctane**

h. 1,3-dimethylbutane

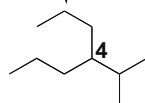
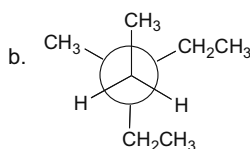
Longest chain not
chosen = **pentane**

**2-methylpentane**

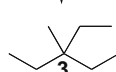
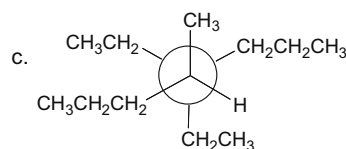
4.44



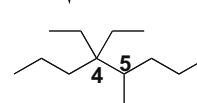
re-draw

**4-isopropylheptane**

re-draw

**3-ethyl-3-methylpentane**

re-draw

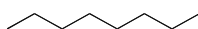
**4,4-diethyl-5-methyloctane**

4.45 Use the rules from Answer 4.15.

a. $\text{CH}_3\text{CH}_2\text{CH}_3$ $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$ $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$
3 C's 4 C's 5 C's
lowest boiling point **highest boiling point**

b. $(\text{CH}_3)_2\text{CHCH}(\text{CH}_3)_2$ $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}(\text{CH}_3)_2$ $\text{CH}_3(\text{CH}_2)_4\text{CH}_3$
most branching least branching
lowest boiling point **highest boiling point**

4.46 a.



$\text{CH}_3(\text{CH}_2)_6\text{CH}_3$
no branching = higher surface area
higher boiling point

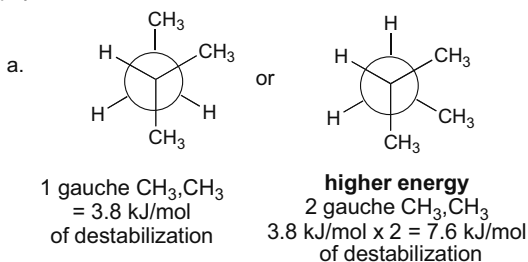


$(\text{CH}_3)_3\text{CC}(\text{CH}_3)_3$
branching = lower surface area
lower boiling point
more spherical, better packing =
higher melting point

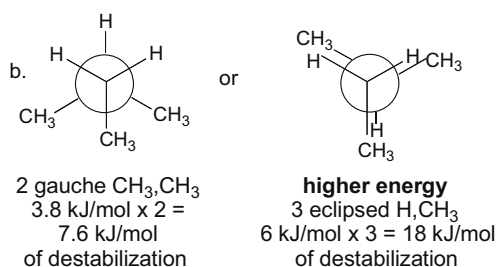
Chapter 4–26

- b. There is a 159° difference in the melting points, but only a 20° difference in the boiling points because the symmetry in $(\text{CH}_3)_3\text{CC}(\text{CH}_3)_3$ allows it to pack more tightly in the solid, thus requiring more energy to melt. In contrast, once the compounds are in the liquid state, symmetry is no longer a factor, the compounds are isomeric alkanes, and the boiling points are closer together.

4.47

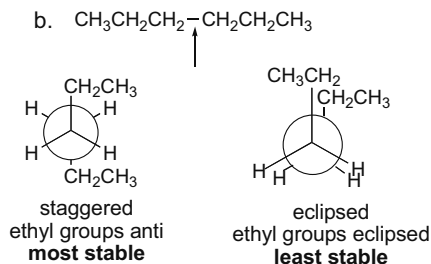
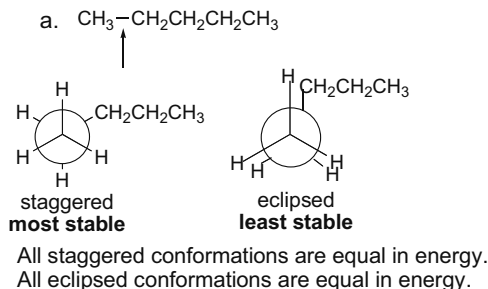


$$\text{Energy difference} = \frac{7.6 \text{ kJ/mol} - 3.8 \text{ kJ/mol}}{1} = \boxed{3.8 \text{ kJ/mol}}$$

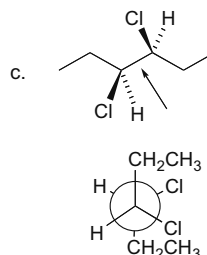
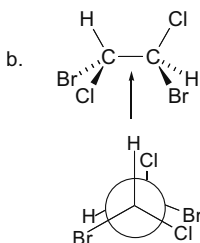
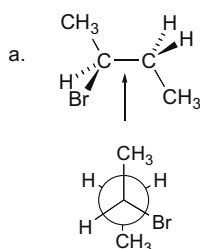


$$\text{Energy difference} = \frac{18 \text{ kJ/mol} - 7.6 \text{ kJ/mol}}{1} = \boxed{10.4 \text{ kJ/mol}}$$

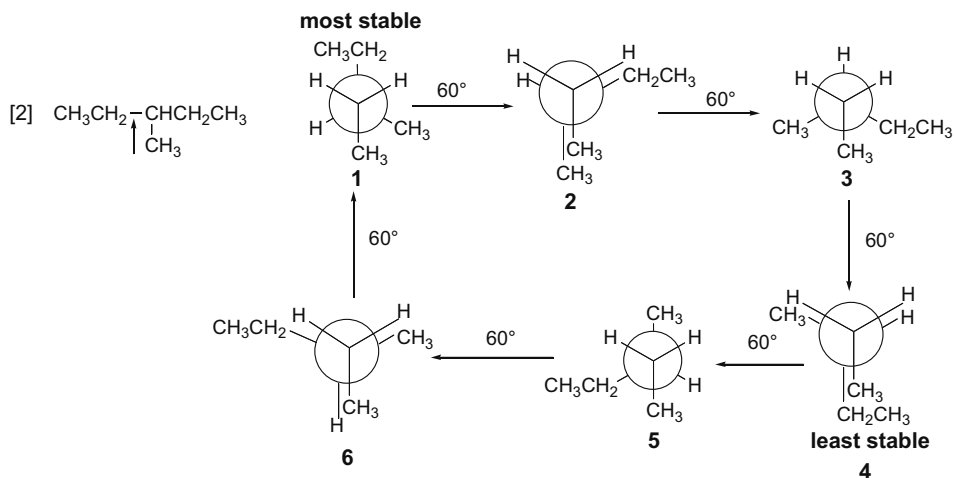
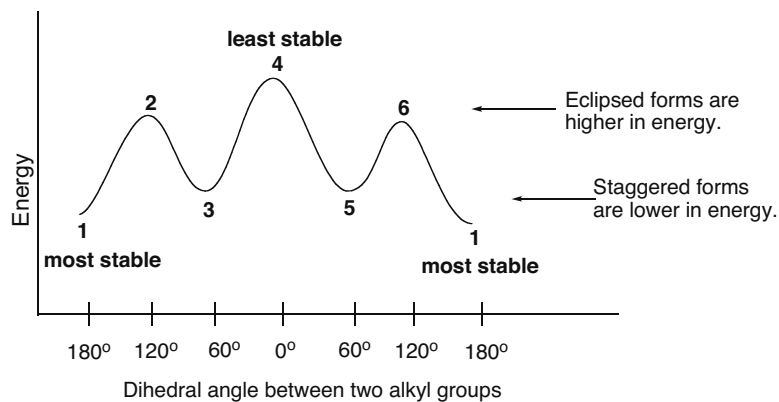
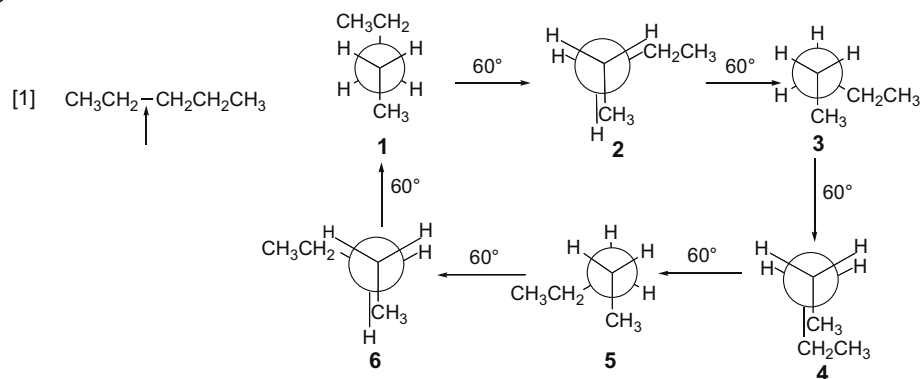
4.48 Use the rules from Answer 4.18 to determine the most and least stable conformations.



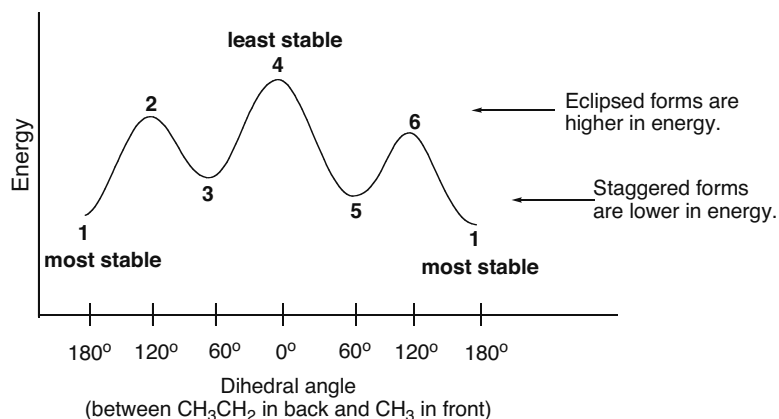
4.49



4.50

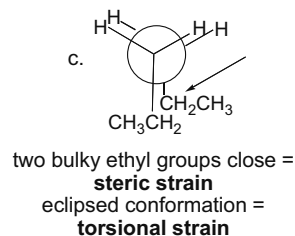
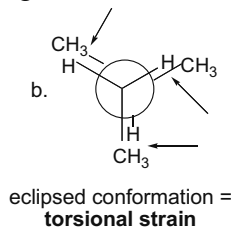
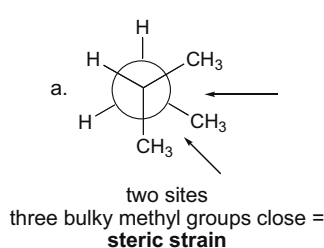


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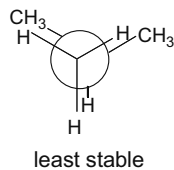
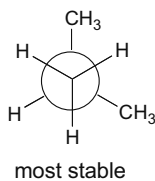
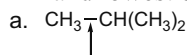


4.51 Two types of strain:

- *Torsional strain* is due to eclipsed groups on adjacent carbon atoms.
- *Steric strain* is due to overlapping electron clouds of large groups (e.g., gauche interactions).

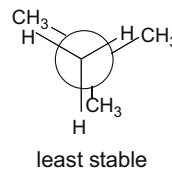
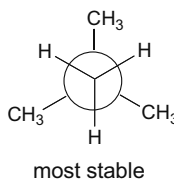
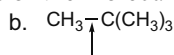


4.52 The barrier to rotation is equal to the difference in energy between the highest energy eclipsed and lowest energy staggered conformations of the molecule.



$$\begin{aligned} \text{Destabilization energy} = \\ & 2 \text{ H,CH}_3 \text{ eclipsing interactions} \\ & \quad 2(6.0 \text{ kJ/mol}) = 12.0 \text{ kJ/mol} \\ & 1 \text{ H,H eclipsing interaction} = 4.0 \text{ kJ/mol} \\ \hline & \text{Total destabilization} = \mathbf{16.0 \text{ kJ/mol}} \end{aligned}$$

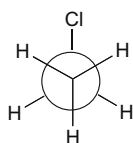
$$\mathbf{16.0 \text{ kJ/mol} = \text{rotation barrier}}$$



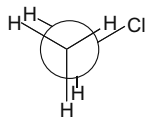
$$\begin{aligned} \text{Destabilization energy} = \\ & 3 \text{ H,CH}_3 \text{ eclipsing interactions} \\ & \quad 3(6.0 \text{ kJ/mol}) = 18.0 \text{ kJ/mol} \\ \hline & \text{Total destabilization} = \mathbf{18.0 \text{ kJ/mol}} \end{aligned}$$

$$\mathbf{18.0 \text{ kJ/mol} = \text{rotation barrier}}$$

4.53



most stable



least stable

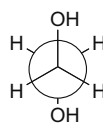
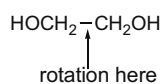
$$2 \text{ H,H eclipsing interactions} = 2(4.0 \text{ kJ/mol}) = 8.0 \text{ kJ/mol}$$

Since the barrier to rotation is 15 kJ/mol, the difference between this value and the destabilization due to H,H eclipsing is the destabilization due to H,Cl eclipsing.

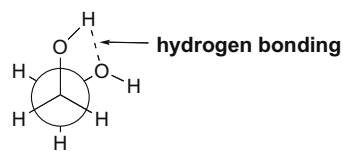
$$15.0 \text{ kJ/mol} - 8.0 \text{ kJ/mol} = 7.0 \text{ kJ/mol}$$

destabilization due to H,Cl eclipsing

4.54 The gauche conformation can intramolecularly hydrogen bond, making it the more stable conformation.



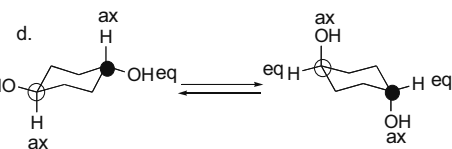
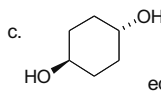
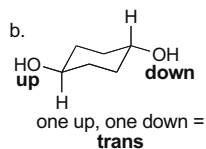
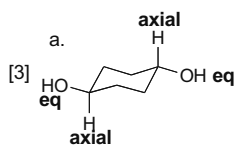
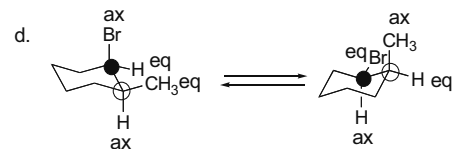
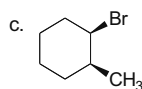
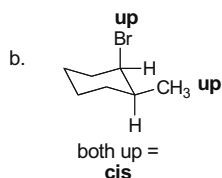
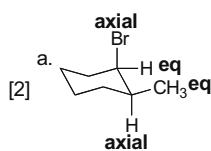
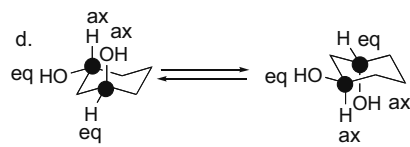
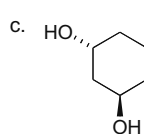
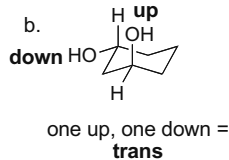
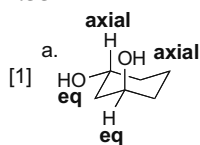
anti



gauche

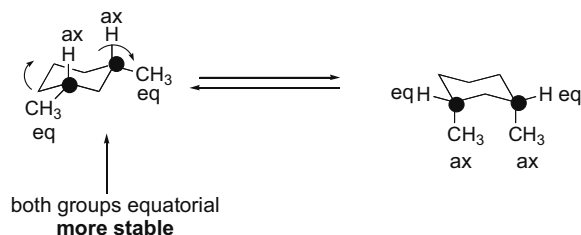
Hydrogen bonding can occur only in the gauche conformation, making it **more stable**.

4.55

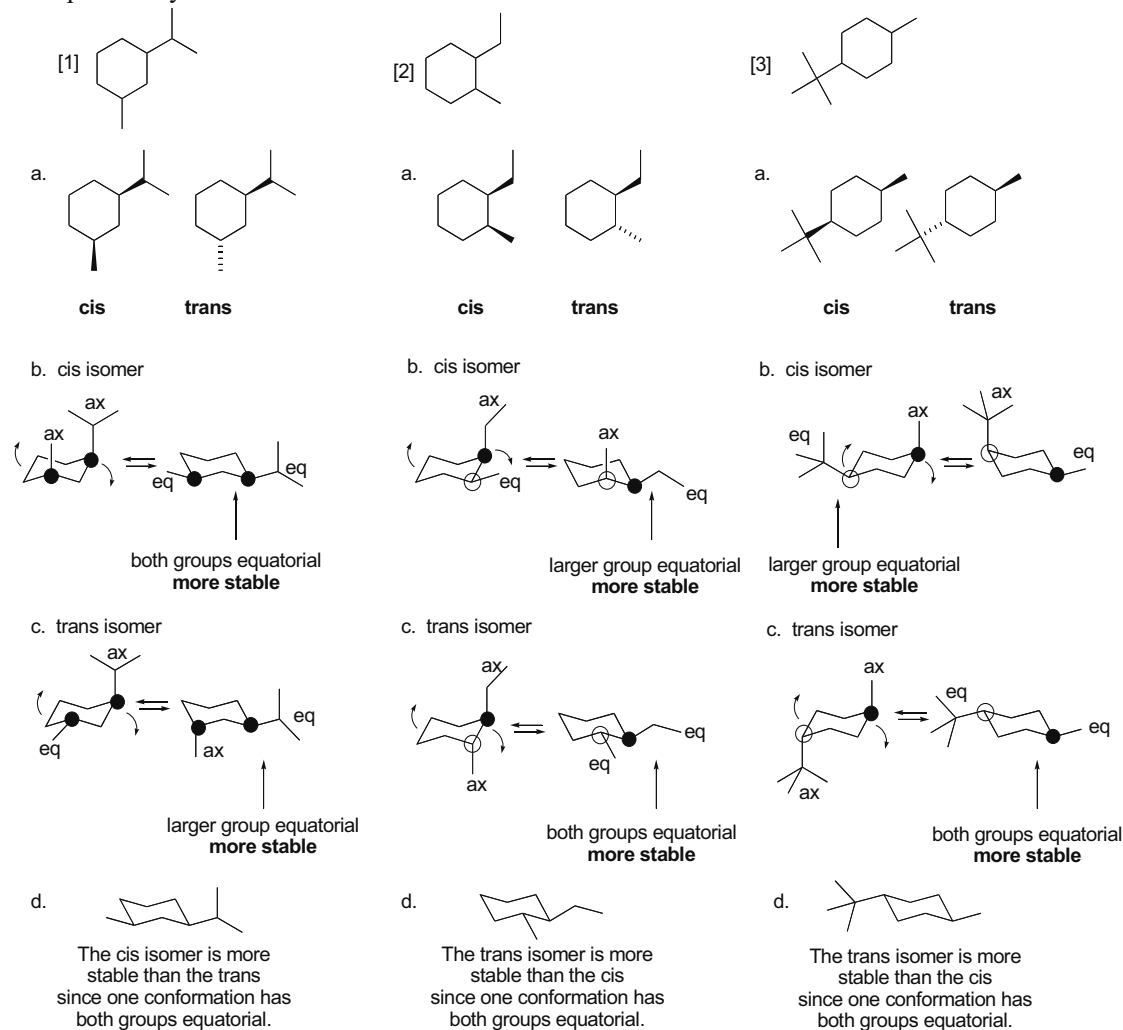


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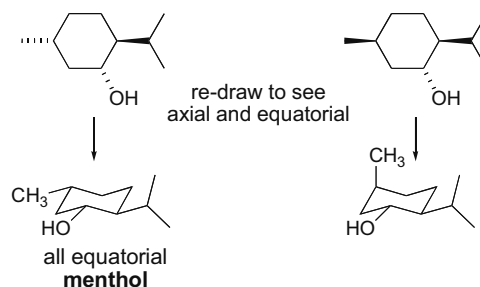
4.56



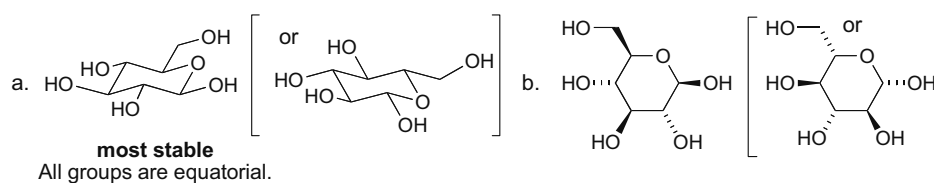
4.57 A **cis isomer** has two groups on the **same side** of the ring. The two groups can be drawn both up or both down. Only one possibility is drawn. A **trans isomer** has one group on one side of the ring and one group on the other side. Either group can be drawn on either side. Only one possibility is drawn.



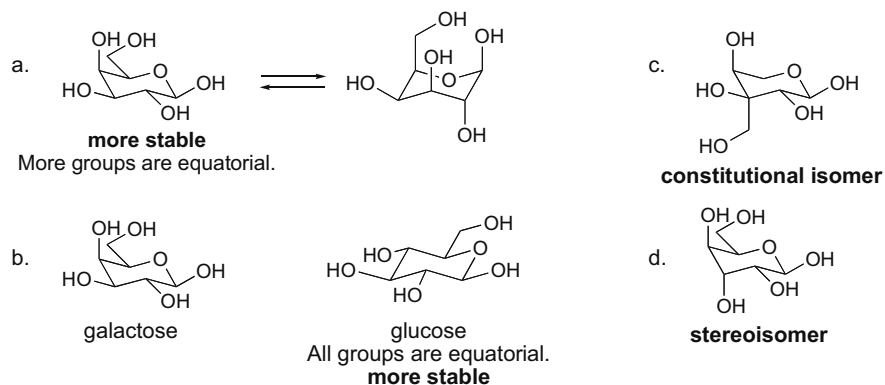
4.58



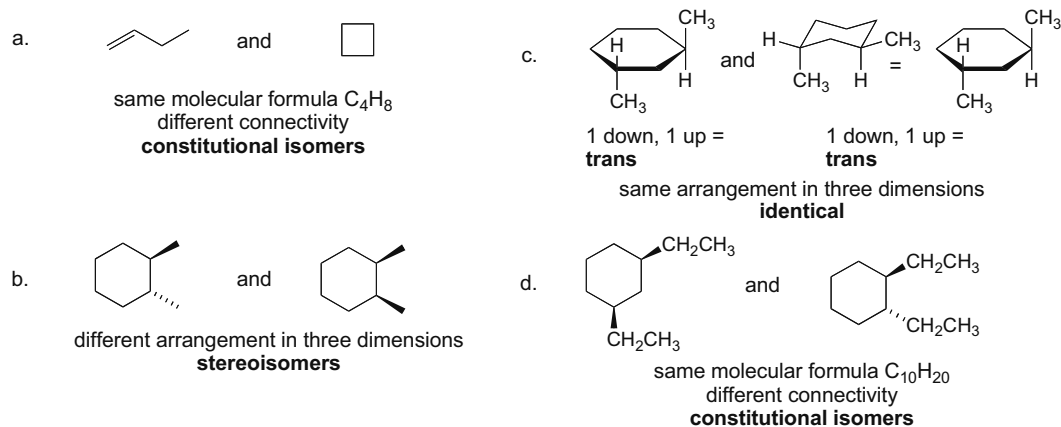
4.59



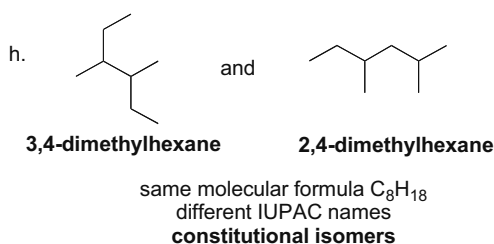
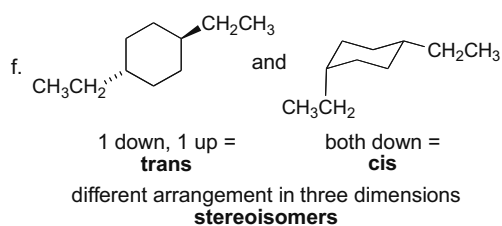
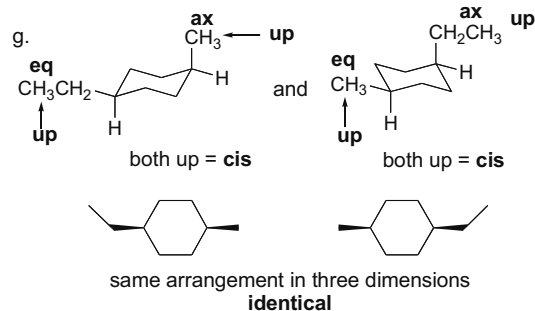
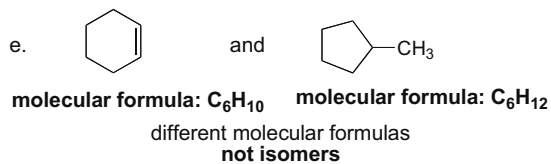
4.60



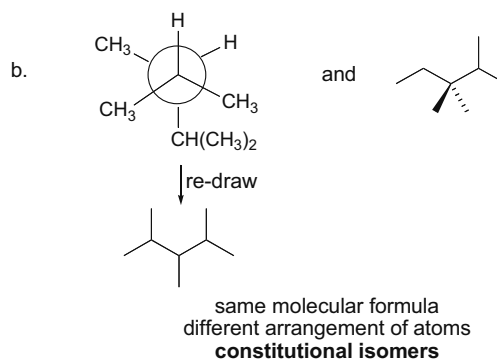
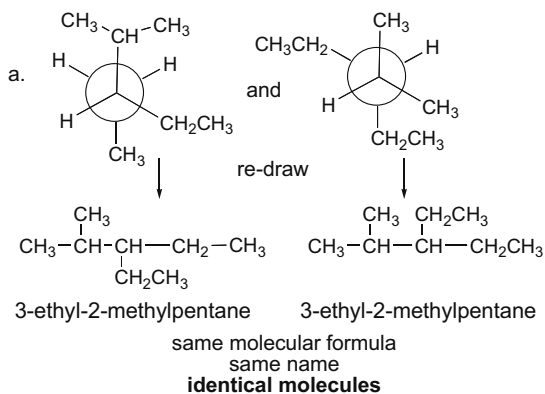
4.61



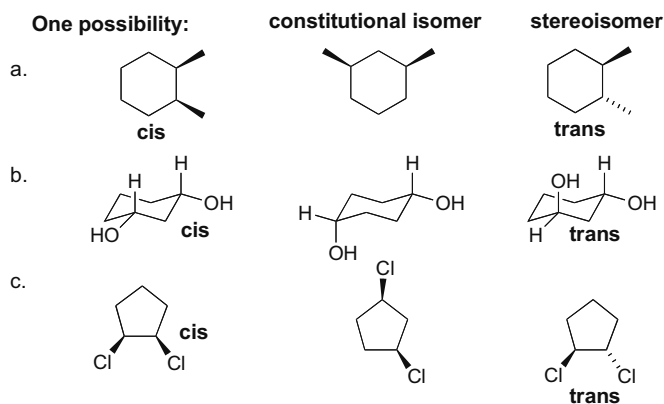
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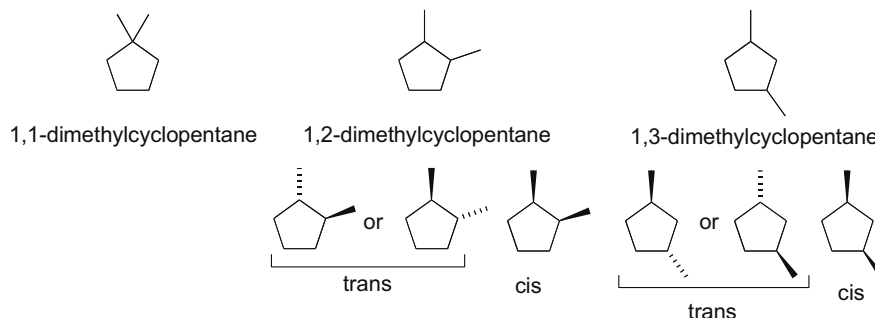
4.62



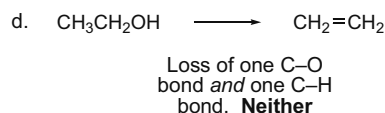
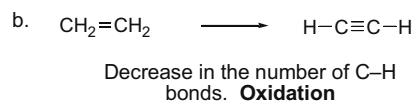
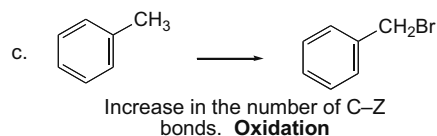
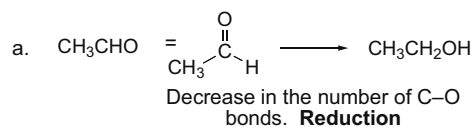
4.63



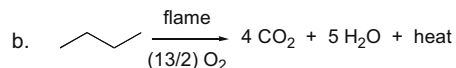
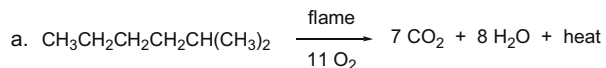
4.64

Three constitutional isomers of C_7H_{14} :

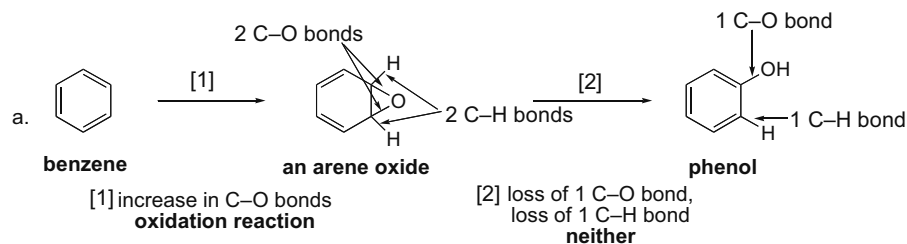
4.65 Use the definitions from Answer 4.29 to classify the reactions.



4.66 Use the rule from Answer 4.30.



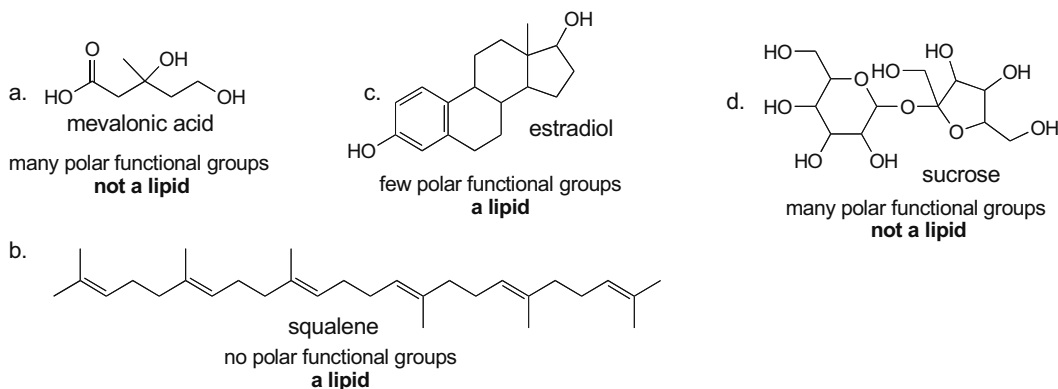
4.67



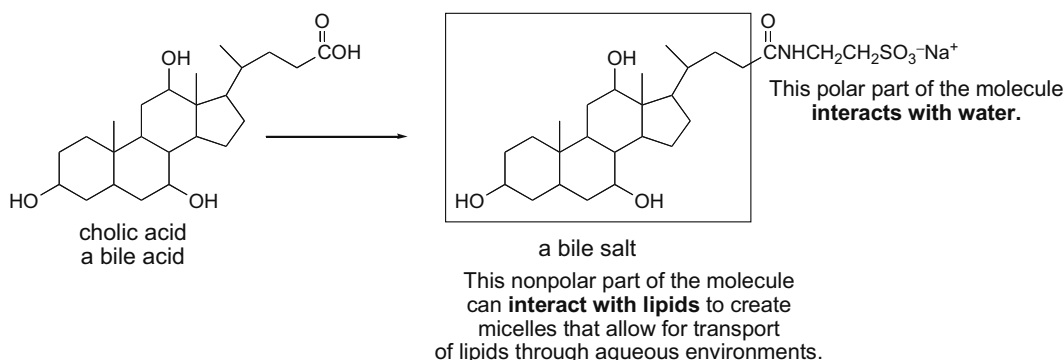
- b. Phenol is more water soluble than benzene because it is **polar (contains an O–H group) and can hydrogen bond with water**, whereas benzene is nonpolar and cannot hydrogen bond.

Chapter 4–34

4.68 Lipids contain many nonpolar C–C and C–H bonds and few polar functional groups.



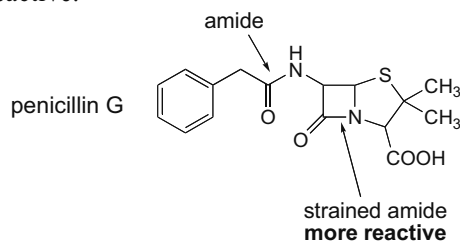
4.69



4.70 The mineral oil can prevent the body's absorption of important fat-soluble vitamins. The vitamins dissolve in the mineral oil, and are thus not absorbed. Instead, they are expelled with the mineral oil.

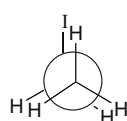
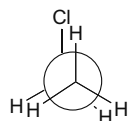
4.71 Cyclopropane has larger angle strain than cyclobutane because the internal angles in the three-membered ring (60°) are smaller than they are in cyclobutane. Although cyclobutane is not flat, as shown in Figure 4.11, there are more C–H bonds than there are in cyclopropane, so there are more sites of torsional strain. Thus cyclopropane has more angle strain but less torsional strain. The result is that both cyclopropane and cyclobutane have roughly similar strain energies.

4.72 The amide in the four-membered ring has 90° bond angles giving it angle strain, which makes it more reactive.

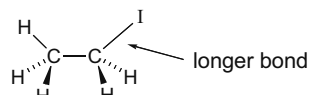
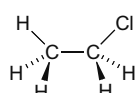


4.73

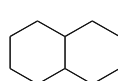
Example:



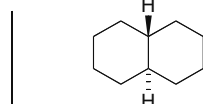
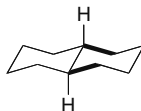
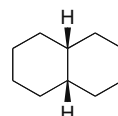
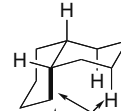
Although I is a much bigger atom than Cl, the C–I bond is also much longer than the C–Cl bond. As a result the eclipsing interaction of the H and I atoms is not very much different in magnitude from the H,Cl eclipsing interaction.



4.74



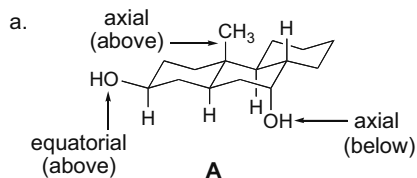
decalin

*trans*-decalin*trans**cis*-decalin*cis*

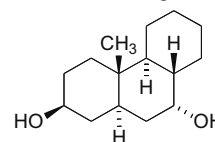
The *trans* isomer is more stable since the carbon groups at the ring junction are both in the favorable equatorial position.

This bond is axial, creating unfavorable 1,3-diaxial interactions.

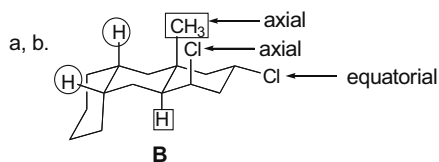
4.75 Re-draw the ball-and-stick model using chair forms.



b. All bonds above the ring are on wedges and all bonds below the ring are on dashed lines.



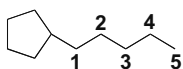
4.76



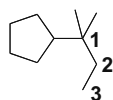
c. The circled H's at one ring fusion are *cis*. The boxed in CH₃ and H at the second ring fusion are *trans*.

Chapter 4–36

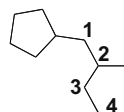
4.77



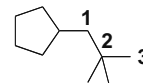
pentylcyclopentane



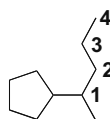
(1,1-dimethylpropyl)cyclopentane



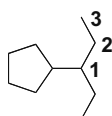
(2-methylbutyl)cyclopentane



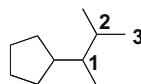
(2,2-dimethylpropyl)cyclopentane



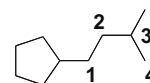
(1-methylbutyl)cyclopentane



(1-ethylpropyl)cyclopentane

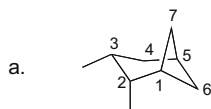


(1,2-dimethylpropyl)cyclopentane

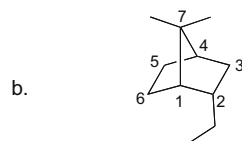


(3-methylbutyl)cyclopentane

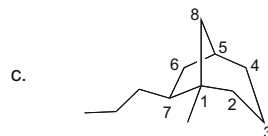
4.78



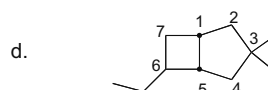
2,3-dimethylbicyclo[3.1.1]heptane



2-ethyl-7,7-dimethylbicyclo[2.2.1]heptane



1-methyl-7-propylbicyclo[3.2.1]octane



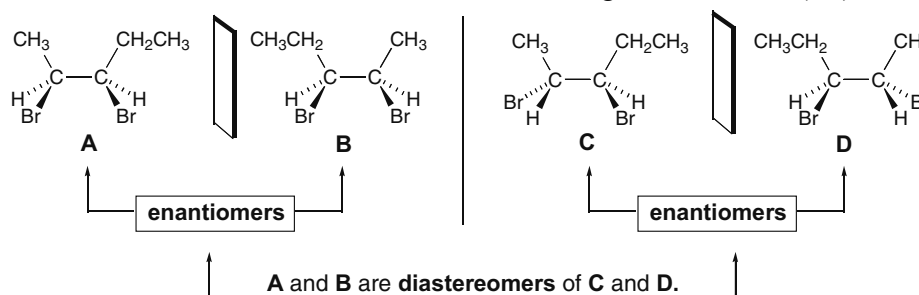
6-ethyl-3,3-dimethylbicyclo[3.2.0]heptane

Chapter 5 Stereochemistry

Chapter Review

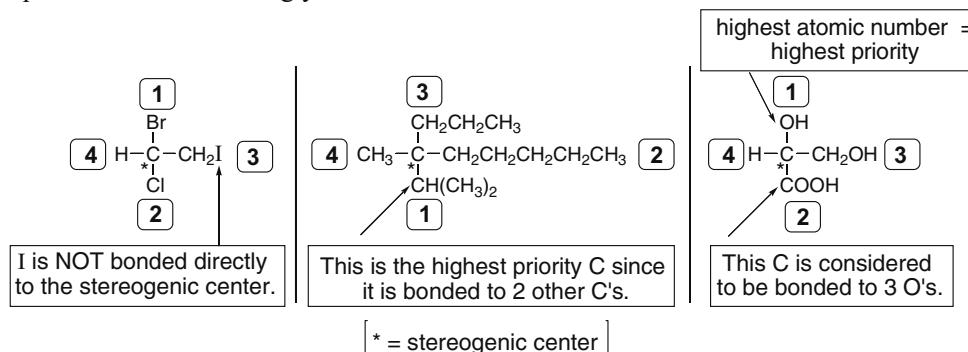
Isomers are different compounds with the same molecular formula (5.2, 5.11).

- [1] **Constitutional isomers**—isomers that differ in the way the atoms are connected to each other. They have:
- different IUPAC names
 - the same or different functional groups
 - different physical and chemical properties.
- [2] **Stereoisomers**—isomers that differ only in the way atoms are oriented in space. They have the same functional group and the same IUPAC name except for prefixes such as *cis*, *trans*, *R*, and *S*.
- **Enantiomers**—stereoisomers that are nonsuperimposable mirror images of each other (5.4).
 - **Diastereomers**—stereoisomers that are not mirror images of each other (5.7).



Assigning priority (5.6)

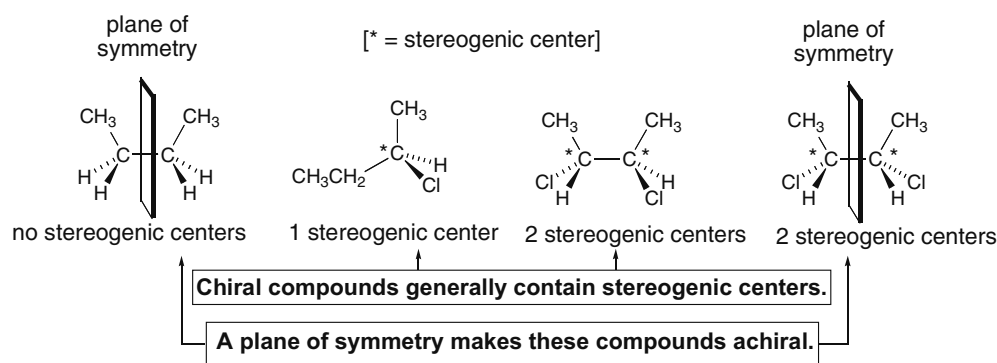
- Assign priorities (1, 2, 3, or 4) to the atoms directly bonded to the stereogenic center in order of decreasing atomic number. The atom of *highest* atomic number gets the *highest* priority (1).
- If two atoms on a stereogenic center are the *same*, assign priority based on the atomic number of the atoms bonded to these atoms. *One* atom of higher atomic number determines a higher priority.
- If two isotopes are bonded to the stereogenic center, assign priorities in order of decreasing *mass* number.
- To assign a priority to an atom that is part of a multiple bond, treat a multiply bonded atom as an equivalent number of singly bonded atoms.



Chapter 5-2

Some basic principles

- When a compound and its mirror image are **superimposable**, they are **identical achiral compounds**. A plane of symmetry in one conformation makes a compound achiral (5.3).
- When a compound and its mirror image are **not superimposable**, they are **different chiral compounds** called **enantiomers**. A chiral compound has no plane of symmetry in any conformation (5.3).
- A **tetrahedral stereogenic center** is a carbon atom bonded to four different groups (5.4, 5.5).
- For n **stereogenic centers**, the maximum number of stereoisomers is 2^n (5.7).



Optical activity is the ability of a compound to rotate plane-polarized light (5.12).

- An optically active solution contains a chiral compound.
- An optically inactive solution contains one of the following:
 - an achiral compound with no stereogenic centers.
 - a meso compound—an achiral compound with two or more stereogenic centers.
 - a racemic mixture—an equal amount of two enantiomers.

The prefixes *R* and *S* compared with *d* and *l*

The prefixes *R* and *S* are labels used in nomenclature. Rules on assigning *R,S* are found in Section 5.6.

- An enantiomer has every stereogenic center opposite in configuration. If a compound with two stereogenic centers has the *R,R* configuration, then its enantiomer has the *S,S* configuration.
- A diastereomer of this same compound has either the *R,S* or *S,R* configuration; one stereogenic center has the same configuration and one is opposite.

The prefixes *d* (or $+$) and *l* (or $-$) tell the direction a compound rotates plane-polarized light (5.12).

- *d* (or $+$) stands for dextrorotatory, rotating polarized light clockwise.
- *l* (or $-$) stands for levorotatory, rotating polarized light counterclockwise.

The physical properties of isomers compared (5.12)

Type of isomer	Physical properties
Constitutional isomers	Different
Enantiomers	Identical except the direction of rotation of polarized light
Diastereomers	Different
Racemic mixture	Possibly different from either enantiomer

Equations

- Specific rotation (5.12C):

$$\text{specific rotation} = [\alpha] = \frac{\alpha}{l \times c}$$

α = observed rotation ($^{\circ}$)
 l = length of sample tube (dm) [dm = decimeter]
 c = concentration (g/mL) [1 dm = 10 cm]

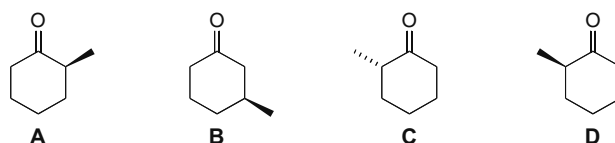
- Enantiomeric excess (5.12D):

$$ee = \% \text{ of one enantiomer} - \% \text{ of other enantiomer}$$

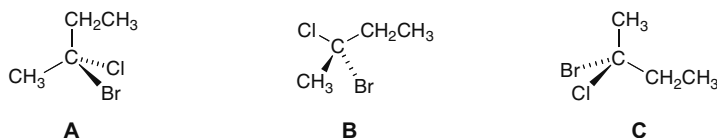
$$= \frac{[\alpha] \text{ mixture}}{[\alpha] \text{ pure enantiomer}} \times 100\%$$

Practice Test on Chapter Review

- 1.a. Which of the following statements is true for compounds **A–D** below?



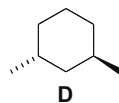
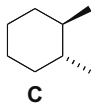
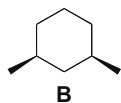
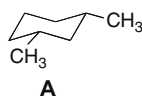
- A** and **B** are separable by physical methods such as distillation.
 - A** and **C** are separable by physical methods such as distillation.
 - A** and **D** are separable by physical methods such as distillation.
 - Statements (1) and (2) are both true.
 - Statements (1), (2), and (3) are all true.
- b. Which of the following statements is true about compounds **A–C** below?



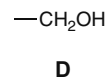
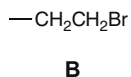
Chapter 5-4

1. **A** and **B** are enantiomers.
2. **A** and **C** are enantiomers.
3. An equal mixture of **B** and **C** is optically active.
4. Statements (1) and (2) are true.
5. Statements (1), (2), and (3) are all true.

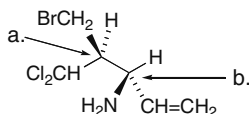
c. Which compound is a diastereomer of **A**?



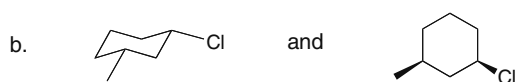
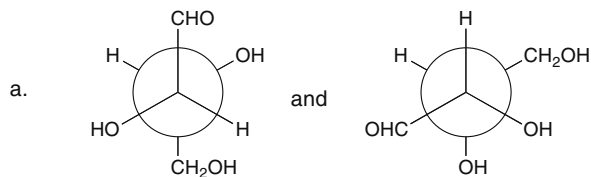
1. **B** only
 2. **C** only
 3. **D** only
 4. Both **B** and **C**
 5. Compounds **B**, **C**, and **D**
2. Rank the following four groups around a stereogenic center in order of decreasing priority. Rank the highest priority group as **1**, the lowest priority group as **4**, and the two groups of intermediate priority as **2** and **3**.



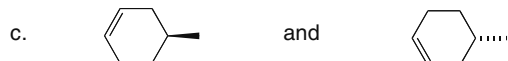
3. Label each stereogenic center in the following compound as *R* or *S*.



4. State how the compounds in each pair are related to each other. Choose from constitutional isomers, enantiomers, diastereomers, or identical compounds.



Stereochemistry 5-5



5. The enantiomeric excess of a mixture of **A** and **B** is 62% with **A** in excess. How much of **A** and **B** are present in the mixture?

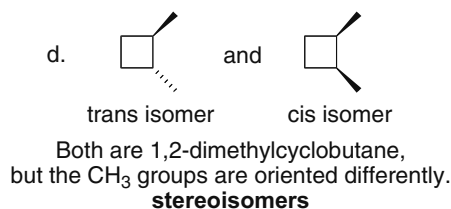
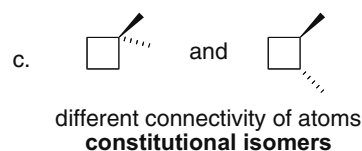
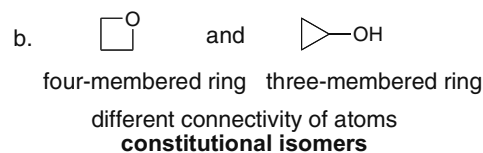
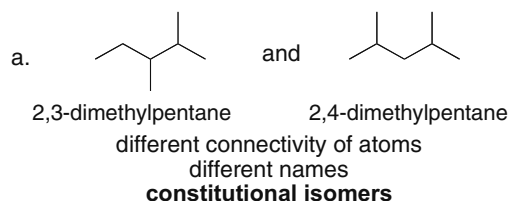
Answers to Practice Test

1. a. 1	2. A -1	3. a. <i>S</i>	4. a. diastereomers	5. 81% A
b. 2	B -4	b. <i>S</i>	b. enantiomers	19% B
c. 3	C -2		c. identical	
	D -3			

Answers to Problems

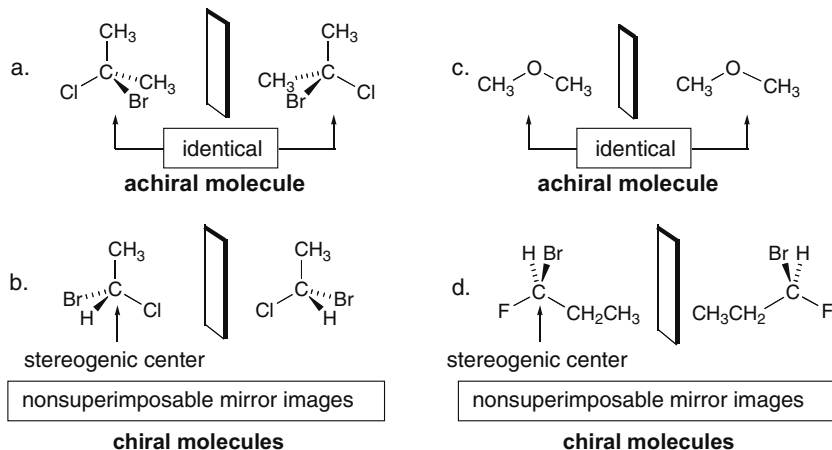
- 5.1** Cellulose consists of long chains held together by intermolecular hydrogen bonds forming sheets that stack in extensive three-dimensional arrays. Most of the OH groups in cellulose are in the interior of this three-dimensional network, unavailable for hydrogen bonding to water. Thus, even though cellulose has many OH groups, its three-dimensional structure prevents many of the OH groups from hydrogen bonding with the solvent and this makes it water insoluble.

- 5.2** **Constitutional isomers** have atoms bonded to different atoms.
Stereoisomers differ only in the three-dimensional arrangement of atoms.

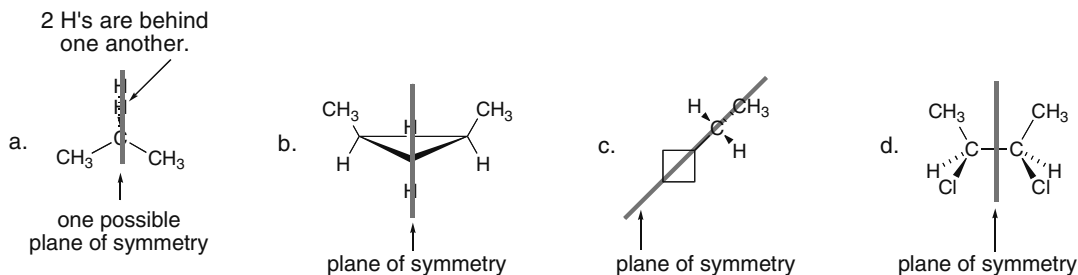


- 5.3** Draw the mirror image of each molecule by drawing a mirror plane and then drawing the molecule's reflection. **A chiral molecule is one that is not superimposable on its mirror image.** A molecule with one stereogenic center is always chiral. A molecule with zero stereogenic centers is not chiral (in general).

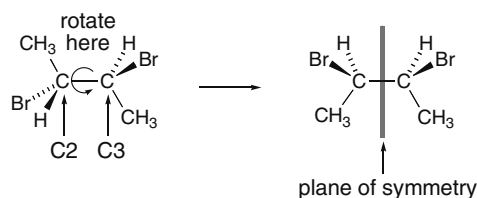
Chapter 5-6



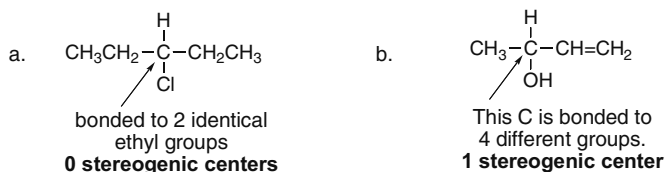
5.4 A plane of symmetry cuts the molecule into **two identical halves**.



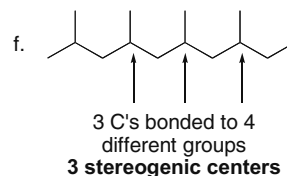
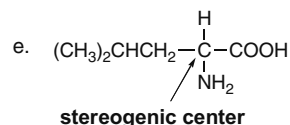
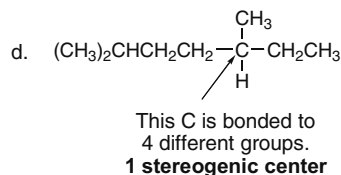
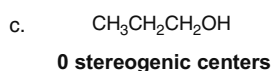
5.5 Rotate around the middle C–C bond so that the Br atoms are eclipsed.



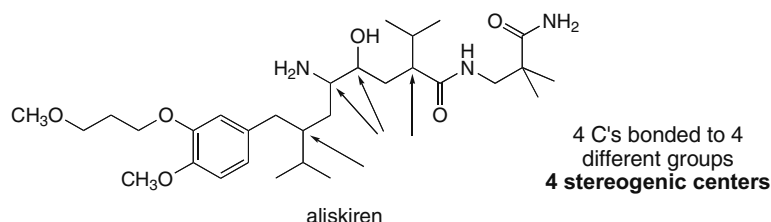
5.6 To locate a stereogenic center, omit all C's with two or more H's, all sp and sp^2 hybridized atoms, and all heteroatoms. (In Chapter 25, we will learn that the N atoms of ammonium salts $[R_4N^+X^-]$ can sometimes be stereogenic centers.) Then evaluate any remaining atoms. A tetrahedral stereogenic center has a carbon bonded to **four different groups**.



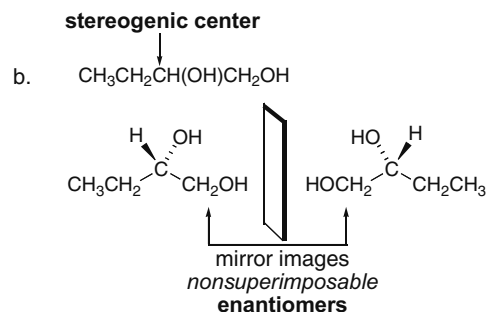
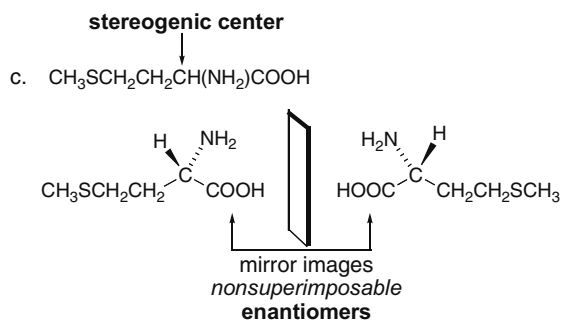
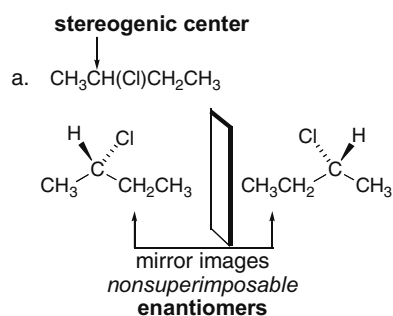
Stereochemistry 5-7



5.7 Use the directions from Answer 5.6 to locate the stereogenic centers.

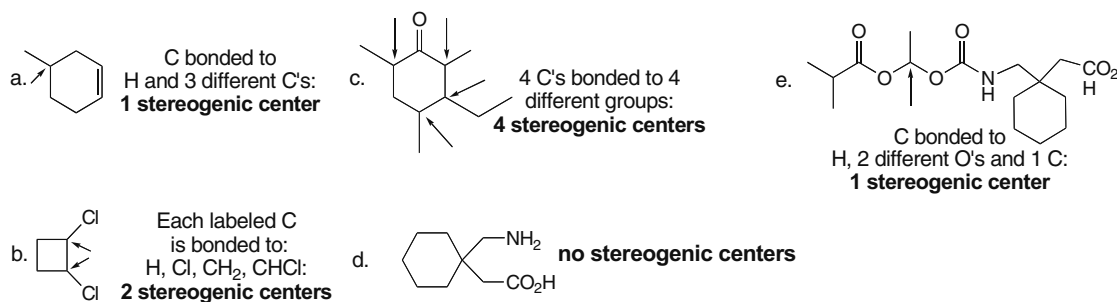


5.8 Find the C bonded to four different groups in each molecule. At the stereogenic center, draw two bonds in the plane of the page, one in front (on a wedge), and one behind (on a dash). Then draw the mirror image (enantiomer).

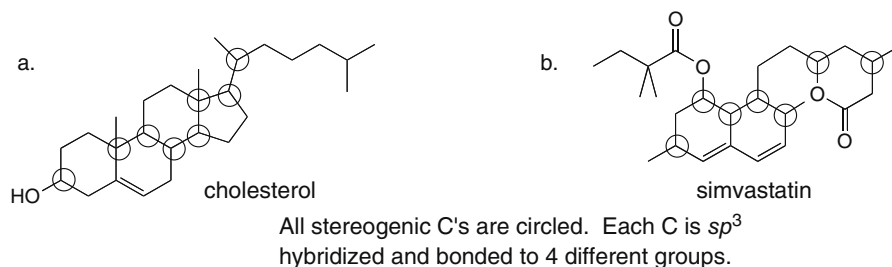


Chapter 5–8

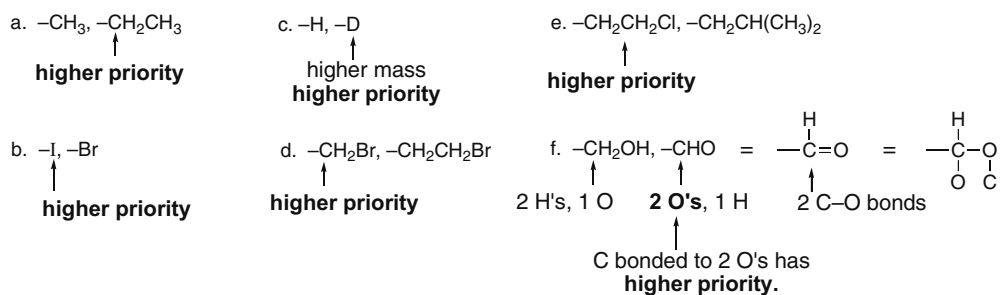
5.9 Use the directions from Answer 5.6 to locate the stereogenic centers.



5.10



5.11 Assign priority based on atomic number: atoms with a higher atomic number get a higher priority. If two atoms are the same, look at what they are bonded to and assign priority based on the atomic number of these atoms.



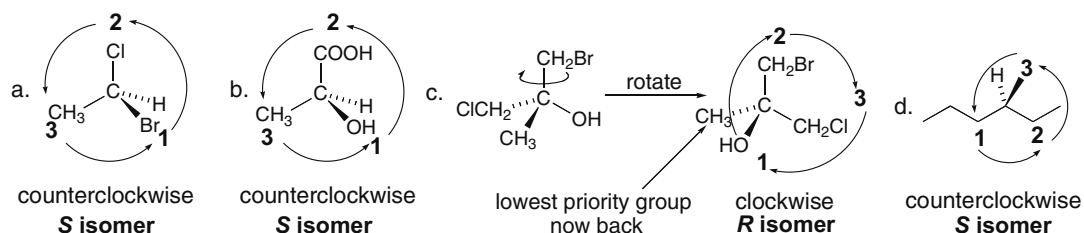
5.12 Rank by decreasing priority. Lower atomic number = lower priority.

Highest priority = 1, Lowest priority = 4			
		priority	
a. $-\text{COOH}$	C = second lowest atomic number	3	
$-\text{H}$	H = lowest atomic number	4	
$-\text{NH}_2$	N = second highest atomic number	2	
$-\text{OH}$	O = highest atomic number	1	
decreasing priority: $-\text{OH}$, $-\text{NH}_2$, $-\text{COOH}$, $-\text{H}$			
b. $-\text{H}$	H = lowest atomic number	4	
$-\text{CH}_3$	C bonded to 3 H's	3	
$-\text{Cl}$	Cl = highest atomic number	1	
$-\text{CH}_2\text{Cl}$	C bonded to 2 H's + 1 Cl	2	
decreasing priority: $-\text{Cl}$, $-\text{CH}_2\text{Cl}$, $-\text{CH}_3$, $-\text{H}$			

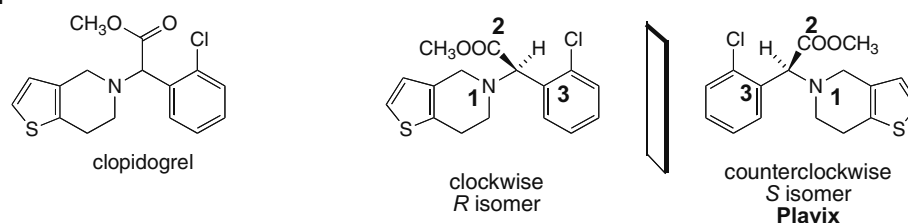
Stereochemistry 5–9

c. $-\text{CH}_2\text{CH}_3$	C bonded to 2 H's + 1 C	priority 2	d. $-\text{CH}=\text{CH}_2$	C bonded to 1 H + 2 C's	priority 2
	$-\text{CH}_3$	C bonded to 3 H's		$-\text{CH}_3$	C bonded to 3 H's
	$-\text{H}$	H = lowest atomic number		$-\text{C}\equiv\text{CH}$	C bonded to 3 C's
	$-\text{CH}(\text{CH}_3)_2$	C bonded to 1 H + 2 C's		$-\text{H}$	H = lowest atomic number
decreasing priority: $-\text{CH}(\text{CH}_3)_2, -\text{CH}_2\text{CH}_3, -\text{CH}_3, -\text{H}$			decreasing priority: $-\text{C}\equiv\text{CH}, -\text{CH}=\text{CH}_2, -\text{CH}_3, -\text{H}$		

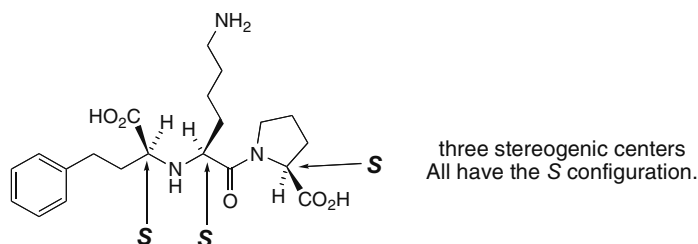
5.13 To assign *R* or *S* to the molecule, first rank the groups. The lowest priority group must be oriented behind the page. If tracing a circle from (1) $\rightarrow$ (2) $\rightarrow$ (3) proceeds in the clockwise direction, then the stereogenic center is labeled *R*; if the circle is counterclockwise, then it is labeled *S*.



5.14



5.15 a, b. Re-draw lisinopril as a skeletal structure, locate the stereogenic centers, and assign *R,S*.



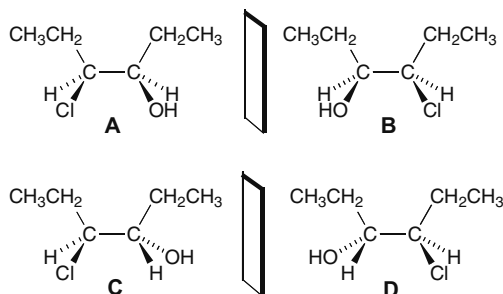
5.16 The maximum number of stereoisomers = 2^n where n = the number of stereogenic centers.

- a. 3 stereogenic centers
 $2^3 = 8$ stereoisomers
- b. 8 stereogenic centers
 $2^8 = 256$ stereoisomers

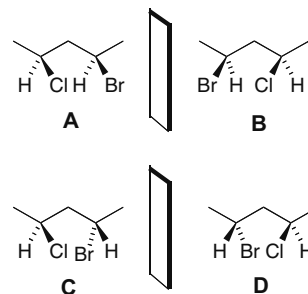
Chapter 5-10

5.17

a. $\text{CH}_3\text{CH}_2\text{CH}(\text{Cl})\text{CH}(\text{OH})\text{CH}_2\text{CH}_3$
 2 stereogenic centers = 4 possible stereoisomers

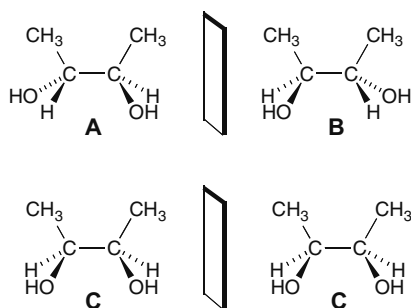


b. $\text{CH}_3\text{CH}(\text{Br})\text{CH}_2\text{CH}(\text{Cl})\text{CH}_3$
 2 stereogenic centers = 4 possible stereoisomers



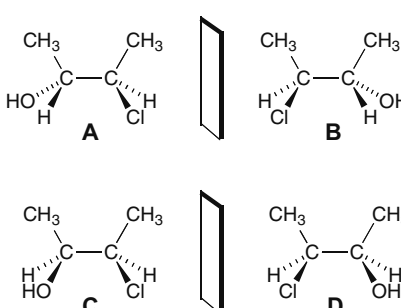
5.18

a. $\text{CH}_3\text{CH}(\text{OH})\text{CH}(\text{OH})\text{CH}_3$
 2 stereogenic centers = 4 possible stereoisomers



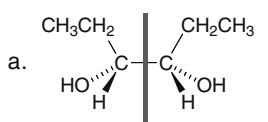
C is a meso compound.
 A and B are enantiomers.
 Pairs of diastereomers: A and C, B and C.

b. $\text{CH}_3\text{CH}(\text{OH})\text{CH}(\text{Cl})\text{CH}_3$
 2 stereogenic centers = 4 possible stereoisomers

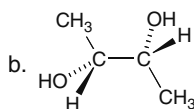


Pairs of enantiomers: A and B, C and D.
 Pairs of diastereomers: A and C, A and D, B and C, B and D.

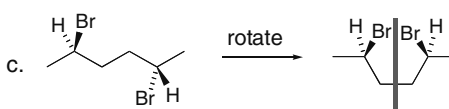
5.19 A meso compound must have at least two stereogenic centers. Usually a meso compound has a plane of symmetry. You may have to rotate around a C-C bond to see the plane of symmetry clearly.



2 stereogenic centers
 plane of symmetry
 meso compound



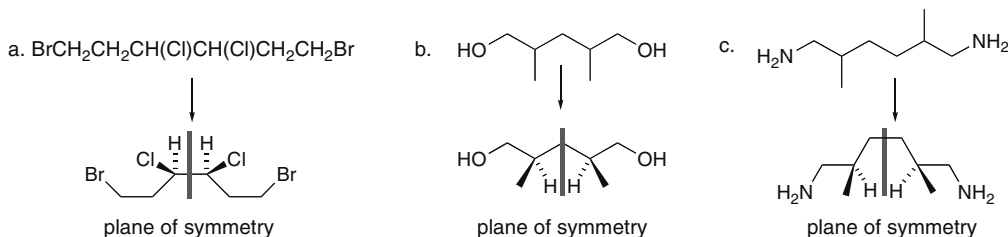
2 stereogenic centers
 no plane of symmetry
 not a meso compound



2 stereogenic centers
 plane of symmetry
 meso compound

Stereochemistry 5-11

5.20 Use the definition in Answer 5.19 to draw the meso compounds.



5.21 The enantiomer must have the exact opposite *R,S* designations. Diastereomers with two stereogenic centers have one center the same and one different.

If a compound is ***R,S***:

Its enantiomer is: ***S,R*** ← Exact opposite: *R* and *S* interchanged.

Its diastereomers are: ***R,R* and *S,S*** ← One designation remains the same, the other changes.

5.22 The enantiomer must have the exact opposite *R,S* designations. For diastereomers, at least one of the *R,S* designations is the same, but not all of them.

a. (*2R,3S*)-2,3-hexanediol and (*2R,3R*)-2,3-hexanediol

One changes; one remains the same:
diastereomers

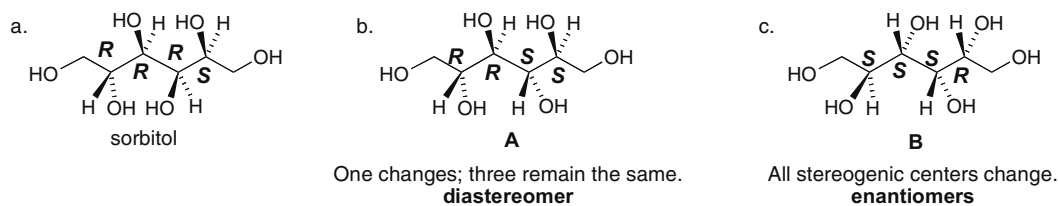
b. (*2R,3R*)-2,3-hexanediol and (*2S,3S*)-2,3-hexanediol

Both *R*'s change to *S*'s:
enantiomers

c. (*2R,3S,4R*)-2,3,4-hexanetriol and (*2S,3R,4R*)-2,3,4-hexanetriol

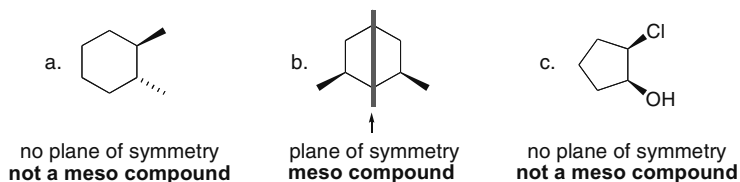
Two change; one remains the same:
diastereomers

5.23 The enantiomer must have the exact opposite *R,S* designations. For diastereomers, at least one of the *R,S* designations is the same, but not all of them.



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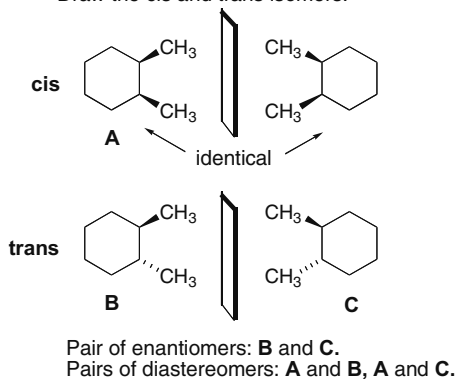
5.24 Meso compounds generally have a plane of symmetry. They cannot have just one stereogenic center.



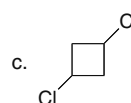
5.25



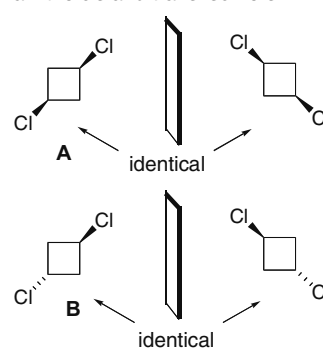
Draw the cis and trans isomers:



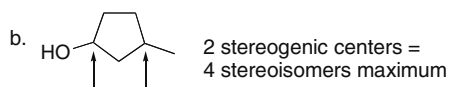
Only 3 stereoisomers exist.



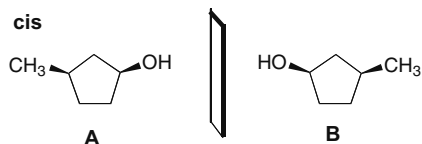
Draw the cis and trans isomers:



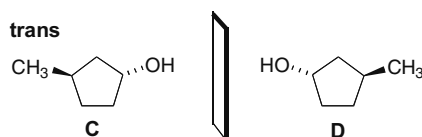
Only 2 stereoisomers exist.



Draw the cis and trans isomers:



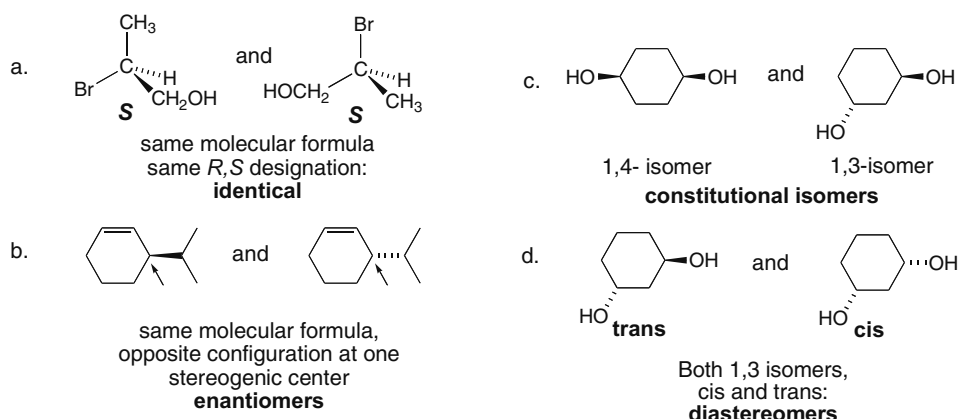
Pairs of enantiomers: **A and B, C and D.**
Pairs of diastereomers: **A and C, A and D, B and C, B and D.**



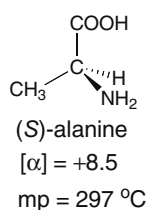
All 4 stereoisomers exist.

5.26 Four facts:

- **Enantiomers** are mirror image isomers.
- **Diastereomers** are stereoisomers that are not mirror images.
- **Constitutional isomers** have the same molecular formula but the atoms are bonded to different atoms.
- **Cis and trans isomers** are always diastereomers.



5.27



- Mp = same as the *S* isomer.
- The mp of a racemic mixture is often different from the melting point of the enantiomers.
- −8.5, same as *S* but opposite sign
- Zero. A racemic mixture is optically inactive.
- Solution of pure (*S*)-alanine: **optically active**
Equal mixture of (*R*)- and (*S*)-alanine: **optically inactive**
75% (*S*)- and 25% (*R*)-alanine: **optically active**

5.28

$$[\alpha] = \frac{\alpha}{l \times c}$$

α = observed rotation
l = length of tube (dm)
c = concentration (g/mL)

$$[\alpha] = \frac{10^\circ}{1 \text{ dm} \times (1 \text{ g}/10 \text{ mL})} = +100 = \text{specific rotation}$$

5.29 Enantiomeric excess = *ee* = % of one enantiomer − % of other enantiomer.

- 95% − 5% = **90% ee**
- 85% − 15% = **70% ee**

5.30

- 90% *ee* means 90% excess of **A** and 10% racemic mixture of **A** and **B** (5% each); therefore, **95% A and 5% B**.
- 99% *ee* means 99% excess of **A** and 1% racemic mixture of **A** and **B** (0.5% each); therefore, **99.5% A and 0.5% B**.
- 60% *ee* means 60% excess of **A** and 40% racemic mixture of **A** and **B** (20% each); therefore, **80% A and 20% B**.

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5.31

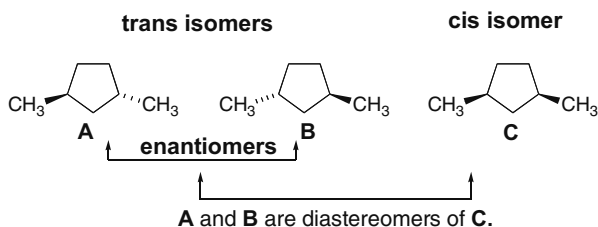
$$ee = \frac{[\alpha] \text{ mixture}}{[\alpha] \text{ pure enantiomer}} \times 100\%$$

- a. $\frac{+10}{+24} \times 100\% = 42\% ee$
 b. $\frac{[\alpha] \text{ solution}}{+24} \times 100\% = 80\% ee$
 $[\alpha] \text{ solution} = +19.2$

5.32

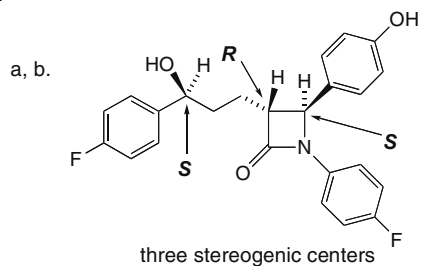
- a. $\frac{[\alpha] \text{ mixture}}{+3.8} \times 100\% = 60\% ee$
 $[\alpha] \text{ mixture} = +2.3$
- b. % one enantiomer – % other enantiomer = ee
 $80\% - 20\% = 60\% ee$
 80% dextrorotatory (+) enantiomer
 20% levorotatory (–) enantiomer

- 5.33 • **Enantiomers have the same physical properties** (mp, bp, solubility), and rotate the plane of polarized light to an equal extent, but in opposite directions.
 • **Diastereomers have different physical properties.**
 • **A racemic mixture is optically inactive.**

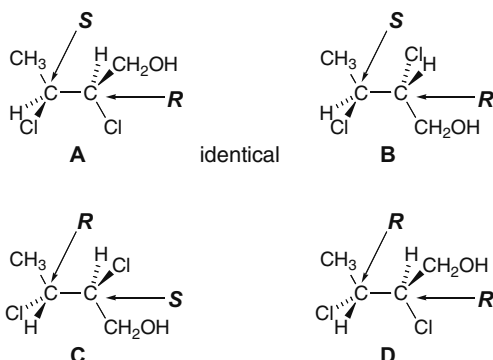


- a. The bp's of **A** and **B** are the same. The bp's of **A** and **C** are different.
 b. Pure **A**: optically active
 Pure **B**: optically active
 Pure **C**: optically inactive
 Equal mixture of **A** and **B**: optically inactive
 Equal mixture of **A** and **C**: optically active
 c. There would be two fractions: one containing **A** and **B** (optically inactive), and one containing **C** (optically inactive).

5.34

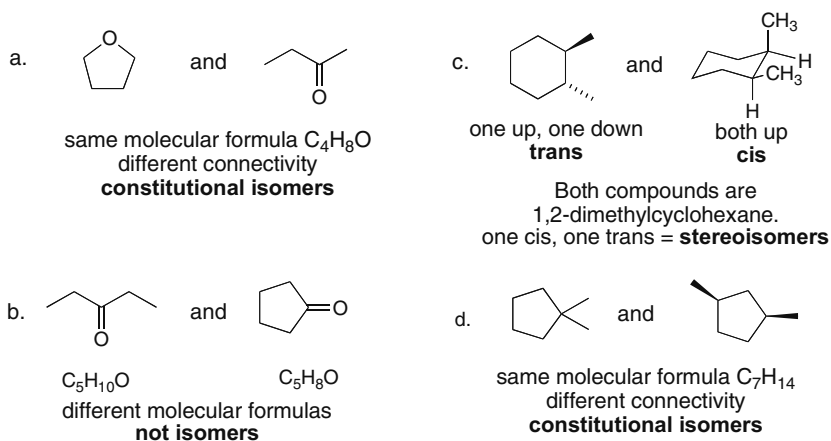


5.35

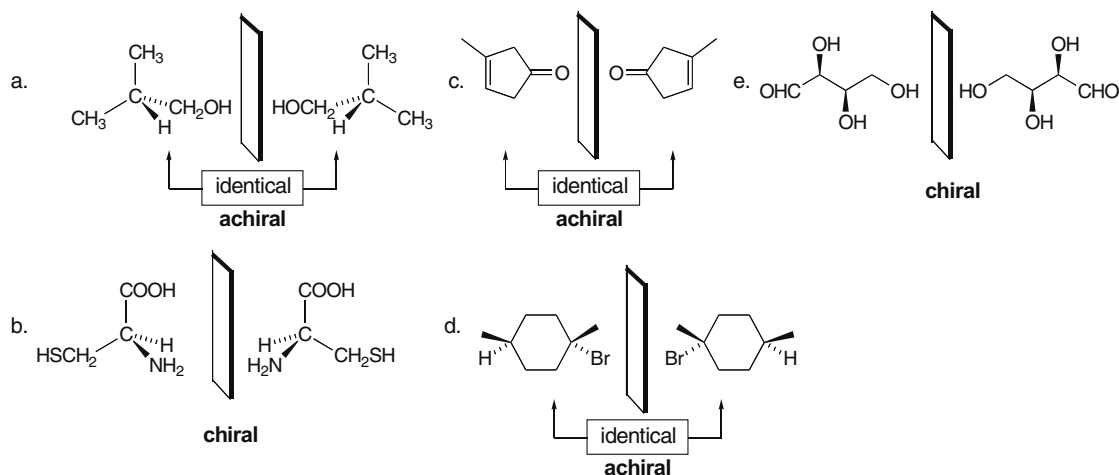


- a. **A** and **B**, same R,S assignment, identical
 b. **A** and **C**, opposite R,S assignment, enantiomers
 c. **A** and **D**, one stereogenic center different, diastereomers
 d. **C** and **D**, one stereogenic center different, diastereomers

5.36 Use the definitions from Answer 5.2.

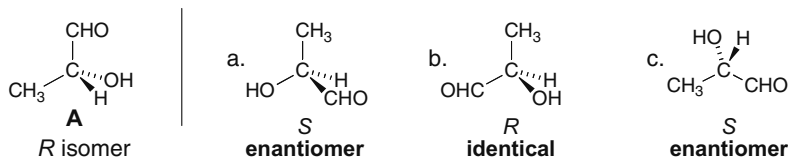
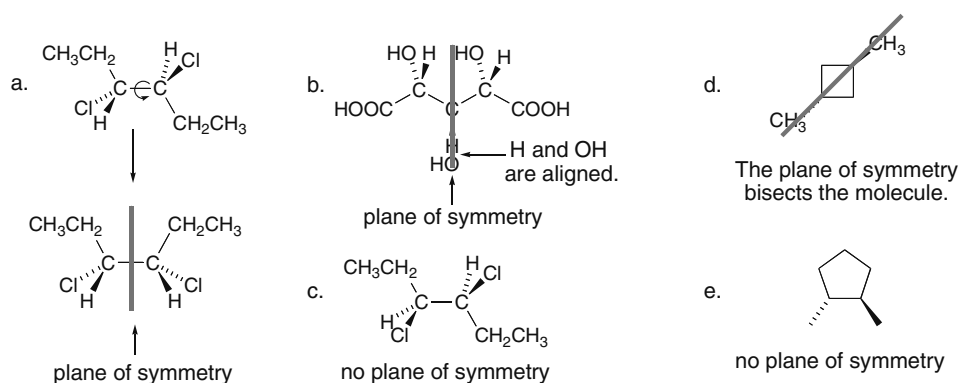


5.37 Use the definitions from Answer 5.3.

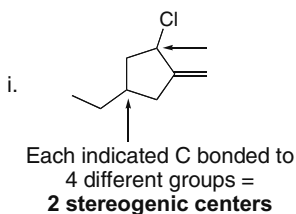
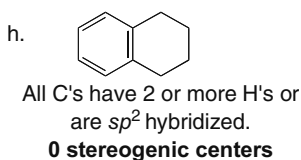
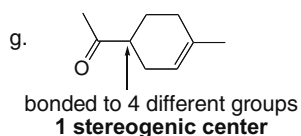
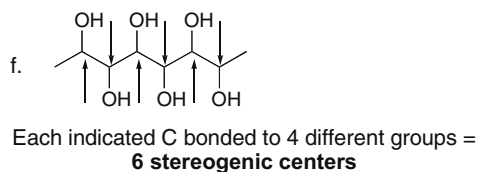
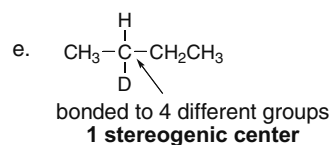
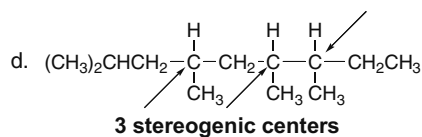
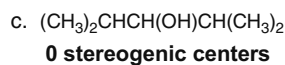
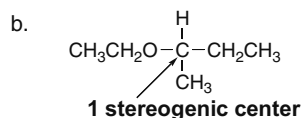
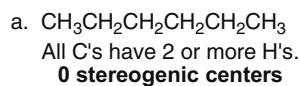


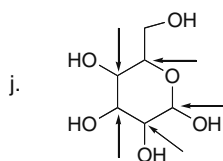
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5.38

5.39 A plane of symmetry cuts the molecule into **two identical halves**.

5.40 Use the directions from Answer 5.6 to locate the stereogenic centers.

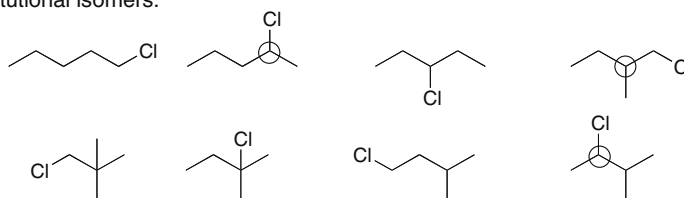




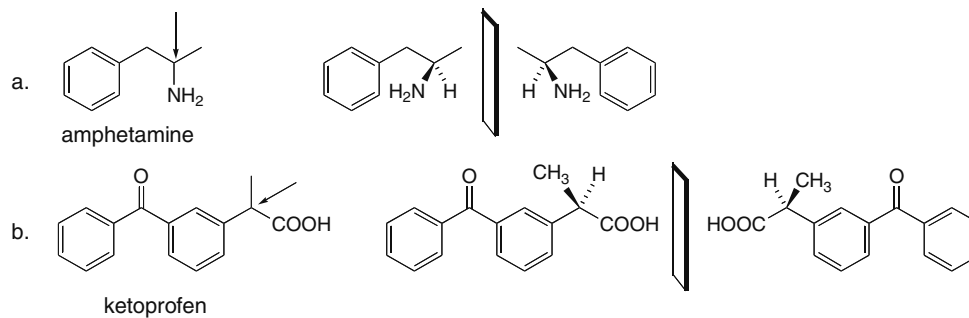
Each indicated C bonded to 4 different groups =
5 stereogenic centers

5.41 Stereogenic centers are circled.

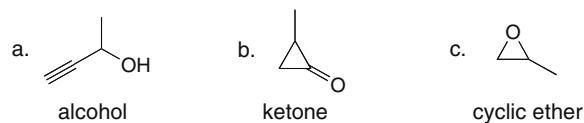
Eight constitutional isomers:



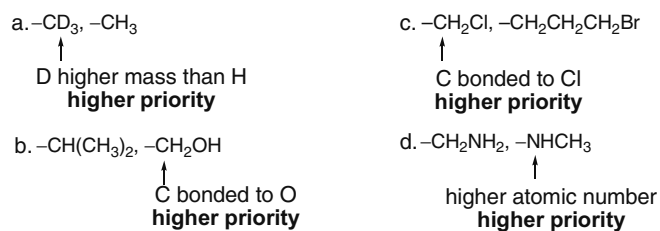
5.42



5.43 Draw a molecule to fit each description.



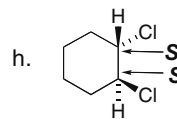
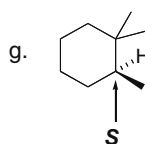
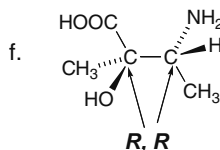
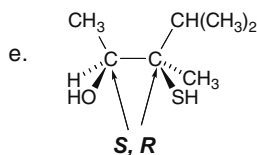
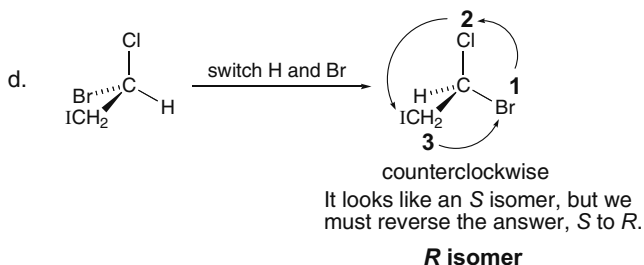
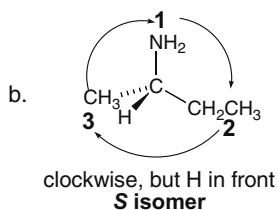
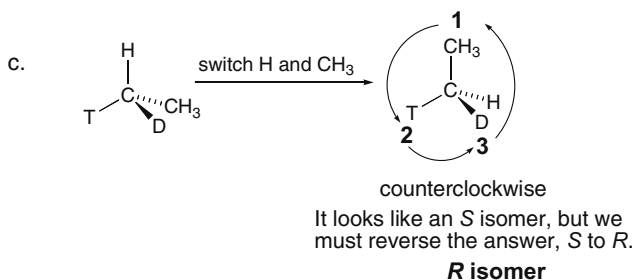
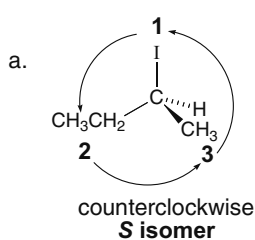
5.44 Assign priority based on the rules in Answer 5.11.



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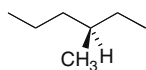
5.45 Assign priority based on the rules in Answer 5.11.

- a. $-F > -OH > -NH_2 > -CH_3$
 b. $-(CH_2)_3CH_3 > -CH_2CH_2CH_3 > -CH_2CH_3 > -CH_3$
 c. $-NH_2 > -CH_2NHCH_3 > -CH_2NH_2 > -CH_3$
 d. $-COOH > -CHO > -CH_2OH > -H$
 e. $-Cl > -SH > -OH > -CH_3$
 f. $-C\equiv CH > -CH=CH_2 > -CH(CH_3)_2 > -CH_2CH_3$

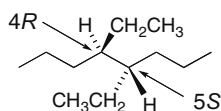
5.46 Use the rules in Answer 5.13 to assign *R* or *S* to each stereogenic center.

5.47

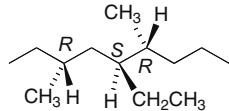
- a. (3
- R*
-)-3-methylhexane



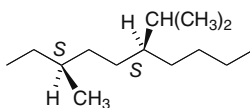
- b. (4
- R*
- ,5
- S*
-)-4,5-diethyloctane



- c. (3
- R*
- ,5
- S*
- ,6
- R*
-)-5-ethyl-3,6-dimethylnonane

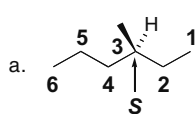


- d. (3
- S*
- ,6
- S*
-)-6-isopropyl-3-methyldecane

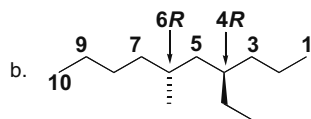


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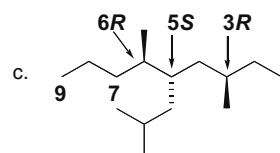
5.48



(3S)-3-methylhexane

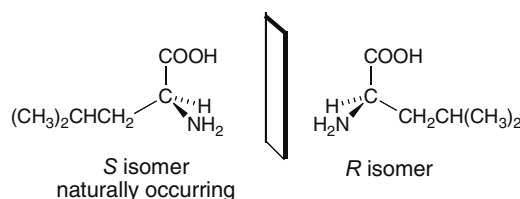


(4R,6R)-4-ethyl-6-methyldecane

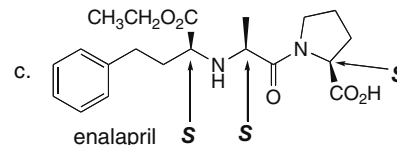
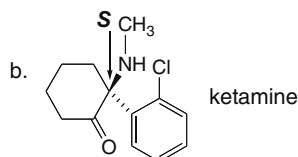
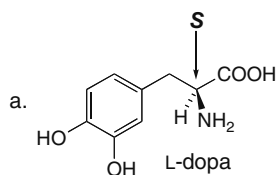


(3R,5S,6R)-5-isobutyl-3,6-dimethylnonane

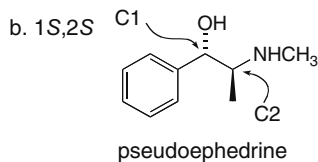
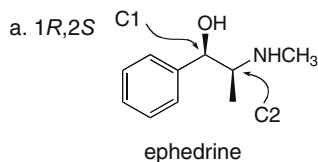
5.49 Two enantiomers of the amino acid leucine.



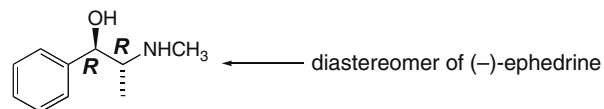
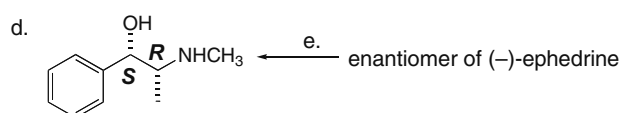
5.50



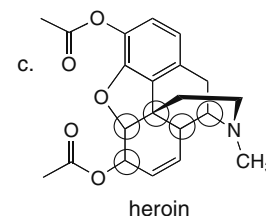
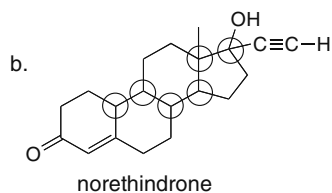
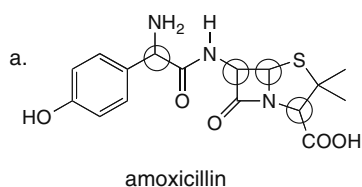
5.51



c. Ephedrine and pseudoephedrine are diastereomers (one stereogenic center is the same; one is different).

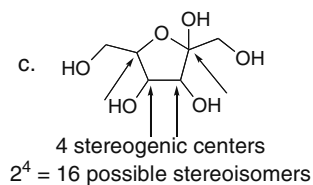
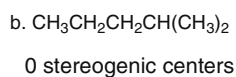
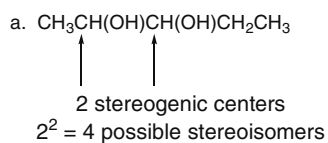


5.52

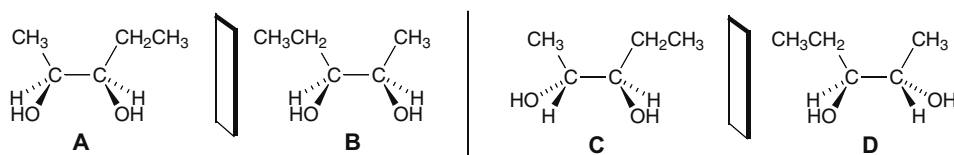
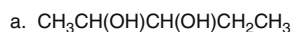


Chapter 5–20

5.53

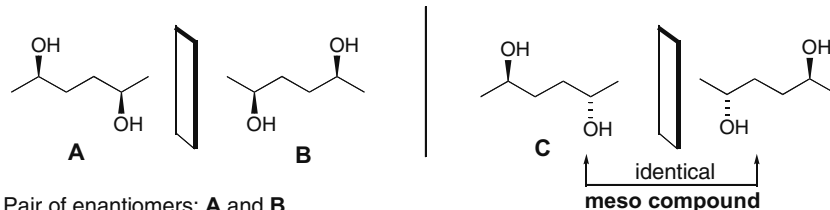
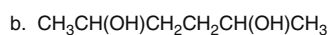


5.54



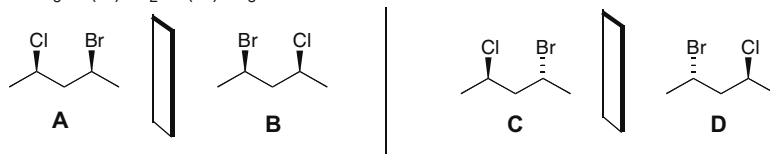
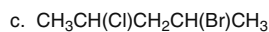
Pairs of enantiomers: **A** and **B**, **C** and **D**.

Pairs of diastereomers: **A** and **C**, **A** and **D**, **B** and **C**, **B** and **D**.



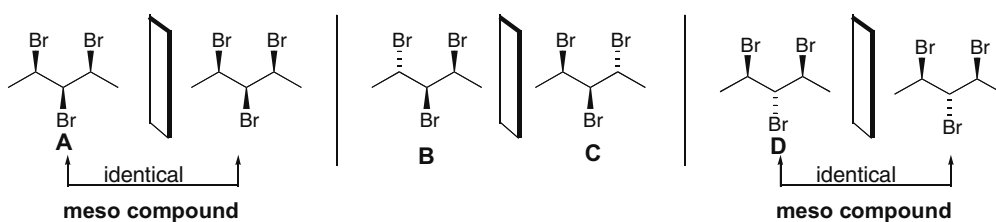
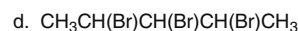
Pair of enantiomers: **A** and **B**.

Pairs of diastereomers: **A** and **C**, **B** and **C**.



Pairs of enantiomers: **A** and **B**, **C** and **D**.

Pairs of diastereomers: **A** and **C**, **A** and **D**, **B** and **C**, **B** and **D**.

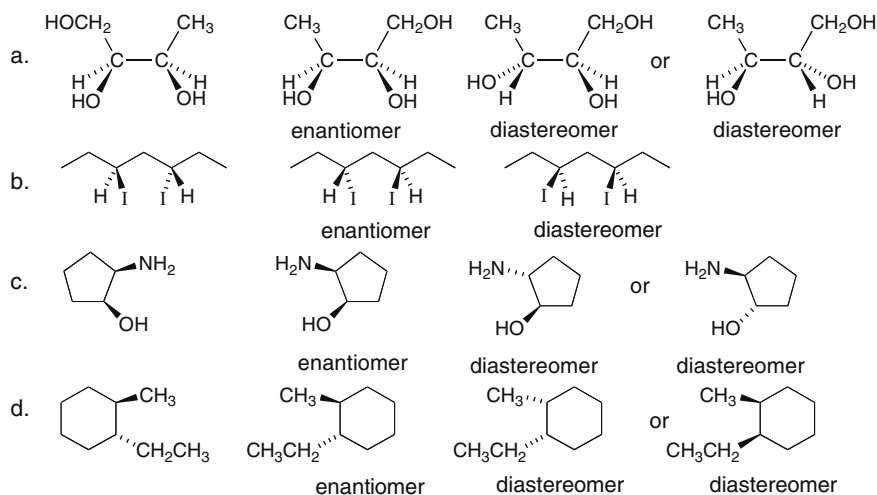


Pair of enantiomers: **B** and **C**.

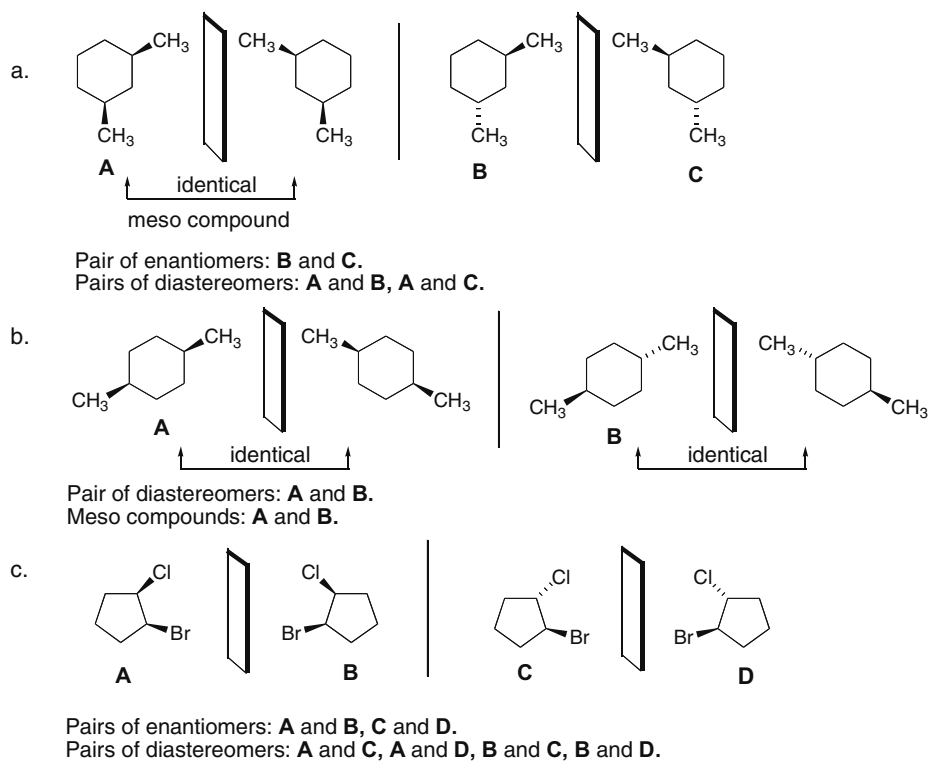
Pairs of diastereomers: **A** and **B**, **A** and **C**, **A** and **D**, **B** and **D**, **C** and **D**.

Stereochemistry 5-21

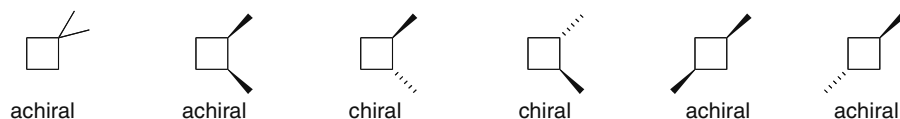
5.55



5.56

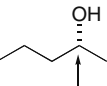
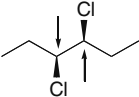
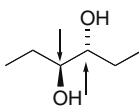
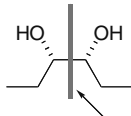
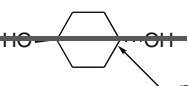


5.57

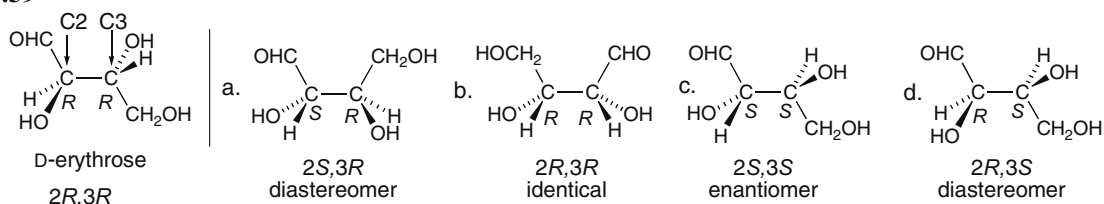
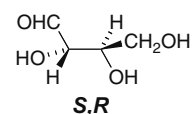
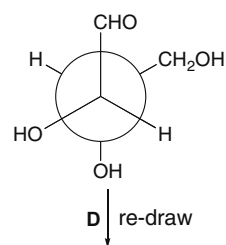
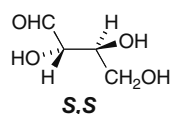
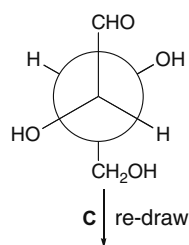
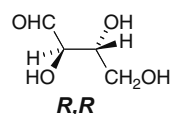
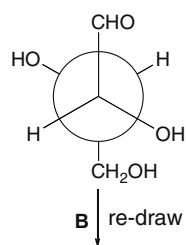
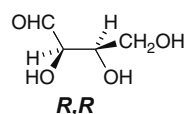
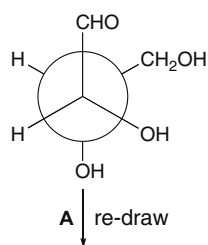


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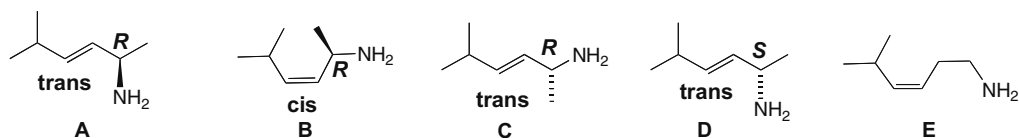
5.58 Explain each statement.

- a.  All molecules have a mirror image, but only chiral molecules have enantiomers. **A** is not chiral, and therefore, does not have an enantiomer.
- b.  **B** has one stereogenic center, and therefore, has an enantiomer. Only compounds with two or more stereogenic centers have diastereomers.
- c.  **C** is chiral and has two stereogenic centers, and therefore, has both an enantiomer and a diastereomer.
- d.  rotate  **D** has two stereogenic centers, but is a meso compound. Therefore, it has a diastereomer, but no enantiomer since it is achiral.
plane of symmetry
- e.  **E** has two stereogenic centers, but is a meso compound. Therefore, it has a diastereomer, but no enantiomer since it is achiral.
plane of symmetry

5.59

5.60 Re-draw each Newman projection and determine the *R,S* configuration. Then determine how the molecules are related.a. **A** and **B** are identical.b. **A** and **C** are enantiomers.c. **A** and **D** are diastereomers.d. **C** and **D** are diastereomers.

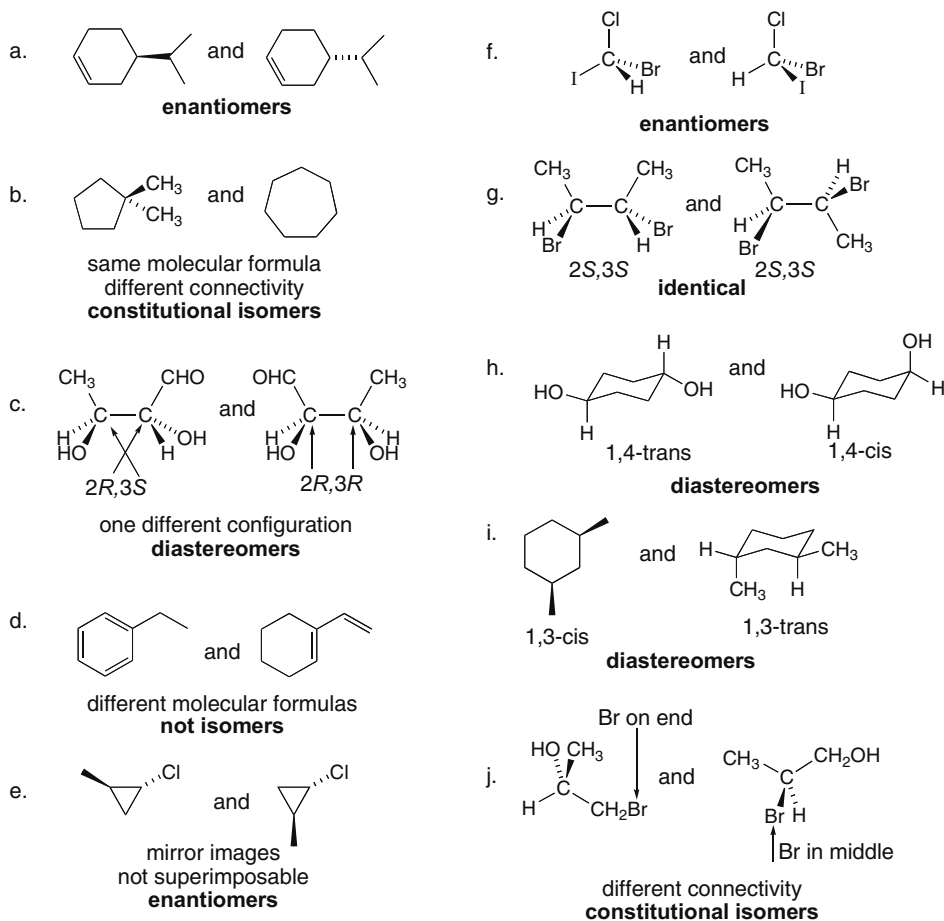
5.61



A (trans, *R*) and **B** (cis, *R*) are diastereomers.
A (trans, *R*) and **C** (trans, *R*) are identical molecules.
A (trans, *R*) and **D** (trans, *S*) are enantiomers.
A (trans, *R*) and **E** are constitutional isomers.

NH₂ group is in a different location.

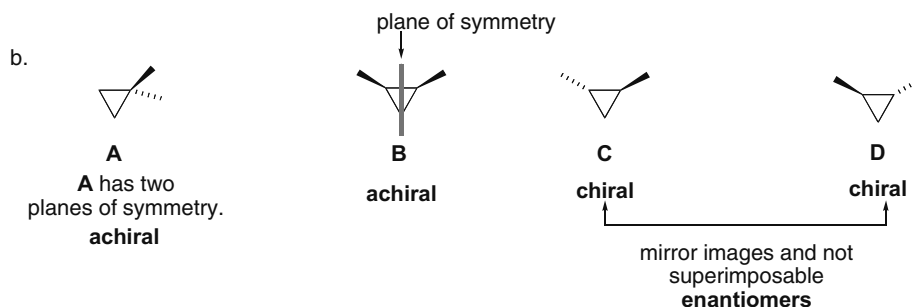
5.62



5.63

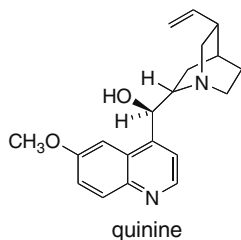
- a. **A** and **B** are constitutional isomers.
A and **C** are constitutional isomers.
B and **C** are diastereomers (cis and trans).
C and **D** are enantiomers.

Chapter 5-24



- c. Alone, **C** and **D** would be optically active.
 d. **A** and **B** have a plane of symmetry.
 e. **A** and **B** have different boiling points.
 B and **C** have different boiling points.
 C and **D** have the same boiling point.
 f. **B** is a meso compound.
 g. An equal mixture of **C** and **D** is optically inactive because it is a racemic mixture.
 An equal mixture of **B** and **C** would be optically active.

5.64

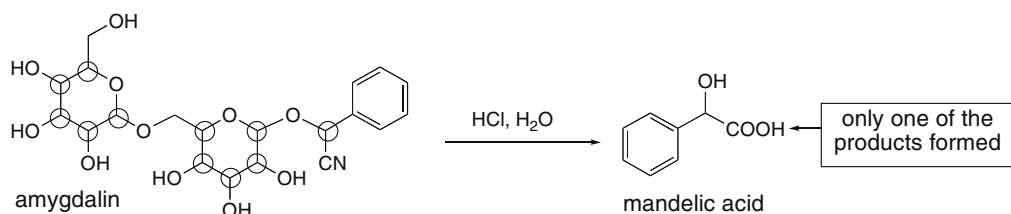


$$ee = \frac{[\alpha] \text{ mixture}}{[\alpha] \text{ pure enantiomer}} \times 100\%$$

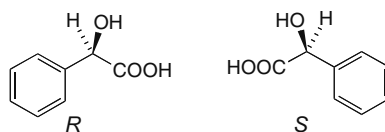
quinine = **A**
 quinine's enantiomer = **B**

- a.
- $$\frac{-50}{-165} \times 100\% = 30\% ee$$
- b. 30% ee = 30% excess one compound (**A**)
 remaining 70% = mixture of 2 compounds (35% each **A** and **B**)
 Amount of **A** = 30 + 35 = **65%**
 Amount of **B** = **35%**
- 50% ee = 50% excess one compound (**A**)
 remaining 50% = mixture of 2 compounds (25% each **A** and **B**)
 Amount of **A** = 50 + 25 = **75%**
 Amount of **B** = **25%**
- 73% ee = 73% excess of one compound (**A**)
 remaining 27% = mixture of 2 compounds (13.5% each **A** and **B**)
 Amount of **A** = 73 + 13.5 = **86.5%**
 Amount of **B** = **13.5%**
- c. $[\alpha] = +165$
 d. $80\% - 20\% = 60\% ee$
- e. $60\% = \frac{[\alpha] \text{ mixture}}{-165} \times 100\%$
 $[\alpha] \text{ mixture} = -99$

5.65



- a. The 11 stereogenic centers are circled. Maximum number of stereoisomers = $2^{11} = 2048$
 b. Enantiomers of mandelic acid:

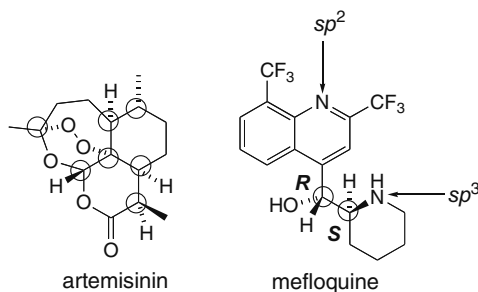


- c. $60\% - 40\% = 20\% \text{ ee}$
 $20\% = [\alpha]_{\text{mixture}} / -154 \times 100\%$
 $[\alpha]_{\text{mixture}} = -31$

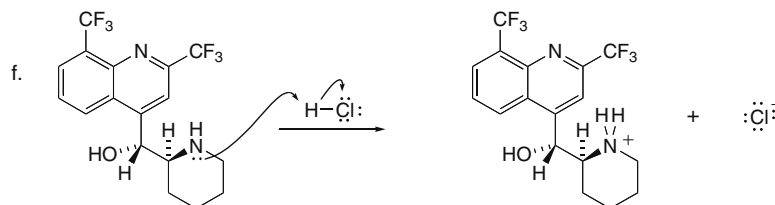
- d.
$$\text{ee} = \frac{+50}{+154} \times 100\% = 32\% \text{ ee}$$

 $[\alpha] \text{ for } (S)\text{-mandelic acid} = +154$
- 32% excess of the *S* enantiomer
 68% of racemic *R* and *S* = 34% *S* and 34% *R*
S enantiomer: 32% + 34% = 66%
R enantiomer = 34%

5.66



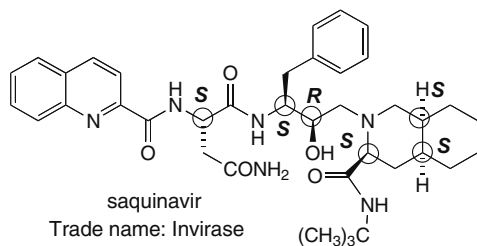
- a. Each stereogenic center is circled.
 b. The stereogenic centers in mefloquine are labeled.
 c. Artemisinin has seven stereogenic centers.
 $2^n = 2^7 = 128$ possible stereoisomers
 d. One N atom in mefloquine is sp^2 and one is sp^3 .
 e. Two molecules of artemisinin cannot intermolecularly H-bond because there are no O-H or N-H bonds.



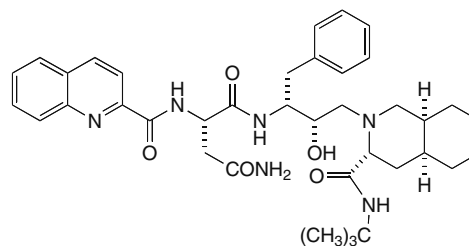
Chapter 5–26

5.67

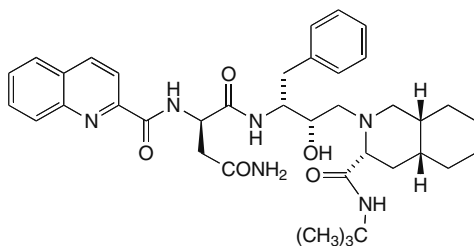
a. Each stereogenic center is circled.



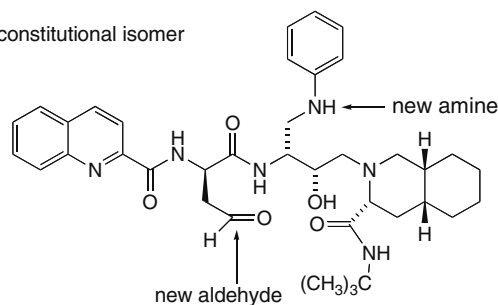
c. diastereomer



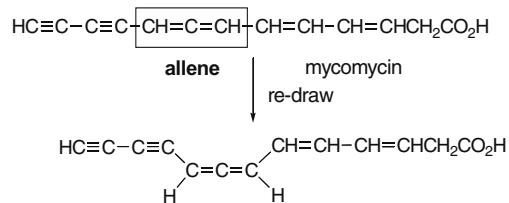
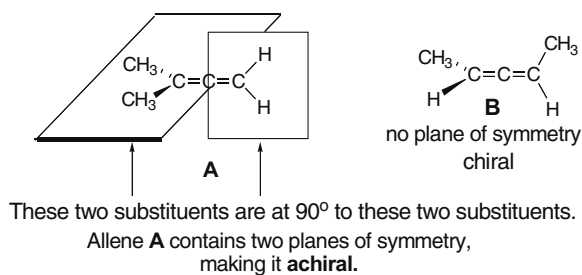
b. enantiomer



d. constitutional isomer

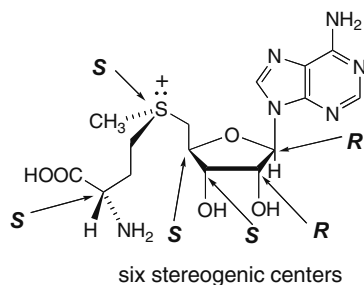


5.68 Allenes contain an sp hybridized carbon atom doubly bonded to two other carbons. This makes the double bonds of an allene perpendicular to each other. When each end of the allene has two like substituents, the allene contains two planes of symmetry and it is achiral. When each end of the allene has two different groups, the allene has no plane of symmetry and it becomes chiral.

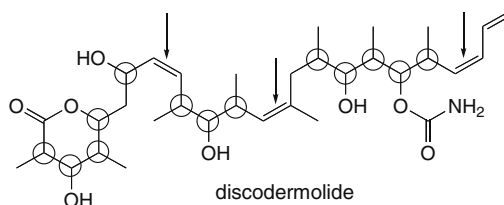


The substituents on each end of the allene in mycomycin are different. Therefore, mycomycin is **chiral**.

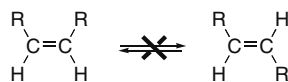
5.69



5.70



- The 13 tetrahedral stereogenic centers are circled.
- Because there is restricted rotation around a C–C double bond, groups on the end of the double bond cannot interconvert. Whenever the substituents on each end of the double bond are different from each other, the double bond is a stereogenic site. Thus, the following two double bonds are isomers:

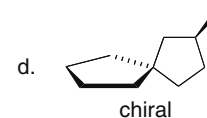
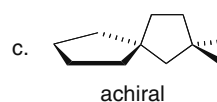
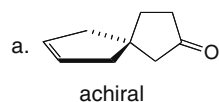


These compounds are isomers.

There are three stereogenic double bonds in discodermolide, labeled with arrows.

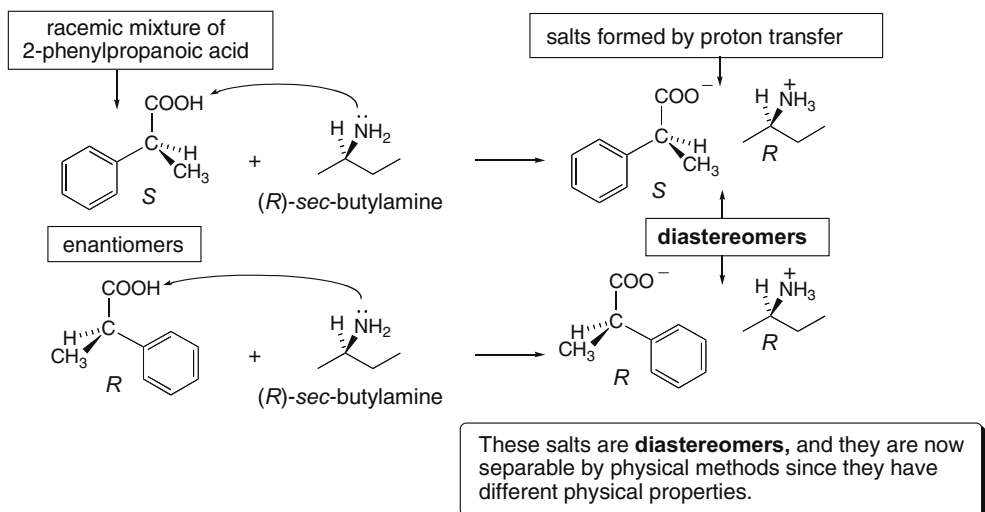
- The maximum number of stereoisomers for discodermolide must include the 13 tetrahedral stereogenic centers and the three double bonds. Maximum number of stereoisomers = $2^{16} = 65,536$.

5.71 When the spiro compound has a plane of symmetry, it is achiral.



Chapter 5–28

5.72

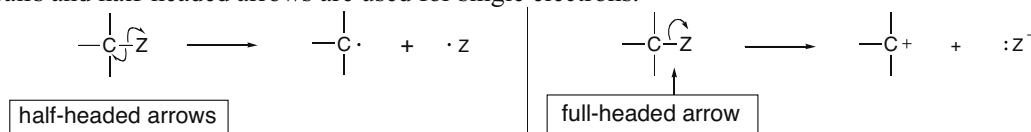


Chapter 6 Understanding Organic Reactions

Chapter Review

Writing organic reactions (6.1)

- Use curved arrows to show the movement of electrons. Full-headed arrows are used for electron pairs and half-headed arrows are used for single electrons.



- Reagents can be drawn either on the left side of an equation or over an arrow. Catalysts are drawn over or under an arrow.

Types of reactions (6.2)

[1] Substitution	$\begin{array}{c} \\ -\text{C}-\text{Z} \\ \end{array} + \text{Y} \longrightarrow \begin{array}{c} \\ -\text{C}-\text{Y} \\ \end{array} + \text{Z} \quad \left[\text{Z} = \text{H or a heteroatom} \right]$ Y replaces Z
[2] Elimination	$\begin{array}{c} \quad \\ -\text{C}-\text{C}- \\ \quad \\ \text{X} \quad \text{Y} \end{array} + \text{reagent} \longrightarrow \begin{array}{c} \diagup \quad \diagdown \\ \text{C}=\text{C} \\ \diagdown \quad \diagup \end{array} + \text{X}-\text{Y}$ Two σ bonds are broken. π bond
[3] Addition	$\begin{array}{c} \diagup \quad \diagdown \\ \text{C}=\text{C} \\ \diagdown \quad \diagup \end{array} + \text{X}-\text{Y} \longrightarrow \begin{array}{c} \quad \\ -\text{C}-\text{C}- \\ \quad \\ \text{X} \quad \text{Y} \end{array}$ This π bond is broken. Two σ bonds are formed.

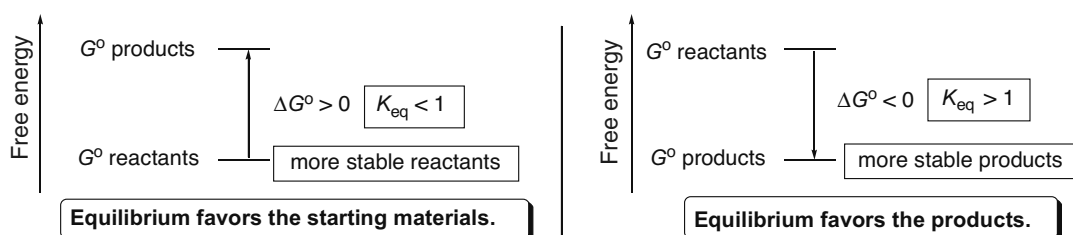
Important trends

Values compared	Trend
Bond dissociation energy and bond strength	The higher the bond dissociation energy, the stronger the bond (6.4). Increasing size of the halogen $\xrightarrow{\hspace{10em}}$ CH_3-F CH_3-Cl CH_3-Br CH_3-I $\Delta H^\circ = 456 \text{ kJ/mol}$ 351 kJ/mol 293 kJ/mol 234 kJ/mol $\xleftarrow{\hspace{10em}}$ Increasing bond strength

Chapter 6–2

E_a and reaction rate	The larger the energy of activation, the slower the reaction (6.9A). Energy Reaction coordinate --- slower reaction — faster reaction
E_a and rate constant	The higher the energy of activation, the smaller the rate constant (6.9B).

Equilibrium always favors the species **lower** in energy.



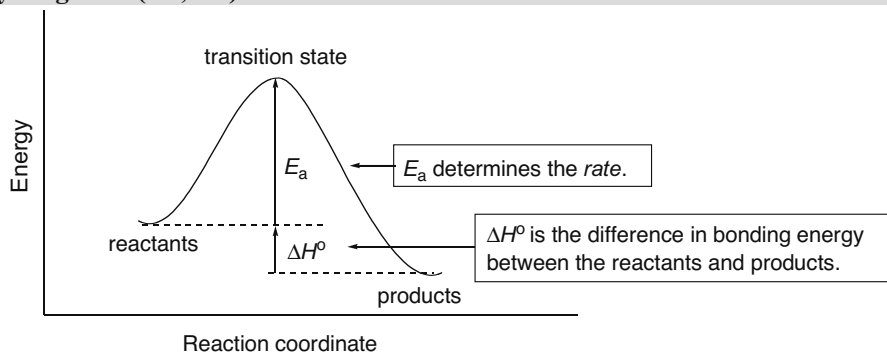
Reactive intermediates (6.3)

- Breaking bonds generates reactive intermediates.
- Homolysis generates radicals with unpaired electrons.
- Heterolysis generates ions.

Reactive intermediate	General structure	Reactive feature	Reactivity
radical	$\text{—}\dot{\text{C}}\text{—}$	unpaired electron	electrophilic
carbocation	$\text{—}\text{C}^+\text{—}$	positive charge; only six electrons around C	electrophilic
carbanion	$\text{—}\text{C}^-\text{—}$	net negative charge; lone electron pair on C	nucleophilic

Understanding Organic Reactions 6-3

Energy diagrams (6.7, 6.8)



Conditions favoring product formation (6.5, 6.6)

Variable	Value	Meaning
K_{eq}	$K_{eq} > 1$	More product than starting material is present at equilibrium.
ΔG°	$\Delta G^\circ < 0$	The energy of the products is lower than the energy of the reactants.
ΔH°	$\Delta H^\circ < 0$	Bonds in the products are stronger than bonds in the reactants.
ΔS°	$\Delta S^\circ > 0$	The product is more disordered than the reactant.

Equations (6.5, 6.6)

$$\Delta G^\circ = -2.303RT \log K_{eq}$$

K_{eq} depends on the energy difference between reactants and products.

$R = 8.314 \text{ J/(K}\cdot\text{mol)}$, the gas constant
 $T = \text{Kelvin temperature (K)}$

$$\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$$

free energy change change in bonding energy change in disorder

$T = \text{Kelvin temperature (K)}$

Factors affecting reaction rate (6.9)

Factor	Effect
energy of activation	higher $E_a \rightarrow$ slower reaction
concentration	higher concentration $\rightarrow$ faster reaction
temperature	higher temperature $\rightarrow$ faster reaction

Chapter 6-4

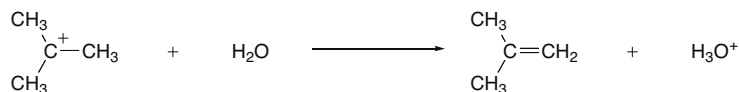
Practice Test on Chapter Review

1. Label each statement as TRUE (T) or FALSE (F) for a reaction with $K_{\text{eq}} = 0.5$ and $E_a = 18$ kJ/mol. Ignore entropy considerations.
 - a. The reaction is faster than a reaction with $K_{\text{eq}} = 8$ and $E_a = 18$ kJ/mol.
 - b. The reaction is faster than a reaction with $K_{\text{eq}} = 0.5$ and $E_a = 12$ kJ/mol.
 - c. ΔG° for the reaction is a positive value.
 - d. The starting materials are lower in energy than the products of the reaction.
 - e. The reaction is exothermic.

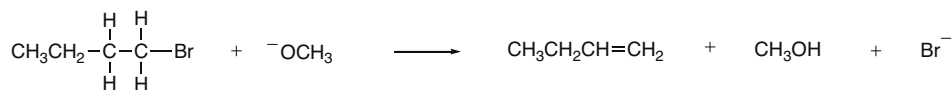
2. a. Which of the following statements is true about an endothermic reaction, ignoring entropy considerations?
 1. The bonds in the products are stronger than the bonds in the starting materials.
 2. $K_{\text{eq}} < 1$.
 3. A catalyst speeds up the rate of the reaction and gives a larger amount of product.
 4. Statements (1) and (2) are both true.
 5. Statements (1), (2), and (3) are all true.

- b. Which of the following statements is true about a reaction with $K_{\text{eq}} = 10^3$ and $E_a = 2.5$ kJ/mol? Ignore entropy considerations.
 1. The reaction is faster than a reaction with $E_a = 4$ kJ/mol.
 2. The starting materials are higher in energy than the products of the reaction.
 3. ΔG° is positive.
 4. Statements (1) and (2) are both true.
 5. Statements (1), (2), and (3) are all true.

3. a. Draw the transition state for the following reaction.



- b. Draw the transition state for the following one-step elimination reaction.



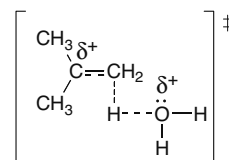
Understanding Organic Reactions 6–5

Answers to Practice Test

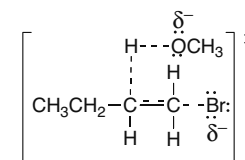
1. a. F
b. F
c. T
d. T
e. F

2. a. 2
b. 4

3. a.

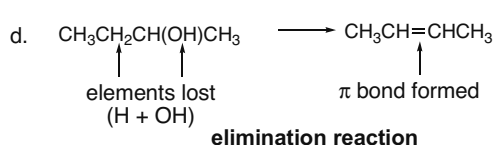
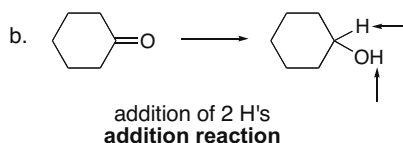
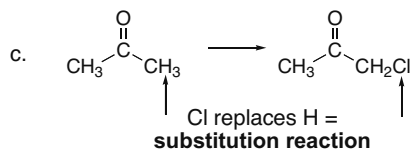
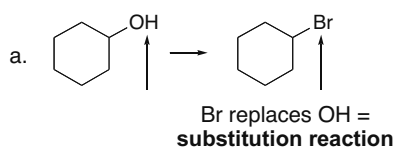


b.

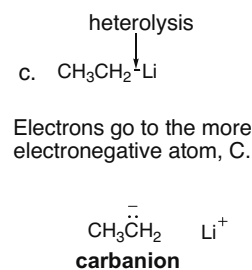
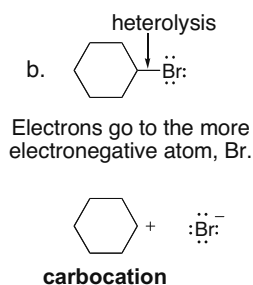
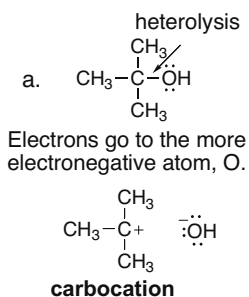


Answers to Problems

- 6.1 [1] In a **substitution reaction**, one group replaces another.
[2] In an **elimination reaction**, elements of the starting material are lost and a π bond is formed.
[3] In an **addition reaction**, elements are added to the starting material.

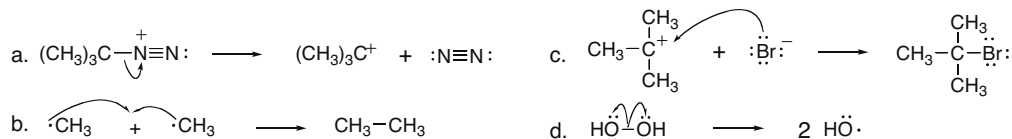


- 6.2 **Heterolysis** means one atom gets both of the electrons when a bond is broken. A carbocation is a C with a positive charge, and a carbanion is a C with a negative charge.

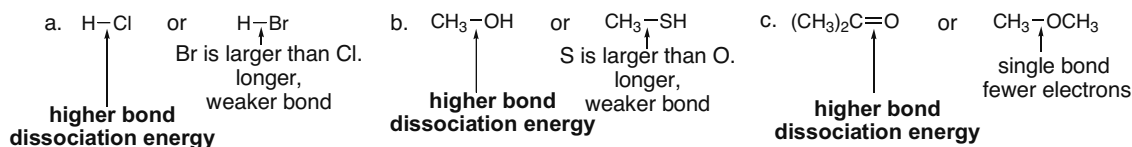


Chapter 6–6

6.3 Use **full-headed arrows** to show the movement of electron pairs, and **half-headed arrows** to show the movement of single electrons.



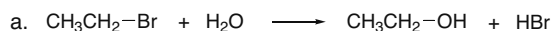
6.4 Increasing number of electrons between atoms = increasing bond strength = increasing bond dissociation energy = decreasing bond length.
 Increasing size of an atom = increasing bond length = decreasing bond strength.



6.5 To determine ΔH° for a reaction:

- [1] Add the bond dissociation energies for all bonds *broken* in the equation (+ values).
- [2] Add the bond dissociation energies for all of the bonds *formed* in the equation (– values).
- [3] *Add the energies together* to get the ΔH° for the reaction.

A **positive ΔH°** means the reaction is **endothermic**. A **negative ΔH°** means the reaction is **exothermic**.

**[1] Bonds broken**

	ΔH° (kJ/mol)
$\text{CH}_3\text{CH}_2-\text{Br}$	+ 285
$\text{H}-\text{OH}$	+ 498
Total	+ 783 kJ/mol

[2] Bonds formed

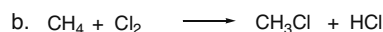
	ΔH° (kJ/mol)
$\text{CH}_3\text{CH}_2-\text{OH}$	– 393
$\text{H}-\text{Br}$	– 368
Total	– 761 kJ/mol

[3] Overall ΔH° =

sum in Step [1]
+
sum in Step [2]
+ 783 kJ/mol
– 761 kJ/mol
+ 22 kJ/mol

ANSWER: + 22 kJ/mol
endothermic

Understanding Organic Reactions 6–7

**[1] Bonds broken**

	ΔH° (kJ/mol)
$\text{CH}_3\text{-H}$	+ 435
Cl-Cl	+ 242
Total	+ 677 kJ/mol

[2] Bonds formed

	ΔH° (kJ/mol)
$\text{CH}_3\text{-Cl}$	- 351
H-Cl	- 431
Total	- 782 kJ/mol

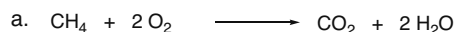
[3] Overall ΔH° =

sum in Step [1] + sum in Step [2]

+ 677 kJ/mol
- 782 kJ/mol

ANSWER: - 105 kJ/mol
exothermic

6.6 Use the directions from Answer 6.5. In determining the number of bonds broken or formed, you must take into account the coefficients needed to balance an equation.

**[1] Bonds broken**

	ΔH° (kJ/mol)
$\text{CH}_3\text{-H}$	+ 435 x 4 = + 1740
O-O	+ 497 x 2 = + 994
Total	+ 2734 kJ/mol

[2] Bonds formed

	ΔH° (kJ/mol)
OC-O	- 535 x 2 = - 1070
HO-H	- 498 x 4 = - 1992
Total	- 3062 kJ/mol

[3] Overall ΔH° =

sum in Step [1] + sum in Step [2]

+ 2734 kJ/mol
- 3062 kJ/mol

ANSWER: - 328 kJ/mol

**[1] Bonds broken**

	ΔH° (kJ/mol)
$\text{CH}_3\text{CH}_2\text{-H}$	+ 410 x 12 = + 4920
O-O	+ 497 x 7 = + 3479
C-C	+ 368 x 2 = + 736
Total	+ 9135 kJ/mol

[2] Bonds formed

	ΔH° (kJ/mol)
OC-O	- 535 x 8 = - 4280
HO-H	- 498 x 12 = - 5976
Total	- 10256 kJ/mol

[3] Overall ΔH° =

sum in Step [1] + sum in Step [2]

+ 9135 kJ/mol
- 10256 kJ/mol

ANSWER: - 1121 kJ/mol

6.7 Use the following relationships to answer the questions:

If $K_{\text{eq}} = 1$, then $\Delta G^\circ = 0$; if $K_{\text{eq}} > 1$, then $\Delta G^\circ < 0$; if $K_{\text{eq}} < 1$, then $\Delta G^\circ > 0$.

- A negative value of ΔG° means the equilibrium favors the product and K_{eq} is > 1 .
Therefore, $K_{\text{eq}} = 1000$ is the answer.
- A lower value of ΔG° means a larger value of K_{eq} , and the products are more favored.
 $K_{\text{eq}} = 10^{-2}$ is larger than $K_{\text{eq}} = 10^{-5}$, so ΔG° is lower.

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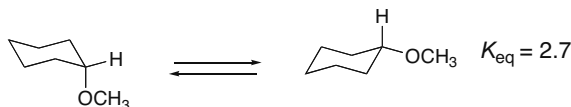
6.8 Use the relationships from Answer 6.7.

- a. $K_{\text{eq}} = 5.5$. $K_{\text{eq}} > 1$ means that the equilibrium favors the **product**.
- b. $\Delta G^\circ = 40 \text{ kJ/mol}$. A positive ΔG° means the equilibrium favors the **starting material**.

6.9 When the *product* is lower in energy than the *starting material*, the equilibrium favors the *product*. When the *starting material* is lower in energy than the *product*, the equilibrium favors the *starting material*.

- a. ΔG° is **positive**, so the equilibrium favors the starting material. Therefore the *starting material is lower in energy than the product*.
- b. K_{eq} is **> 1**, so the equilibrium favors the product. Therefore the *product is lower in energy than the starting material*.
- c. ΔG° is **negative**, so the equilibrium favors the product. Therefore the *product is lower in energy than the starting material*.
- d. K_{eq} is **< 1**, so the equilibrium favors the starting material. Therefore *the starting material is lower in energy than the product*.

6.10



- a. The K_{eq} is **> 1**, so the **product** (the conformation on the right) is favored at equilibrium.
- b. The ΔG° for this process must be **negative**, because the product is favored.
- c. ΔG° is somewhere between 0 and -6 kJ/mol .

6.11 A positive ΔH° favors the starting material. A negative ΔH° favors the product.

- a. ΔH° is positive (80 kJ/mol). The starting material is favored.
- b. ΔH° is negative (-40 kJ/mol). The product is favored.

6.12

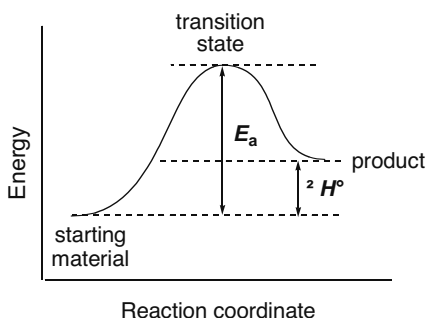
- a. **False**. The reaction is endothermic.
- b. **True**. This assumes that ΔG° is approximately equal to ΔH° .
- c. **False**. $K_{\text{eq}} < 1$.
- d. **True**.
- e. **False**. The starting material is favored at equilibrium.

6.13

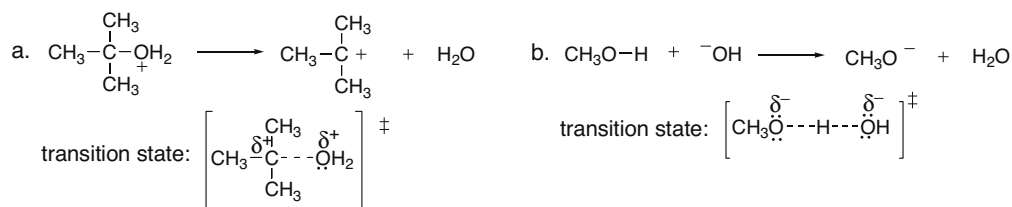
- a. **True**.
- b. **False**. ΔG° for the reaction is negative.
- c. **True**.
- d. **False**. The bonds in the product are stronger than the bonds in the starting material.
- e. **True**.

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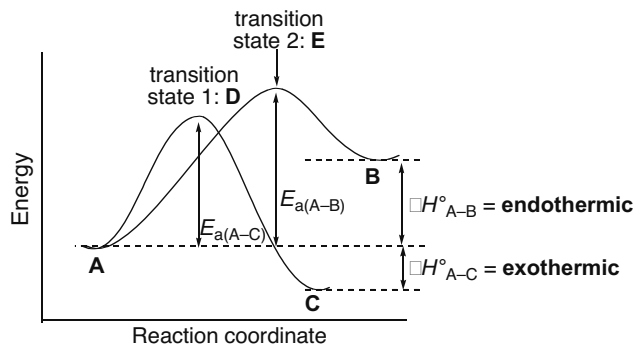
6.14



6.15 A transition state is drawn with dashed lines to indicate the partially broken and partially formed bonds. Any atom that gains or loses a charge contains a partial charge in the transition state.

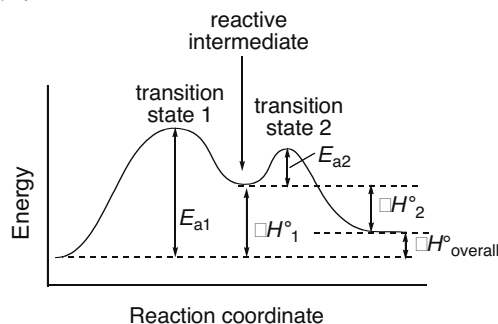


6.16



- Reaction A–C is exothermic.
Reaction A–B is endothermic.
- Reaction A–C is faster.
- Reaction A–C generates a lower-energy product.
- See labels.
- See labels.
- See labels.

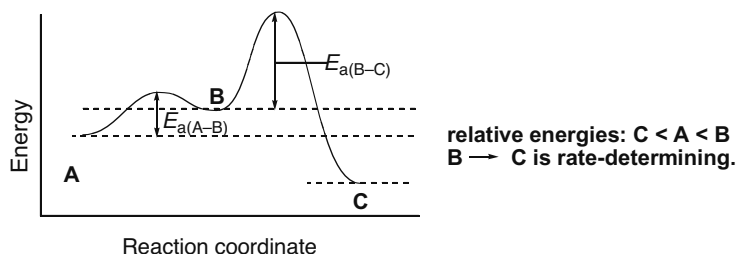
6.17



- Two steps, because there are two energy barriers.
- See labels.
- See labels.
- One reactive intermediate is formed (see label).
- The first step is rate-determining, because its transition state is at higher energy.
- The overall reaction is endothermic, because the energy of the products is higher than the energy of the reactants.

Chapter 6–10

6.18



6.19 E_a , concentration, and temperature affect reaction rate. ΔH° , ΔG° , and K_{eq} do not affect reaction rate.

- $E_a = 4 \text{ kJ/mol}$ corresponds to a faster reaction rate.
- A temperature of 25°C will have a faster reaction rate, because a higher temperature corresponds to a faster reaction.
- No change:** K_{eq} does not affect reaction rate.
- No change:** ΔH° does not affect reaction rate.

6.20

- False.** The reaction occurs at the same rate as a reaction with $K_{eq} = 8$ and $E_a = 80 \text{ kJ/mol}$.
- False.** The reaction is slower than a reaction with $K_{eq} = 0.8$ and $E_a = 40 \text{ kJ/mol}$.
- True.**
- True.**
- False.** The reaction is endothermic.

6.21 All reactants in the rate equation determine the rate of the reaction.

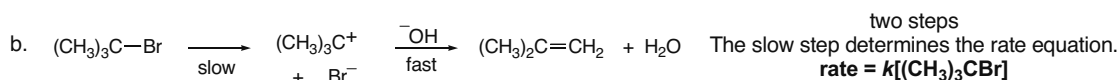
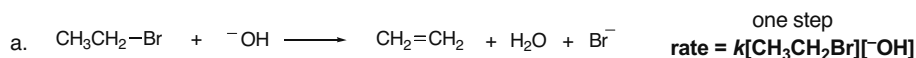
$$[1] \text{ rate} = k[\text{CH}_3\text{CH}_2\text{Br}][^-\text{OH}]$$

- Tripling the concentration of $\text{CH}_3\text{CH}_2\text{Br}$ only $\rightarrow$ **The rate is tripled.**
- Tripling the concentration of ^-OH only $\rightarrow$ **The rate is tripled.**
- Tripling the concentration of both $\text{CH}_3\text{CH}_2\text{Br}$ and $^-\text{OH} \rightarrow$ **The rate increases by a factor of 9 ($3 \times 3 = 9$).**

$$[2] \text{ rate} = k[(\text{CH}_3)_3\text{COH}]$$

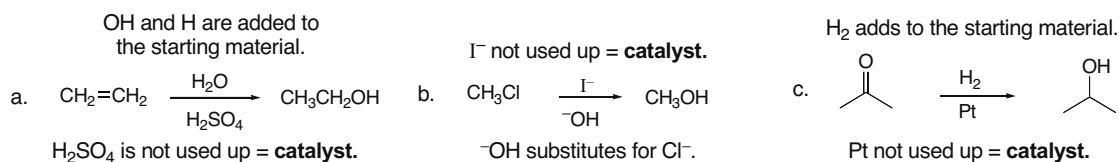
- Doubling the concentration of $(\text{CH}_3)_3\text{COH} \rightarrow$ **The rate is doubled.**
- Increasing the concentration of $(\text{CH}_3)_3\text{COH}$ by a factor of 10 $\rightarrow$ **The rate increases by a factor of 10.**

6.22 The rate equation is determined by the rate-determining step.

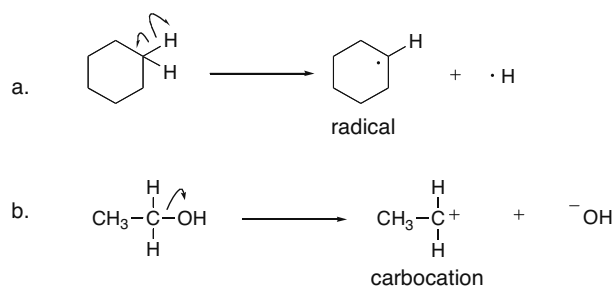


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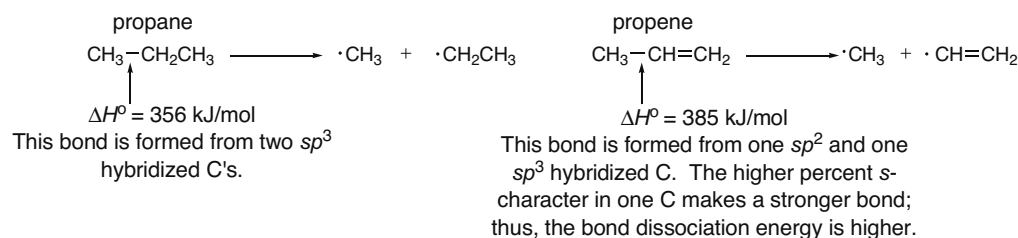
6.23 A catalyst is not used up or changed in the reaction. It only speeds up the reaction rate.



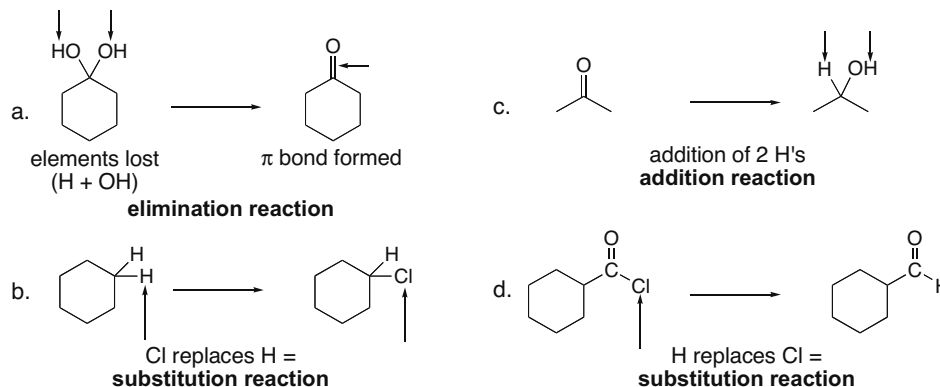
6.24



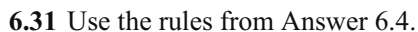
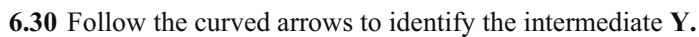
6.25



6.26 Use the directions from Answer 6.1.

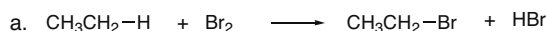


6.27 Use the rules in Answer 6.3 to draw the arrows.



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6.32 Use the directions from Answer 6.5.



[1] Bonds broken

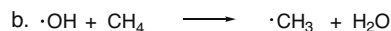
	ΔH° (kJ/mol)
$\text{CH}_3\text{CH}_2\text{-H}$	+ 410
Br-Br	+ 192
Total	+ 602 kJ/mol

[2] Bonds formed

	ΔH° (kJ/mol)
$\text{CH}_3\text{CH}_2\text{-Br}$	- 285
H-Br	- 368
Total	- 653 kJ/mol

[3] Overall $\Delta H^\circ =$

+ 602 kJ/mol
- 653 kJ/mol
ANSWER: - 51 kJ/mol



[1] Bonds broken

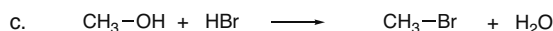
	ΔH° (kJ/mol)
$\text{CH}_3\text{-H}$	+ 435 kJ/mol

[2] Bonds formed

	ΔH° (kJ/mol)
H-OH	- 498 kJ/mol

[3] Overall $\Delta H^\circ =$

+ 435 kJ/mol
- 498 kJ/mol
ANSWER: - 63 kJ/mol



[1] Bonds broken

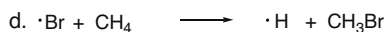
	ΔH° (kJ/mol)
$\text{CH}_3\text{-OH}$	+ 389
H-Br	+ 368
Total	+ 757 kJ/mol

[2] Bonds formed

	ΔH° (kJ/mol)
$\text{CH}_3\text{-Br}$	- 293
H-OH	- 498
Total	- 791 kJ/mol

[3] Overall $\Delta H^\circ =$

+ 757 kJ/mol
- 791 kJ/mol
ANSWER: - 34 kJ/mol



[1] Bonds broken

	ΔH° (kJ/mol)
$\text{CH}_3\text{-H}$	+ 435 kJ/mol

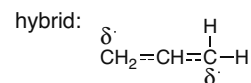
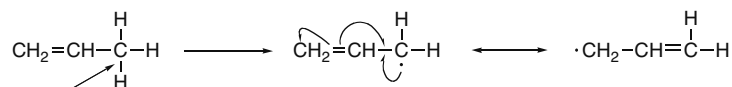
[2] Bonds formed

	ΔH° (kJ/mol)
$\text{CH}_3\text{-Br}$	-293 kJ/mol

[3] Overall $\Delta H^\circ =$

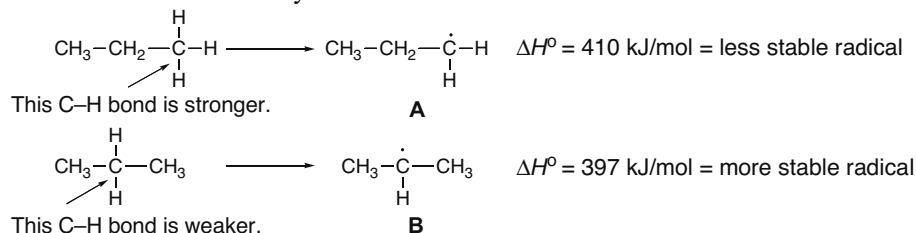
+ 435 kJ/mol
- 293 kJ/mol
ANSWER: + 142 kJ/mol

6.33



Chapter 6–14

6.34 The more stable radical is formed by a reaction with a smaller ΔH° .



Because the bond dissociation for cleavage of the C–H bond to form radical **A** is higher, more energy must be added to form it. This makes **A** higher in energy and therefore less stable than **B**.

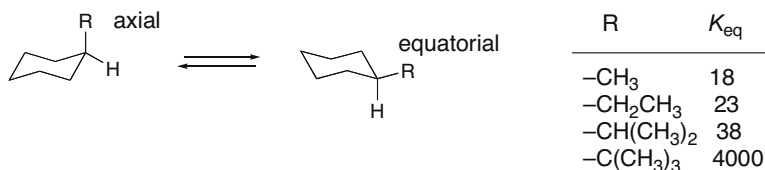
6.35 Use the rules from Answer 6.9.

- $K_{\text{eq}} = 0.5$. K_{eq} is less than one, so the **starting material** is favored.
- $\Delta G^\circ = -100 \text{ kJ/mol}$. ΔG° is less than 0, so the **product** is favored.
- $\Delta H^\circ = 8.0 \text{ kJ/mol}$. ΔH° is positive, so the **starting material** is favored.
- $K_{\text{eq}} = 16$. K_{eq} is greater than one, so the **product** is favored.
- $\Delta G^\circ = 2.0 \text{ kJ/mol}$. ΔG° is greater than zero, so the **starting material** is favored.
- $\Delta H^\circ = 200 \text{ kJ/mol}$. ΔH° is positive, so the **starting material** is favored.
- $\Delta S^\circ = 8 \text{ J/(K}\cdot\text{mol)}$. ΔS° is greater than zero, so the **product** is more disordered and favored.
- $\Delta S^\circ = -8 \text{ J/(K}\cdot\text{mol)}$. ΔS° is less than zero, so the **starting material** is more disordered and favored.

6.36

- A negative ΔG° must have $K_{\text{eq}} > 1$. $K_{\text{eq}} = 10^2$.
- $K_{\text{eq}} = [\text{products}]/[\text{reactants}] = [1]/[5] = 0.2 = K_{\text{eq}}$. ΔG° is positive.
- A negative ΔG° has $K_{\text{eq}} > 1$, and a positive ΔG° has $K_{\text{eq}} < 1$. $\Delta G^\circ = -8 \text{ kJ/mol}$ will have a larger K_{eq} .

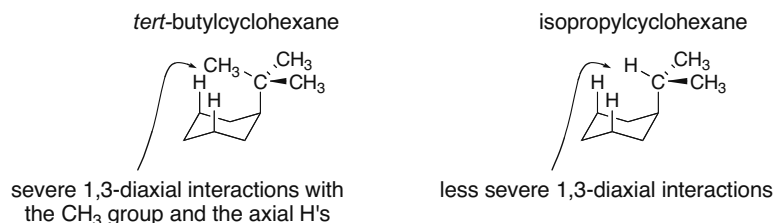
6.37



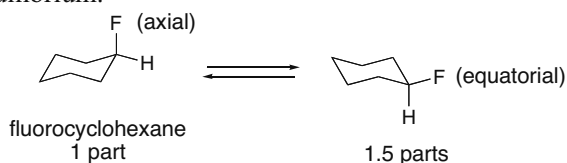
- The equatorial conformation is always present in the larger amount at equilibrium, because the K_{eq} for all R groups is greater than 1.
- The cyclohexane with the –C(CH₃)₃ group will have the greatest amount of equatorial conformation at equilibrium, because this group has the highest K_{eq} .
- The cyclohexane with the –CH₃ group will have the greatest amount of axial conformation at equilibrium, because this group has the lowest K_{eq} .
- The cyclohexane with the –C(CH₃)₃ group will have the most negative ΔG° , because it has the largest K_{eq} .
- The larger the R group, the more favored the equatorial conformation.

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- f. The K_{eq} for *tert*-butylcyclohexane is much higher because the *tert*-butyl group is bulkier than the other groups. With a *tert*-butyl group, a CH_3 group is always oriented over the ring when the group is axial, creating severe 1,3-diaxial interactions. With all other substituents, the larger CH_3 groups can be oriented away from the ring, placing a H over the ring, making the 1,3-diaxial interactions less severe. Compare:

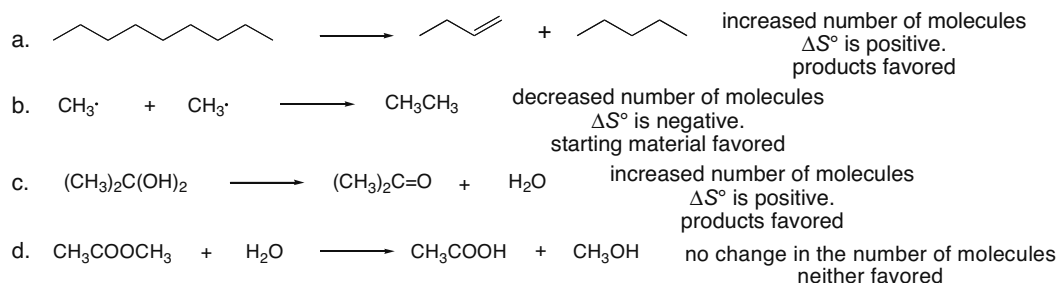


- 6.38 Calculate K_{eq} , and then find the percentage of axial and equatorial conformations present at equilibrium.

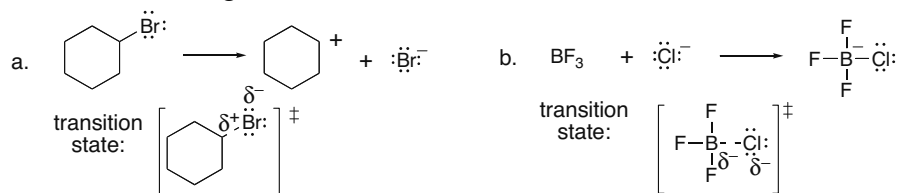


- a. $\Delta G^\circ = -5.9 \log K_{eq}$
 $\Delta G^\circ = -1.0 \text{ kJ/mol}$
 $-1.0 \text{ kJ/mol} = -5.9 \log K_{eq}$
 $K_{eq} = 1.5$
- b. $K_{eq} = [\text{products}]/[\text{reactants}]$
 $1.5 = [\text{products}]/[\text{reactants}]$
 $1.5[\text{reactants}] = [\text{products}]$
 $[\text{reactants}] = 0.4 = 40\% \text{ axial}$
 $[\text{products}] = 0.6 = 60\% \text{ equatorial}$

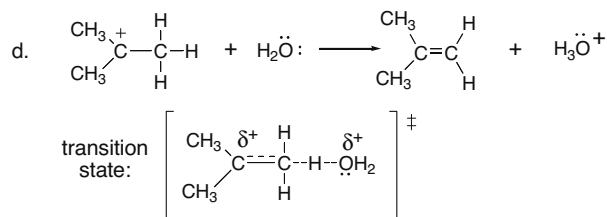
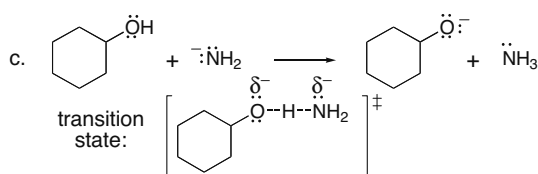
- 6.39 Reactions resulting in an increase in entropy are favored. When a single molecule forms two molecules, there is an increase in entropy.



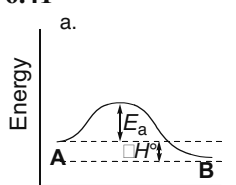
- 6.40 Use the directions in Answer 6.15 to draw the transition state. Nonbonded electron pairs are drawn in at reacting sites.



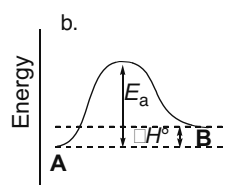
Chapter 6–16



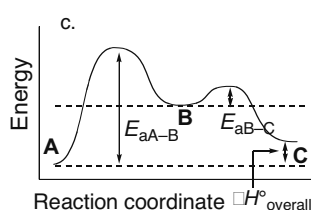
6.41



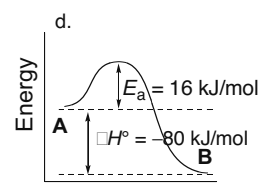
- Reaction coordinate
- one step $A \rightarrow B$
 - exothermic since B lower than A
 - low E_a (small energy barrier)



- Reaction coordinate
- one step $A \rightarrow B$
 - endothermic since B higher than A
 - high E_a (large energy barrier)

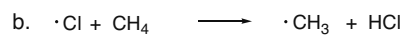
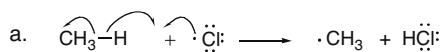


- Reaction coordinate $\Delta H^\circ_{\text{overall}}$
- two steps
 - A lowest energy
 - B highest energy
 - $E_{a(A-B)}$ is rate-determining, since the transition state for Step [1] is higher in energy.



- Reaction coordinate
- one step $A \rightarrow B$
 - exothermic since B lower than A

6.42



[1] Bonds broken

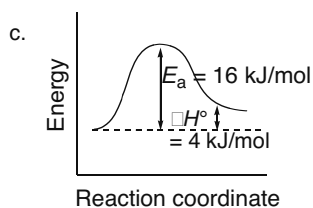
ΔH° (kJ/mol)
$\text{CH}_3\text{--H} \quad + 435 \text{ kJ/mol}$

[2] Bonds formed

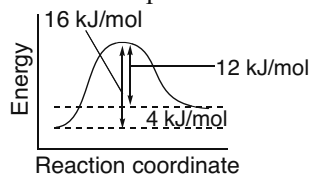
ΔH° (kJ/mol)
$\text{H--Cl} \quad - 431 \text{ kJ/mol}$

[3] Overall $\Delta H^\circ =$

$+ 435 \text{ kJ/mol}$
$- 431 \text{ kJ/mol}$
ANSWER: $+ 4 \text{ kJ/mol}$

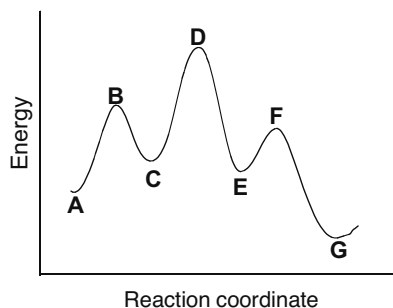


- d. The E_a for the reverse reaction is the difference in energy between the products and the transition state, 12 kJ/mol.



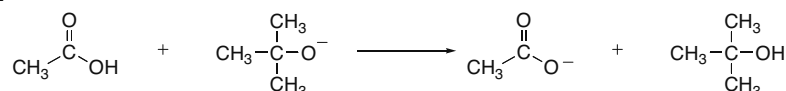
Understanding Organic Reactions 6-17

6.43



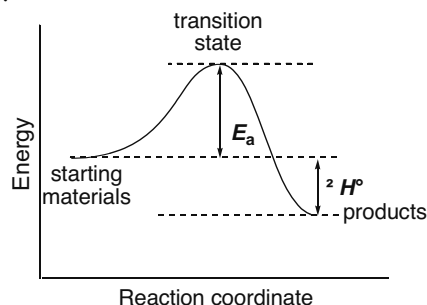
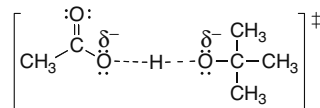
- B, D, and F are transition states.
- C and E are reactive intermediates.
- The overall reaction has **three steps**.
- A-C is endothermic.
C-E is exothermic.
E-G is exothermic.
- The overall reaction is exothermic.

6.44

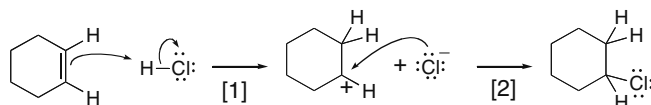


Since $\text{p}K_a(\text{CH}_3\text{CO}_2\text{H}) = 4.8$ and $\text{p}K_a[(\text{CH}_3)_3\text{COH}] = 18$, the weaker acid is formed as product, and equilibrium favors the products. Thus, ΔH° is negative, and the products are lower in energy than the starting materials.

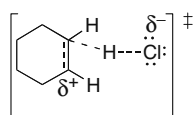
transition state:



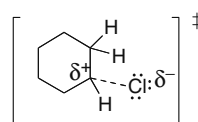
6.45



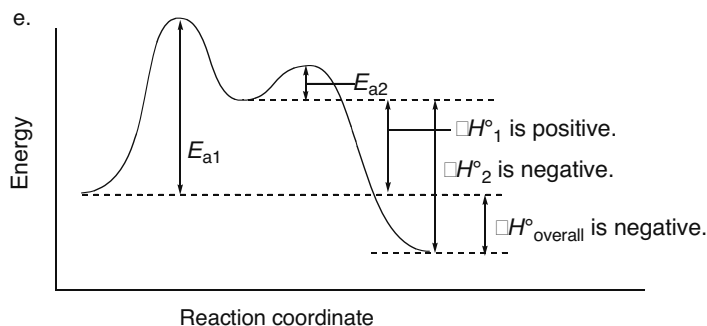
- Step [1] breaks one π bond and the H-Cl bond, and one C-H bond is formed. The ΔH° for this step should be positive, because more bonds are broken than formed.
- Step [2] forms one bond. The ΔH° for this step should be negative, because one bond is formed and none is broken.
- Step [1] is rate-determining, because it is more difficult.
- Transition state for Step [1]:



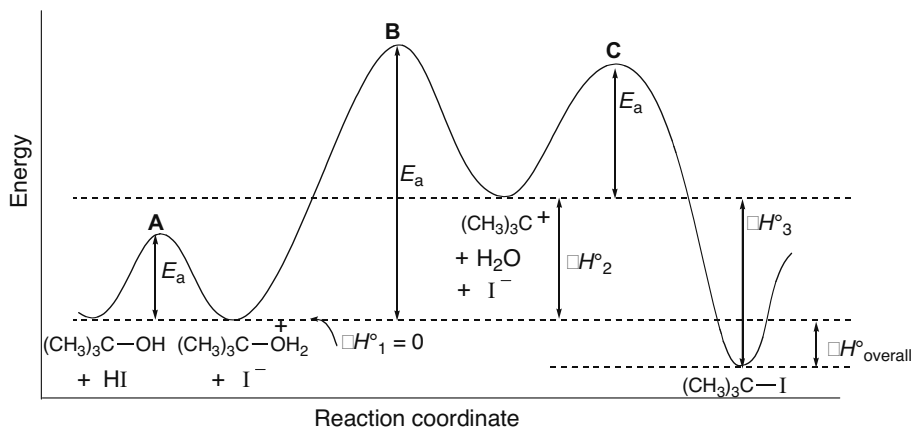
Transition state for Step [2]:



Chapter 6–18



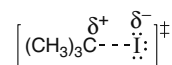
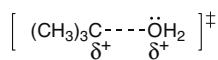
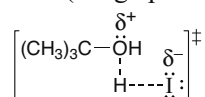
6.46



a. The reaction has three steps, because there are three energy barriers.

b. See above.

c. Transition state A (see graph for location): Transition state B: Transition state C:



d. Step [2] is rate-determining, because this step has the highest energy transition state.

6.47 E_a , concentration, catalysts, rate constant, and temperature affect reaction rate so (c), (d), (e), (g), and (h) affect rate.

6.48

a. **rate** = $k[\text{CH}_3\text{Br}][\text{NaCN}]$

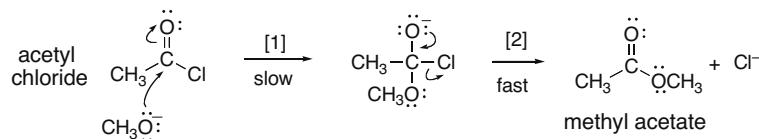
b. Double $[\text{CH}_3\text{Br}]$ = **rate doubles**.

c. Halve $[\text{NaCN}]$ = **rate halved**.

d. Increase both $[\text{CH}_3\text{Br}]$ and $[\text{NaCN}]$ by factor of 5 = $[5][5]$ = **rate increases by a factor of 25**.

Understanding Organic Reactions 6-19

6.49



- Only the slow step is included in the rate equation: **Rate** = $k[\text{CH}_3\text{O}^-][\text{CH}_3\text{COCl}]$
- CH_3O^- is in the rate equation. Increasing its concentration by 10 times would increase the rate by **10 times**.
- When both reactant concentrations are increased by 10 times, the rate increases by **100 times** ($10 \times 10 = 100$).
- This is a **substitution reaction** (OCH_3 substitutes for Cl).

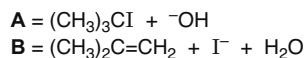
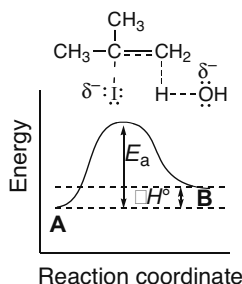
6.50

- True:** Increasing temperature increases reaction rate.
- True:** If a reaction is fast, then it has a large rate constant.
- False: Corrected**—There is no relationship between ΔG° and reaction rate.
- False: Corrected**—When the E_a is large, *the rate constant is small*.
- False: Corrected**—There is no relationship between K_{eq} and reaction rate.
- False: Corrected**—Increasing the concentration of a reactant increases the rate of a reaction *only if the reactant appears in the rate equation*.

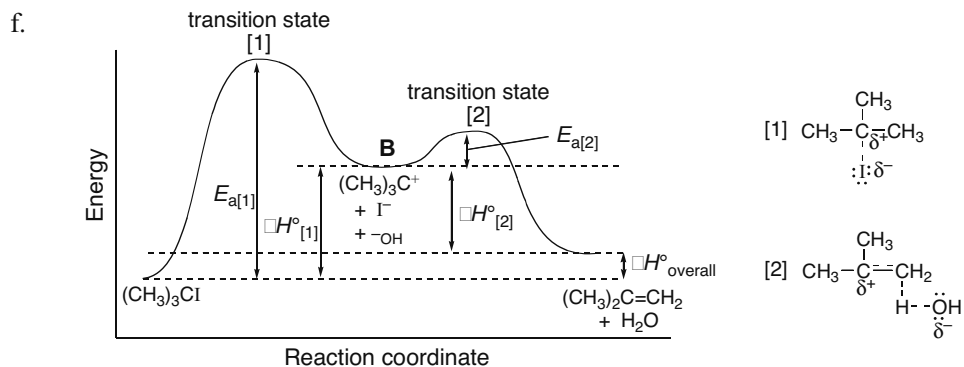
6.51

- The first mechanism has one step: **Rate** = $k[(\text{CH}_3)_3\text{CI}][^-\text{OH}]$
- The second mechanism has two steps, but only the first step would be in the rate equation, because it is slow and therefore rate-determining: **Rate** = $k[(\text{CH}_3)_3\text{CI}]$
- Possibility [1] is second order; possibility [2] is first order.
- These rate equations can be used to show which mechanism is plausible by changing the concentration of ^-OH . If this affects the rate, then possibility [1] is reasonable. If it does not affect the rate, then possibility [2] is reasonable.

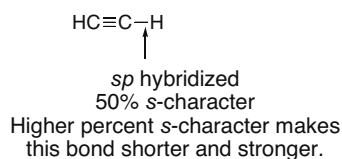
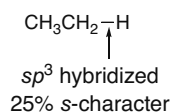
e.



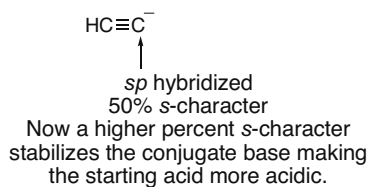
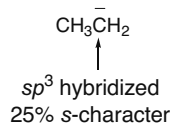
Chapter 6–20



- 6.52** The difference in both the acidity and the bond dissociation energy of CH₃CH₃ versus HC≡CH is due to the same factor: percent *s*-character. The difference results because one process is based on homolysis and one is based on heterolysis.
Bond dissociation energy:

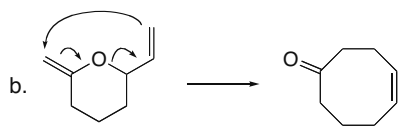
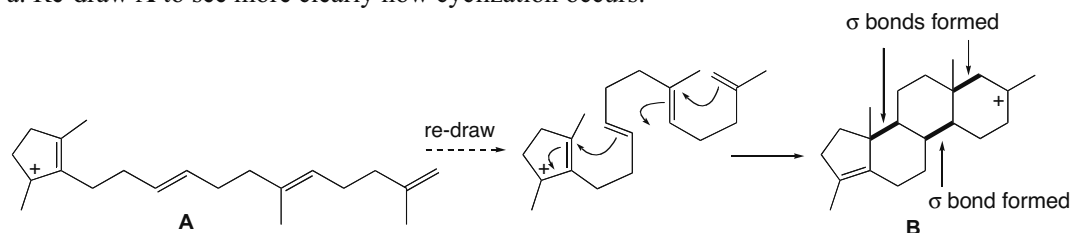


Acidity: To compare acidity, we must compare the stability of the conjugate bases:

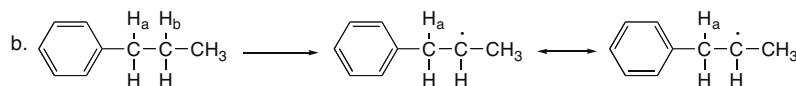
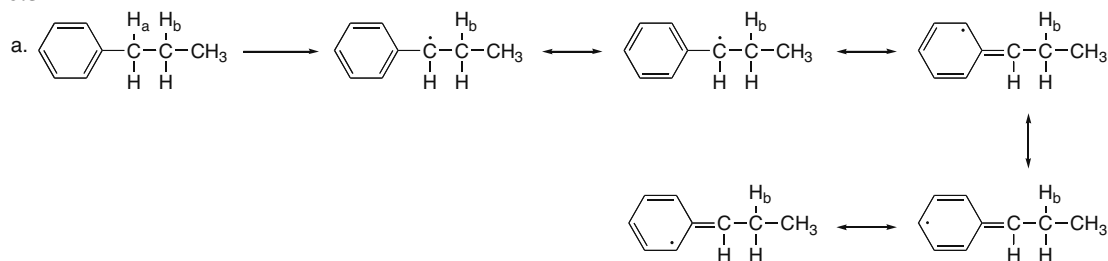


Understanding Organic Reactions 6-21

6.53 a. Re-draw A to see more clearly how cyclization occurs.



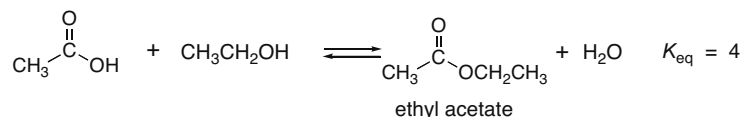
6.54



c. C-H_a is weaker than C-H_b since the carbon radical formed when the C-H_a bond is broken is highly resonance stabilized. This means the bond dissociation energy for C-H_a is lower.

6.55 In Reaction [1], the number of molecules of reactants and products stays the same, so entropy is not a factor. In Reaction [2], a single molecule of starting material forms two molecules of products, so entropy increases. This makes ΔG° more favorable, thus increasing K_{eq} .

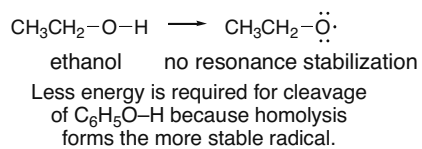
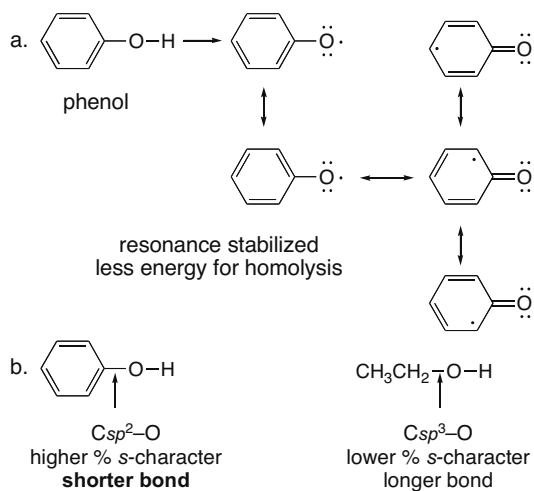
6.56



To increase the yield of ethyl acetate, H₂O can be removed from the reaction mixture, or there can be a large excess of one of the starting materials.

Chapter 6–22

6.57



Chapter 7 Alkyl Halides and Nucleophilic Substitution

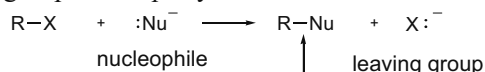
Chapter Review

General facts about alkyl halides

- Alkyl halides contain a halogen atom X bonded to an sp^3 hybridized carbon (7.1).
- Alkyl halides are named as halo alkanes, with the halogen as a substituent (7.2).
- Alkyl halides have a polar C–X bond, so they exhibit dipole–dipole interactions but are incapable of intermolecular hydrogen bonding (7.3).
- The polar C–X bond containing an electrophilic carbon makes alkyl halides reactive towards nucleophiles and bases (7.5).

The central theme (7.6)

- Nucleophilic substitution is one of the two main reactions of alkyl halides. A nucleophile replaces a leaving group on an sp^3 hybridized carbon.



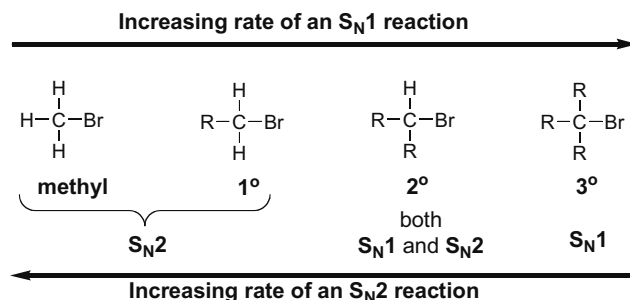
The electron pair in the C–Nu bond comes from the nucleophile.

- One σ bond is broken and one σ bond is formed.
- There are two possible mechanisms: S_N1 and S_N2 .

S_N1 and S_N2 mechanisms compared

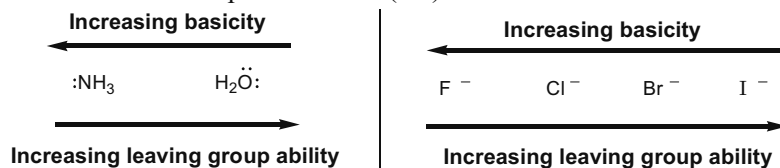
	S_N2 mechanism	S_N1 mechanism
[1] Mechanism	One step (7.11B)	Two steps (7.13B)
[2] Alkyl halide	Order of reactivity: $\text{CH}_3\text{X} > \text{RCH}_2\text{X} > \text{R}_2\text{CHX} > \text{R}_3\text{CX}$ (7.11D)	Order of reactivity: $\text{R}_3\text{CX} > \text{R}_2\text{CHX} > \text{RCH}_2\text{X} > \text{CH}_3\text{X}$ (7.13D)
[3] Rate equation	$\text{rate} = k[\text{RX}][\text{:Nu}^-]$ - second-order kinetics (7.11A)	$\text{rate} = k[\text{RX}]$ - first-order kinetics (7.13A)
[4] Stereochemistry	- backside attack of the nucleophile (7.11C) - inversion of configuration at a stereogenic center	- trigonal planar carbocation intermediate (7.13C) - racemization at a stereogenic center
[5] Nucleophile	favoured by stronger nucleophiles (7.17B)	favoured by weaker nucleophiles (7.17B)
[6] Leaving group	better leaving group $\rightarrow$ faster reaction (7.17C)	better leaving group $\rightarrow$ faster reaction (7.17C)
[7] Solvent	favoured by polar aprotic solvents (7.17D)	favoured by polar protic solvents (7.17D)

Chapter 7-2

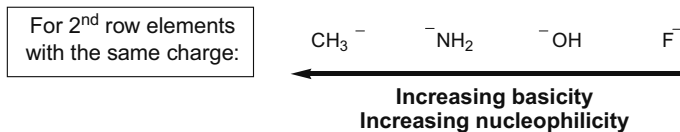


Important trends

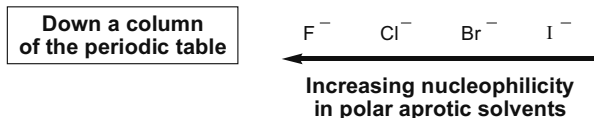
- The best leaving group is the weakest base. Leaving group ability increases left to right across a row and down a column of the periodic table (7.7).



- Nucleophilicity decreases across a row of the periodic table (7.8A).



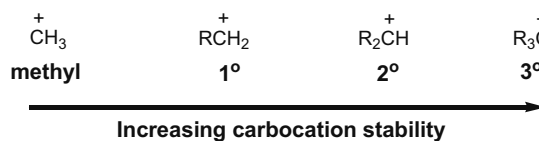
- Nucleophilicity decreases down a column of the periodic table in polar aprotic solvents (7.8C).



- Nucleophilicity increases down a column of the periodic table in polar protic solvents (7.8C).



- The stability of a carbocation increases as the number of R groups bonded to the positively charged carbon increases (7.14).



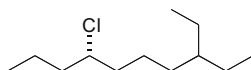
Alkyl Halides and Nucleophilic Substitution 7-3

Important principles

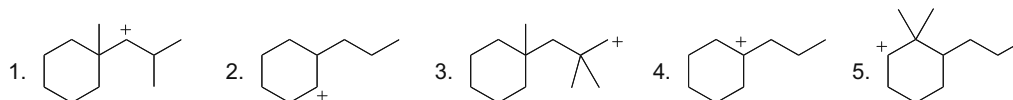
Principle	Example
- Electron-donating groups (such as R groups) stabilize a positive charge (7.14A). - Steric hindrance decreases nucleophilicity but not basicity (7.8B). - Hammond postulate: In an endothermic reaction, the more stable product is formed faster. In an exothermic reaction, this fact is not necessarily true (7.15). - Planar, sp^2 hybridized atoms react with reagents from both sides of the plane (7.13C).	3° Carbocations (R_3C^+) are more stable than 2° Carbocations (R_2CH^+), which are more stable than 1° carbocations (RCH_2^+). $(CH_3)_3CO^-$ is a stronger base but a weaker nucleophile than $CH_3CH_2O^-$. S_N1 reactions are faster when more stable (more substituted) carbocations are formed, because the rate-determining step is endothermic. - A trigonal planar carbocation reacts with nucleophiles from both sides of the plane.

Practice Test on Chapter Review

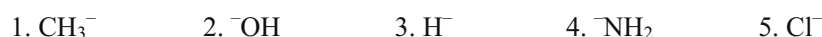
1. Give the IUPAC name for the following compound, including the appropriate *R,S* prefix.



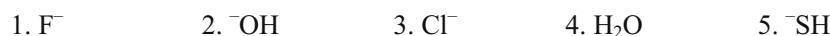
2. a. Which of the following carbocations is the most stable?



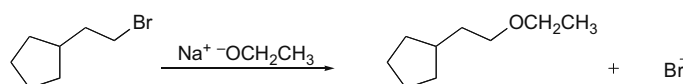
- b. Which of the following anions is the best leaving group?



- c. Which species is the strongest nucleophile in polar protic solvents?

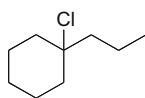
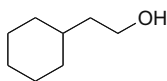
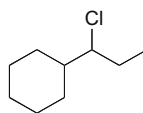
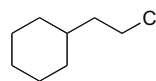


- d. Which of the following statements is true about the given reaction?

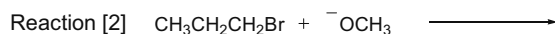
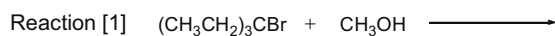


Chapter 7-4

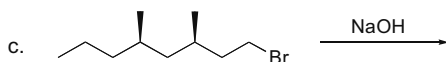
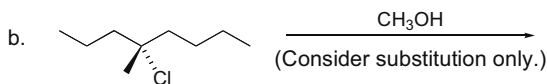
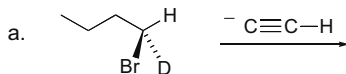
- The reaction follows second-order kinetics.
 - The rate of the reaction increases when the solvent is changed from $\text{CH}_3\text{CH}_2\text{OH}$ to DMSO.
 - The rate of the reaction increases when the leaving group is changed from Br to F.
 - Statements (1) and (2) are both true.
 - Statements (1), (2), and (3) are all true.
3. Rank the following compounds in order of **increasing reactivity in an $\text{S}_{\text{N}}1$ reaction**. Rank the **least reactive** compound as **1**, the **most reactive** compound as **4**, and the compounds of intermediate reactivity as **2** and **3**.

**A****B****C****D**

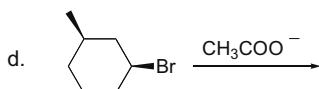
4. Consider the following two nucleophilic substitution reactions, labeled Reaction [1] and Reaction [2]. (Only the starting materials are drawn.) Then answer True (T) or False (F) to each of the following statements.



- The rate equation for Reaction [1] is $\text{rate} = k[(\text{CH}_3\text{CH}_2)_3\text{CBr}][\text{CH}_3\text{OH}]$.
 - Changing the leaving group from Br^- to Cl^- decreases the rate of both reactions.
 - Changing the solvent from CH_3OH to $(\text{CH}_3)_2\text{S}=\text{O}$ increases the rate of Reaction [2].
 - Doubling the concentration of both $\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}$ and $^-\text{OCH}_3$ in Reaction [2] doubles the rate of the reaction.
 - If entropy is ignored and K_{eq} for Reaction [1] is < 1 , then the reaction is exothermic.
 - If entropy is ignored and ΔH° is negative for Reaction [1], then the bonds in the product are stronger than the bonds in the starting materials.
 - The energy diagram for Reaction [2] exhibits only one energy barrier.
5. Draw the organic products formed in the following reactions. **Use wedges and dashes to show stereochemistry in compounds with stereogenic centers.**



Alkyl Halides and Nucleophilic Substitution 7-5



Answers to Practice Test

1. (7*S*)-7-chloro-3-ethyldecane

3. A-4

B-1

C-3

D-2

2. a. 4

b. 5

c. 5

d. 4

4. a. F

b. T

c. T

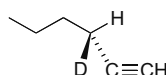
d. F

e. F

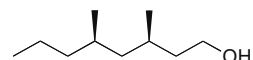
f. T

g. T

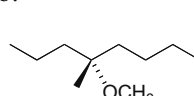
5. a.



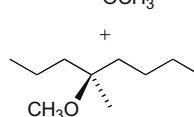
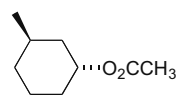
c.



b.

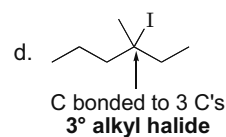
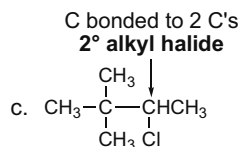
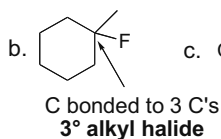
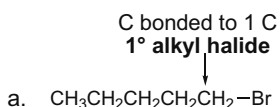


d.

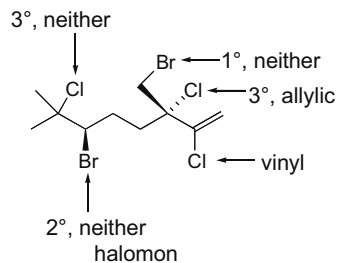
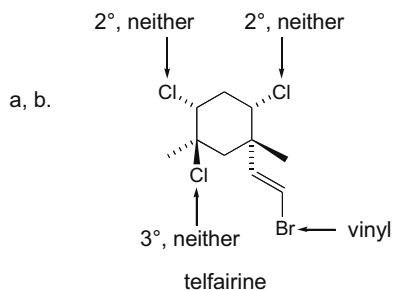


Answers to Problems

7.1 Classify the alkyl halide as 1°, 2°, or 3° by counting the number of carbons bonded directly to the carbon bonded to the halogen.

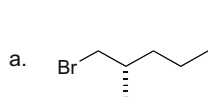


7.2 Use the directions from Answer 7.1.

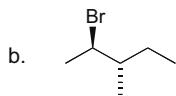


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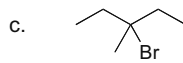
7.3 Draw a compound of molecular formula $C_6H_{13}Br$ to fit each description.



1° alkyl halide
one stereogenic center



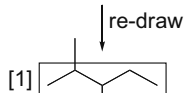
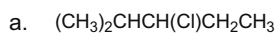
2° alkyl halide
two stereogenic centers



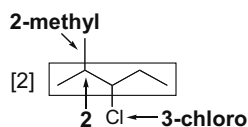
3° alkyl halide
no stereogenic centers

7.4 To name a compound with the IUPAC system:

- [1] **Name the parent** chain by finding the longest carbon chain.
- [2] **Number the chain** so the first substituent gets the lower number. Then **name and number all substituents**, giving like substituents a prefix (di, tri, etc.). **To name the halogen substituent, change the -ine ending to -o.**
- [3] **Combine all parts**, alphabetizing substituents, and ignoring all prefixes except iso.

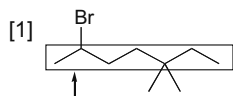


5 carbon alkane = **pentane**

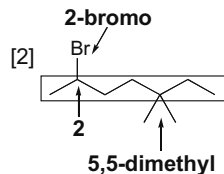


[3] **3-chloro-2-methylpentane**

b.

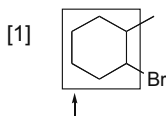


7 carbon alkane = **heptane**

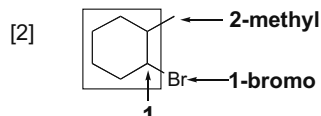


[3] **2-bromo-5,5-dimethylheptane**

c.

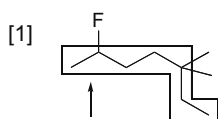


6 carbon cycloalkane =
cyclohexane

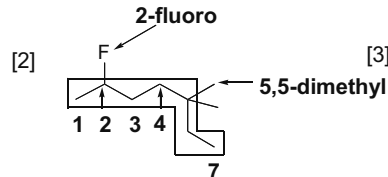


[3] **1-bromo-2-methylcyclohexane**

d.



7 carbon alkane = **heptane**



[3] **2-fluoro-5,5-dimethylheptane**

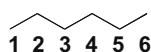
7.5 To work backwards from a name to a structure:

- [1] Find the parent name and draw that number of carbons. Use the suffix to identify the functional group (**-ane = alkane**).
- [2] Arbitrarily number the carbons in the chain. Add the substituents to the appropriate carbon.

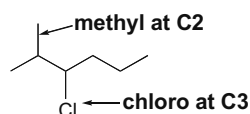
Alkyl Halides and Nucleophilic Substitution 7-7

a. 3-chloro-2-methylhexane

[1] 6 carbon alkane

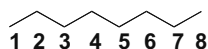


[2]

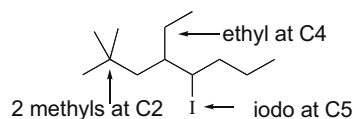


b. 4-ethyl-5-iodo-2,2-dimethyloctane

[1] 8 carbon alkane



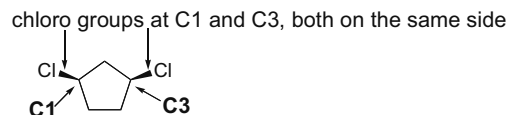
[2]

c. *cis*-1,3-dichlorocyclopentane

[1] 5 carbon cycloalkane



[2]

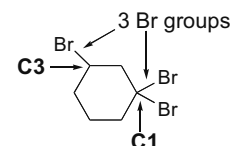


d. 1,1,3-tribromocyclohexane

[1] 6 carbon cycloalkane

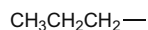


[2]

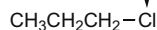


e. propyl chloride

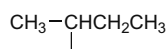
[1] 3 carbon alkyl group



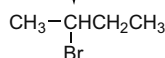
[2] chloride on end

f. *sec*-butyl bromide

[1] 4 carbon alkyl group

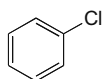


[2] bromide

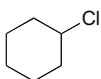
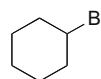


7.6 a. Because an sp^2 hybridized C has a higher percent s -character than an sp^3 hybridized C, it holds electron density closer to C. This pulls a little more electron density towards C, away from Cl, and thus a $C_{sp^2}-\text{Cl}$ bond is less polar than a $C_{sp^3}-\text{Cl}$ bond.

b.

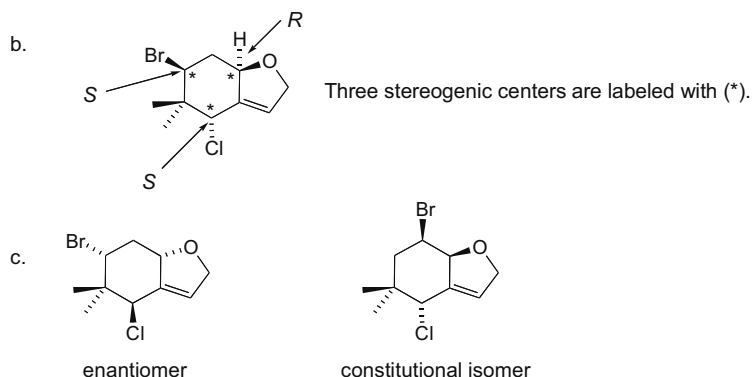


lowest boiling point

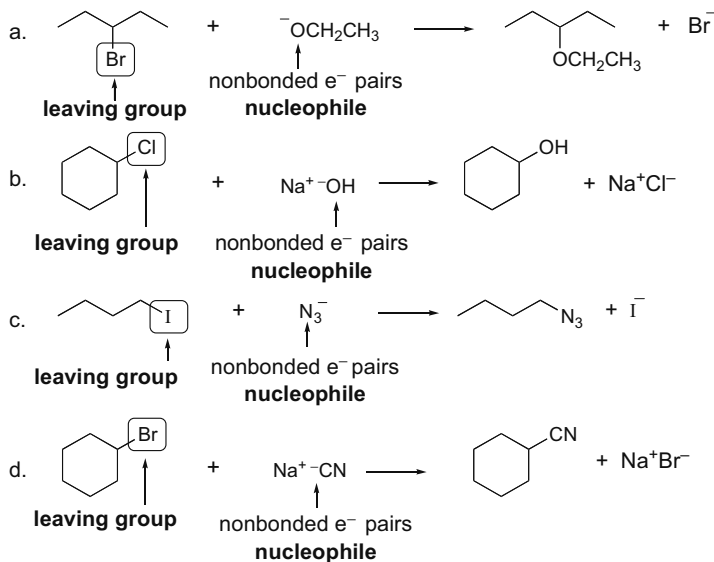

 sp^3 C-Cl bond
intermediate
boiling point

 larger halogen, sp^3 C-Br bond
highest boiling point

7.7 a. Since chondrocole A has 10 C's and only one functional group capable of hydrogen bonding to water (an ether), it is insoluble in H_2O . Because it is organic, it is soluble in CH_2Cl_2 .

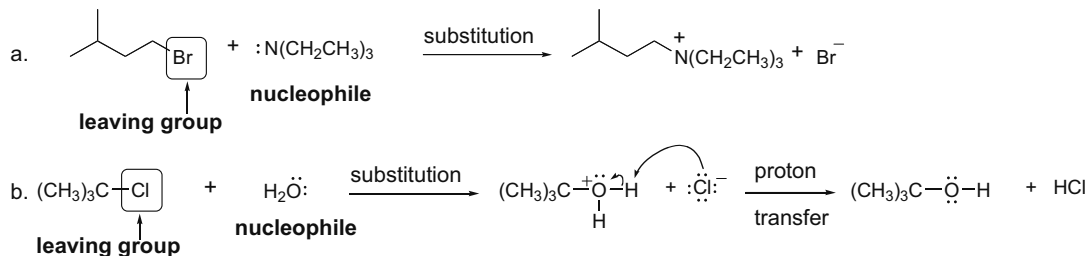
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- 7.8** To draw the products of a nucleophilic substitution reaction:
- Find the sp^3 hybridized electrophilic carbon** with a leaving group.
 - Find the nucleophile** with lone pairs or electrons in π bonds.
 - Substitute the nucleophile for the leaving group** on the electrophilic carbon.

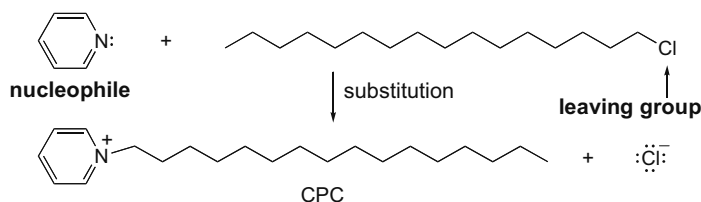


- 7.9** Use the steps from Answer 7.8 and then draw the proton transfer reaction.



Alkyl Halides and Nucleophilic Substitution 7-9

7.10 Draw the structure of CPC using the steps from Answer 7.8.



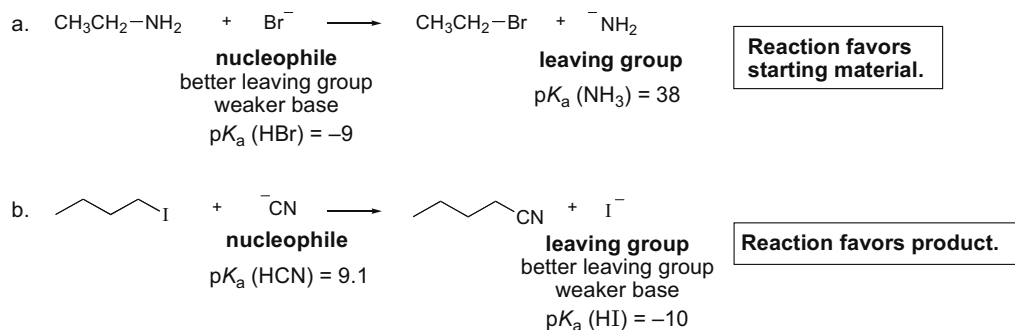
7.11 Compare the leaving groups based on these trends:

- Better leaving groups are weaker bases.
 - A neutral leaving group is always better than its conjugate base.
- | | | |
|--|--|---|
| <p>a. Cl^-, I^-</p> <p>↑</p> <p>farther down a column
of the periodic table
less basic
better leaving group</p> | <p>b. NH_3, NH_2^-</p> <p>↑</p> <p>neutral compound
less basic
better leaving group</p> | <p>c. H_2O, H_2S</p> <p>↑</p> <p>farther down a column
of the periodic table
less basic
better leaving group</p> |
|--|--|---|

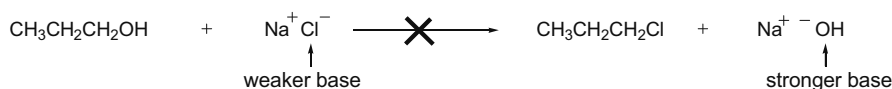
7.12 Good leaving groups include Cl^- , Br^- , I^- , and H_2O .

a. $\text{CH}_3\text{CH}_2\text{CH}_2\text{-Br}$ ↑ Br^- is a good leaving group.	b. $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ No good leaving group. $^- \text{OH}$ is too strong a base.	c. $\text{CH}_3\text{CH}_2\text{CH}_2\text{-OH}_2^+$ ↑ H_2O is a good leaving group.	d. CH_3CH_3 No good leaving group. H^- is too strong a base.

7.13 To decide whether the equilibrium favors the starting material or the products, **compare the nucleophile and the leaving group**. The reaction proceeds towards the weaker base.



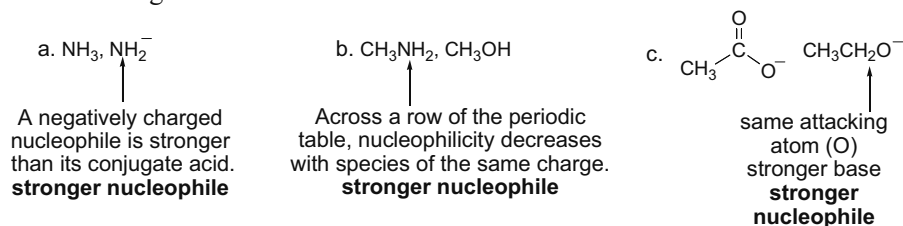
7.14 It is not possible to convert $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ to $\text{CH}_3\text{CH}_2\text{CH}_2\text{Cl}$ by nucleophilic substitution with NaCl because $^- \text{OH}$ is a stronger base and poorer leaving group than Cl^- . The equilibrium favors the reactants, not the products.



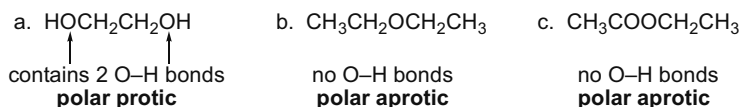
Chapter 7–10

7.15 Use these three rules to find the stronger nucleophile in each pair:

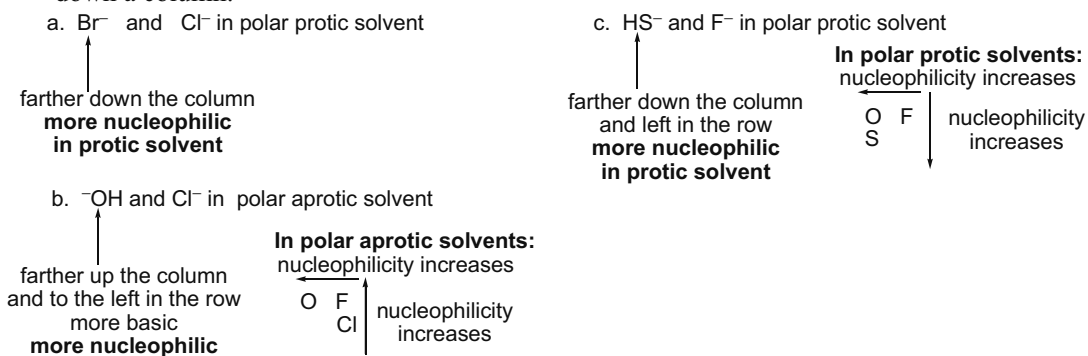
- [1] Comparing two nucleophiles having the **same attacking atom**, the stronger base is a **stronger nucleophile**.
- [2] **Negatively charged nucleophiles** are always **stronger than their conjugate acids**.
- [3] **Across a row of the periodic table**, nucleophilicity decreases when comparing species of similar charge.



7.16 **Polar protic solvents** are capable of **hydrogen bonding**, and therefore must contain a **H bonded to an electronegative O or N**. **Polar aprotic solvents** are incapable of hydrogen bonding, and therefore do not contain any O–H or N–H bonds.



- 7.17
- In **polar protic solvents**, the trend in nucleophilicity is **opposite to the trend in basicity** down a column of the periodic table so that nucleophilicity increases.
 - In **polar aprotic solvents**, the trend is **identical to basicity** so that nucleophilicity decreases down a column.



Alkyl Halides and Nucleophilic Substitution 7-11

7.18 The stronger base is the stronger nucleophile except in polar protic solvents when nucleophilicity increases down a column. For other rules, see Answers 7.15 and 7.17.

- a. H_2O (no charge, **weakest nucleophile**) OH^- (negatively charged, **intermediate nucleophile**) NH_2^- (negatively charged, farther left in periodic table, **strongest nucleophile**)
- b. Br^- (Basicity decreases down a column in polar aprotic solvents, **weakest nucleophile**) F^- (Basicity decreases across a row, **intermediate nucleophile**) OH^- (**strongest nucleophile**)
- c. H_2O (**weakest nucleophile**) CH_3COO^- (weaker base than OH^- , **intermediate nucleophile**) OH^- (**strongest nucleophile**)

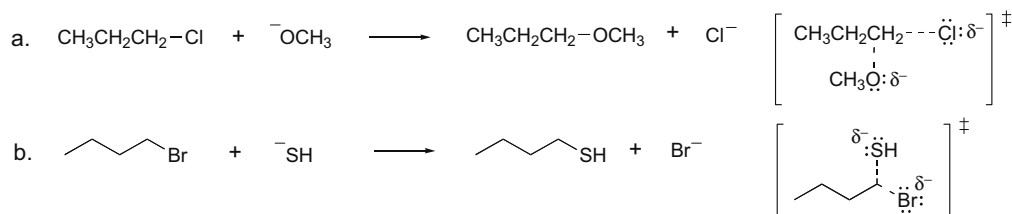
7.19 To determine what nucleophile is needed to carry out each reaction, look at the product to see what has replaced the leaving group.

- a. $(\text{CH}_3)_2\text{CHCH}_2\text{CH}_2-\text{Br} \longrightarrow (\text{CH}_3)_2\text{CHCH}_2\text{CH}_2-\text{SH}$
SH replaces Br.
 HS^- is needed.
- c. $(\text{CH}_3)_2\text{CHCH}_2\text{CH}_2-\text{Br} \longrightarrow (\text{CH}_3)_2\text{CHCH}_2\text{CH}_2-\text{OCOCH}_3$
 OCOCH_3 replaces Br.
 CH_3COO^- is needed.
- b. $(\text{CH}_3)_2\text{CHCH}_2\text{CH}_2-\text{Br} \longrightarrow (\text{CH}_3)_2\text{CHCH}_2\text{CH}_2-\text{OCH}_2\text{CH}_3$
 OCH_2CH_3 replaces Br.
 $\text{CH}_3\text{CH}_2\text{O}^-$ is needed.
- d. $(\text{CH}_3)_2\text{CHCH}_2\text{CH}_2-\text{Br} \longrightarrow (\text{CH}_3)_2\text{CHCH}_2\text{CH}_2-\text{C}\equiv\text{CH}$
 $\text{C}\equiv\text{CH}$ replaces Br.
 $\text{HC}\equiv\text{C}^-$ is needed.

7.20 The general rate equation for an $\text{S}_\text{N}2$ reaction is $\text{rate} = k[\text{RX}][:\text{Nu}^-]$.

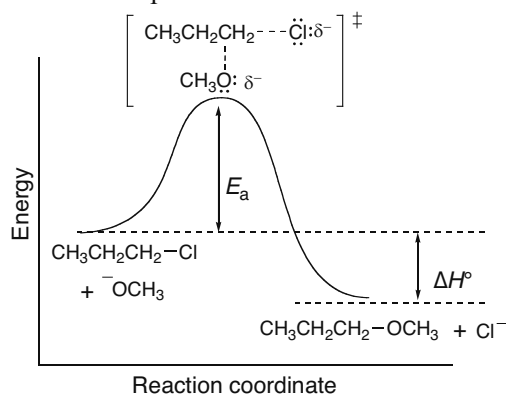
- a. $[\text{RX}]$ is tripled, and $[:\text{Nu}^-]$ stays the same: **rate triples.**
- b. Both $[\text{RX}]$ and $[:\text{Nu}^-]$ are tripled: **rate increases by a factor of 9 ($3 \times 3 = 9$).**
- c. $[\text{RX}]$ is halved, and $[:\text{Nu}^-]$ stays the same: **rate halved.**
- d. $[\text{RX}]$ is halved, and $[:\text{Nu}^-]$ is doubled: **rate stays the same ($1/2 \times 2 = 1$).**

7.21 The transition state in an $\text{S}_\text{N}2$ reaction has **dashed bonds to both the leaving group and the nucleophile**, and must contain partial charges.

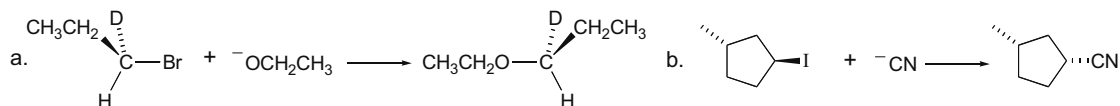


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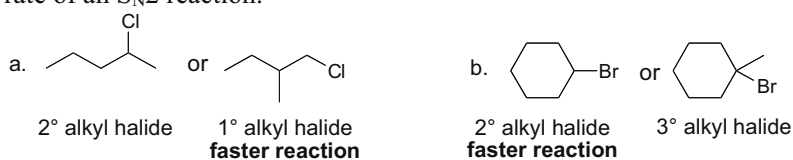
7.22 All S_N2 reactions have one step.



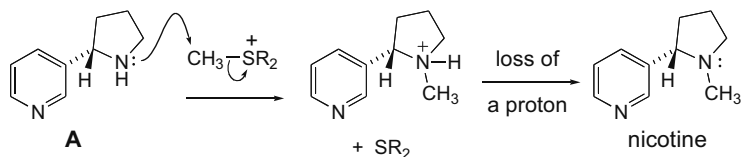
7.23 To draw the products of S_N2 reactions, **replace the leaving group by the nucleophile, and then draw the stereochemistry with *inversion* at the stereogenic center.**



7.24 Increasing the number of R groups *increases* crowding of the transition state and *decreases* the rate of an S_N2 reaction.



7.25

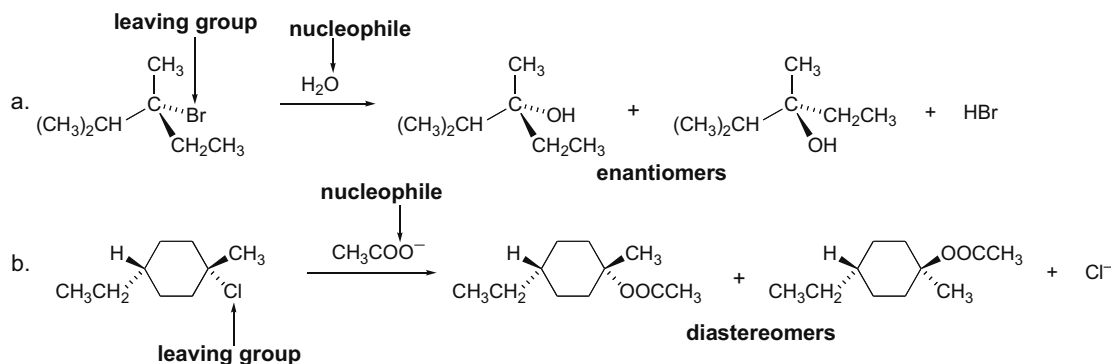


7.26 In a first-order reaction, **the rate changes with any change in [RX]**. The rate is independent of any change in $[\text{:Nu}^-]$.

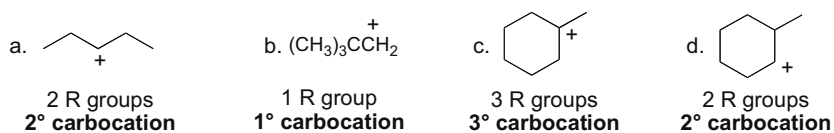
- [RX] is tripled, and $[\text{:Nu}^-]$ stays the same: **rate triples.**
- Both [RX] and $[\text{:Nu}^-]$ are tripled: **rate triples.**
- [RX] is halved, and $[\text{:Nu}^-]$ stays the same: **rate halved.**
- [RX] is halved, and $[\text{:Nu}^-]$ is doubled: **rate halved.**

Alkyl Halides and Nucleophilic Substitution 7-13

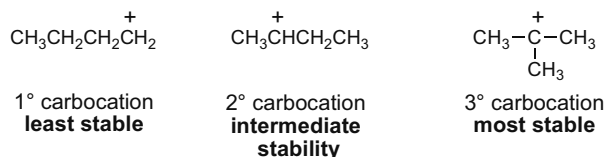
7.27 In S_N1 reactions, racemization always occurs at a stereogenic center. Draw two products, with the two possible configurations at the stereogenic center.



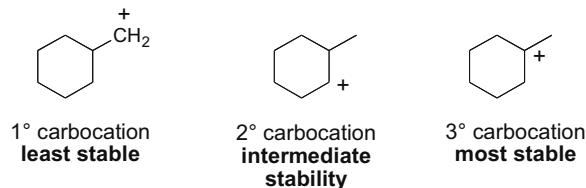
7.28 Carbocations are classified by the number of R groups bonded to the carbon:
 0 R groups = methyl, 1 R group = 1° , 2 R groups = 2° , and 3 R groups = 3° .



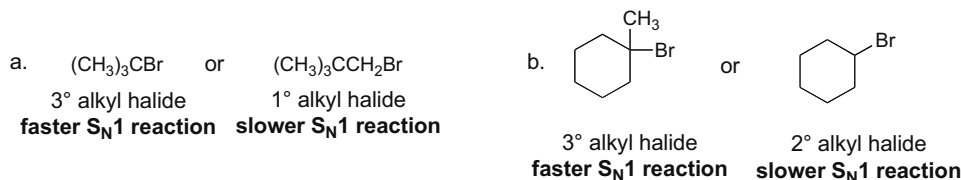
7.29 For carbocations: Increasing number of R groups = Increasing stability.



7.30 For carbocations: Increasing number of R groups = Increasing stability.



7.31 The rate of an S_N1 reaction increases with increasing alkyl substitution.

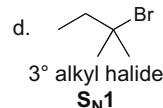
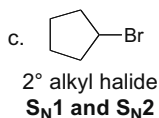
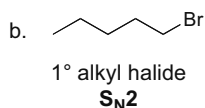
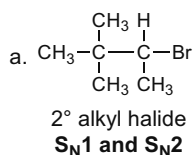


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7.32 • For **methyl and 1° alkyl halides**, only S_N2 will occur.

• For **2° alkyl halides**, S_N1 and S_N2 will occur.

• For **3° alkyl halides**, only S_N1 will occur.

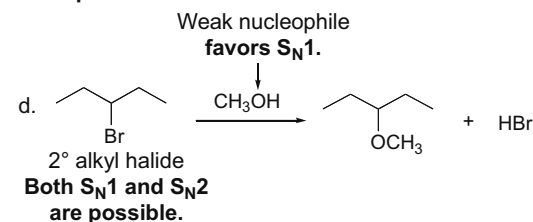
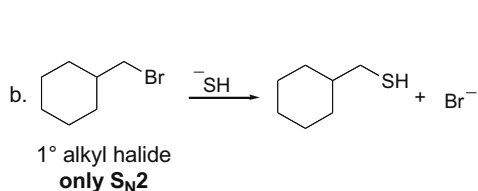
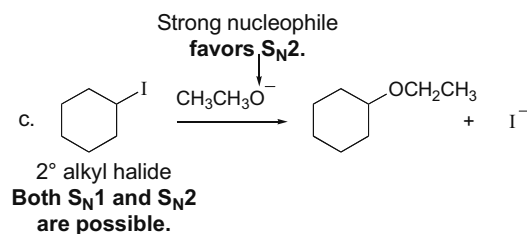
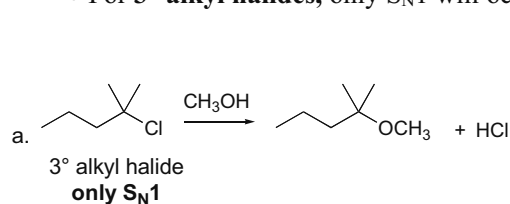


7.33 • Draw the product of nucleophilic substitution for each reaction.

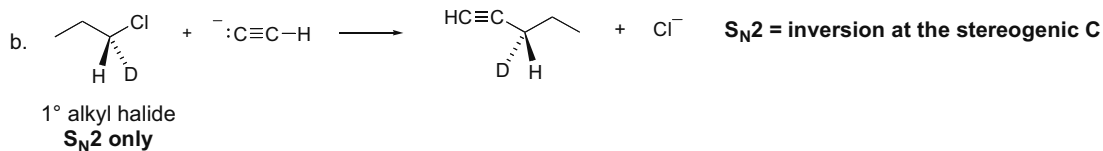
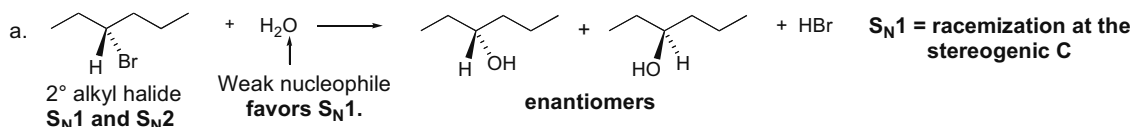
• For **methyl and 1° alkyl halides**, only S_N2 will occur.

• For **2° alkyl halides**, S_N1 and S_N2 will occur and other factors determine which mechanism operates.

• For **3° alkyl halides**, only S_N1 will occur.

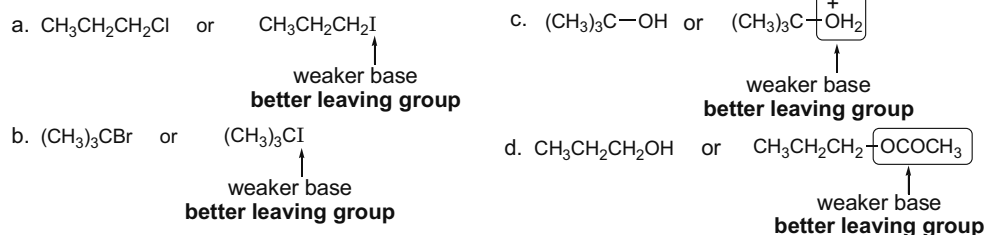


7.34 First decide whether the reaction will proceed via an S_N1 or S_N2 mechanism. Then draw the products with stereochemistry.



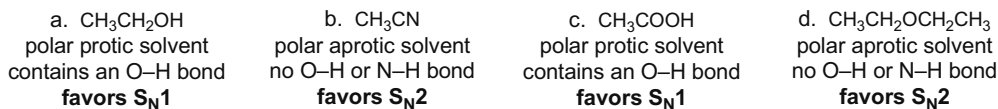
Alkyl Halides and Nucleophilic Substitution 7-15

7.35 Compounds with better leaving groups react faster. Weaker bases are better leaving groups.

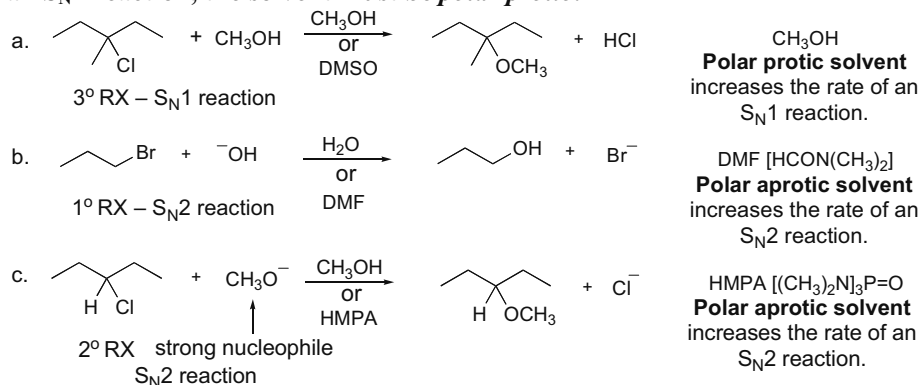


7.36 • **Polar protic solvents** favor the $\text{S}_{\text{N}}1$ mechanism by solvating the intermediate carbocation and halide.

• **Polar aprotic solvents** favor the $\text{S}_{\text{N}}2$ mechanism by making the nucleophile stronger.

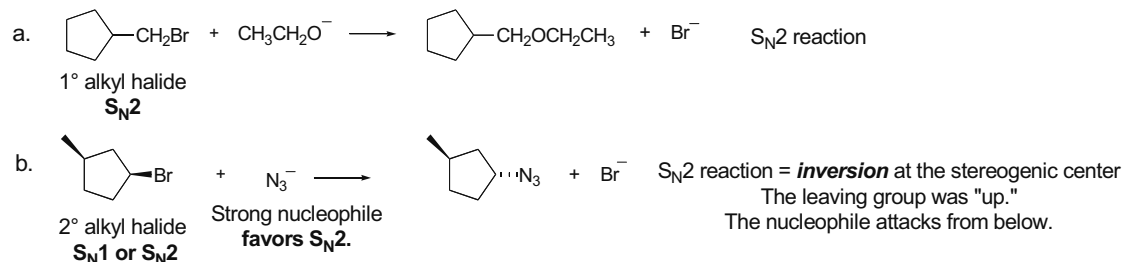


7.37 Compare the solvents in the reactions below. For the solvent to increase the reaction rate of an $\text{S}_{\text{N}}1$ reaction, the solvent must be **polar protic**.

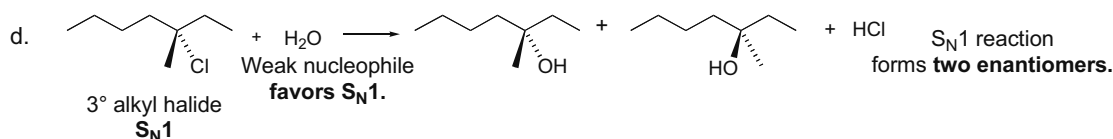
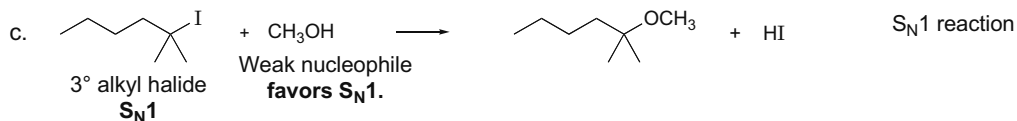


7.38 To predict whether the reaction follows an $\text{S}_{\text{N}}1$ or $\text{S}_{\text{N}}2$ mechanism:

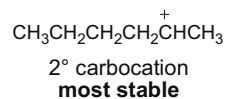
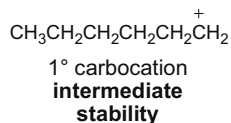
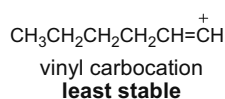
- [1] **Classify RX as a methyl, 1°, 2°, or 3° halide.** (Methyl, 1° = $\text{S}_{\text{N}}2$; 3° = $\text{S}_{\text{N}}1$; 2° = either.)
- [2] **Classify the nucleophile as strong or weak.** (Strong favors $\text{S}_{\text{N}}2$; weak favors $\text{S}_{\text{N}}1$.)
- [3] **Classify the solvent as polar protic or polar aprotic.** (Polar protic favors $\text{S}_{\text{N}}1$; polar aprotic favors $\text{S}_{\text{N}}2$.)



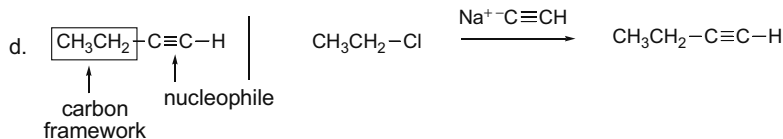
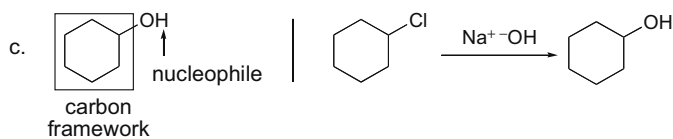
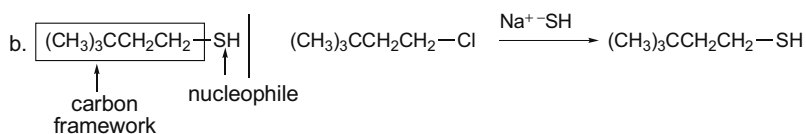
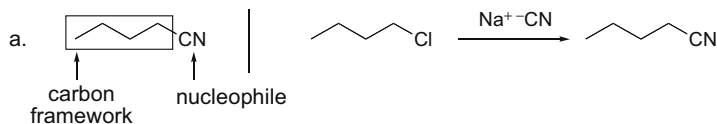
Chapter 7–16



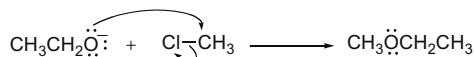
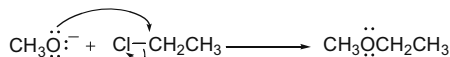
7.39 Vinyl carbocations are even less stable than 1° carbocations.



7.40 Convert each ball-and-stick model to a skeletal or condensed structure and draw the reactants.

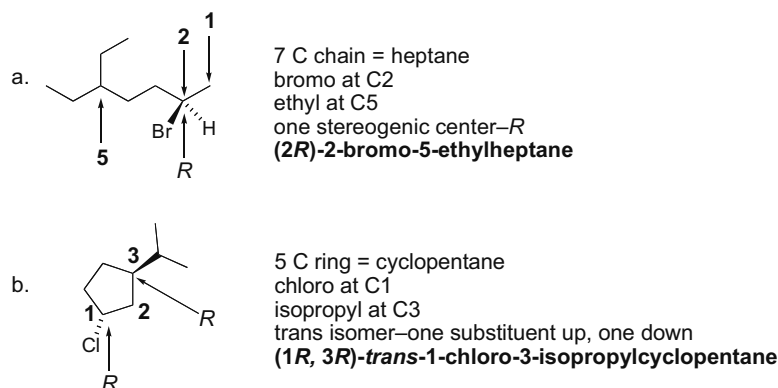


7.41

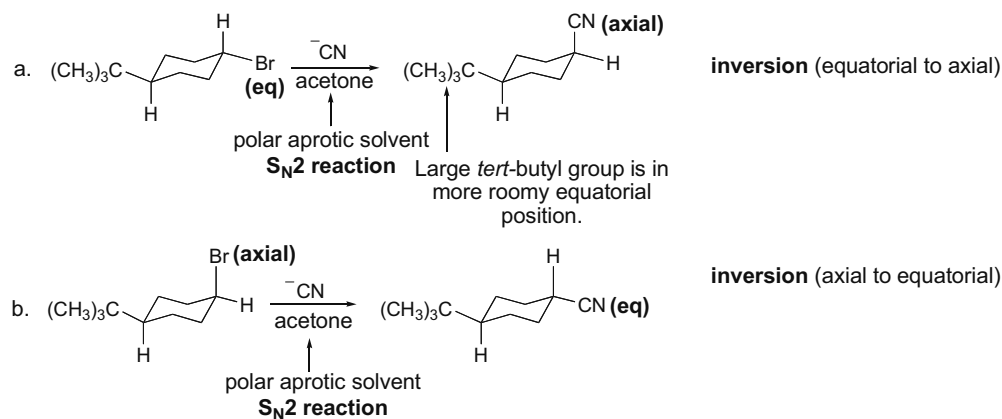


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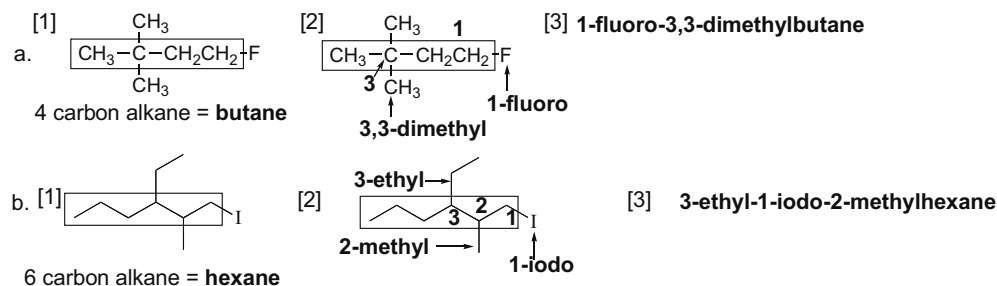
7.42 Use the directions from Answer 7.4 to name the compounds.



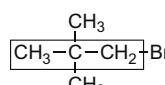
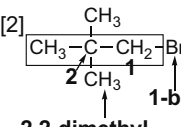
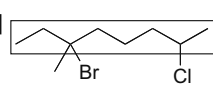
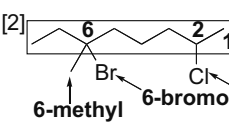
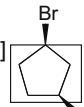
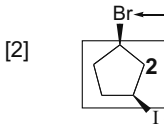
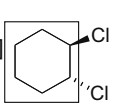
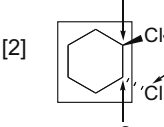
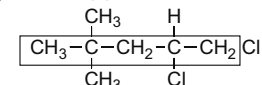
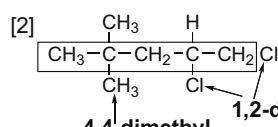
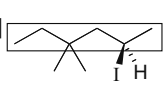
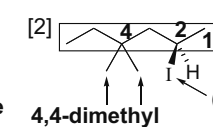
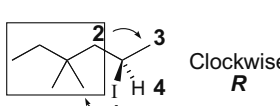
7.43



7.44 Use the directions from Answer 7.4 to name the compounds.

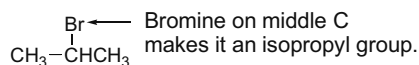


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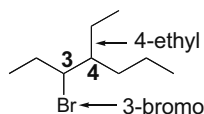
- c. [1] $(\text{CH}_3)_3\text{CCH}_2\text{Br}$

 3 carbon alkane = **propane**
- [2] 
2,2-dimethyl **1-bromo**
- [3] **1-bromo-2,2-dimethylpropane**
- d. [1] 
 8 carbon alkane = **octane**
- [2] 
6-methyl **6-bromo** **2-chloro**
- [3] **6-bromo-2-chloro-6-methyloctane**
- e. [1] 
 5 carbon cycloalkane = **cyclopentane**
- [2] 
1-bromo **3-iodo**
- [3] **cis-1-bromo-3-iodocyclopentane**
- f. [1] 
 6 carbon cycloalkane = **cyclohexane**
- [2] 
trans-1,2-dichloro
- [3] **trans-1,2-dichlorocyclohexane**
- g. [1] $(\text{CH}_3)_3\text{CCH}_2\text{CH}(\text{Cl})\text{CH}_2\text{Cl}$

 5 carbon alkane = **pentane**
- [2] 
4,4-dimethyl **1,2-dichloro**
- [3] **1,2-dichloro-4,4-dimethylpentane**
- h. [1] 
 6 carbon alkane = **hexane**
 (Indicate the R,S designation also)
- [2] 
4,4-dimethyl **(2R)-2-iodo**
- [3] **(2R)-2-iodo-4,4-dimethylhexane**
-  Clockwise **R**

7.45 To work backwards to a structure, use the directions in Answer 7.5.

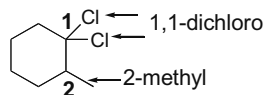
a. **isopropyl bromide**



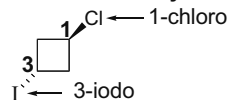
b. **3-bromo-4-ethylheptane**



c. **1,1-dichloro-2-methylcyclohexane**

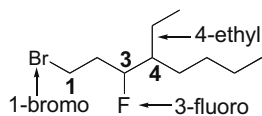


d. **trans-1-chloro-3-iodocyclobutane**

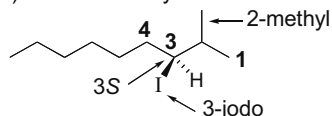


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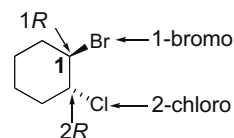
e. 1-bromo-4-ethyl-3-fluorooctane



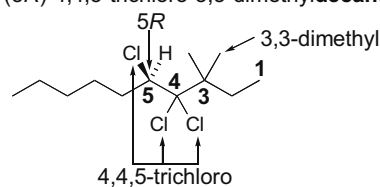
f. (3S)-3-iodo-2-methylnonane



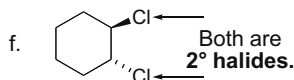
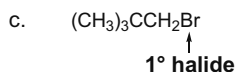
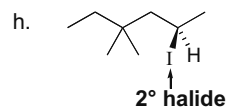
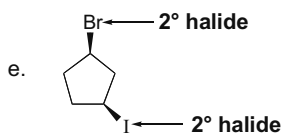
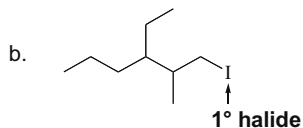
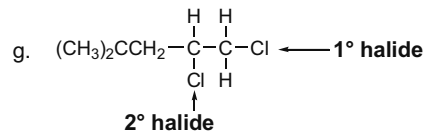
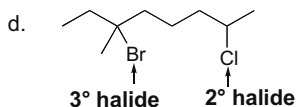
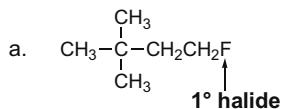
g. (1R,2R)-trans-1-bromo-2-chlorocyclohexane



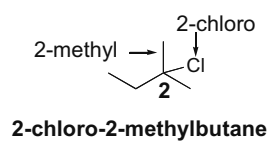
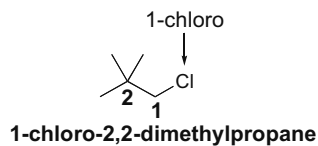
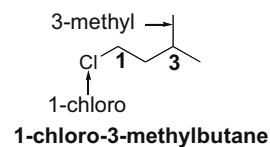
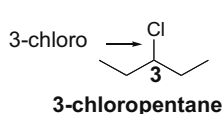
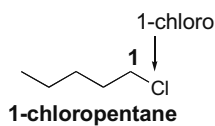
h. (5R)-4,4,5-trichloro-3,3-dimethyldecane



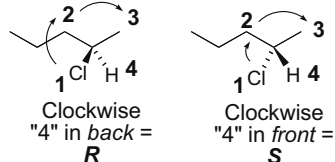
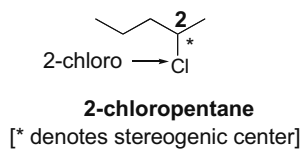
7.46



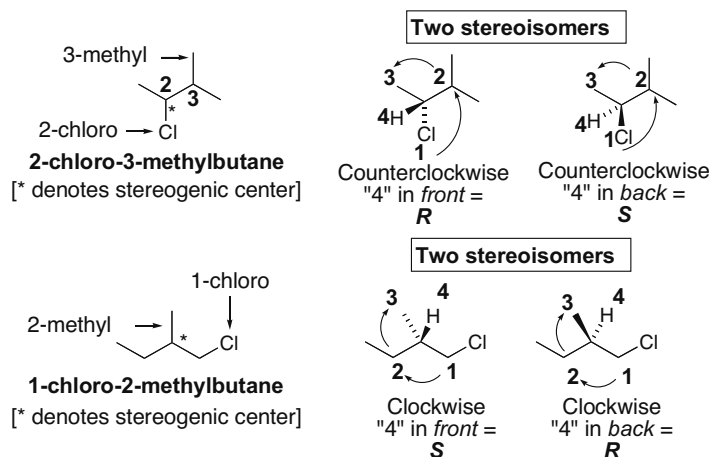
7.47



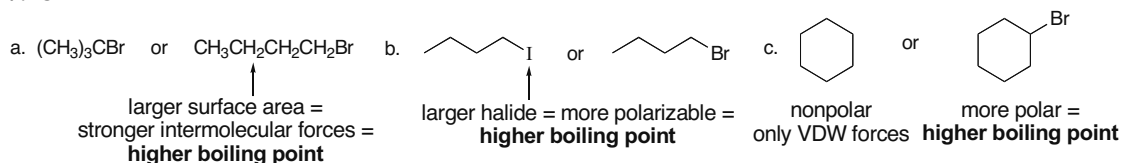
Two stereoisomers



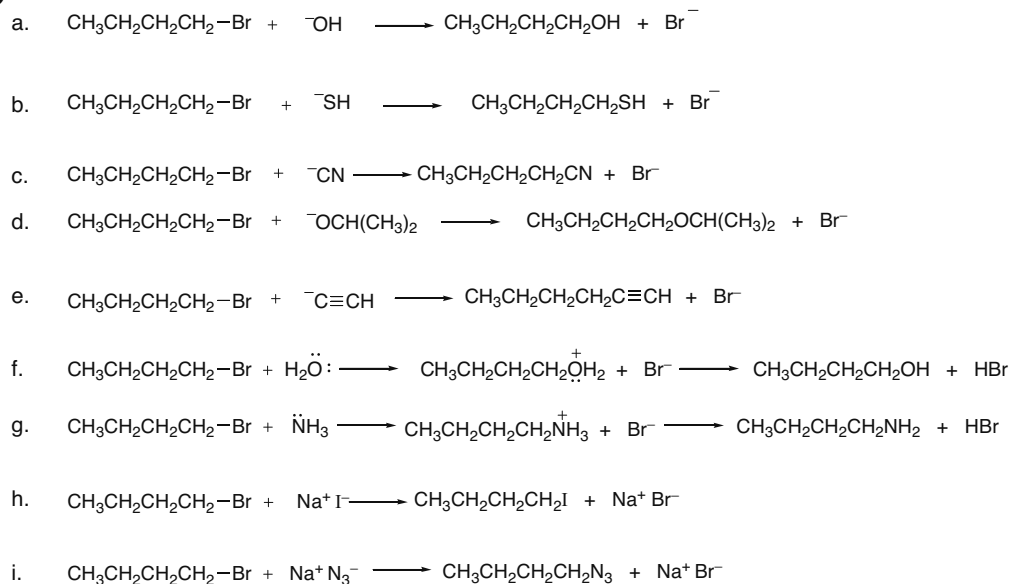
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7.48

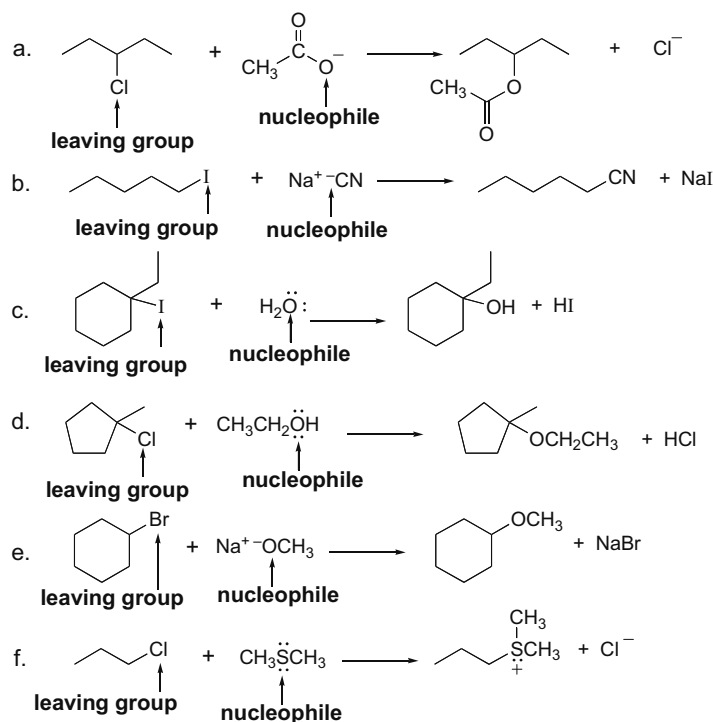


7.49

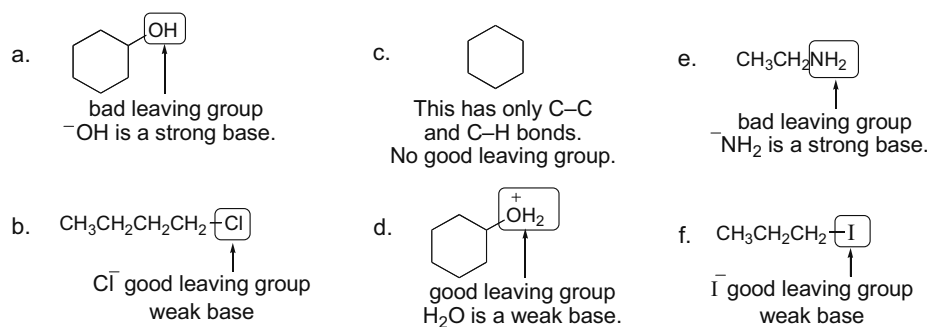


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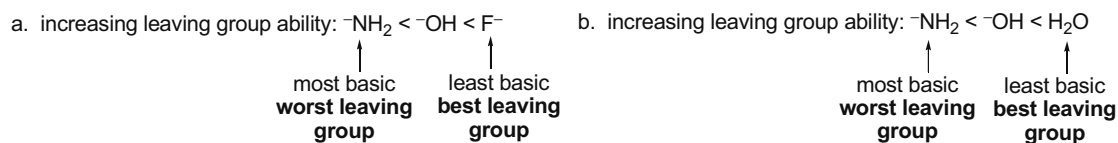
7.50 Use the steps from Answer 7.8 and then draw the proton transfer reaction, when necessary.



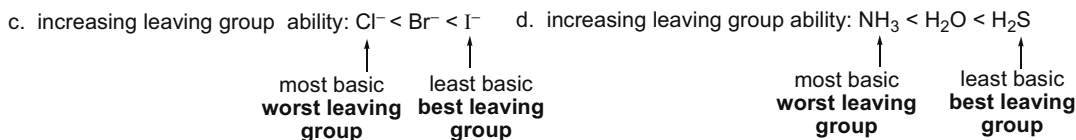
7.51 A good leaving group is a weak base.



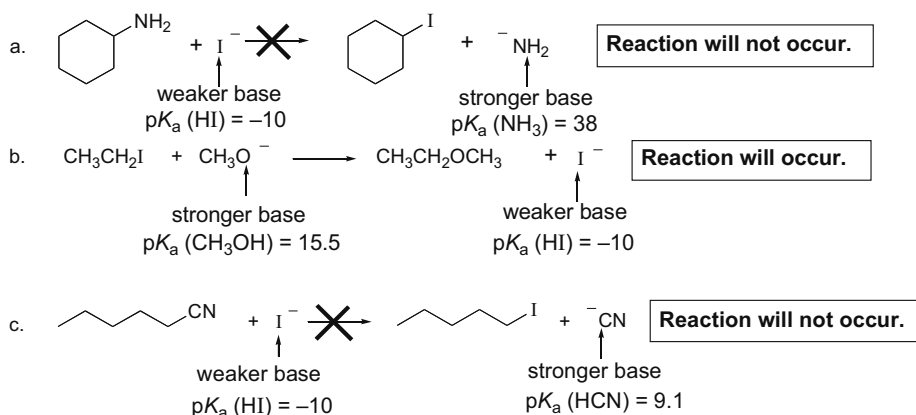
7.52 Use the rules from Answer 7.11.



Chapter 7-22



7.53 Compare the nucleophile and the leaving group in each reaction. The reaction will occur if it proceeds towards the weaker base. Remember that the stronger the acid (lower pK_a), the weaker the conjugate base.



7.54 Use the directions in Answer 7.15.

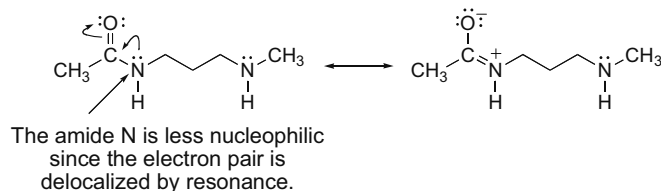
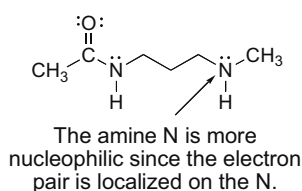
- a. Across a row of the periodic table nucleophilicity decreases.
 $\text{OH}^- < \text{NH}_2^- < \text{CH}_3^-$
- b. • In a **polar protic solvent** (CH_3OH), nucleophilicity *increases down a column* of the periodic table, so: SH^- is more nucleophilic than OH^- .
 • *Negatively charged species* are more nucleophilic than neutral species so OH^- is more nucleophilic than H_2O .
 $\text{H}_2\text{O} < \text{OH}^- < \text{SH}^-$
- c. • In a **polar protic solvent** (CH_3OH), nucleophilicity *increases down a column* of the periodic table, so: $\text{CH}_3\text{CH}_2\text{S}^-$ is more nucleophilic than $\text{CH}_3\text{CH}_2\text{O}^-$.
 • For two species with the same attacking atom, the more basic is the more nucleophilic so $\text{CH}_3\text{CH}_2\text{O}^-$ is more nucleophilic than CH_3COO^- .
 $\text{CH}_3\text{COO}^- < \text{CH}_3\text{CH}_2\text{O}^- < \text{CH}_3\text{CH}_2\text{S}^-$
- d. Compare the nucleophilicity of N, S, and O. In a polar aprotic solvent (acetone), nucleophilicity parallels basicity.
 $\text{CH}_3\text{SH} < \text{CH}_3\text{OH} < \text{CH}_3\text{NH}_2$
- e. In a **polar aprotic solvent** (acetone), nucleophilicity parallels basicity. Across a row and down a column of the periodic table nucleophilicity decreases.
 $\text{Cl}^- < \text{F}^- < \text{OH}^-$
- f. Nucleophilicity decreases across a row so SH^- is more nucleophilic than Cl^- . In a **polar protic solvent** (CH_3OH), nucleophilicity increases down a column so Cl^- is more nucleophilic than F^- .
 $\text{F}^- < \text{Cl}^- < \text{SH}^-$

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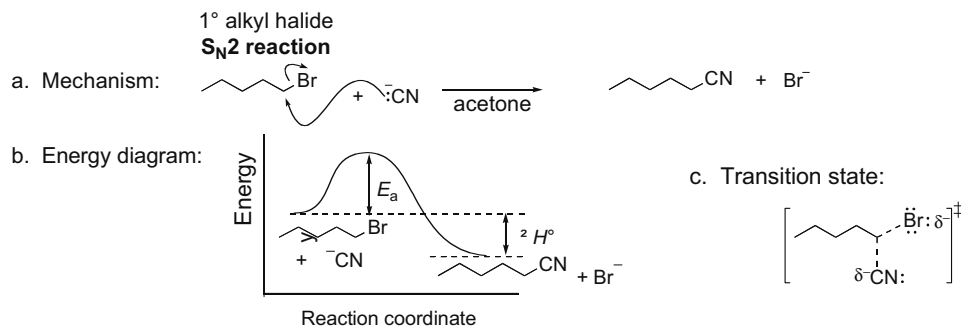
7.55 Polar protic solvents are capable of hydrogen bonding, so they must contain a H bonded to an electronegative O or N. **Polar aprotic solvents are incapable of hydrogen bonding**, so they do not contain any O–H or N–H bonds.

a. $(\text{CH}_3)_2\text{CHOH}$ contains O–H bond protic	c. CH_2Cl_2 no O–H or N–H bond aprotic	e. $\text{N}(\text{CH}_3)_3$ no O–H or N–H bond aprotic
b. CH_3NO_2 no O–H or N–H bond aprotic	d. NH_3 contains N–H bond protic	f. HCONH_2 contains an N–H bond protic

7.56



7.57



d. Rate equation: one-step reaction with both nucleophile and alkyl halide in the only step:

$$\text{rate} = k[\text{R-Br}][\text{CN}^-]$$

e. [1] The leaving group is changed from Br^- to I^- :

Leaving group becomes less basic $\rightarrow$ a better leaving group $\rightarrow$ faster reaction.

[2] The solvent is changed from acetone to $\text{CH}_3\text{CH}_2\text{OH}$:

Solvent changed to polar protic $\rightarrow$ decreases reaction rate.

[3] The alkyl halide is changed from $\text{CH}_3(\text{CH}_2)_4\text{Br}$ to $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}(\text{Br})\text{CH}_3$:

Changed from 1° to 2° alkyl halide $\rightarrow$ the alkyl halide gets more crowded and the reaction rate decreases.

[4] The concentration of CN^- is increased by a factor of 5.

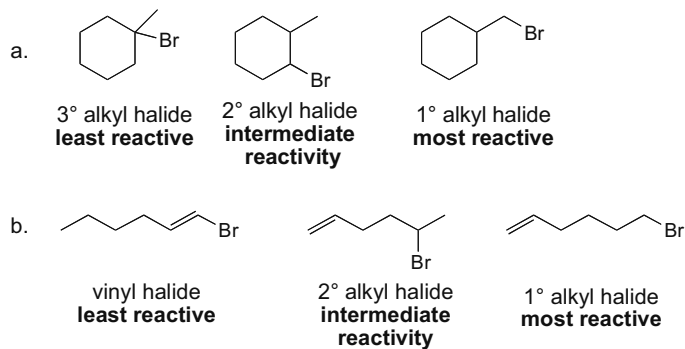
Reaction rate will increase by a factor of 5.

[5] The concentration of both the alkyl halide and CN^- are increased by a factor of 5:

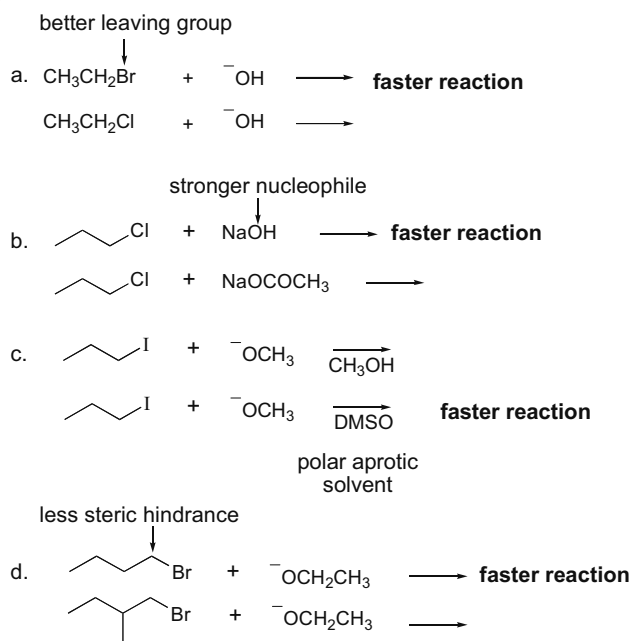
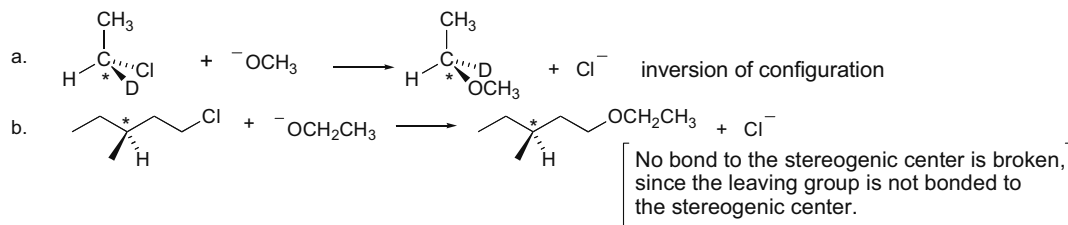
Reaction rate will increase by a factor of 25 ($5 \times 5 = 25$).

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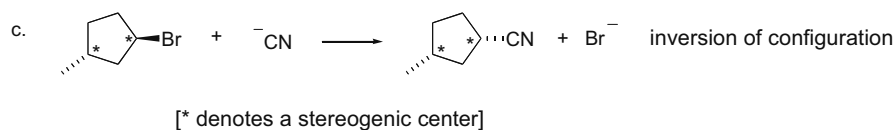
7.58 Use the directions from Answer 7.24.



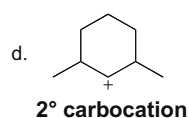
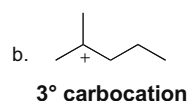
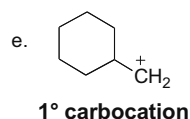
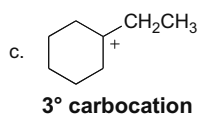
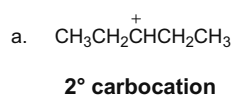
7.59

7.60 All $\text{S}_{\text{N}}2$ reactions proceed with backside attack of the nucleophile. When nucleophilic attack occurs at a stereogenic center, inversion of configuration occurs.

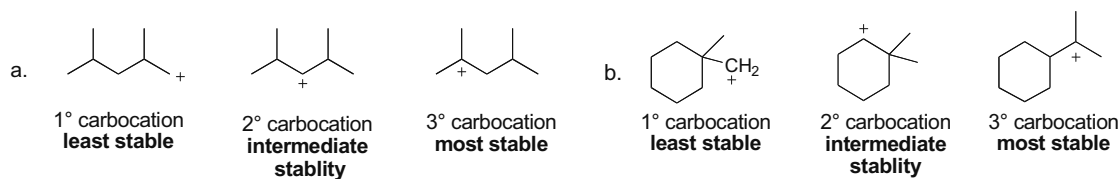
Alkyl Halides and Nucleophilic Substitution 7-25



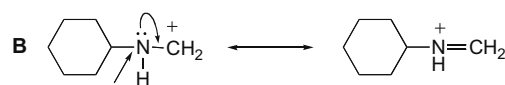
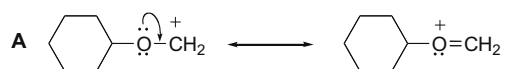
7.61 Follow the definitions from Answer 7.28.



7.62 For carbocations: **Increasing number of R groups = Increasing stability.**



7.63 Both **A** and **B** are resonance stabilized, but the N atom in **B** is more basic and therefore more willing to donate its electron pair.

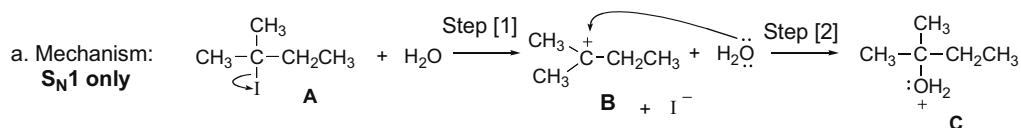


more basic
N atom

This resonance form stabilizes the carbocation
more than the equivalent resonance structure for **A**.

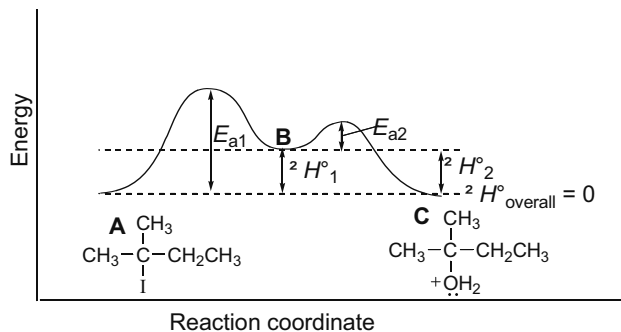
Thus, **B** is more stable than **A**.

7.64

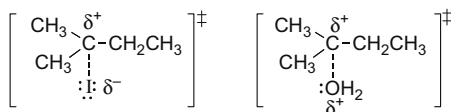
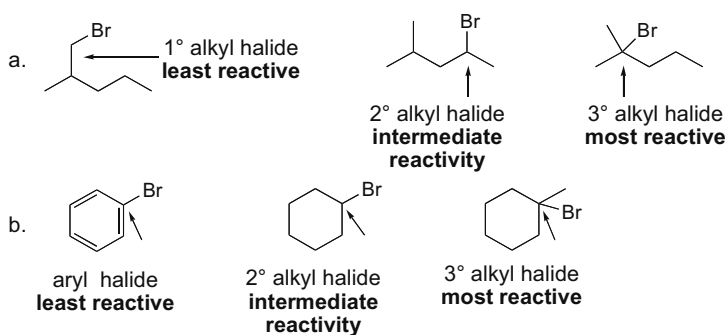
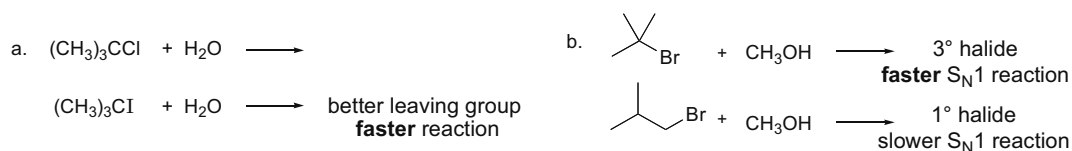


Chapter 7–26

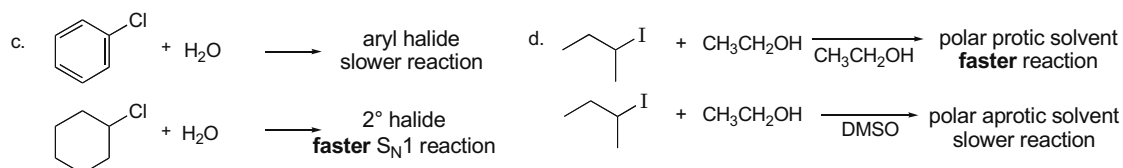
b. Energy diagram:



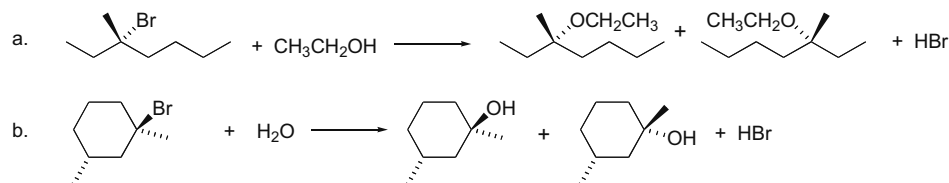
c. Transition states:

d. rate equation: **rate = $k[(\text{CH}_3)_2\text{CICH}_2\text{CH}_3]$** e. [1] Leaving group changed from I^- to Cl^- : **rate decreases** since I^- is a better leaving group.[2] Solvent changed from H_2O (polar protic) to DMF (polar aprotic):**rate decreases** since polar protic solvent favors $\text{S}_\text{N}1$.[3] Alkyl halide changed from 3° to 2° : **rate decreases** since 2° carbocations are less stable.[4] $[\text{H}_2\text{O}]$ increased by factor of five: **no change in rate** since H_2O is not in rate equation.[5] $[\text{R-X}]$ and $[\text{H}_2\text{O}]$ increased by factor of five: **rate increases** by a factor of five. (Only the concentration of R-X affects the rate.)**7.65 The rate of an $\text{S}_\text{N}1$ reaction increases with increasing alkyl substitution.****7.66 The rate of an $\text{S}_\text{N}1$ reaction increases with increasing alkyl substitution, polar protic solvents, and better leaving groups.**

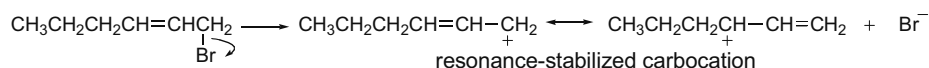
Alkyl Halides and Nucleophilic Substitution 7-27



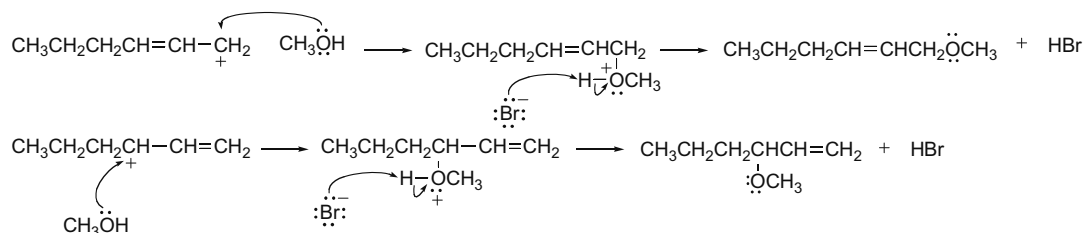
7.67



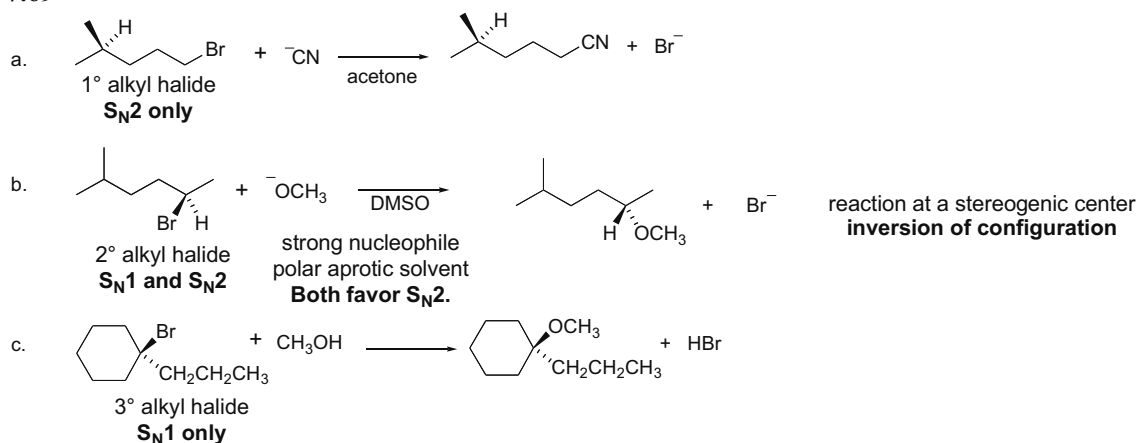
7.68 The 1° alkyl halide is also allylic, so it forms a resonance-stabilized carbocation. Increasing the stability of the carbocation by resonance, increases the rate of the S_N1 reaction.



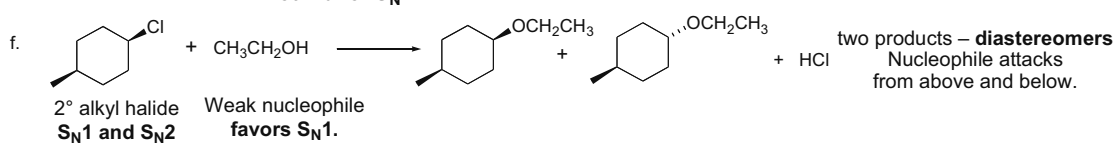
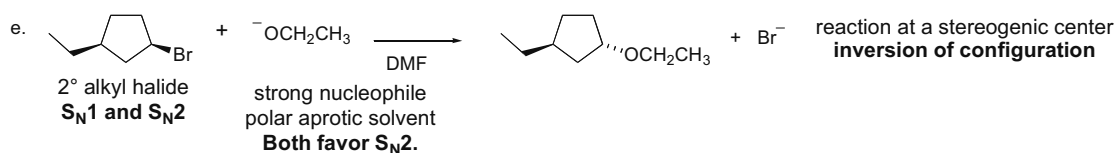
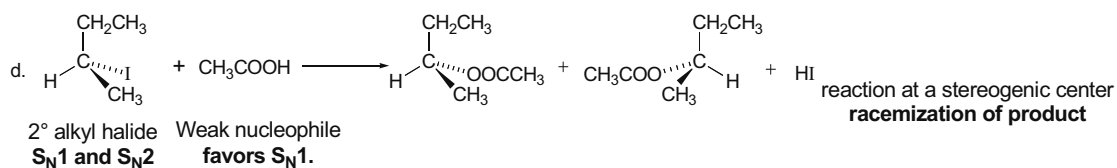
Use each resonance structure individually to continue the mechanism:



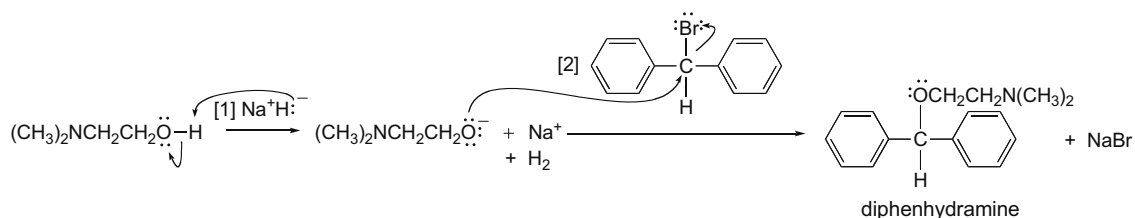
7.69



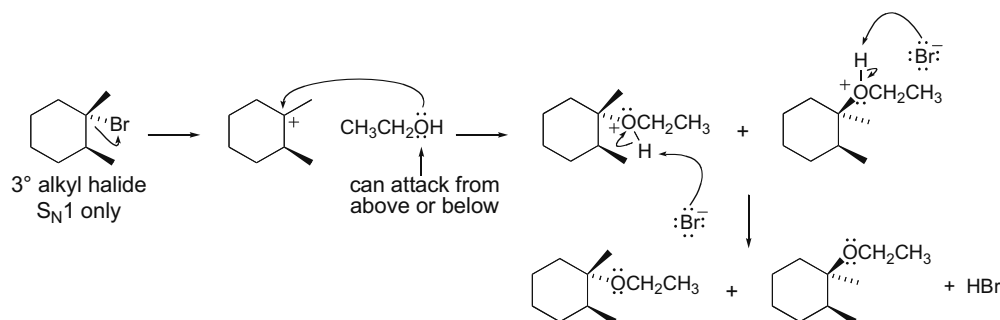
Chapter 7–28



7.70

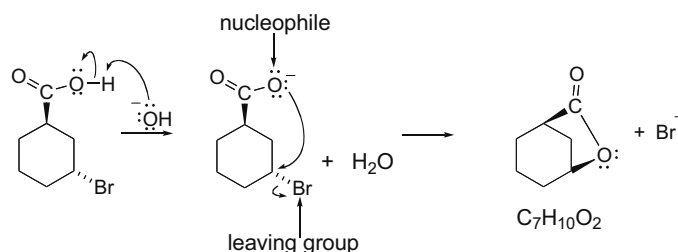


7.71 First decide whether the reaction will proceed via an $\text{S}_{\text{N}}1$ or $\text{S}_{\text{N}}2$ mechanism (Answer 7.38), and then draw the mechanism.

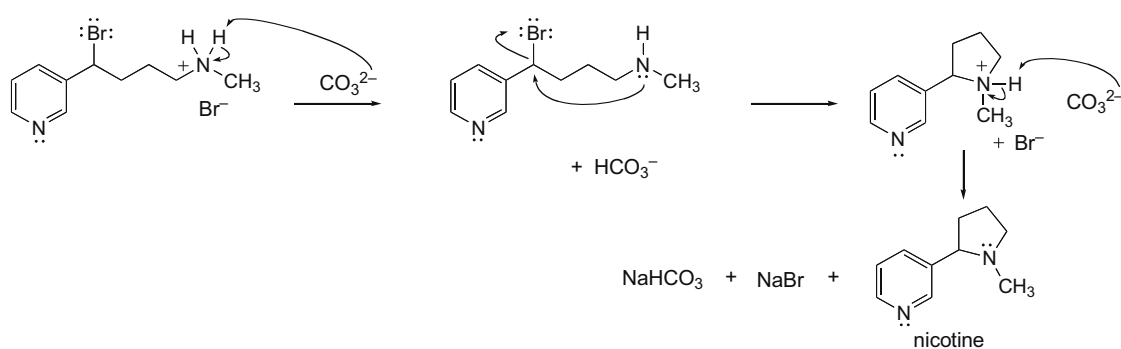


Alkyl Halides and Nucleophilic Substitution 7-29

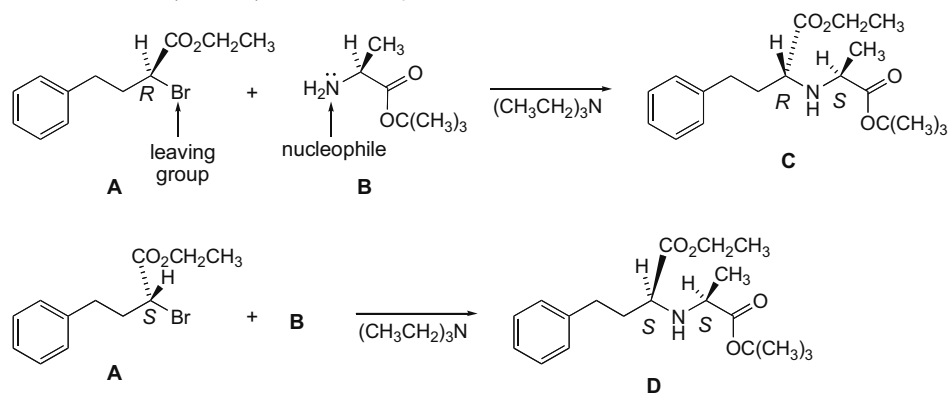
7.72



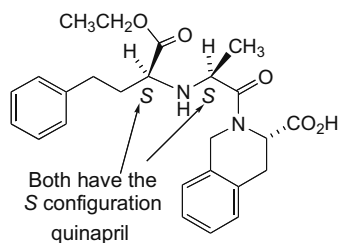
7.73



7.74

a. Two diastereomers (**C** and **D**) are formed as products from the two enantiomers of **A**.

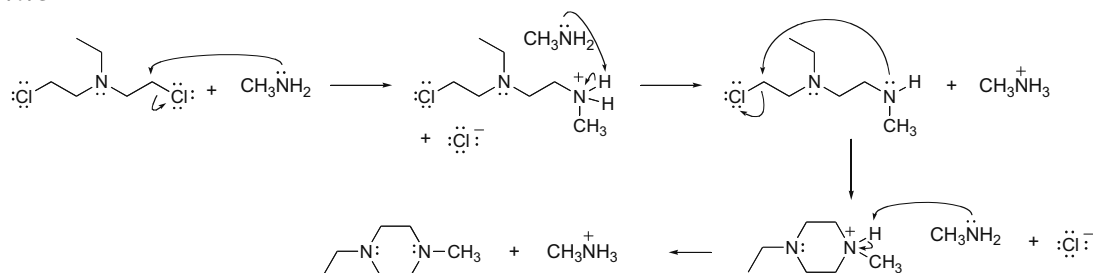
b.



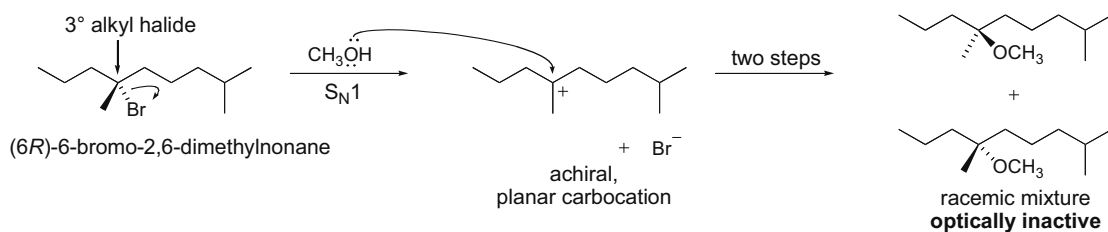
Since both stereogenic centers in **D** have the S configuration and the corresponding stereogenic centers in quinapril are also S, **D** is needed to synthesize the drug.

Chapter 7–30

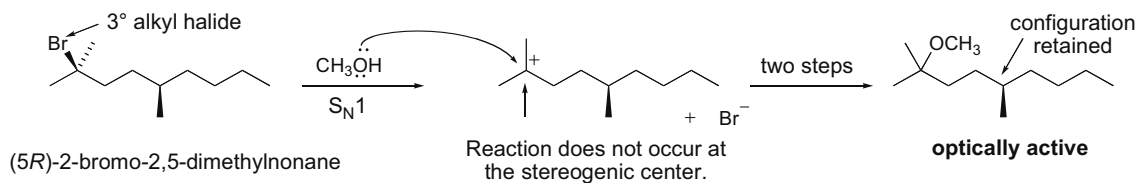
7.75



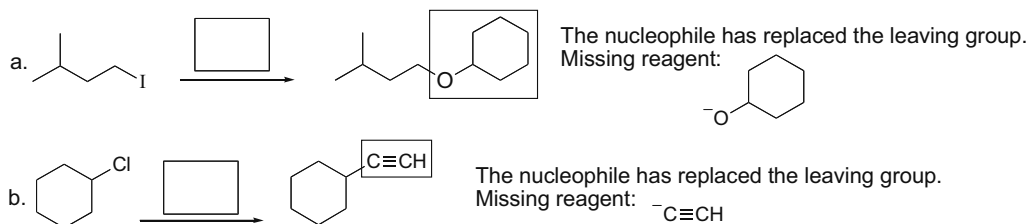
7.76 In the first reaction, substitution occurs at the stereogenic center. Since an achiral, planar carbocation is formed, the nucleophile can attack from either side, thus generating a racemic mixture.



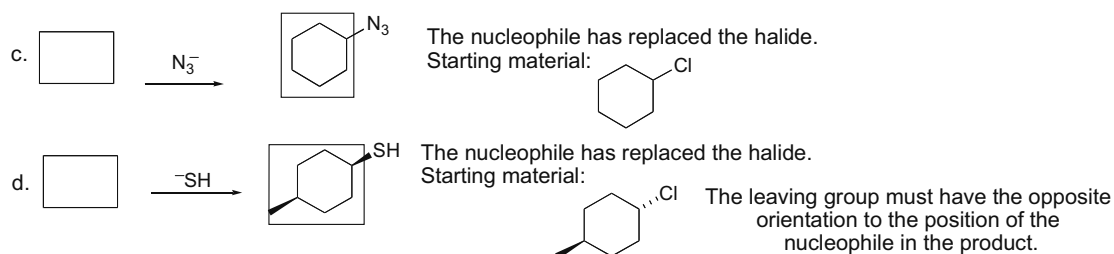
In the second reaction, the starting material contains a stereogenic center, but the nucleophile does not attack at that carbon. Since a bond to the stereogenic center is not broken, the configuration is retained and a chiral product is formed.



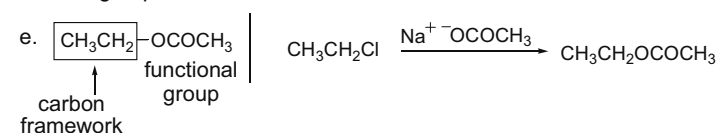
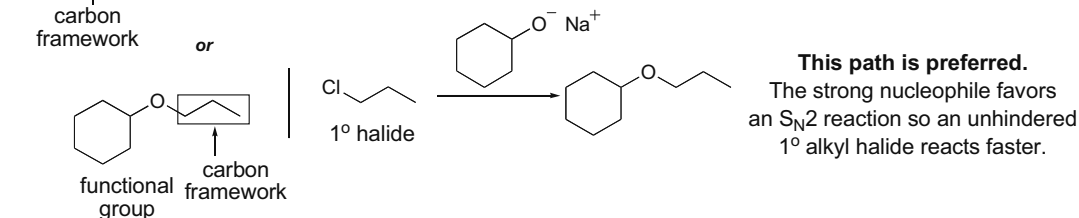
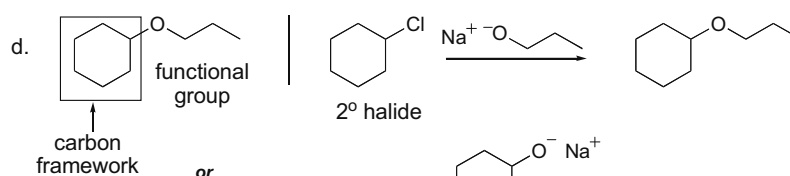
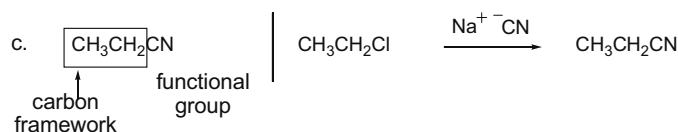
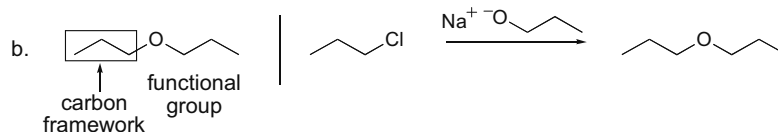
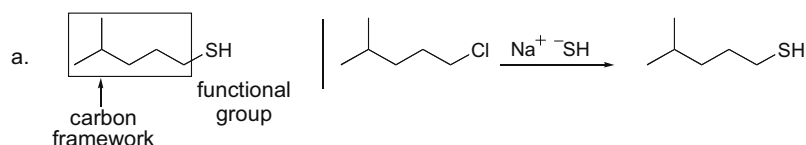
7.77



Alkyl Halides and Nucleophilic Substitution 7-31

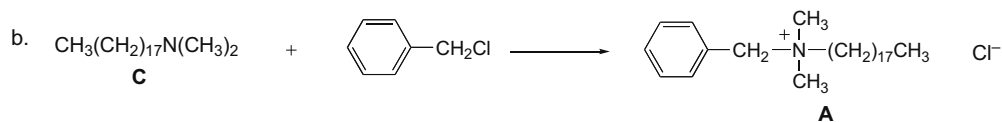
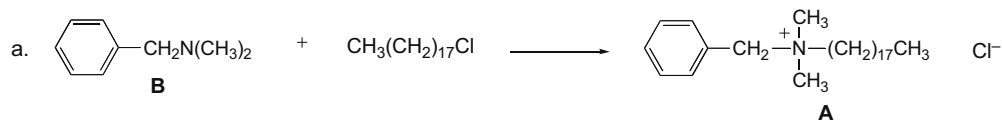


7.78 To devise a synthesis, look for the carbon framework and the functional group in the product.
The carbon framework is from the alkyl halide and the functional group is from the nucleophile.

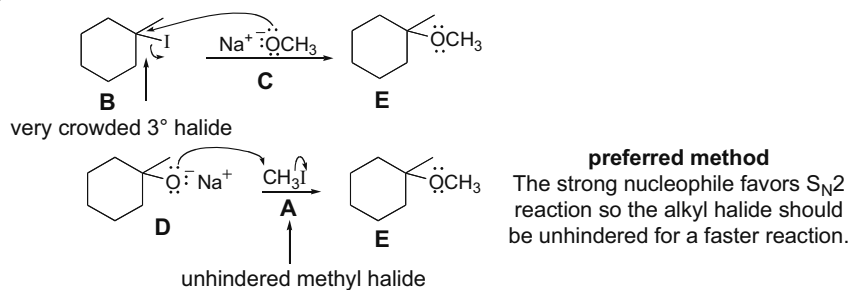


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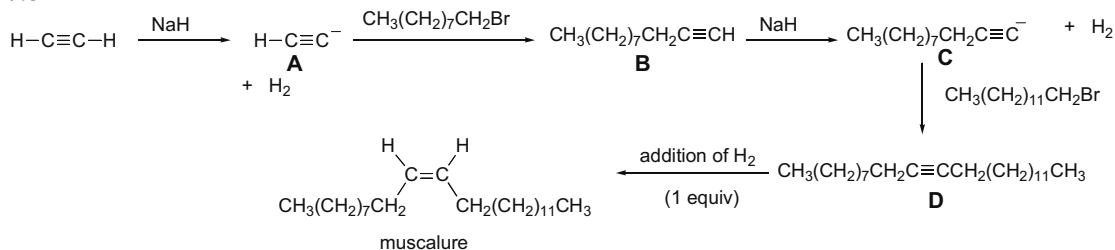
7.79 Work backwards to determine the alkyl chloride needed to prepare benzalkonium chloride **A**.



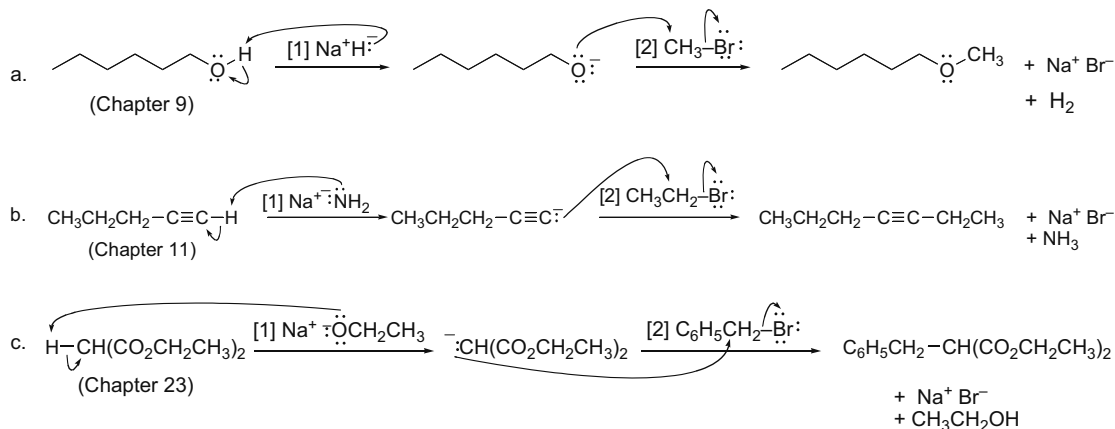
7.80



7.81

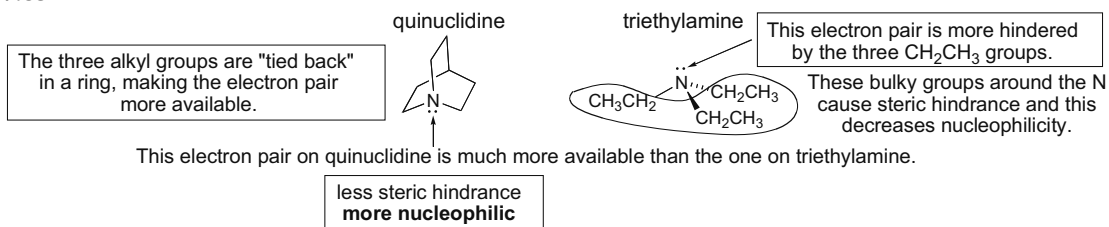


7.82

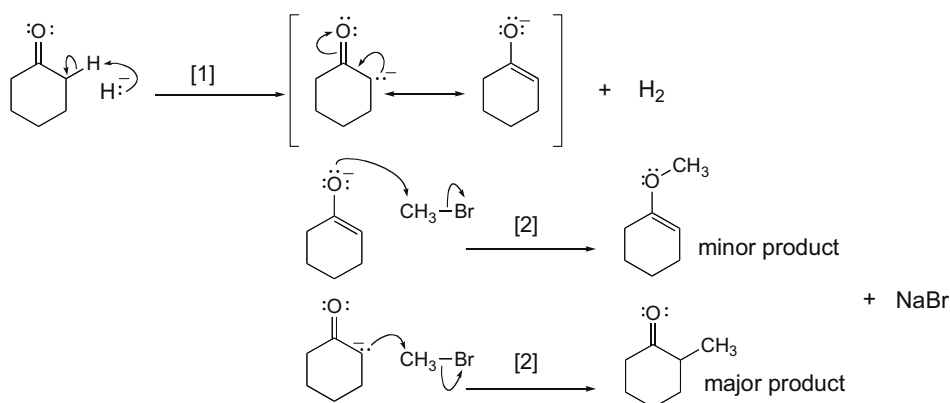


Alkyl Halides and Nucleophilic Substitution 7-33

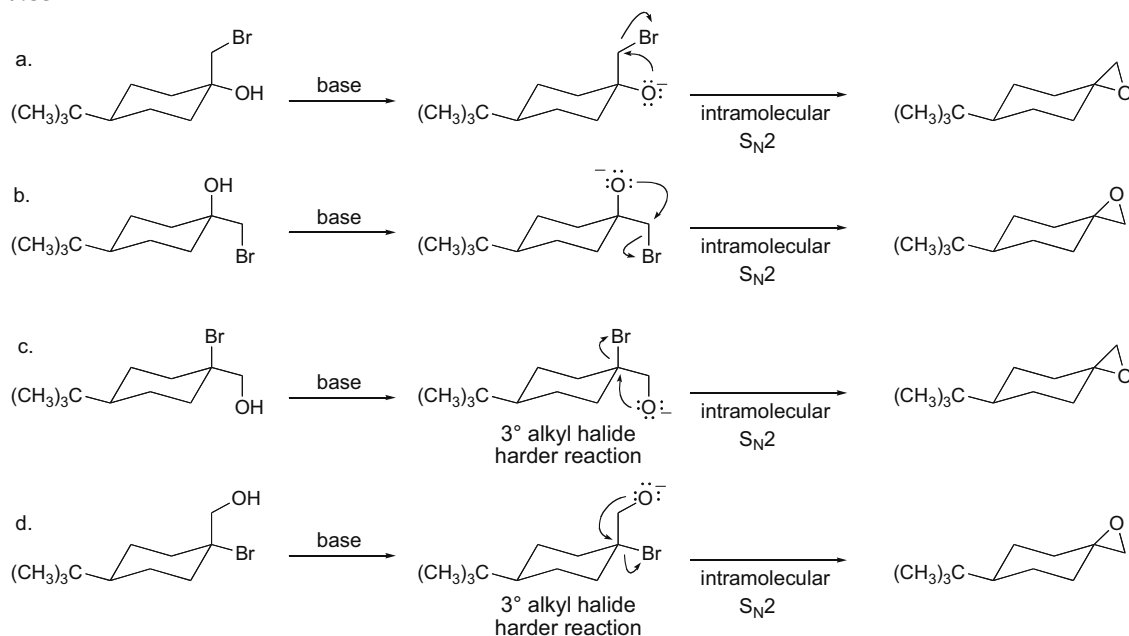
7.83



7.84

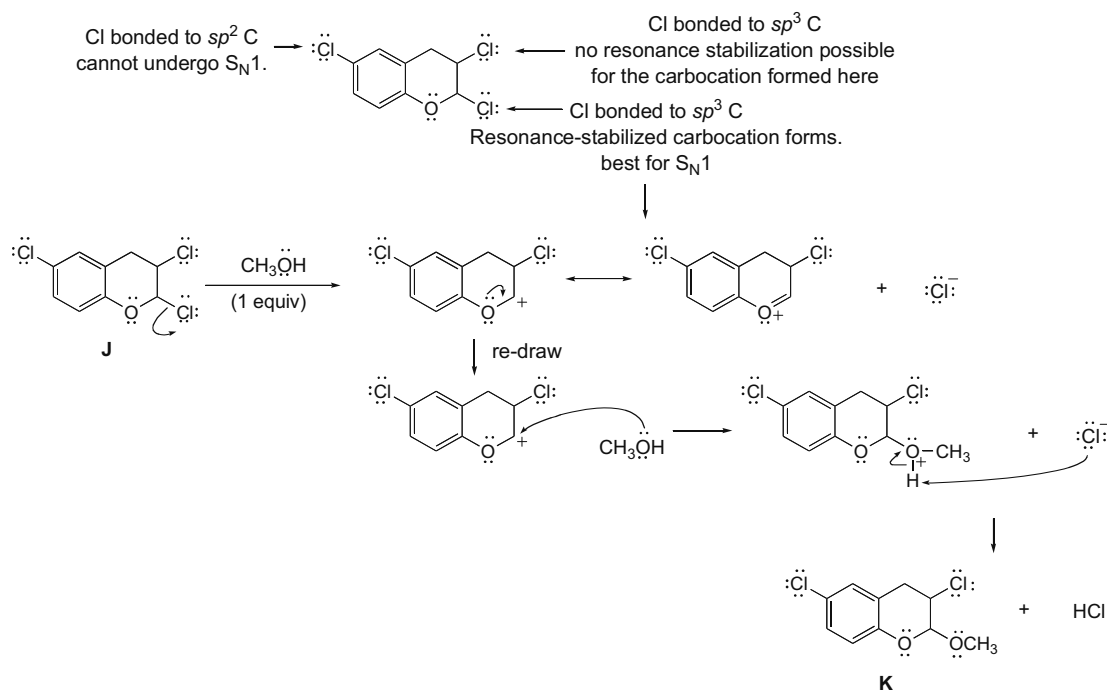


7.85

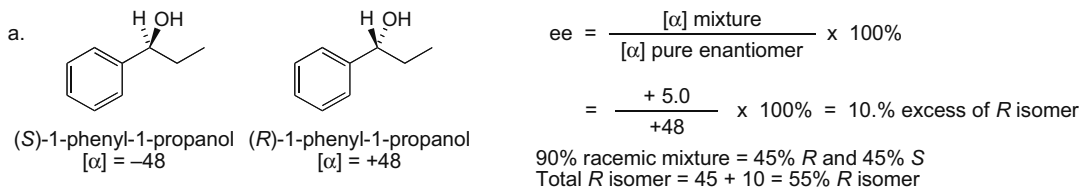


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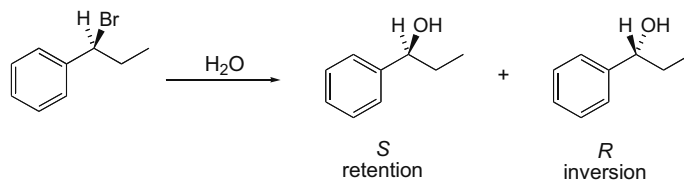
7.86



7.87



b. The *R* product is the product of inversion and it predominates.



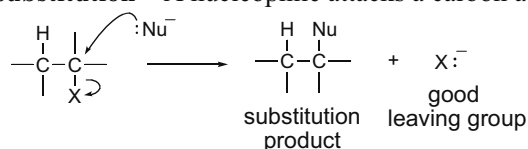
c. The weak nucleophile favors an S_N1 reaction, which occurs by way of an intermediate carbocation. Perhaps there is more inversion than retention because H_2O attacks the intermediate carbocation while the Br^- leaving group is still in the vicinity of the carbocation. The Br^- would then shield one side of the carbocation and backside attack would be slightly favored.

Chapter 8 Alkyl Halides and Elimination Reactions

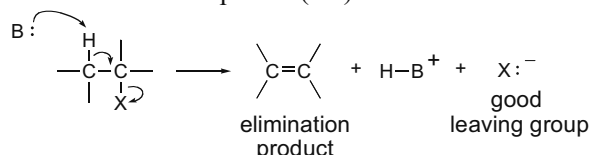
Chapter Review

A comparison between nucleophilic substitution and β -elimination

Nucleophilic substitution—A nucleophile attacks a carbon atom (7.6).



β -Elimination—A base attacks a proton (8.1).

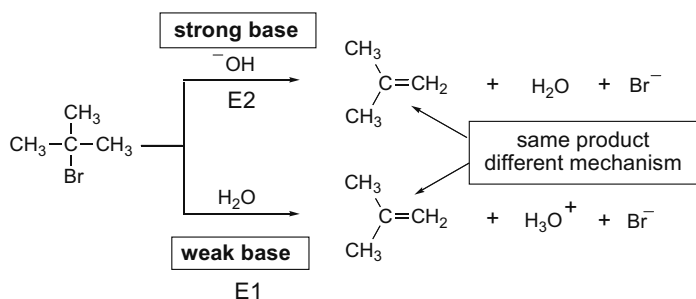


Similarities	Differences
- In both reactions RX acts as an electrophile, reacting with an electron-rich reagent. - Both reactions require a good leaving group X⁻ willing to accept the electron density in the C-X bond.	- In substitution, a nucleophile attacks a single carbon atom. - In elimination, a Brønsted-Lowry base removes a proton to form a π bond, and two carbons are involved in the reaction.

The importance of the base in E2 and E1 reactions (8.9)

The strength of the base determines the mechanism of elimination.

- Strong bases favor E2 reactions.
- Weak bases favor E1 reactions.



Chapter 8–2

E1 and E2 mechanisms compared

	E2 mechanism	E1 mechanism
[1] Mechanism	• one step (8.4B)	• two steps (8.6B)
[2] Alkyl halide	• rate: $R_3CX > R_2CHX > RCH_2X$ (8.4C)	• rate: $R_3CX > R_2CHX > RCH_2X$ (8.6C)
[3] Rate equation	• rate = $k[RX][B:]$ • second-order kinetics (8.4A)	• rate = $k[RX]$ • first-order kinetics (8.6A)
[4] Stereochemistry	• anti periplanar arrangement of H and X (8.8)	• trigonal planar carbocation intermediate (8.6B)
[5] Base	• favored by strong bases (8.4B)	• favored by weak bases (8.6C)
[6] Leaving group	• better leaving group $\rightarrow$ faster reaction (8.4B)	• better leaving group $\rightarrow$ faster reaction (Table 8.4)
[7] Solvent	• favored by polar aprotic solvents (8.4B)	• favored by polar protic solvents (Table 8.4)
[8] Product	• more substituted alkene favored (Zaitsev rule, 8.5)	• more substituted alkene favored (Zaitsev rule, 8.6C)

Summary chart on the four mechanisms: S_N1 , S_N2 , E1, and E2

Alkyl halide type	Conditions	Mechanism
1° RCH_2X	strong nucleophile strong bulky base	S_N2 E2
2° R_2CHX	strong base and nucleophile strong bulky base weak base and nucleophile	$S_N2 + E2$ E2 $S_N1 + E1$
3° R_3CX	weak base and nucleophile strong base	$S_N1 + E1$ E2

Zaitsev rule

- β -Elimination affords the more stable product having the more substituted double bond.
- Zaitsev products predominate in E2 reactions except when a cyclohexane ring prevents trans diaxial arrangement.

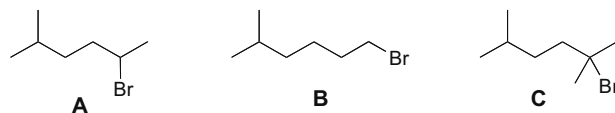
Alkyl Halides and Elimination Reactions 8–3

Practice Test on Chapter Review

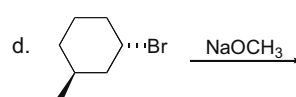
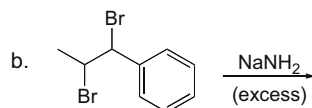
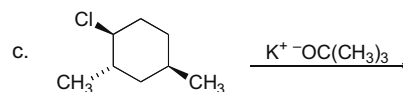
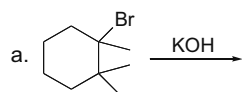
- Which of the following is true about an E1 reaction?
 - The reaction is faster with better leaving groups.
 - The reaction is fastest with 3° alkyl halides.
 - The reaction is faster with stronger bases.
 - Statements (1) and (2) are true.
 - Statements (1), (2), and (3) are all true.
- Consider the S_N2 and E1 reaction mechanisms. What effect on the rate of the reaction is observed when each of the following changes is made? Fill in each box of the table with one of the following phrases: **increases**, **decreases**, or **remains the same**.

Change	S _N 2 Mechanism	E1 Mechanism
a. The alkyl halide is changed from (CH ₃) ₃ CBr to CH ₃ CH ₂ CH ₂ CH ₂ Br.		
b. The solvent is changed from (CH ₃) ₂ CO to CH ₃ CH ₂ OH.		
c. The nucleophile/base is changed from ⁻ OH to H ₂ O.		
d. The alkyl halide is changed from CH ₃ CH ₂ Cl to CH ₃ CH ₂ I.		
e. The concentration of the base/nucleophile is increased by a factor of five.		

- Rank the following compounds in order of **increasing reactivity in an E2 elimination** reaction. Rank the **most reactive** compound as **3**, the **least reactive** compound as **1**, and the compound of intermediate reactivity as **2**.

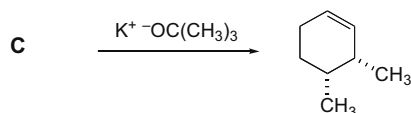


- Draw the organic products formed in the following reactions.

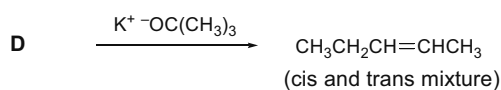


Chapter 8-4

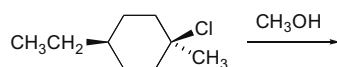
5. a. Fill in the appropriate alkyl halide needed to synthesize the following compound as a single product using the given reagents.



- b. What starting material is needed for the following reaction? The starting material must yield product cleanly, in one step without any other organic side products.



6. Draw all products formed in the following reaction.



Answers to Practice Test

1. 4

2. $\text{S}_{\text{N}}2$

a. increases

b. decreases

c. decreases

d. increases

e. increases

$\text{E}1$

decreases

increases

same

increases

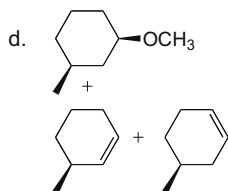
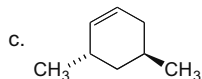
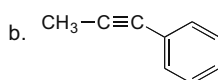
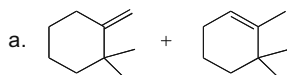
same

3. A-2

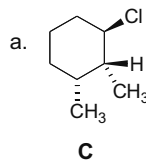
B-1

C-3

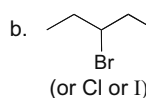
4.



5.



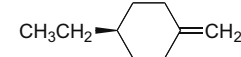
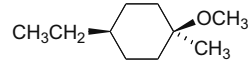
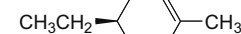
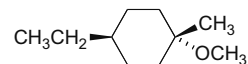
c



(or Cl or I)

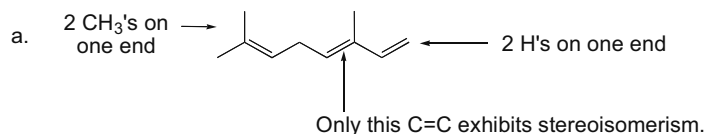
D

6.

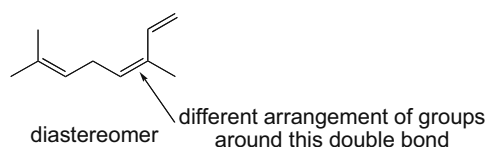


Chapter 8-6

8.4

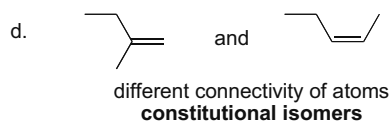
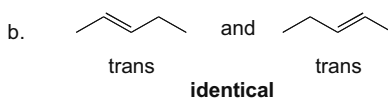
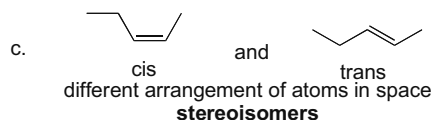
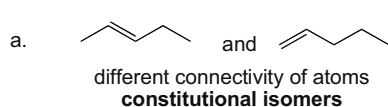


- b. A diastereomer has a different 3-D arrangement of groups but the carbon skeleton and the double bonds must stay in the original positions.



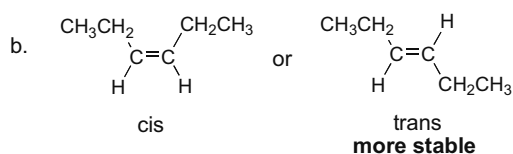
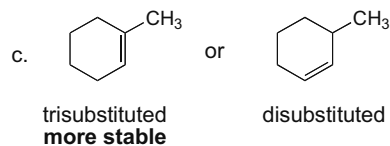
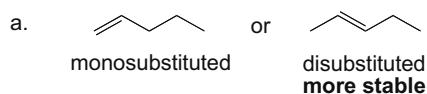
8.5 Two definitions:

- **Constitutional isomers** differ in the connectivity of the atoms.
- **Stereoisomers** differ only in the 3-D arrangement of the atoms in space.



8.6 Two rules to predict the relative stability of alkenes:

- [1] Trans alkenes are generally more stable than cis alkenes.
[2] The stability of an alkene increases as the number of R groups on the C=C increases.



Alkyl Halides and Elimination Reactions 8-7

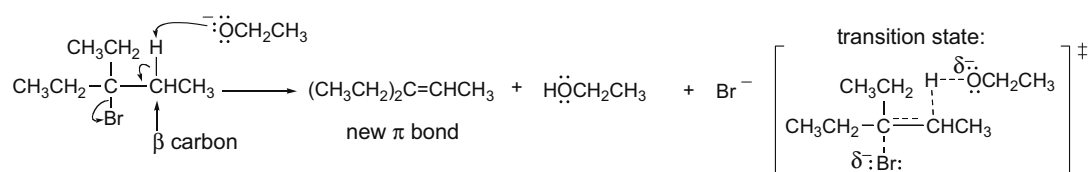
8.7

**A****B**

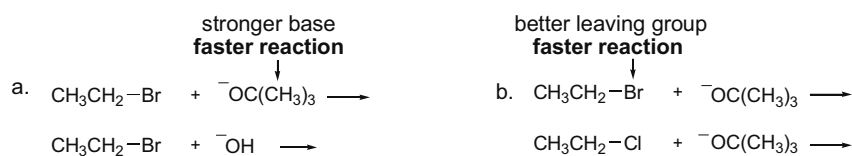
Alkene **A** is more stable than alkene **B** because the double bond in **A** is in a six-membered ring. The double bond in **B** is in a four-membered ring, which has considerable angle strain due to the small ring size.

8.8 In an E2 mechanism, four bonds are involved in the single step. Use curved arrows to show these simultaneous actions:

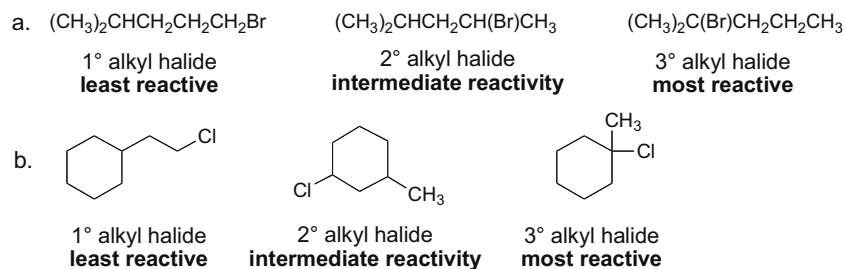
- [1] The base attacks a hydrogen on a β carbon.
- [2] A π bond forms.
- [3] The leaving group comes off.



8.9 In both cases, the rate of elimination decreases.



8.10 As the number of R groups on the carbon with the leaving group increases, the rate of an E2 reaction increases.



8.11 Use the following characteristics of an E2 reaction to answer the questions:

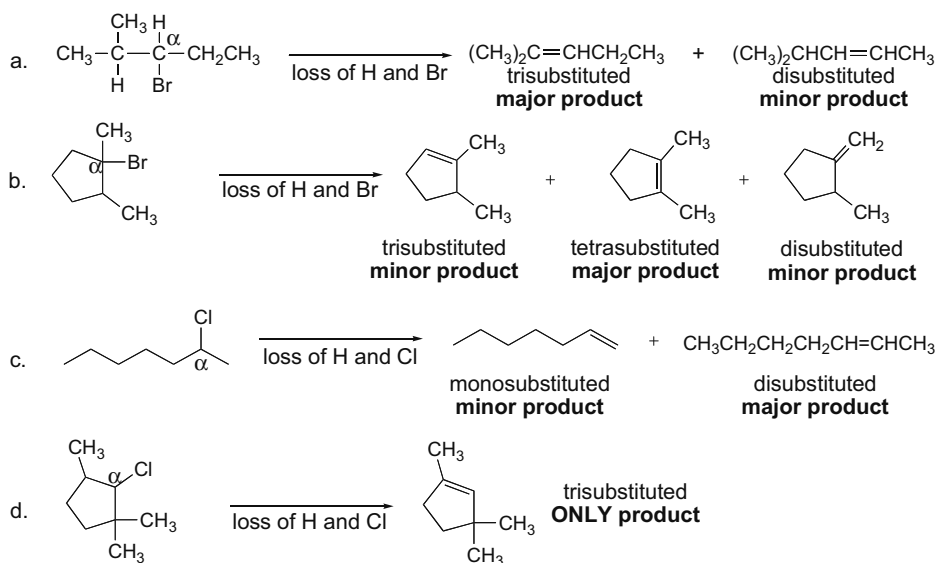
- [1] E2 reactions are second order and one step.
- [2] More substituted halides react faster.
- [3] Reactions with strong bases or better leaving groups are faster.
- [4] Reactions with polar aprotic solvents are faster.

Chapter 8–8

Rate equation: rate = $k[\text{RX}][\text{Base}]$

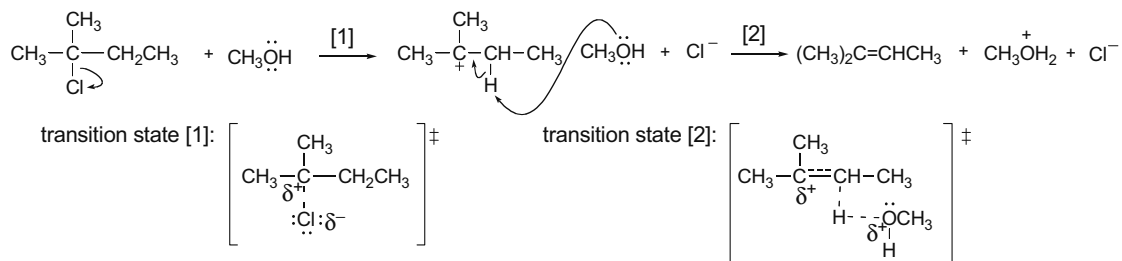
- tripling the concentration of the alkyl halide = **rate triples**
- halving the concentration of the base = **rate halved**
- changing the solvent from CH_3OH to DMSO = **rate increases** (Polar aprotic solvent is better for E_2 .)
- changing the leaving group from I^- to Br^- = **rate decreases** (I^- is a better leaving group.)
- changing the base from OH^- to H_2O = **rate decreases** (weaker base)
- changing the alkyl halide from $\text{CH}_3\text{CH}_2\text{Br}$ to $(\text{CH}_3)_2\text{CHBr}$ = **rate increases** (More substituted halide reacts faster.)

8.12 The Zaitsev rule states: In a β -elimination reaction, the major product has the more substituted double bond.



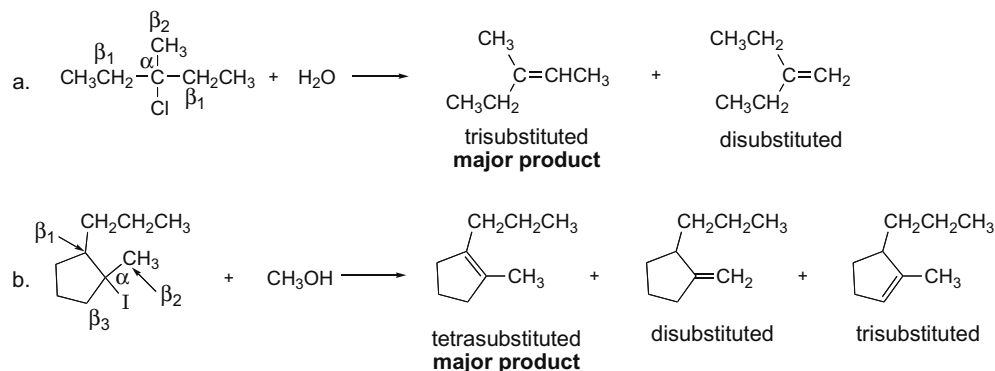
8.13 An E_1 mechanism has two steps:

- [1] The leaving group comes off, creating a carbocation.
- [2] A base pulls off a proton from a β carbon, and a π bond forms.



Alkyl Halides and Elimination Reactions 8–9

8.14 The Zaitsev rule states: In a β -elimination reaction, the major product has the more substituted double bond.



8.15 Use the following characteristics of an **E1 reaction** to answer the questions:

- [1] E1 reactions are first order and two steps.
- [2] More substituted halides react faster.
- [3] Weaker bases are preferred.
- [4] Reactions with better leaving groups are faster.
- [5] Reactions in polar protic solvents are faster.

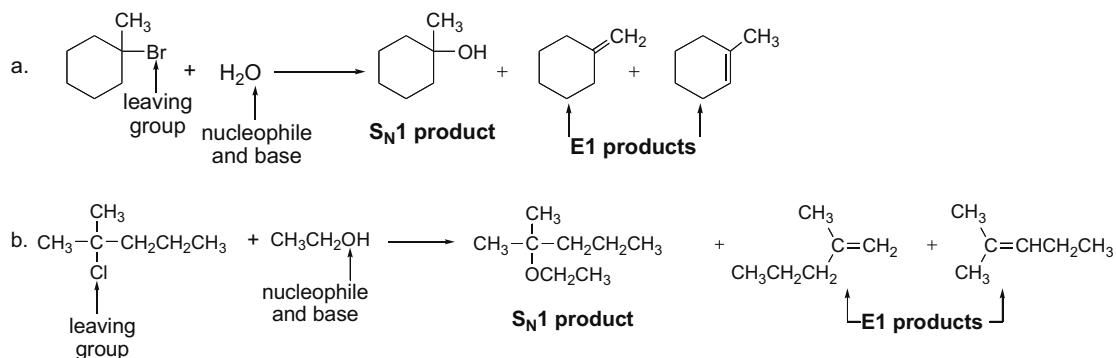
Rate equation: rate = $k[\text{RX}]$. The base doesn't affect rate.

- a. doubling the concentration of the alkyl halide = **rate doubles**
- b. doubling the concentration of the base = **no change** (Base is not in the rate equation.)
- c. changing the alkyl halide from $(\text{CH}_3)_3\text{CBr}$ to $\text{CH}_3\text{CH}_2\text{CH}_2\text{Br}$ = **rate decreases** (More substituted halides react faster.)
- d. changing the leaving group from Cl^- to Br^- = **rate increases** (better leaving group)
- e. changing the solvent from DMSO to CH_3OH = **rate increases** (Polar protic solvent favors E1.)

8.16 Both $\text{S}_{\text{N}}1$ and E1 reactions occur by forming a carbocation. To draw the products:

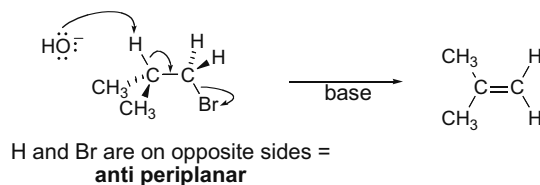
[1] **For the $\text{S}_{\text{N}}1$ reaction**, substitute the nucleophile for the leaving group.

[2] **For the E1 reaction**, remove a proton from a β carbon and create a new π bond.

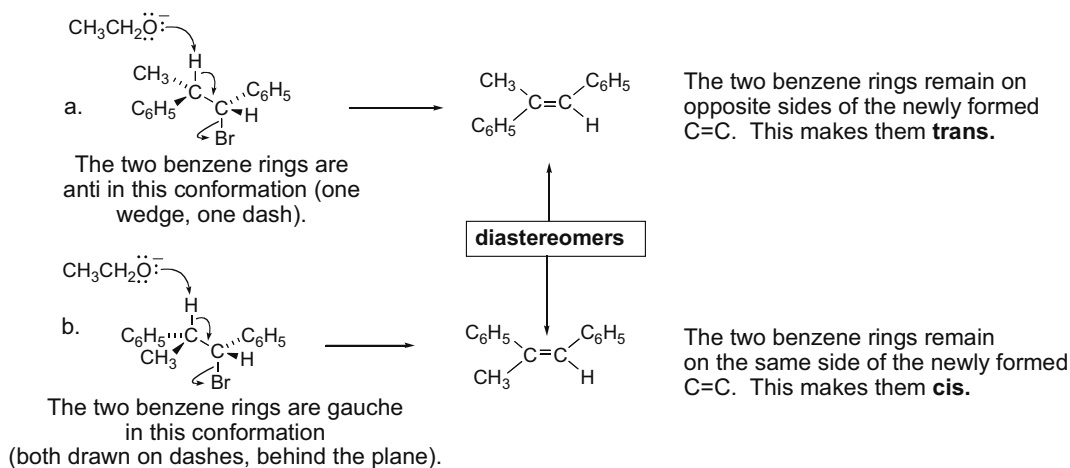


Chapter 8–10

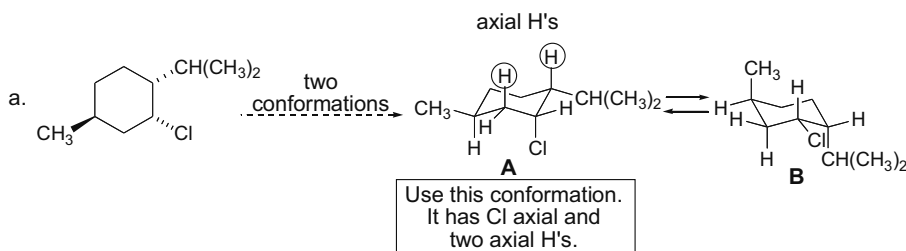
8.17 E2 reactions occur with anti periplanar geometry. **The anti periplanar arrangement uses a staggered conformation and has the H and X on opposite sides of the C–C bond.**



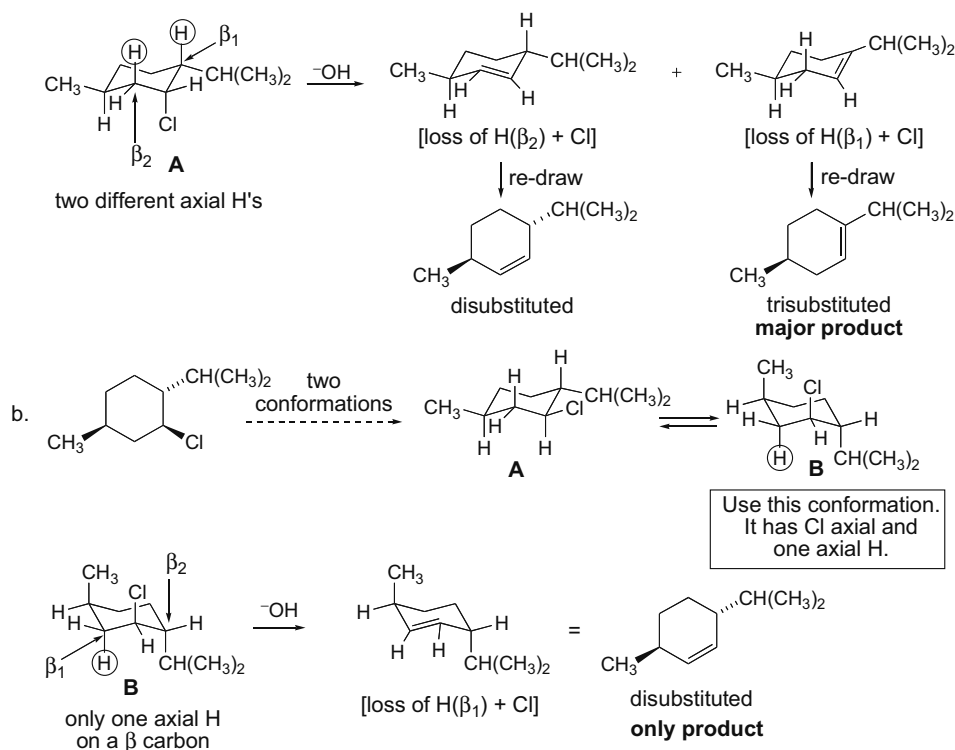
8.18 The E2 elimination reactions will occur in the anti periplanar orientation as drawn. To draw the product of elimination, maintain the orientation of the remaining groups around the C=C.



8.19 Note: The Zaitsev products predominate in E2 elimination *except* when substituents on a cyclohexane ring prevent a **trans diaxial** arrangement of H and X.

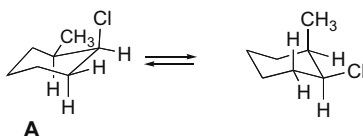


Alkyl Halides and Elimination Reactions 8–11



8.20 Draw the chair conformations of *cis*-1-chloro-2-methylcyclohexane and its trans isomer. For E2 elimination reactions to occur, **there must be a H and X trans diaxial to each other.**

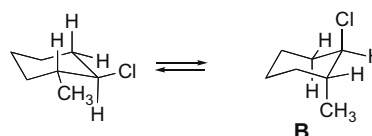
Two conformations of the *cis* isomer:



reacting conformation (axial Cl)

This reacting conformation has only one group axial, making it more stable and present in a higher concentration than **B**. This makes a **faster elimination reaction with the cis isomer.**

Two conformations of the *trans* isomer:



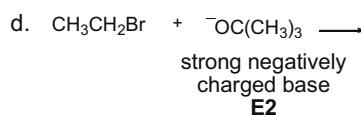
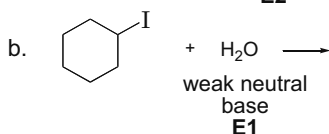
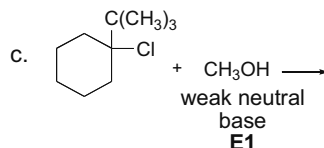
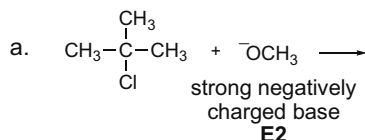
reacting conformation (axial Cl)

This conformation is less stable than **A**, since both CH_3 and Cl are axial. **This slows the rate of elimination from the trans isomer.**

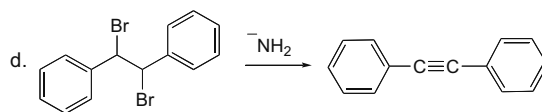
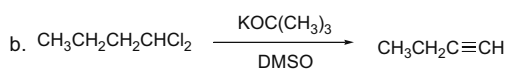
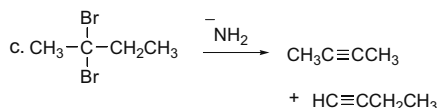
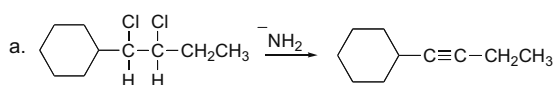
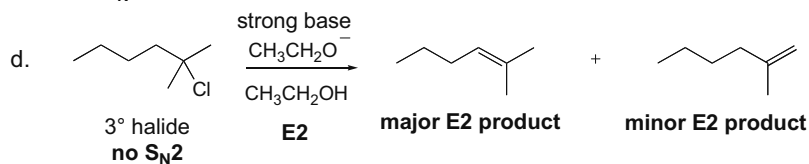
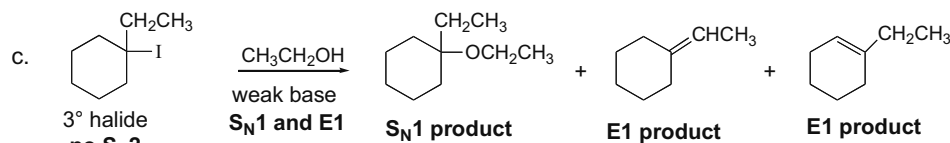
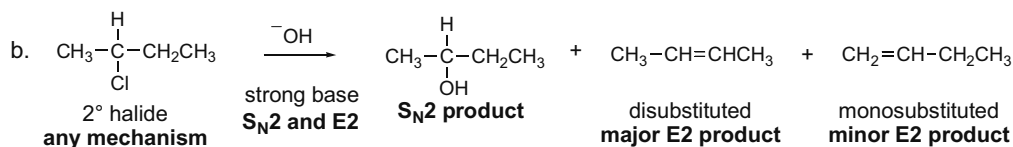
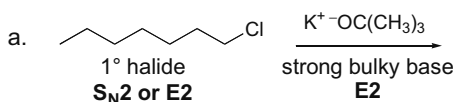
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8.21 E2 reactions are favored by strong negatively charged bases and occur with 1°, 2°, and 3° halides, with 3° being the most reactive.

E1 reactions are favored by weaker neutral bases and do not occur with 1° halides since they would have to form highly unstable carbocations.

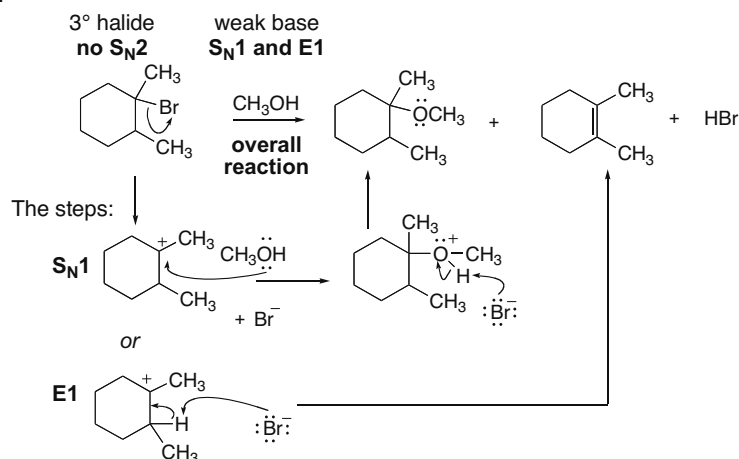


8.22 Draw the alkynes that result from removal of two equivalents of HX.

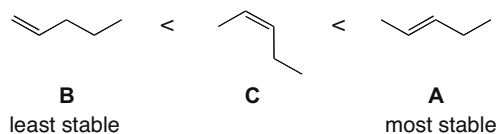
**8.23**

Alkyl Halides and Elimination Reactions 8-13

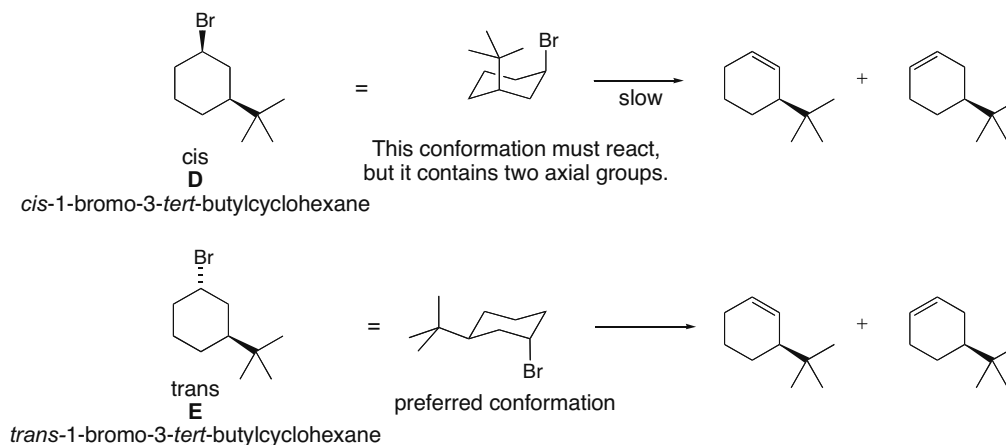
8.24



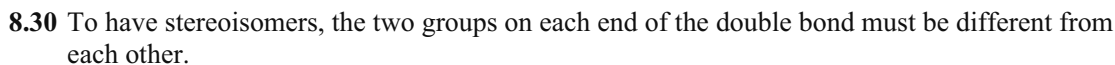
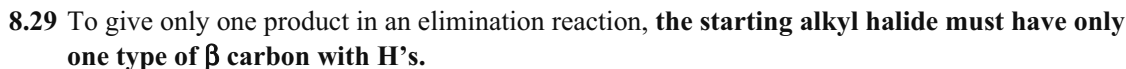
8.25 More substituted alkenes are more stable. Trans alkenes are generally more stable than cis alkenes. Order of stability:



8.26 The trans isomer reacts faster. During elimination, Br must be axial to give trans diaxial elimination. In the trans isomer, the more stable conformation has the bulky *tert*-butyl group in the more roomy equatorial position. In the cis isomer, elimination can occur only when both the *tert*-butyl and Br groups are axial, a conformation that is not energetically favorable.

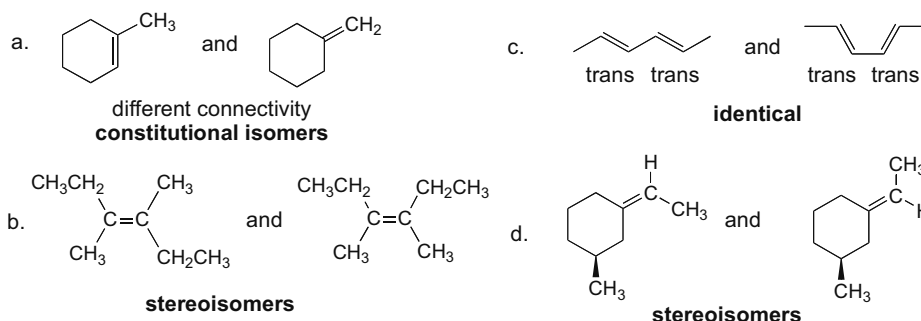


8.27 Translate each model to a structure and arrange H and Br to be anti periplanar.

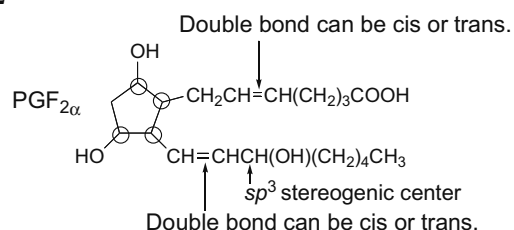


Alkyl Halides and Elimination Reactions 8–15

8.31 Use the definitions in Answer 8.5.

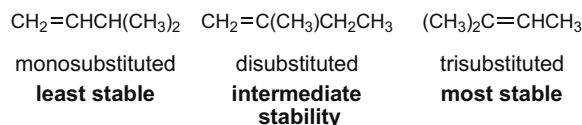


8.32

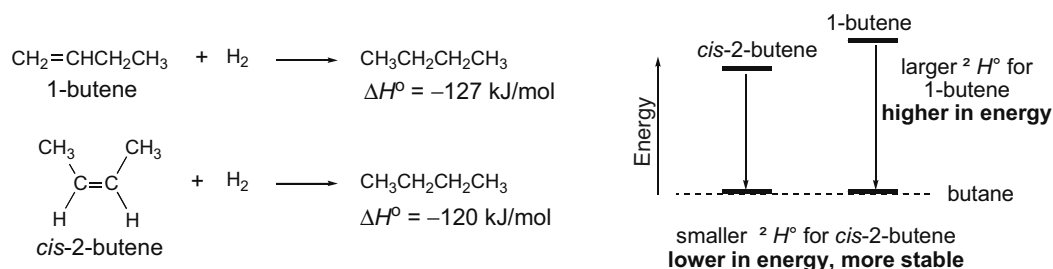


- a. five sp^3 stereogenic centers (four circled, one labeled)
b. Two double bonds can both be cis or trans.
c. $2^7 = 128$ stereoisomers possible

8.33 Use the rules from Answer 8.6 to rank the alkenes.

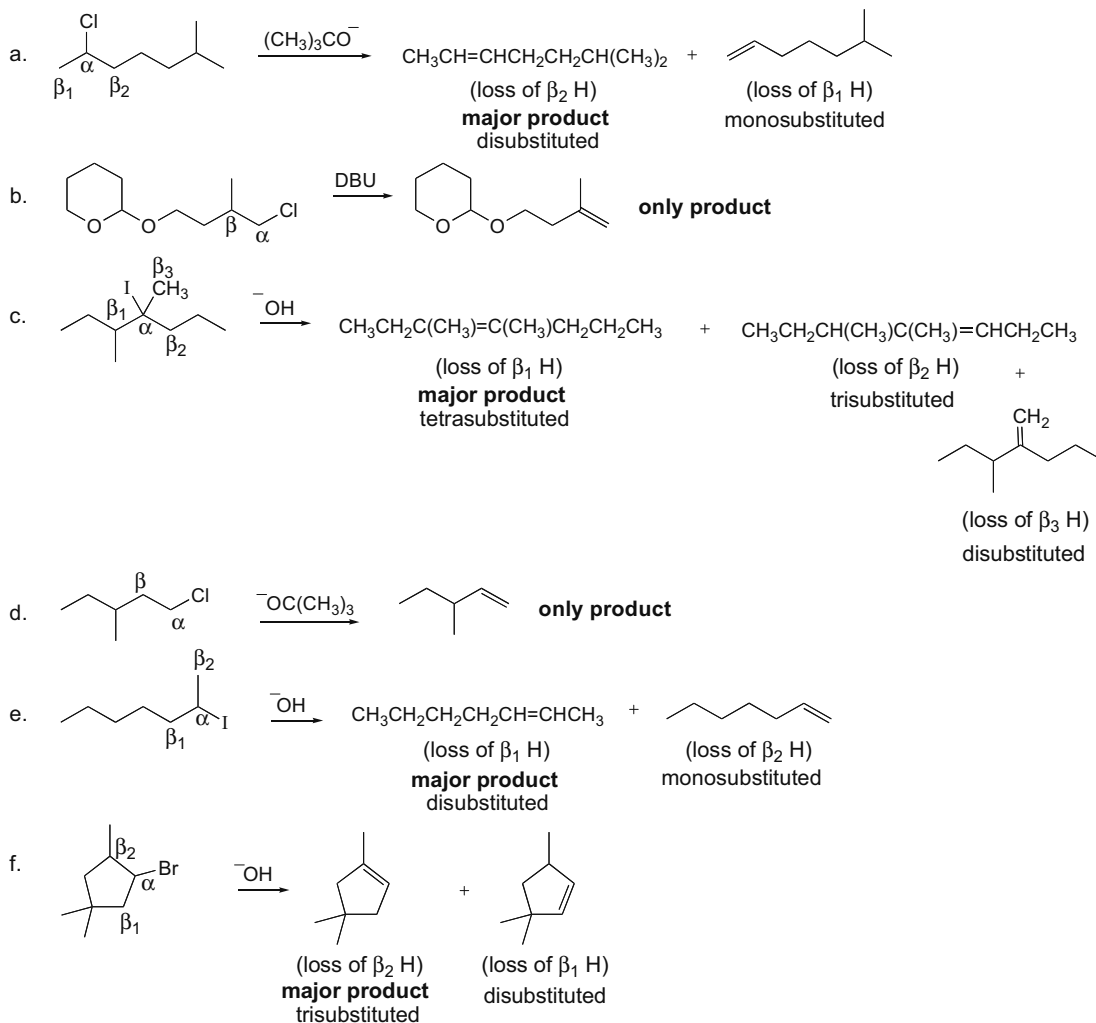


8.34 A larger negative value for ΔH° means the reaction is more exothermic. Since both 1-butene and *cis*-2-butene form the same product (butane), these data show that 1-butene was higher in energy to begin with, since more energy is released in the hydrogenation reaction.



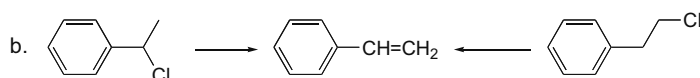
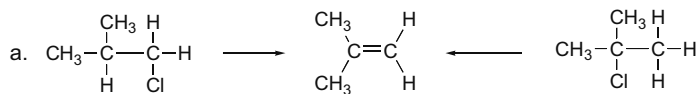
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8.35

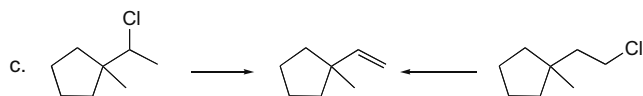


8.36 To give only one alkene as the product of elimination, the alkyl halide must have either:

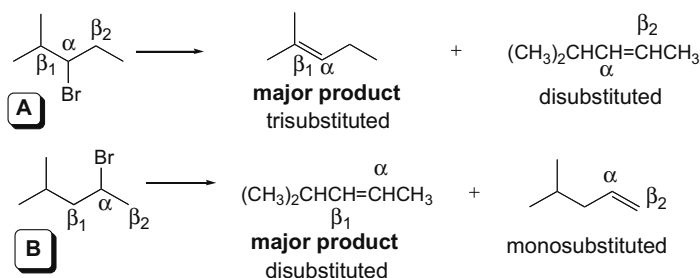
- only one β carbon with a hydrogen atom
- all identical β carbons, so the resulting elimination products are identical



Alkyl Halides and Elimination Reactions 8-17



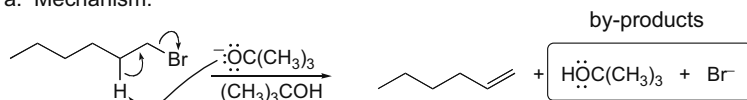
8.37 Draw the products of the E2 reaction and compare the number of C's bonded to the C=C.



A yields a trisubstituted alkene as the major product and a disubstituted alkene as minor product. **B** yields a disubstituted alkene as the major product and a monosubstituted alkene as minor product. Since the major and minor products formed from **A** have more alkyl groups on the C=C (making them more stable) than those formed from **B**, **A** reacts faster in an elimination reaction.

8.38

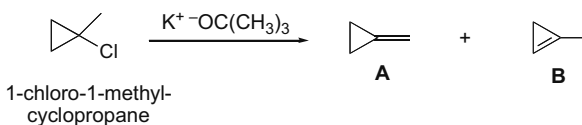
a. Mechanism:



b. Rate = $k[\text{R-Br}][^-\text{OC}(\text{CH}_3)_3]$

- [1] Solvent changed to DMF (polar aprotic) = **rate increases**
- [2] $^-\text{OC}(\text{CH}_3)_3$ decreased = **rate decreases**
- [3] Base changed to ^-OH = **rate decreases** (weaker base)
- [4] Halide changed to 2° = **rate increases** (More substituted RX reacts faster.)
- [5] Leaving group changed to I^- = **rate increases** (better leaving group)

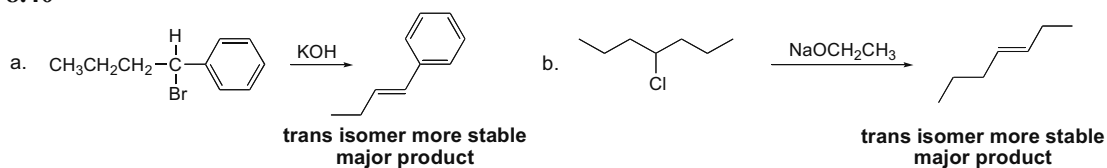
8.39



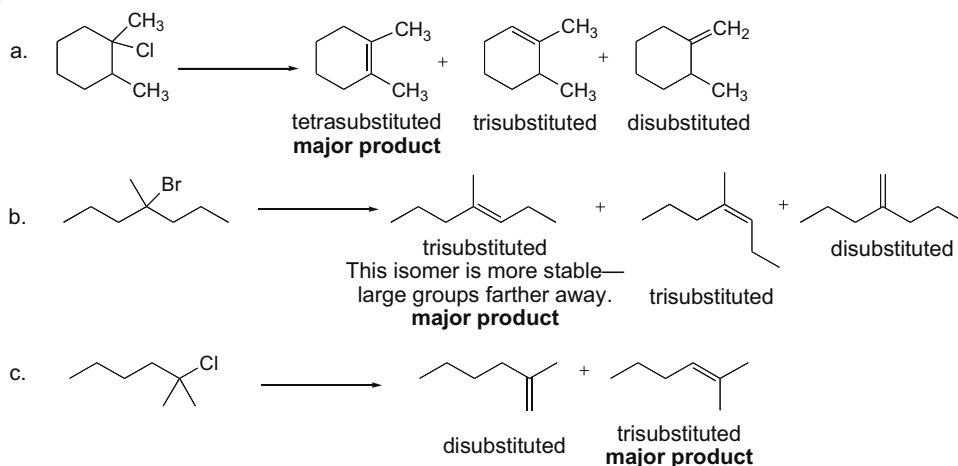
The dehydrohalogenation of an alkyl halide usually forms the more stable alkene. In this case, **A** is more stable than **B** even though **A** contains a disubstituted C=C whereas **B** contains a trisubstituted C=C. The double bond in **B** is part of a three-membered ring, and is less stable than **A** because of severe angle strain around both C's of the double bond.

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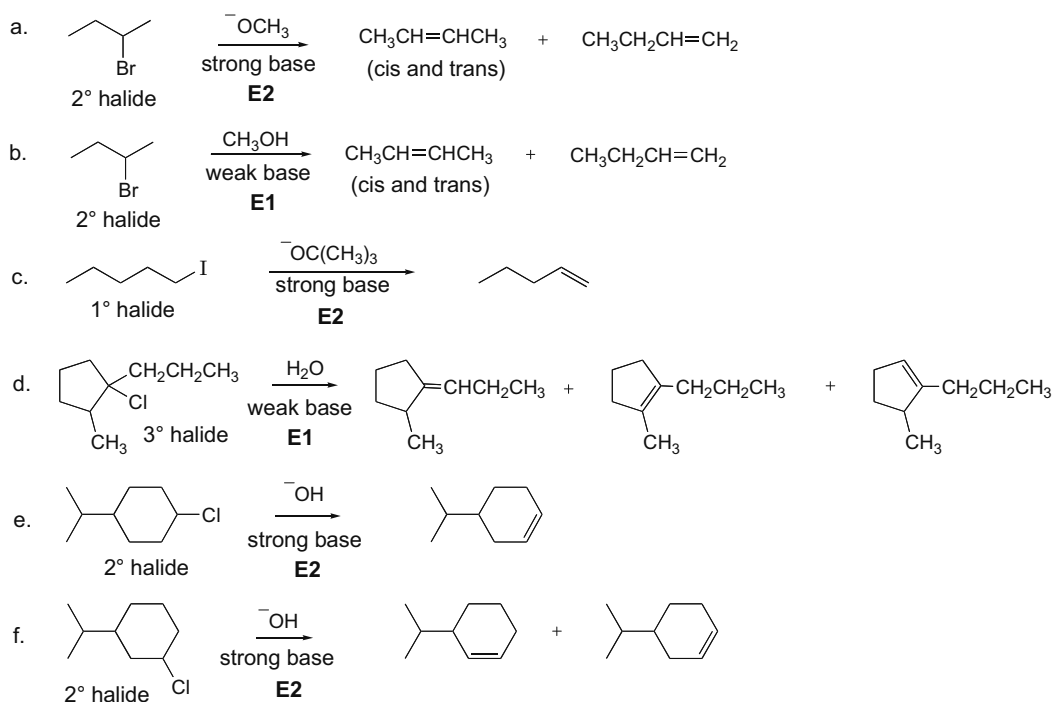
8.40



8.41

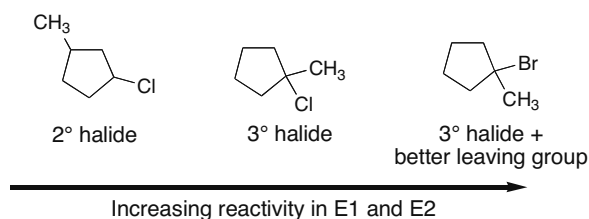


8.42 Use the rules from Answer 8.21.

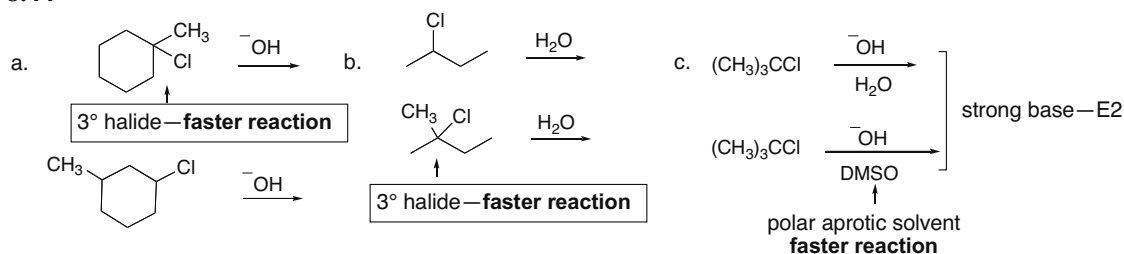


Alkyl Halides and Elimination Reactions 8–19

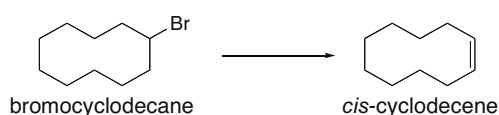
8.43 The order of reactivity is the same for both E2 and E1: $1^\circ < 2^\circ < 3^\circ$.



8.44

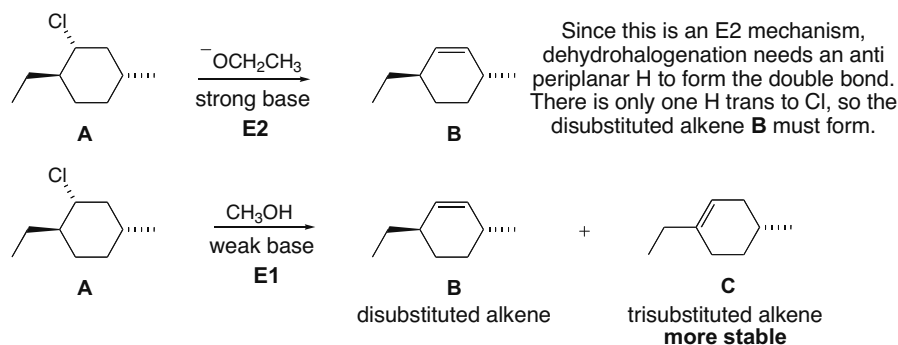


8.45



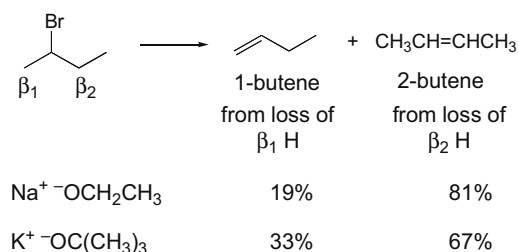
In a ten-membered ring, the cis isomer is more stable and, therefore, the preferred elimination product. The trans isomer is less stable because strain is introduced when two ends of the double bond are connected in a trans arrangement in this medium-sized ring.

8.46 With the strong base $^-\text{OCH}_2\text{CH}_3$, the mechanism is E2, whereas with dilute base, the mechanism is E1. E2 elimination proceeds with anti periplanar arrangement of H and X. In the E1 mechanism there is no requirement for elimination to proceed with anti periplanar geometry. In this case the major product is always the most stable, more substituted alkene. Thus, **C** is the major product under E1 conditions. (In Chapter 9, we will learn that additional elimination products may form in the E1 reaction due to carbocation rearrangement.)



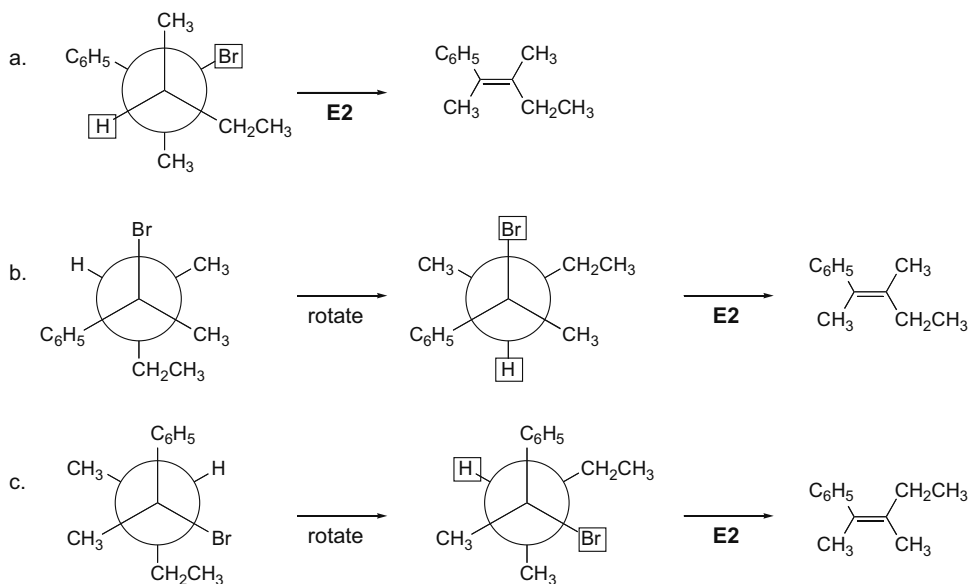
Chapter 8–20

8.47

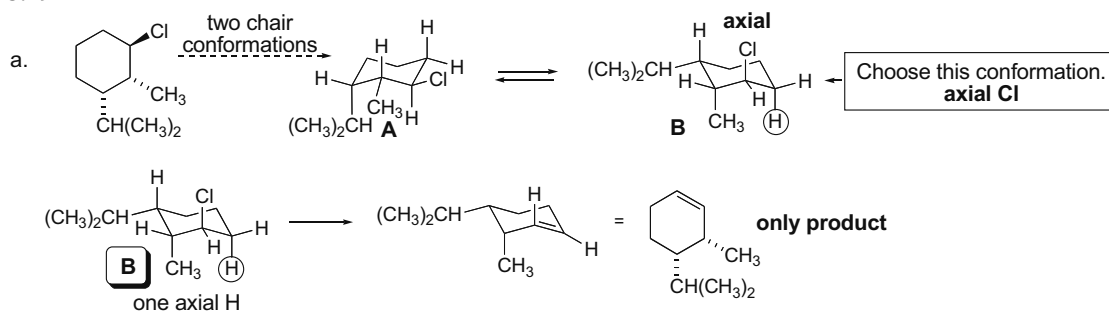


The H's on the CH₂ group of the β_2 carbon are more sterically hindered than the H's on the CH₃ group of the β_1 carbon. Since K⁺ -OC(CH₃)₃ is a much bulkier base than Na⁺ -OCH₂CH₃, it is easier to remove the more accessible H on β_1 , giving it a higher percentage of 1-butene.

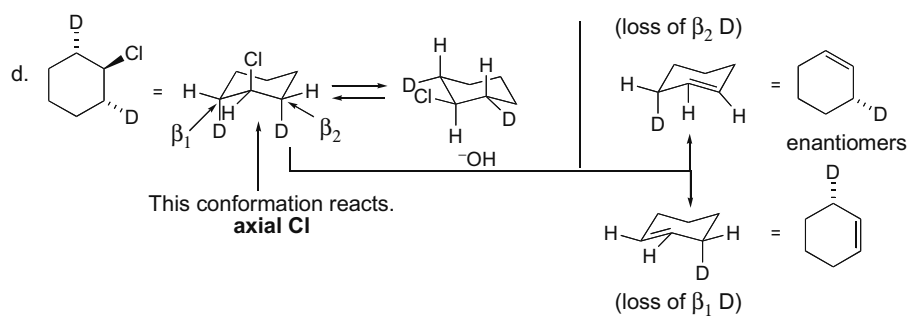
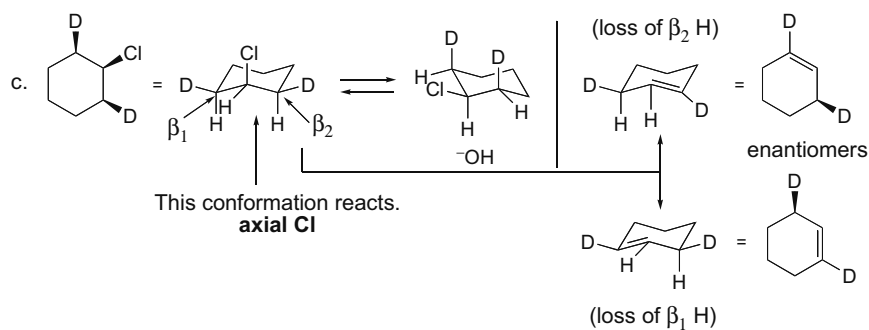
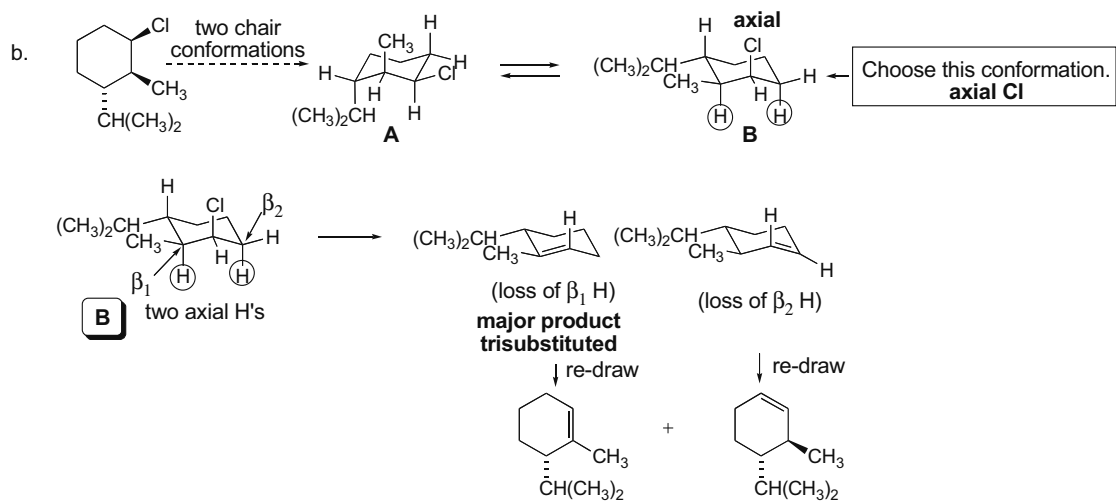
8.48 H and Br must be anti during the E2 elimination. Rotate if necessary to make them anti; then eliminate.



8.49



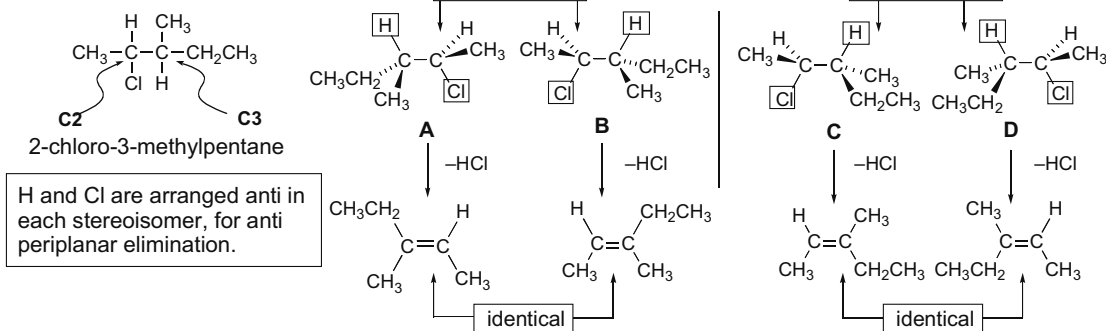
Alkyl Halides and Elimination Reactions 8–21



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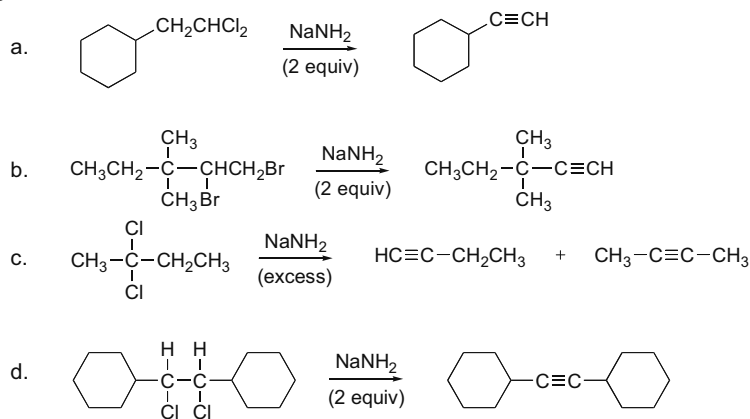
8.50

a.

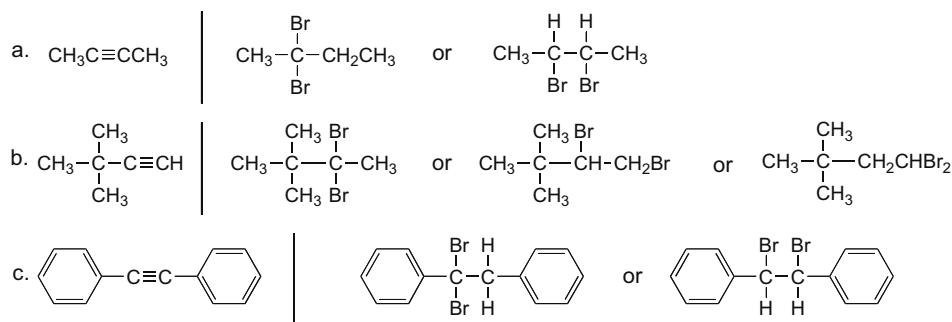


- b. Two different alkenes are formed as products.
- c. The products are diastereomers: Two enantiomers (**A** and **B**) give identical products. **A** and **B** are diastereomers of **C** and **D**. Each pair of enantiomers gives a single alkene. Thus, diastereomers give diastereomeric products.

8.51

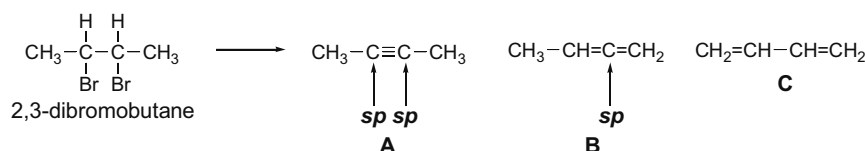


8.52



Alkyl Halides and Elimination Reactions 8-23

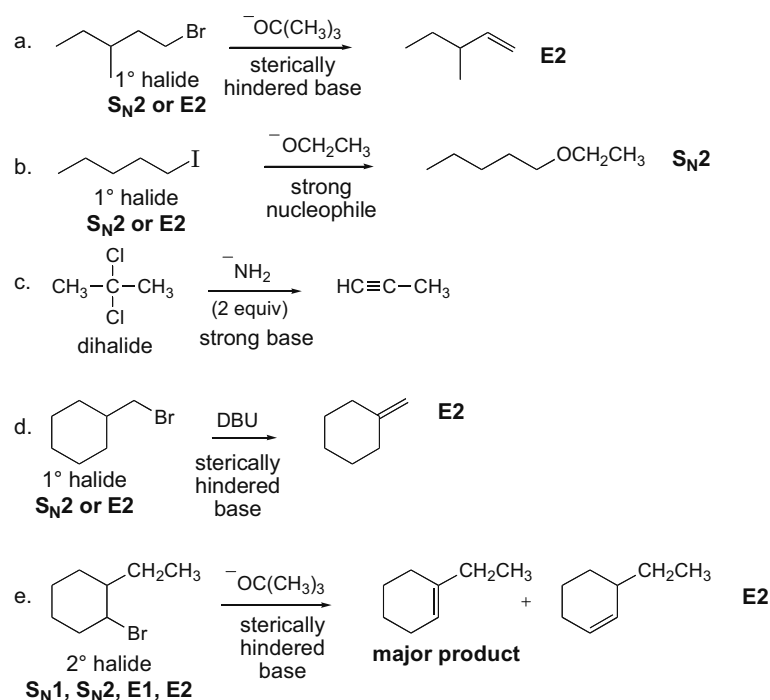
8.53



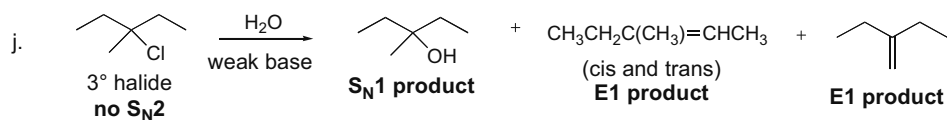
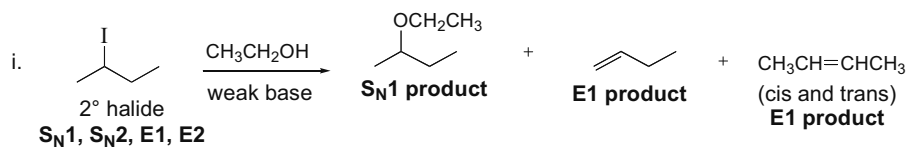
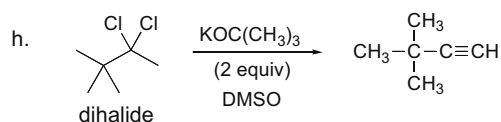
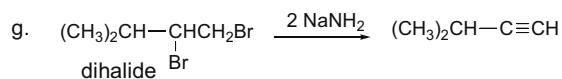
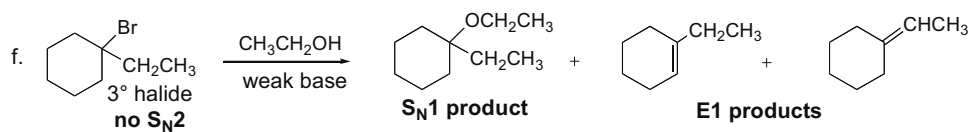
8.54 Use the “Summary chart on the four mechanisms: S_N1, S_N2, E1, or E2” on p. 8-2 to answer the questions.

- Both S_N1 and E1 involve carbocation intermediates.
- Both S_N1 and E1 have two steps.
- S_N1, S_N2, E1, and E2 all have increased reaction rates with better leaving groups.
- Both S_N2 and E2 have increased rates when changing from CH₃OH (a protic solvent) to (CH₃)₂SO (an aprotic solvent).
- In S_N1 and E1 reactions, the rate depends on only the alkyl halide concentration.
- Both S_N2 and E2 are concerted reactions.
- CH₃CH₂Br and NaOH react by an S_N2 mechanism.
- Racemization occurs in S_N1 reactions.
- In S_N1, E1, and E2 mechanisms, 3° alkyl halides react faster than 1° or 2° halides.
- E2 and S_N2 reactions follow second-order rate equations.

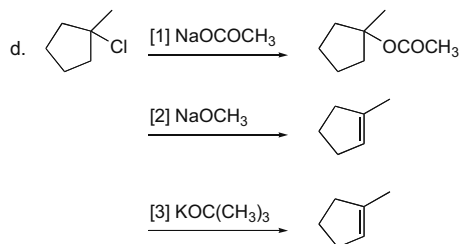
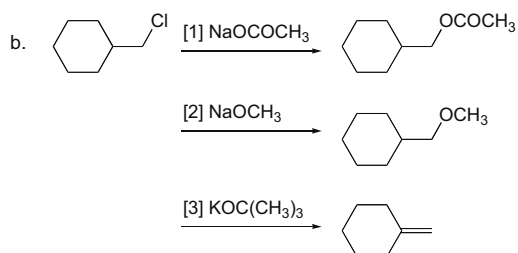
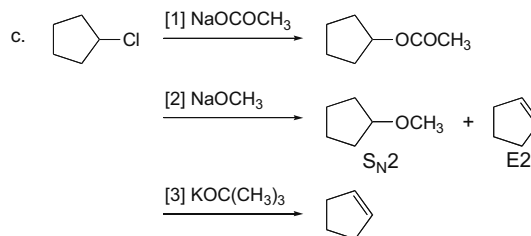
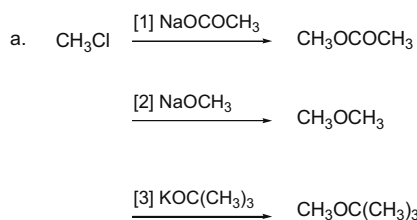
8.55



Chapter 8–24



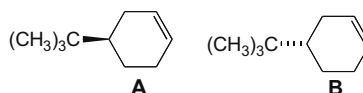
8.56 [1] $NaOCOCH_3$ is a good nucleophile and weak base, and substitution is favored. [3] $KOC(CH_3)_3$ is a strong, bulky base that reacts by E2 elimination when there is a β hydrogen in the alkyl halide.



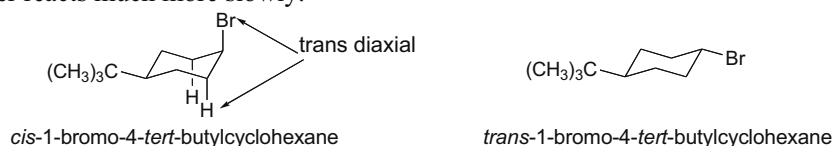
Alkyl Halides and Elimination Reactions 8–25

8.57

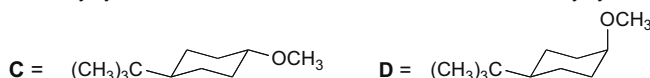
a. two enantiomers:



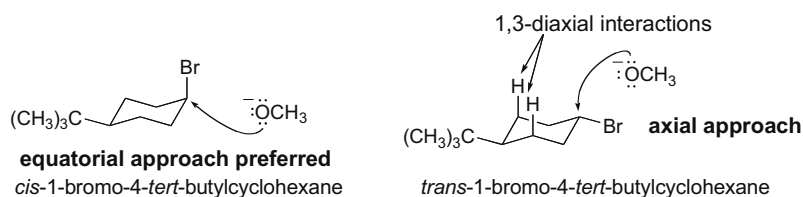
b. The bulky *tert*-butyl group anchors the cyclohexane ring and occupies the more roomy equatorial position. The *cis* isomer has the Br atom axial, while the *trans* isomer has the Br atom equatorial. For dehydrohalogenation to occur on a halo cyclohexane, the halogen must be axial to afford *trans* diaxial elimination of H and X. The *cis* isomer readily reacts since the Br atom is axial. The only way for the *trans* isomer to react is for the six-membered ring to flip into a highly unstable conformation having both $(\text{CH}_3)_3\text{C}$ and Br axial. Thus, the *trans* isomer reacts much more slowly.



c. two products:

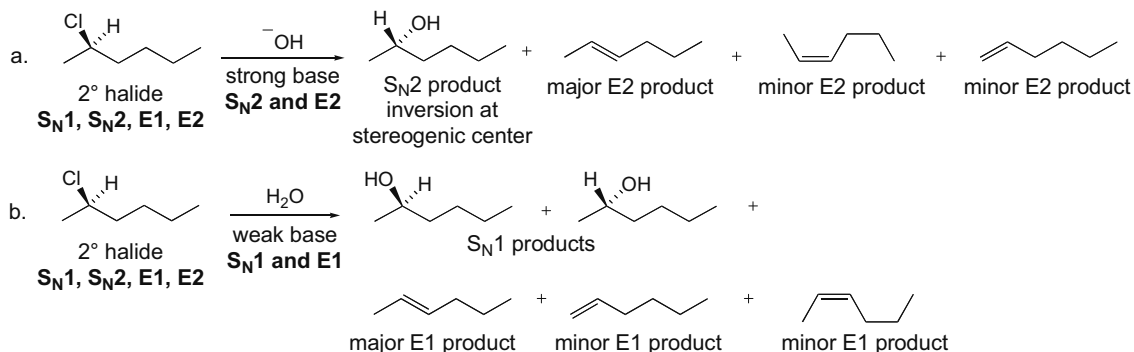


d. *cis*-1-Bromo-4-*tert*-butylcyclohexane reacts faster. With the strong nucleophile $^-\text{OCH}_3$, backside attack occurs by an $\text{S}_\text{N}2$ reaction, and with the *cis* isomer, the nucleophile can approach from the equatorial direction, avoiding 1,3-diaxial interactions.

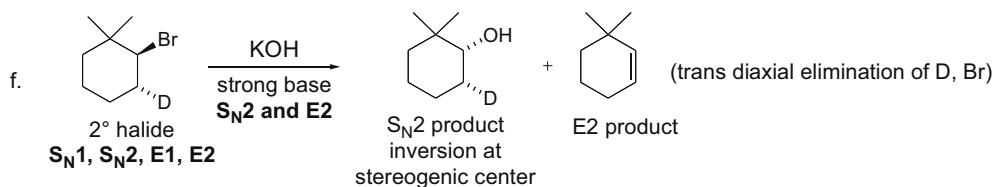
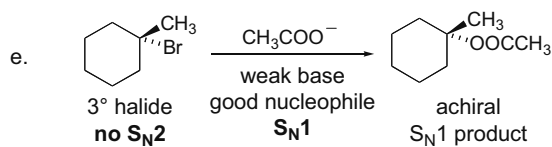
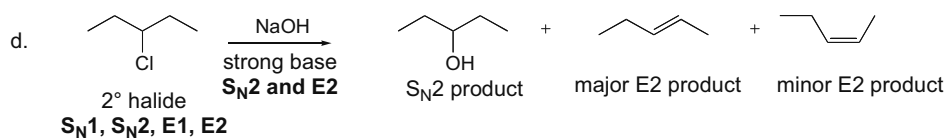
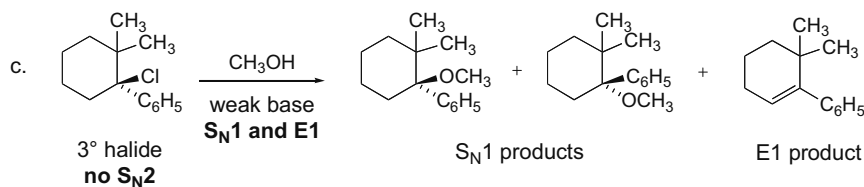


e. The bulky base $^-\text{OC}(\text{CH}_3)_3$ favors elimination by an E2 mechanism, affording a mixture of two enantiomers, **A** and **B**. The strong nucleophile $^-\text{OCH}_3$ favors nucleophilic substitution by an $\text{S}_\text{N}2$ mechanism. Inversion of configuration results from backside attack of the nucleophile.

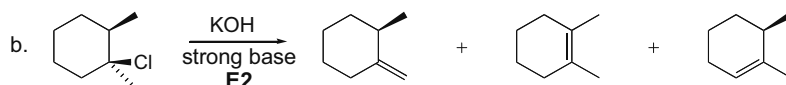
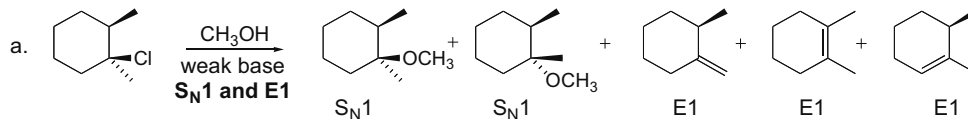
8.58



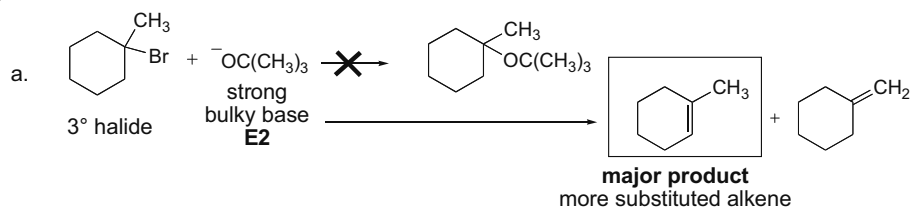
Chapter 8–26



8.59

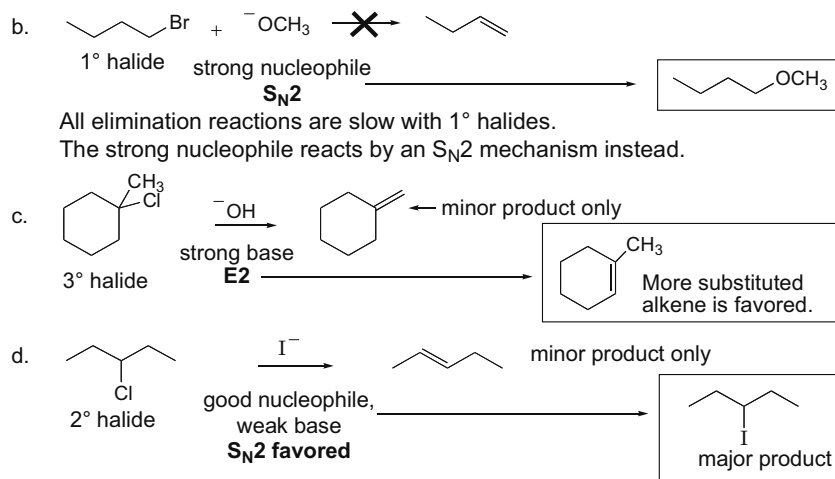


8.60



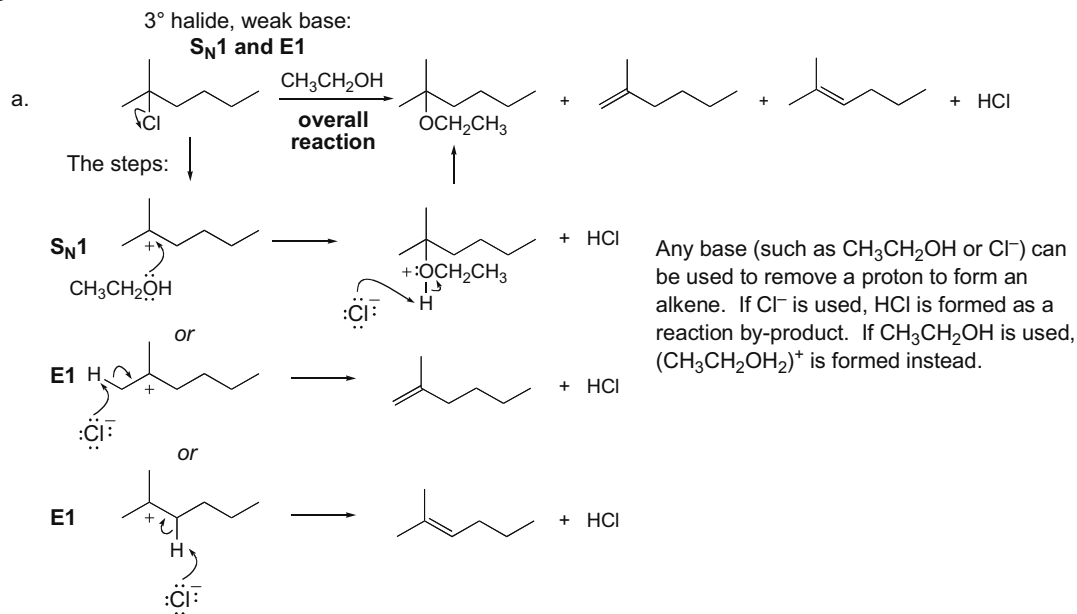
No substitution occurs with a strong bulky base and a 3° RX. The C with the leaving group is too crowded for an S_N2 substitution to occur. Elimination occurs instead by an E2 mechanism.

Alkyl Halides and Elimination Reactions 8–27



The 2° halide can react by an E2 or $\text{S}_\text{N}2$ reaction with a negatively charged nucleophile or base. Since I^- is a weak base, substitution by an $\text{S}_\text{N}2$ mechanism is favored.

8.61



b.

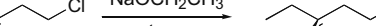
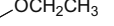
3° halide
strong base
E2

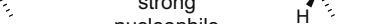
overall reaction

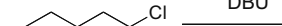
Each product:

one step

one step

a.  $\xrightarrow[\text{strong nucleophile}]{\text{NaOCH}_2\text{CH}_3}$ 
S_N2

b.  $\xrightarrow[\text{strong nucleophile}]{\text{KCN}}$ 
S_N2

c.  $\xrightarrow[\text{sterically hindered base}]{\text{DBU}}$ 
E2

The reaction mechanism for the acid-catalyzed hydration of 1-bromo-1,2,3,4,5,6-hexahydronaphthalene is shown below. The starting material is 1-bromo-1,2,3,4,5,6-hexahydronaphthalene. The mechanism proceeds via a carbocation intermediate at C1.

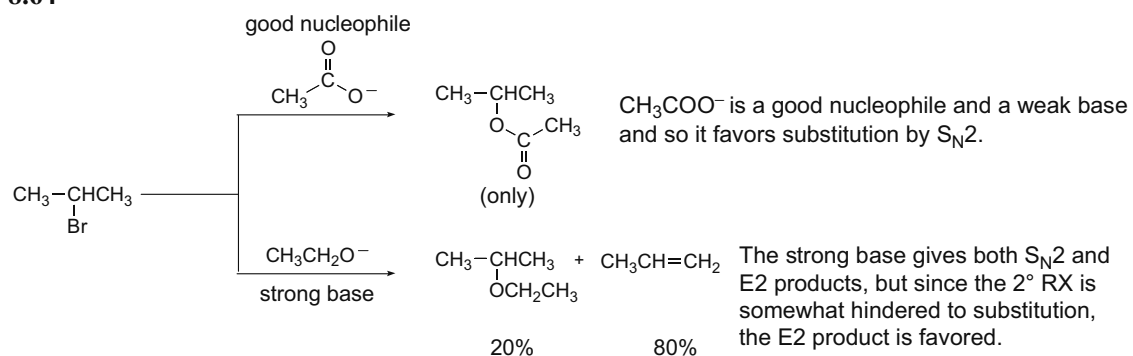
Pathway 1 (Top): The carbocation intermediate at C1 undergoes a hydride shift from C2 to C1, forming a more stable tertiary carbocation at C2. This intermediate is then attacked by water (H_2O) to form a protonated alcohol, which is subsequently deprotonated by another water molecule to yield 1,2-dihydronaphthalen-1-ol and HBr .

Pathway 2 (Bottom): The carbocation intermediate at C1 undergoes a methyl shift from C6 to C1, forming a more stable tertiary carbocation at C6. This intermediate is then attacked by water (H_2O) to form a protonated alcohol, which is subsequently deprotonated by another water molecule to yield 1,2-dihydronaphthalen-1-ol and HBr .

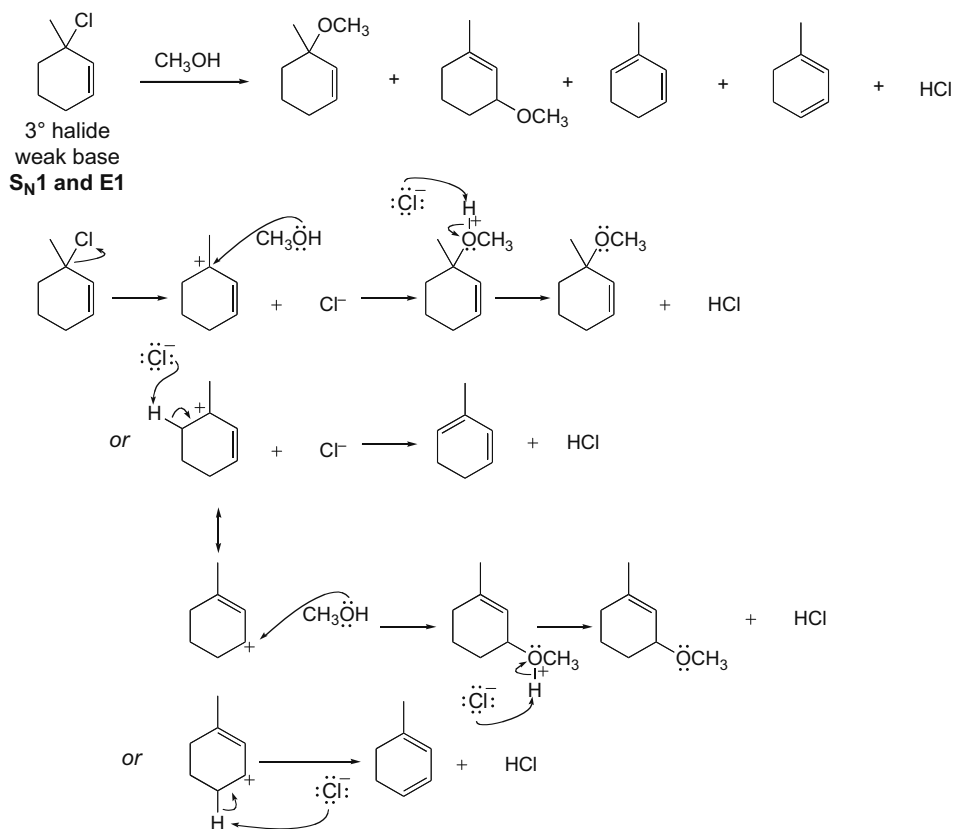
Pathway 3 (Bottom): The carbocation intermediate at C1 undergoes deprotonation at C2 by a bromide ion (Br^-) to form 1,2,3,4,5,6-hexahydronaphthalene and HBr .

Alkyl Halides and Elimination Reactions 8-29

8.64

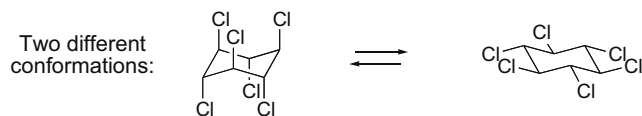


8.65



Chapter 8–30

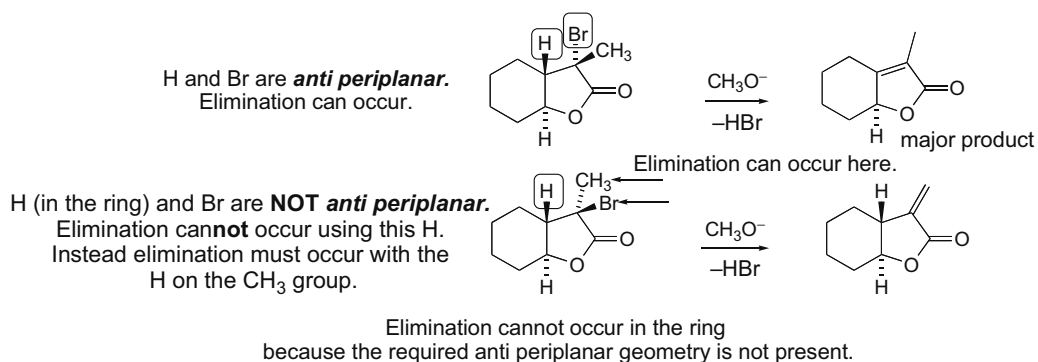
8.66 E2 elimination needs a leaving group and a hydrogen in the **trans diaxial** position.



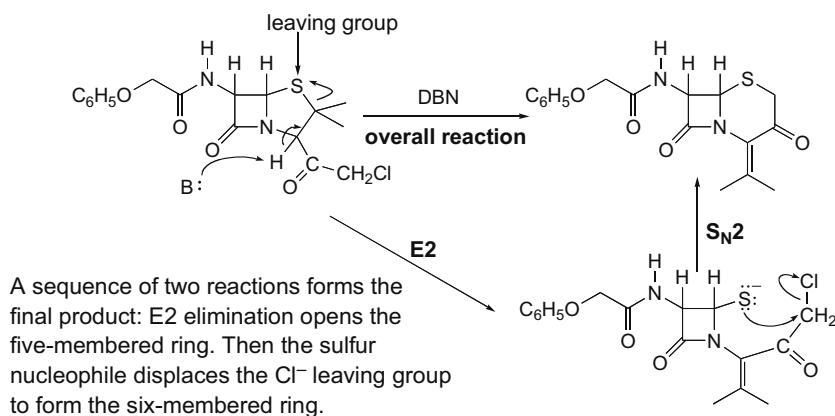
This conformation has Cl's axial, but no H's axial. This conformation has no Cl's axial.

For elimination to occur, a cyclohexane must have a H and Cl in the trans diaxial arrangement. Neither conformation of this isomer has both atoms—H and Cl—axial; thus, this isomer only slowly loses HCl by elimination.

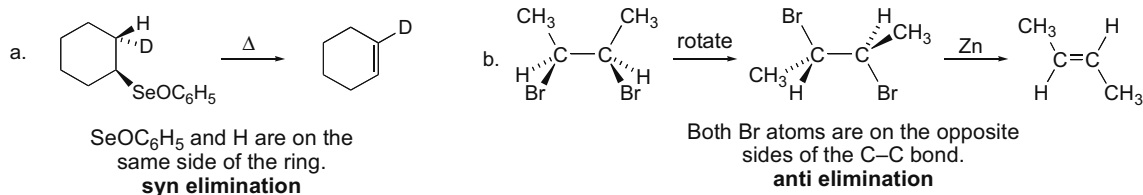
8.67



8.68

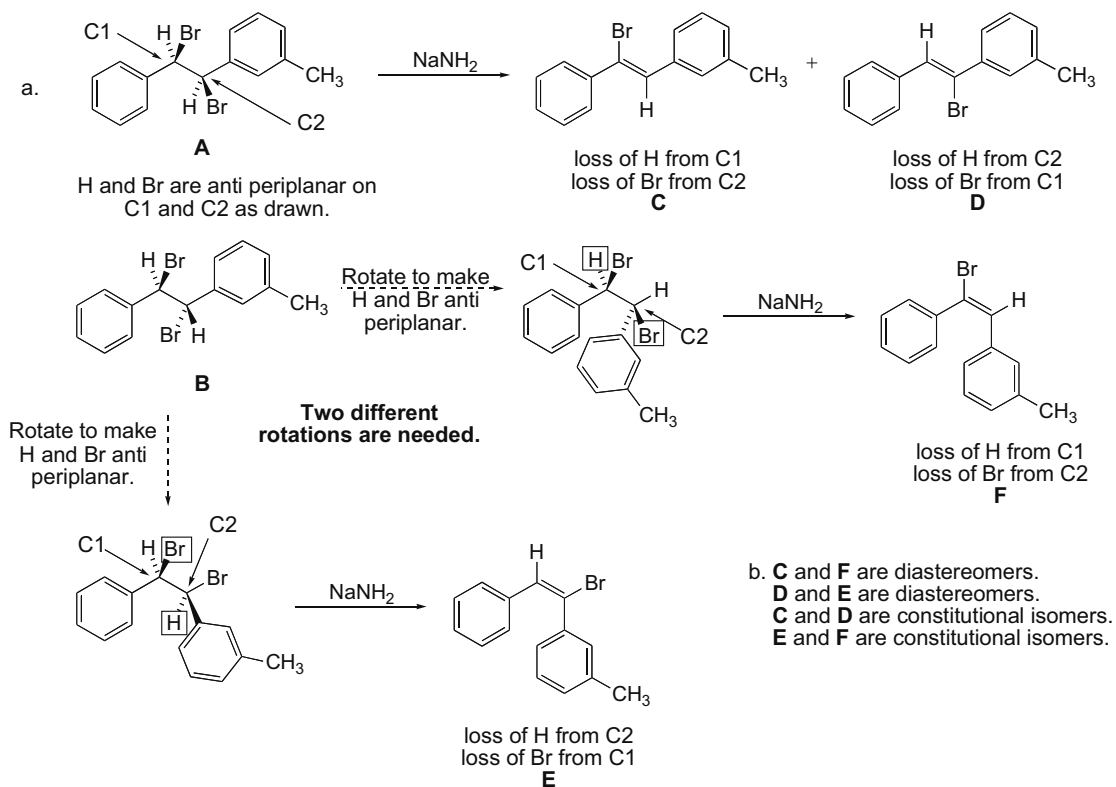


8.69



Alkyl Halides and Elimination Reactions 8-31

8.70 One equivalent of NaNH_2 removes one mole of HBr in an anti periplanar fashion from each dibromide. Two modes of elimination are possible for each compound.

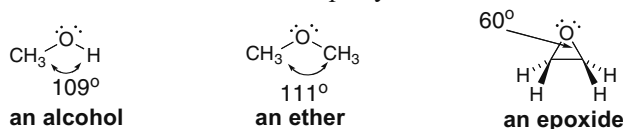


Chapter 9 Alcohols, Ethers, and Epoxides

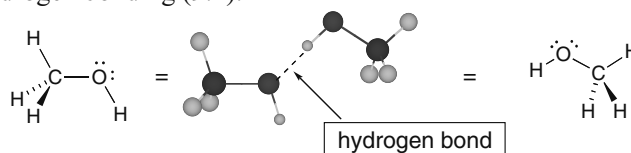
Chapter Review

General facts about ROH, ROR, and epoxides

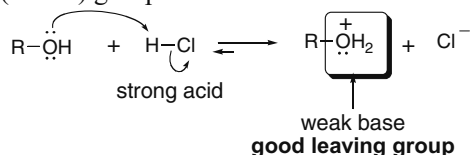
- All three compounds contain an O atom that is sp^3 hybridized and tetrahedral (9.2).



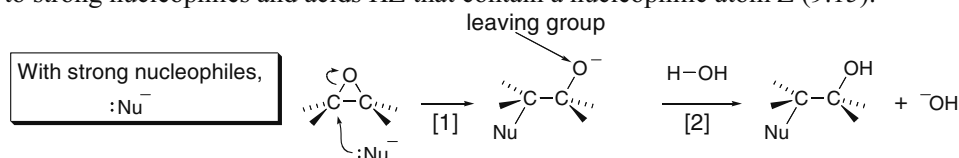
- All three compounds have polar C-O bonds, but only alcohols have an O-H bond for intermolecular hydrogen bonding (9.4).



- Alcohols and ethers do not contain a good leaving group. Nucleophilic substitution can occur only after the OH (or OR) group is converted to a better leaving group (9.7A).

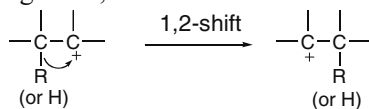


- Epoxides have a leaving group located in a strained three-membered ring, making them reactive to strong nucleophiles and acids HZ that contain a nucleophilic atom Z (9.15).



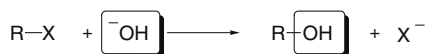
A new reaction of carbocations (9.9)

- Less stable carbocations rearrange to more stable carbocations by shift of a hydrogen atom or an alkyl group. Besides rearrangement, carbocations also react with nucleophiles (7.13) and bases (8.6).



Preparation of alcohols, ethers, and epoxides (9.6)

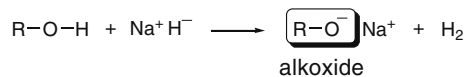
[1] Preparation of alcohols



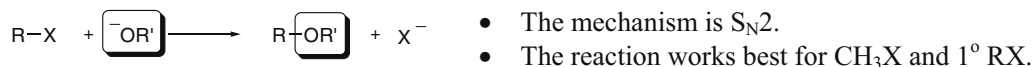
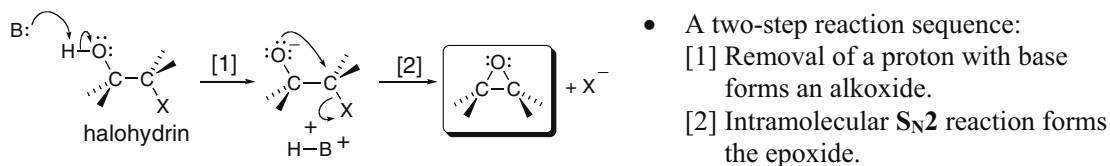
- The mechanism is $\text{S}_{\text{N}}2$.
- The reaction works best for CH_3X and 1°RX .

Chapter 9-2

[2] Preparation of alkoxides (a Brønsted–Lowry acid–base reaction)

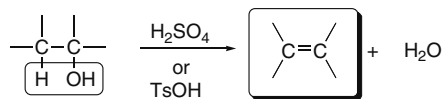


[3] Preparation of ethers (Williamson ether synthesis)

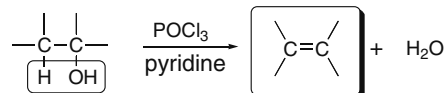
[4] Preparation of epoxides (intramolecular $\text{S}_{\text{N}}2$ reaction)**Reactions of alcohols**

[1] Dehydration to form alkenes

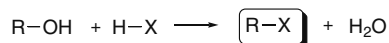
[a] Using strong acid (9.8, 9.9)



- Order of reactivity: $\text{R}_3\text{COH} > \text{R}_2\text{CHOH} > \text{RCH}_2\text{OH}$.
- The mechanism for 2° and 3°ROH is $\text{E}1$; carbocations are intermediates and rearrangements occur.
- The mechanism for 1°ROH is $\text{E}2$.
- The Zaitsev rule is followed.

[b] Using POCl_3 and pyridine (9.10)

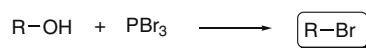
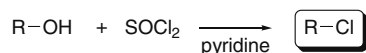
- The mechanism is $\text{E}2$.
- No carbocation rearrangements occur.

[2] Reaction with HX to form RX (9.11)

- Order of reactivity: $\text{R}_3\text{COH} > \text{R}_2\text{CHOH} > \text{RCH}_2\text{OH}$.
- The mechanism for 2° and 3°ROH is $\text{S}_{\text{N}}1$; carbocations are intermediates and rearrangements occur.
- The mechanism for CH_3OH and 1°ROH is $\text{S}_{\text{N}}2$.

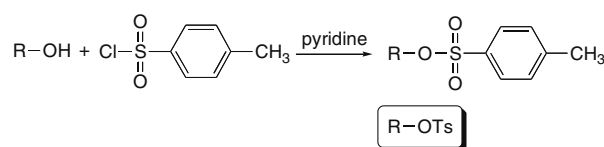
Alcohols, Ethers, and Epoxides 9-3

[3] Reaction with other reagents to form RX (9.12)



- Reactions occur with CH_3OH and 1° and 2° ROH.
- The reactions follow an $\text{S}_\text{N}2$ mechanism.

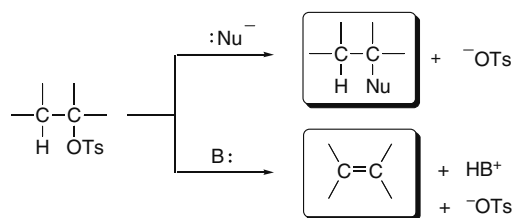
[4] Reaction with tosyl chloride to form alkyl tosylates (9.13A)



- The C-O bond is not broken so the configuration at a stereogenic center is retained.

Reactions of alkyl tosylates

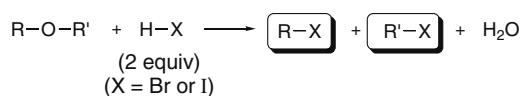
Alkyl tosylates undergo either substitution or elimination depending on the reagent (9.13B).



- Substitution is carried out with strong :Nu^- , so the mechanism is $\text{S}_\text{N}2$.
- Elimination is carried out with strong bases, so the mechanism is $\text{E}2$.

Reactions of ethers

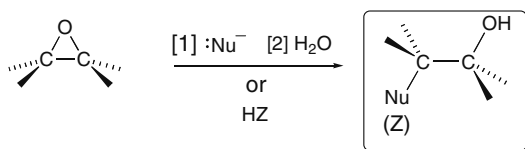
Only one reaction is useful: Cleavage with strong acids (9.14)



- With 2° and 3° R groups, the mechanism is $\text{S}_\text{N}1$.
- With CH_3 and 1° R groups the mechanism is $\text{S}_\text{N}2$.

Reactions of epoxides

Epoxide rings are opened with nucleophiles :Nu^- and acids HZ (9.15).

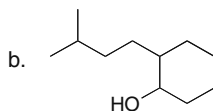
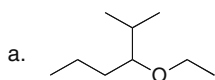


- The reaction occurs with backside attack, resulting in trans or anti products.
- With :Nu^- , the mechanism is $\text{S}_\text{N}2$, and nucleophilic attack occurs at the less substituted C.
- With HZ , the mechanism is between $\text{S}_\text{N}1$ and $\text{S}_\text{N}2$, and attack of Z^- occurs at the more substituted C.

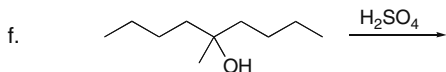
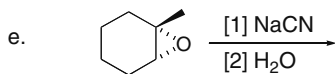
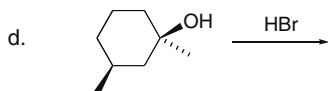
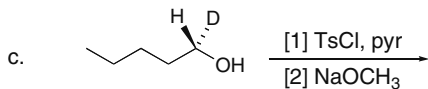
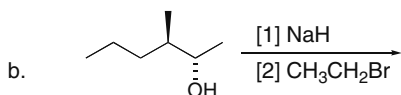
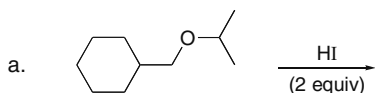
Chapter 9-4

Practice Test on Chapter Review

1. Give the IUPAC name for each of the following compounds.

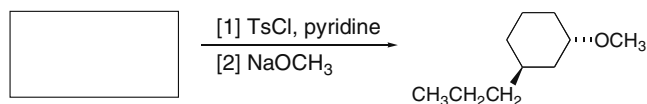


2. Draw the organic products formed in each reaction. Draw all stereogenic centers using wedges and dashes.

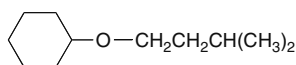


Alcohols, Ethers, and Epoxides 9–5

3. What starting material is needed for the following reaction?



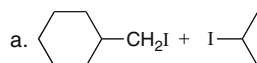
4. What alkoxide and alkyl halide are needed to make the following ether?



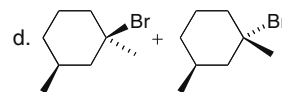
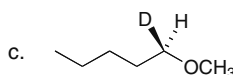
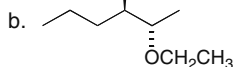
Answers to Practice Test

1. a. 3-ethoxy-2-methylhexane

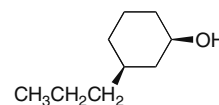
2.



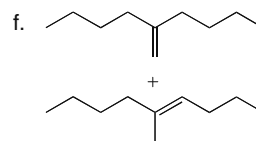
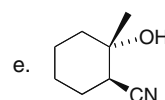
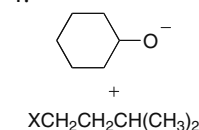
b. 4-ethyl-7-methyl-3-octanol



3.



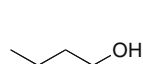
4.



Answers to Problems

9.1 • **Alcohols** are classified as 1°, 2°, or 3°, depending on the number of carbon atoms bonded to the carbon with the OH group.

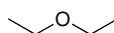
• **Symmetrical ethers** have two identical R groups, and **unsymmetrical ethers** have R groups that are different.



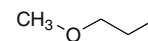
1° alcohol



2° alcohol



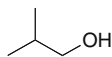
symmetrical ether



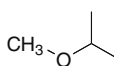
unsymmetrical ether



3° alcohol



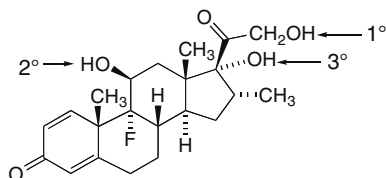
1° alcohol



unsymmetrical ether

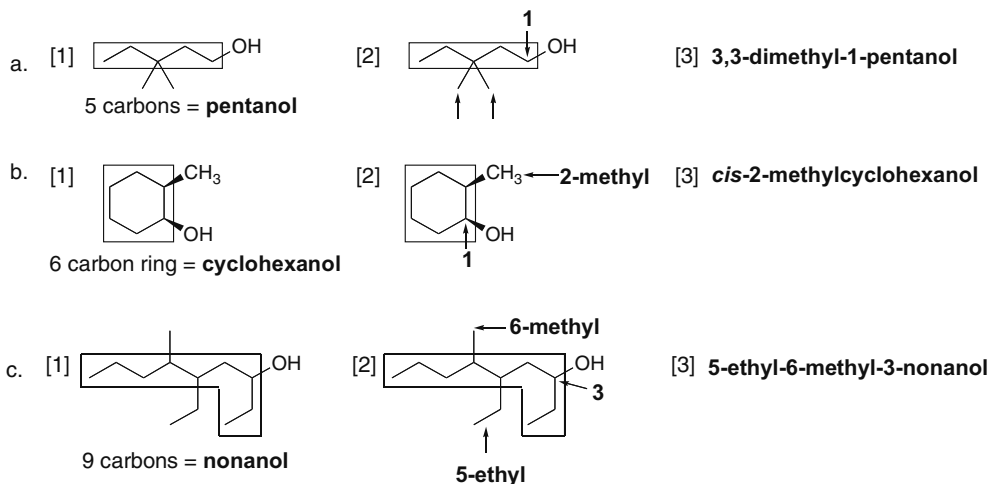
Chapter 9–6

9.2 Use the definitions in Answer 9.1.



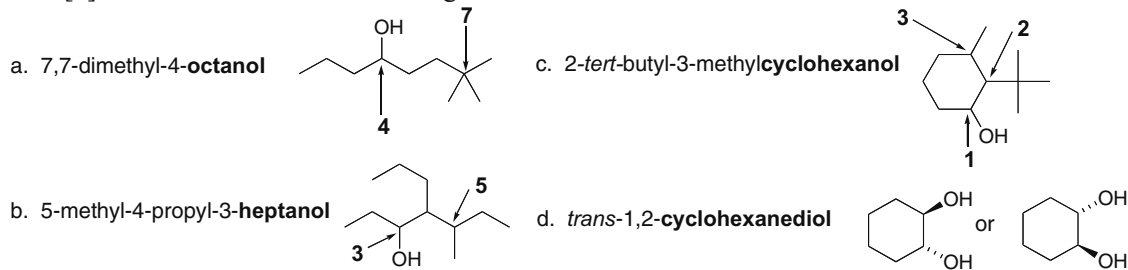
9.3 To name an alcohol:

- [1] **Find the longest chain that has the OH group as a substituent.** Name the molecule as a derivative of that number of carbons by changing the *-e* ending of the alkane to the suffix *-ol*.
- [2] **Number the carbon chain to give the OH group the lower number.** When the OH group is bonded to a ring, the ring is numbered beginning with the OH group, and the “1” is usually omitted.
- [3] Apply the other rules of nomenclature to complete the name.



9.4 To work backwards from a name to a structure:

- [1] Find the parent name and draw its structure.
- [2] Add the substituents to the long chain.



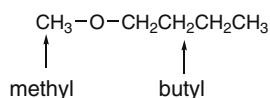
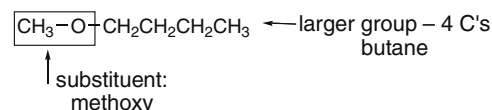
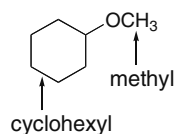
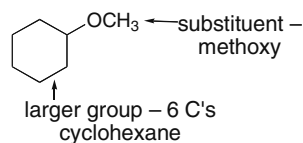
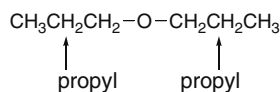
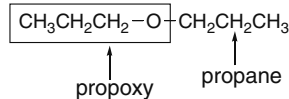
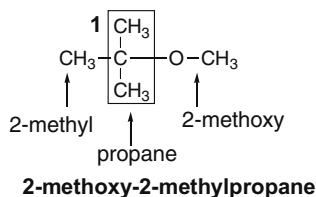
Alcohols, Ethers, and Epoxides 9–7

9.5 To name simple ethers:

- [1] Name both alkyl groups bonded to the oxygen.
- [2] Arrange these names alphabetically and add the word **ether**. For symmetrical ethers, name the alkyl group and add the prefix **di**.

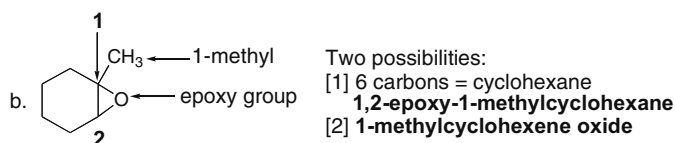
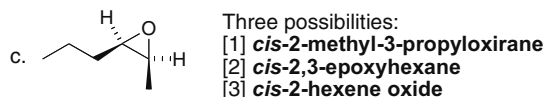
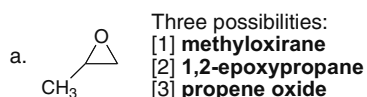
To name ethers using the IUPAC system:

- [1] Find the two alkyl groups bonded to the ether oxygen. The smaller chain becomes the substituent, named as an alkoxy group.
- [2] Number the chain to give the lower number to the first substituent.

a. common name:**butyl methyl ether****IUPAC name:****1-methoxybutane****b. common name:****cyclohexyl methyl ether****IUPAC name:****methoxycyclohexane****c. common name:****dipropyl ether****IUPAC name:****1-propoxypropane****9.6 Name the ether using the rules from Answer 9.5.****9.7 Three ways to name epoxides:**

- [1] Epoxides are named as derivatives of oxirane, the simplest epoxide.
- [2] Epoxides can be named by considering the oxygen as a substituent called an **epoxy** group, bonded to a hydrocarbon chain or ring. Use two numbers to designate which two atoms the oxygen is bonded to.
- [3] Epoxides can be named as **alkene oxides** by mentally replacing the epoxide oxygen by a double bond. Name the alkene (Chapter 10) and add the word **oxide**.

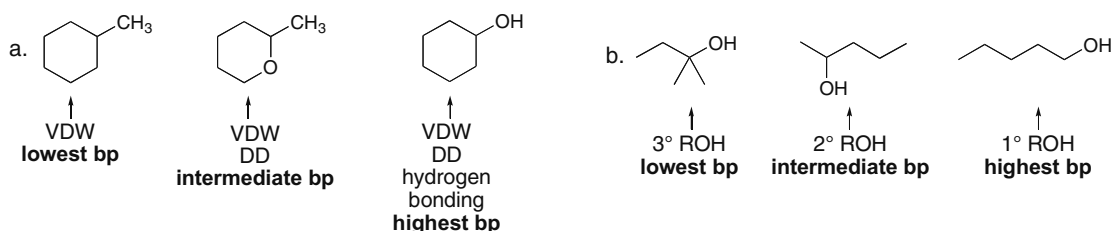
Chapter 9-8



9.8 Two rules for boiling point:

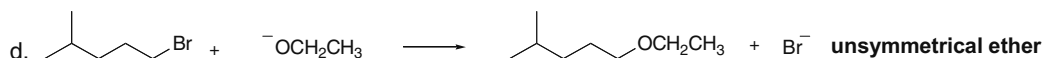
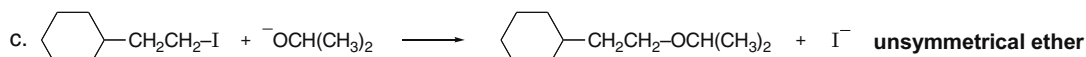
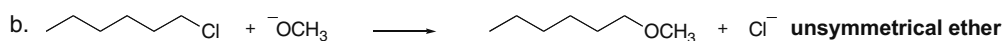
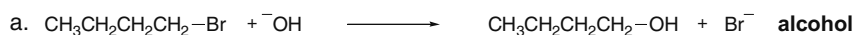
[1] **The stronger the forces the higher the bp.**

[2] **Bp increases as the extent of the hydrogen bonding increases.** For alcohols with the same number of carbon atoms: hydrogen bonding and bp's increase: $3^\circ \text{ ROH} < 2^\circ \text{ ROH} < 1^\circ \text{ ROH}$.



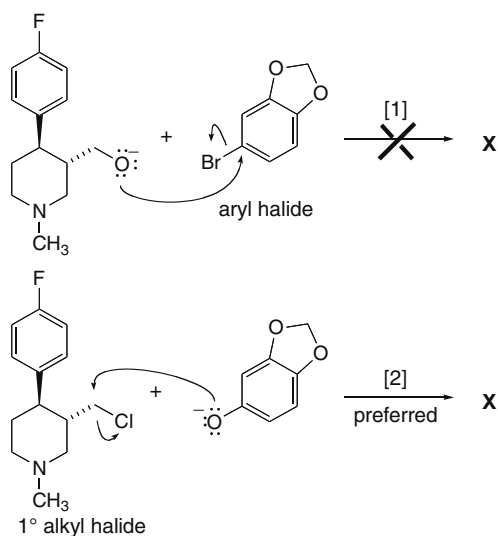
9.9 Strong nucleophiles (like CN^-) favor $\text{S}_\text{N}2$ reactions. The use of crown ethers in nonpolar solvents increases the nucleophilicity of the anion, and this increases the rate of the $\text{S}_\text{N}2$ reaction. The nucleophile does not appear in the rate equation for the $\text{S}_\text{N}1$ reaction. Nonpolar solvents cannot solvate carbocations, so this disfavors $\text{S}_\text{N}1$ reactions as well.

9.10 Draw the products of substitution in the following reactions by substituting OH or OR for X in the starting material.

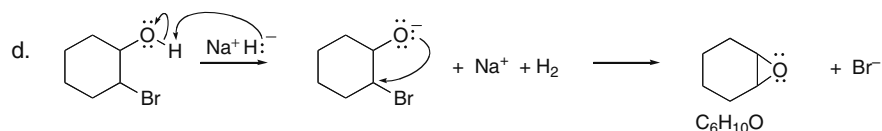
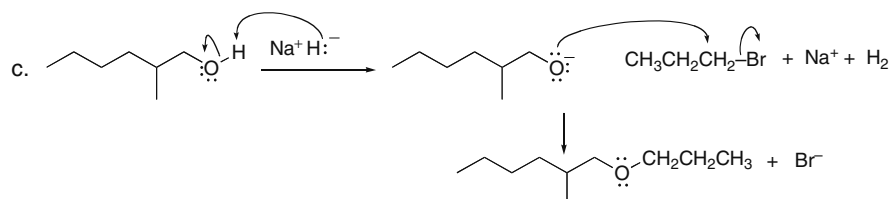
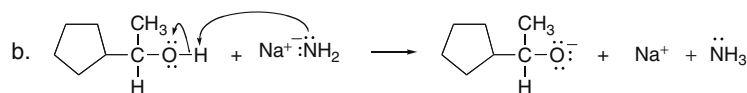
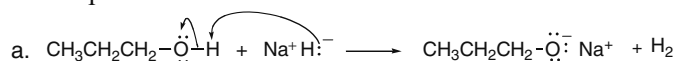


9.11 Two possible routes to **X** are shown. Path [2] with a 1° alkyl halide is preferred. Path [1] cannot occur because the leaving group would be bonded to an sp^2 hybridized C, making it an unreactive aryl halide.

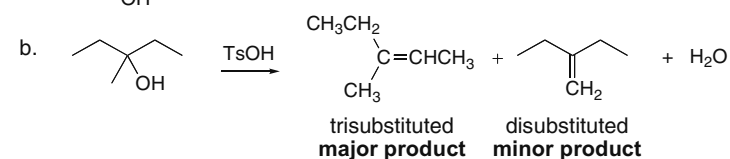
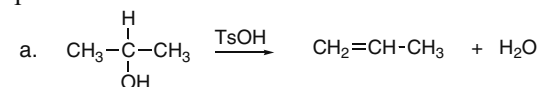
Alcohols, Ethers, and Epoxides 9-9



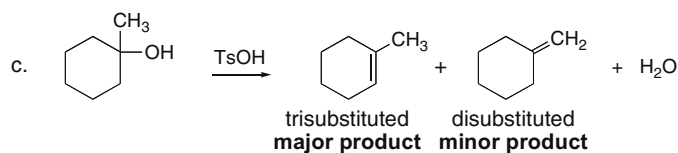
9.12 NaH and NaNH₂ are strong bases that will remove a proton from an alcohol, creating a nucleophile.



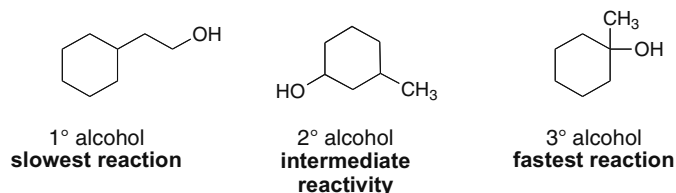
9.13 Dehydration follows the Zaitsev rule, so the more stable, more substituted alkene is the major product.



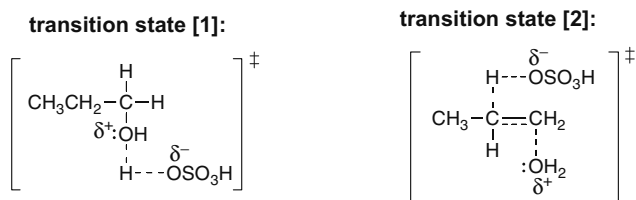
Chapter 9–10



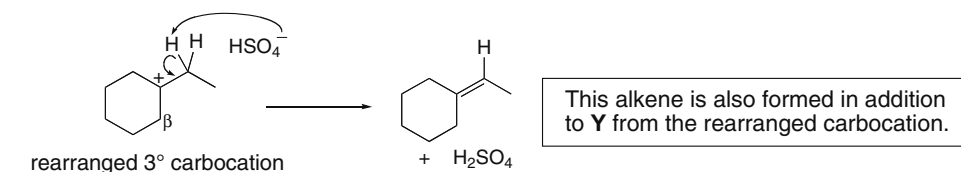
9.14 The rate of dehydration increases as the number of R groups increases.



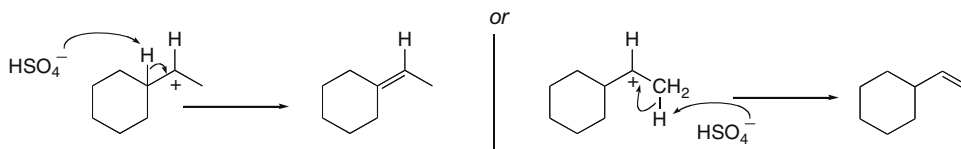
9.15



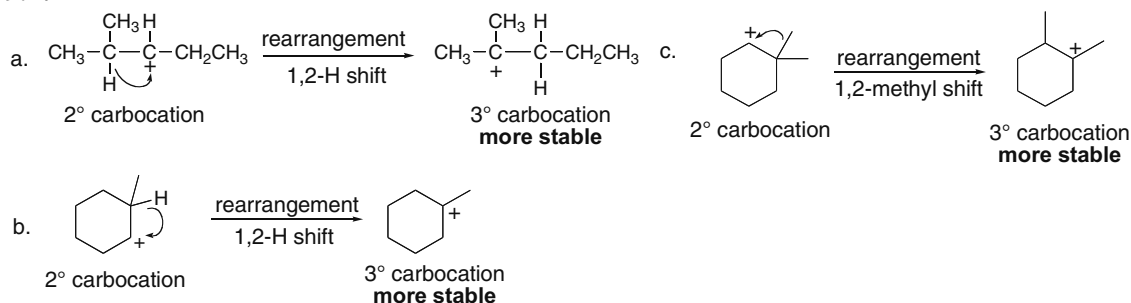
9.16



The initially formed 2° carbocation gives two alkenes:

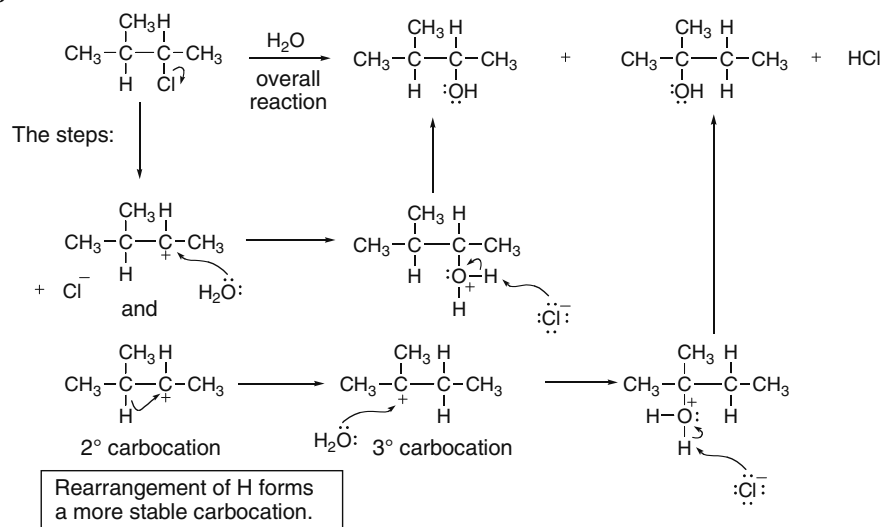


9.17

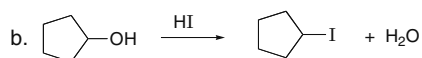
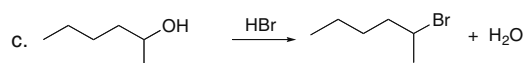
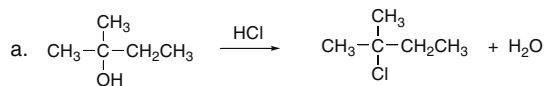


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9.18

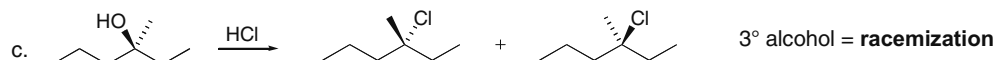
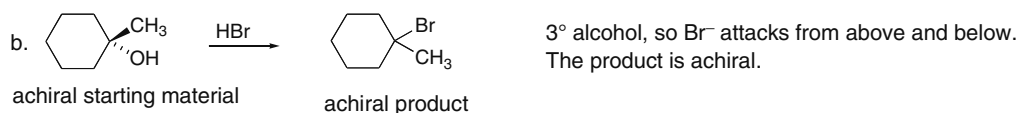
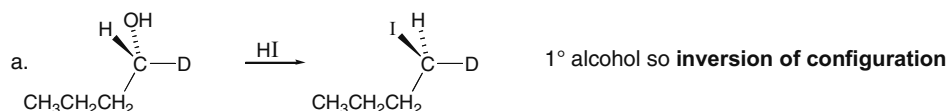


9.19



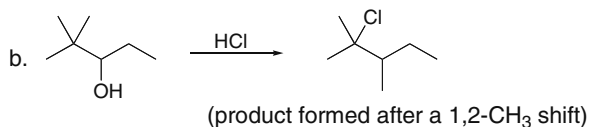
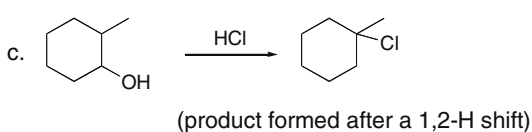
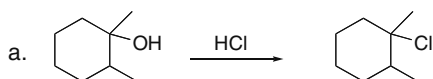
9.20 • **CH₃OH and 1° alcohols** follow an S_N2 mechanism, which results in inversion of configuration.

- **Secondary (2°) and 3° alcohols** follow an S_N1 mechanism, which results in racemization at a stereogenic center.

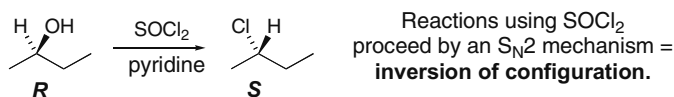


Chapter 9–12

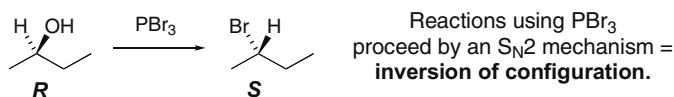
9.21



9.22 Substitution reactions of alcohols using SOCl₂ proceed by an S_N2 mechanism. Therefore, there is **inversion of configuration** at a stereogenic center.

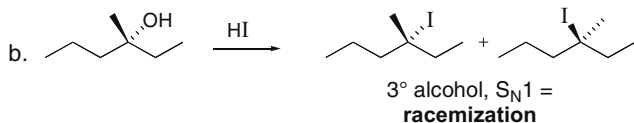
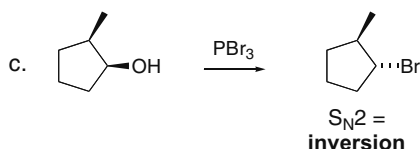
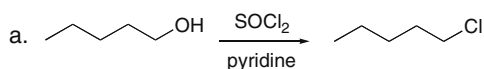


9.23 Substitution reactions of alcohols using PBr₃ proceed by an S_N2 mechanism. Therefore, there is inversion of configuration at a stereogenic center.



9.24 Stereochemistry for conversion of ROH to RX by reagent:

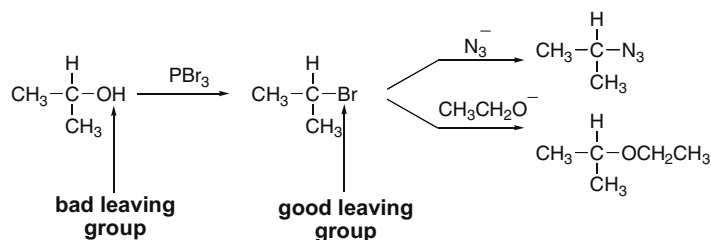
- [1] **HX**—with 1°, S_N2, so inversion of configuration; with 2° and 3°, S_N1, so racemization.
- [2] **SOCl₂**—S_N2, so inversion of configuration.
- [3] **PBr₃**—S_N2, so inversion of configuration.



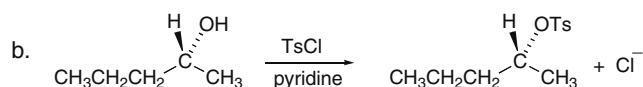
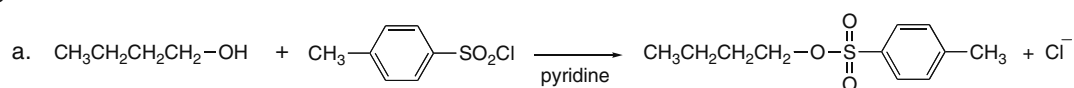
9.25 To do a two-step synthesis with this starting material:

- [1] Convert the OH group into a good leaving group (by using either PBr₃ or SOCl₂).
- [2] Add the nucleophile for the S_N2 reaction.

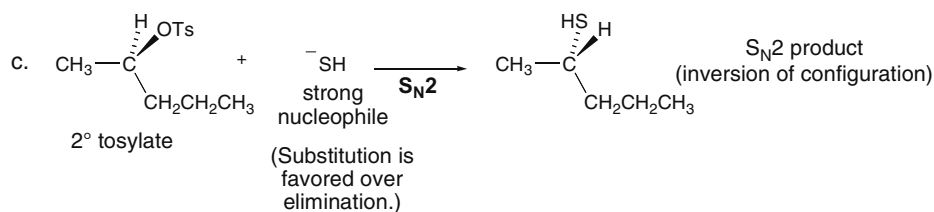
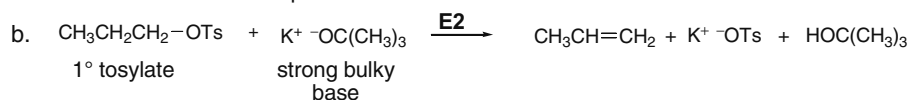
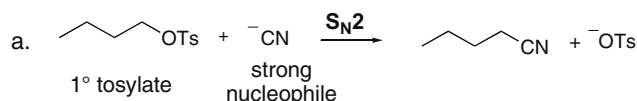
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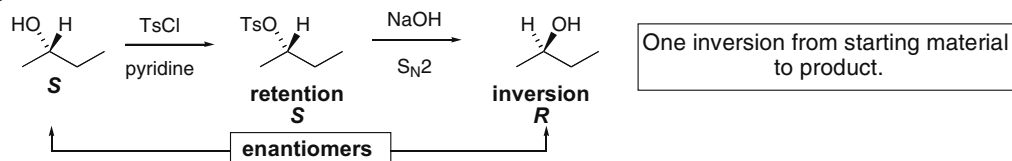
9.26



9.27



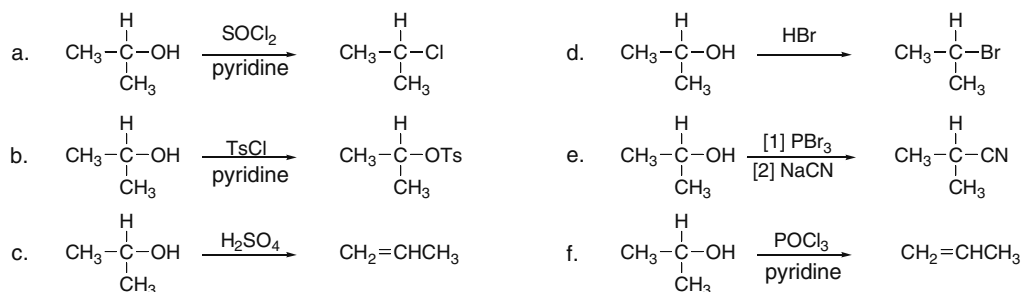
9.28



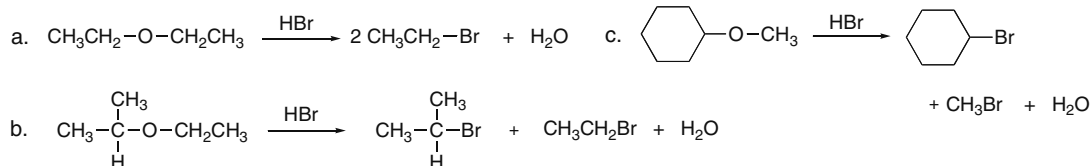
9.29 These reagents can be classified as:

- [1] SOCl_2 , PBr_3 , HCl , and HBr replace OH with X by a substitution reaction.
- [2] Tosyl chloride (TsCl) makes OH a better leaving group by converting it to OTs.
- [3] Strong acids (H_2SO_4) and POCl_3 (pyridine) result in elimination by dehydration.

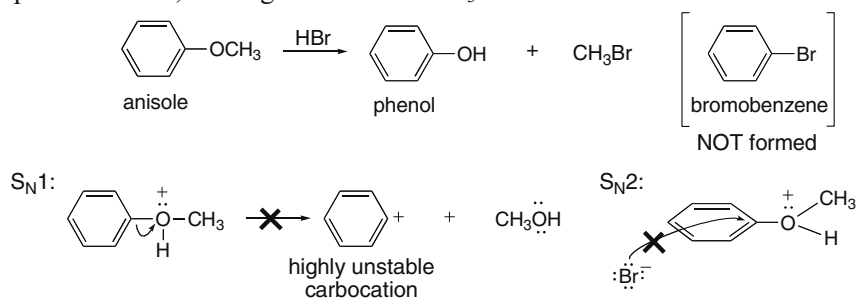
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9.30

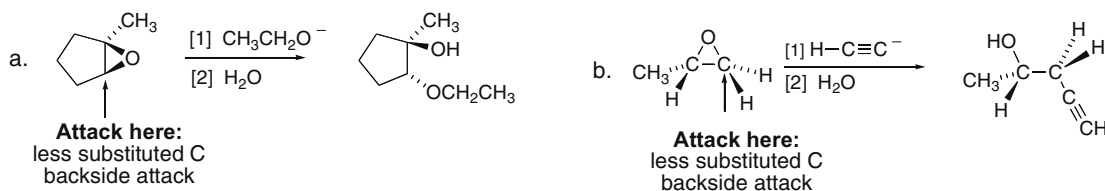


9.31 Ether cleavage can occur by either an $\text{S}_{\text{N}}1$ or $\text{S}_{\text{N}}2$ mechanism, but neither mechanism can occur when the ether O atom is bonded to an aromatic ring. An $\text{S}_{\text{N}}1$ reaction would require formation of a highly unstable carbocation on a benzene ring, a process that does not occur. An $\text{S}_{\text{N}}2$ reaction would require backside attack through the plane of the aromatic ring, which is also not possible. Thus, cleavage of the Ph-OCH_3 bond does not occur.

**9.32** Two rules for reaction of an epoxide:

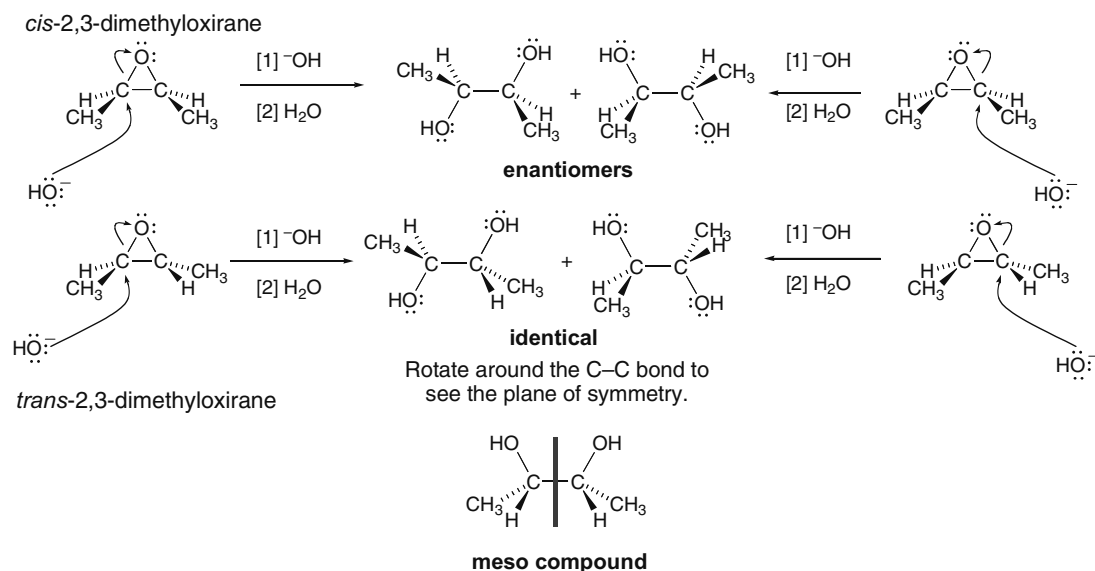
[1] Nucleophiles attack from the **back side** of the epoxide.

[2] Negatively charged nucleophiles attack at the **less substituted carbon**.



Alcohols, Ethers, and Epoxides 9-15

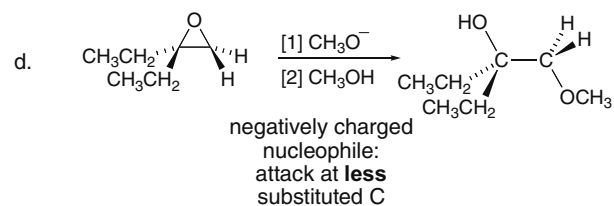
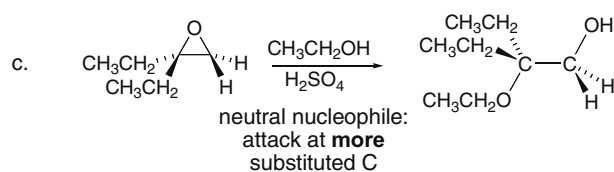
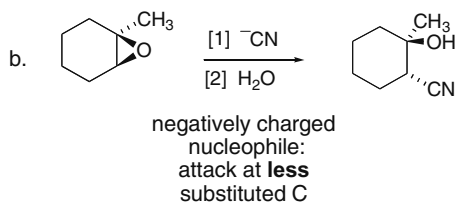
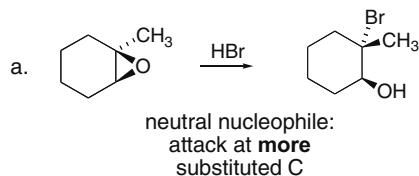
9.33 In both isomers, OH^- attacks from the back side at either C–O bond.



9.34 Remember the difference between negatively charged nucleophiles and neutral nucleophiles:

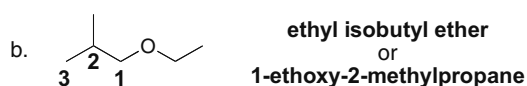
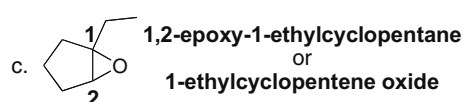
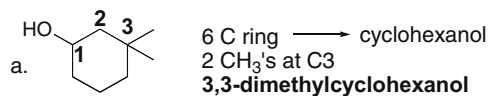
- **Negatively charged nucleophiles attack first**, followed by protonation, and the nucleophile attacks at the **less substituted carbon**.
- **Neutral nucleophiles have protonation first**, followed by nucleophilic attack at the **more substituted carbon**.

But, trans or anti products are always formed regardless of the nucleophile.



Chapter 9–16

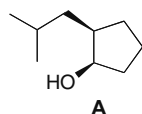
9.35



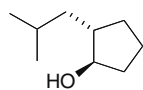
9.36

a. (1*R*,2*R*)-2-isobutylcyclopentanol

b. 2° alcohol

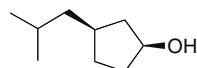


c. stereoisomer



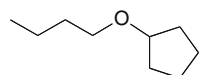
(1*R*,2*S*)-2-isobutylcyclopentanol

d. constitutional isomer

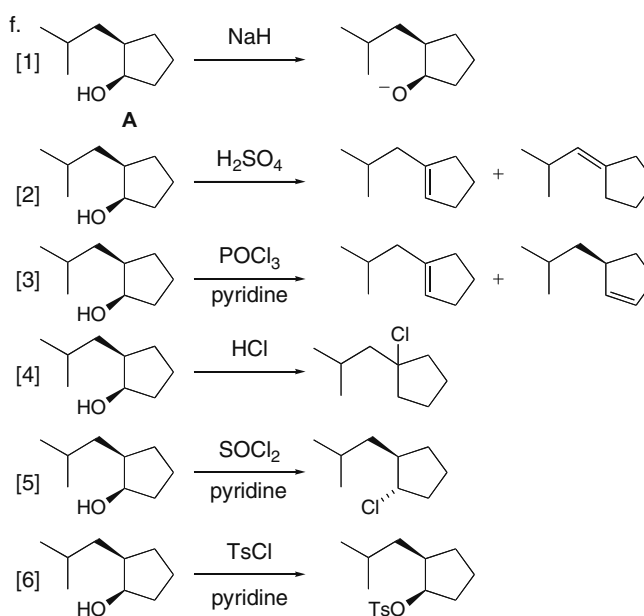


(1*S*,3*S*)-3-isobutylcyclopentanol

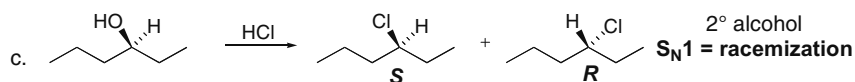
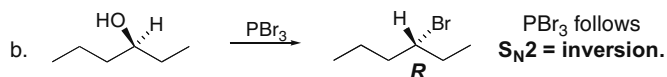
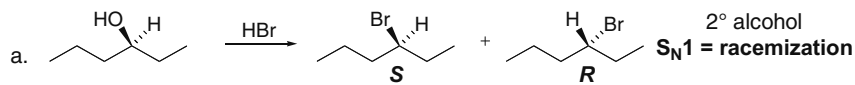
e. constitutional isomer with an ether



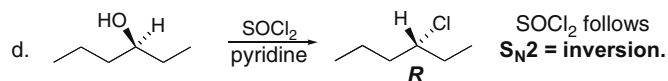
butoxycyclopentane



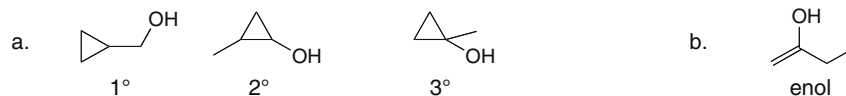
9.37



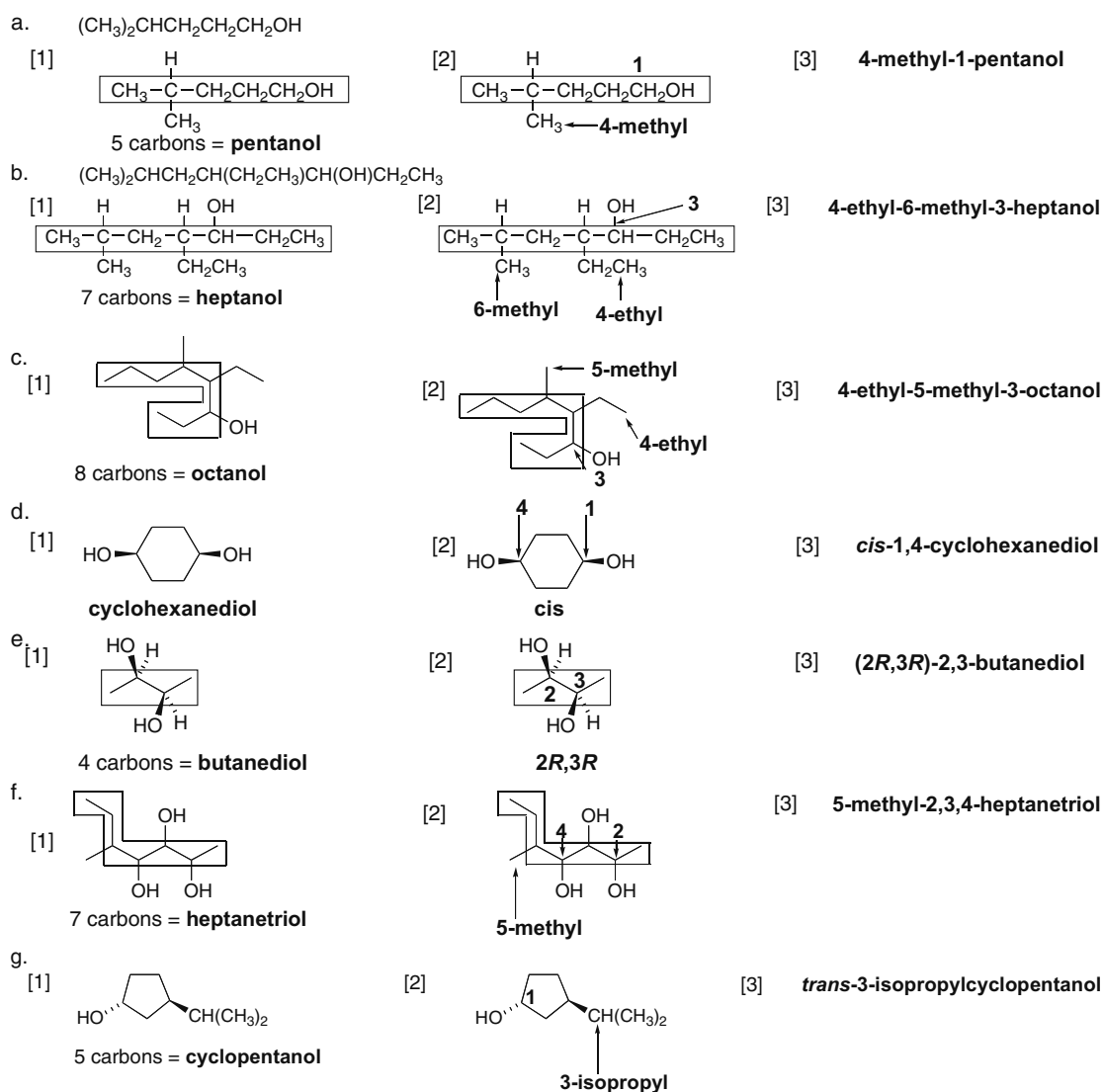
Alcohols, Ethers, and Epoxides 9-17



9.38 Draw the structure of each alcohol, using the definitions in Answer 9.1.

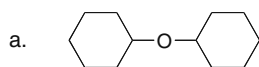
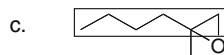
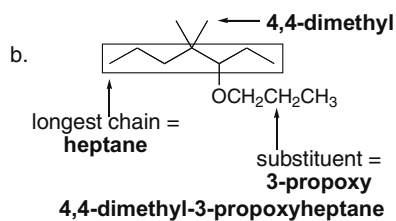
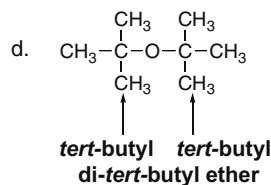


9.39 Use the directions from Answer 9.3.



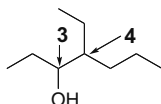
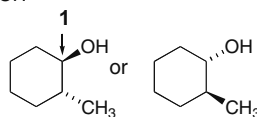
Chapter 9–18

9.40 Use the rules from Answers 9.5 and 9.7.

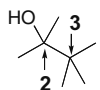
**dicyclohexyl ether****1,2-epoxy-2-methylhexane**
or **2-butyl-2-methyloxirane**
or **2-methylhexene oxide**

9.41 Use the directions from Answer 9.4.

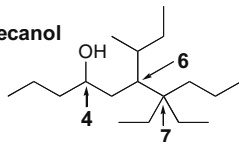
a. 4-ethyl-3-heptanol

b. *trans*-2-methylcyclohexanol

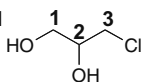
c. 2,3,3-trimethyl-2-butanol



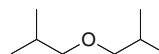
d. 6-sec-butyl-7,7-diethyl-4-decanol



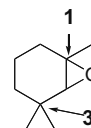
e. 3-chloro-1,2-propanediol



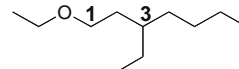
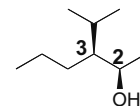
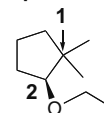
f. diisobutyl ether



g. 1,2-epoxy-1,3,3-trimethylcyclohexane



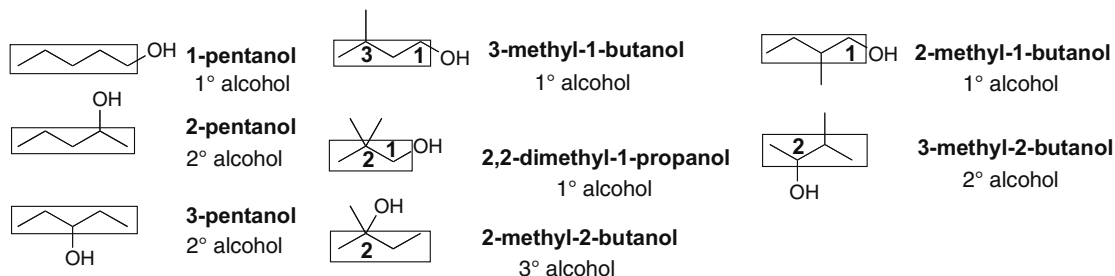
h. 1-ethoxy-3-ethylheptane

i. (2*R*,3*S*)-3-isopropyl-2-hexanolj. (2*S*)-2-ethoxy-1,1-dimethylcyclopentane

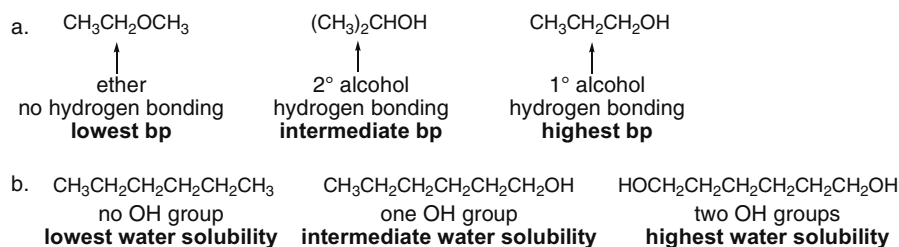
Alcohols, Ethers, and Epoxides 9–19

9.42

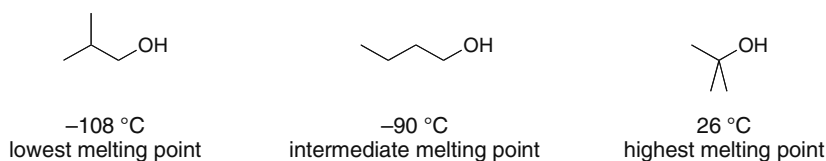
Eight constitutional isomers of molecular formula $C_5H_{12}O$ containing an OH group:



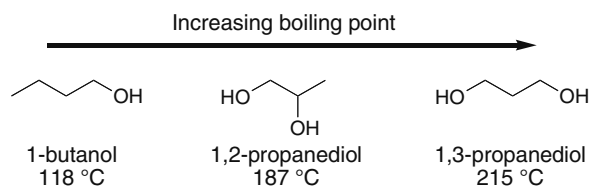
9.43 Use the boiling point rules from Answer 9.8.



9.44 Melting points depend on intermolecular forces and symmetry. $(CH_3)_2CHCH_2OH$ has a lower melting point than $CH_3CH_2CH_2CH_2OH$ because branching decreases surface area and makes $(CH_3)_2CHCH_2OH$ less symmetrical so it packs less well. Although $(CH_3)_3COH$ has the most branching and least surface area, it is the most symmetrical, so it packs best in a crystalline lattice, giving it the highest melting point.



9.45 Stronger intermolecular forces increase boiling point. All of the compounds can hydrogen bond, but both diols have more opportunity for hydrogen bonding since they have two OH groups, making their bp's higher than the bp of 1-butanol. 1,2-Propanediol can also intramolecularly hydrogen bond. Intramolecular hydrogen bonding decreases the amount of intermolecular hydrogen bonding, so the bp of 1,2-propanediol is somewhat lower.

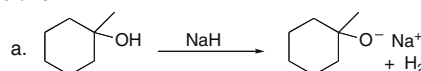
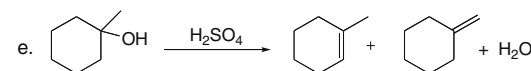
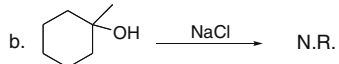
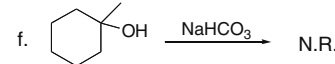
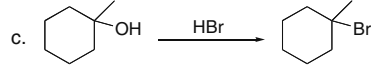
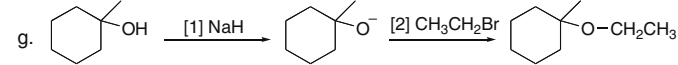
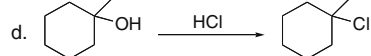
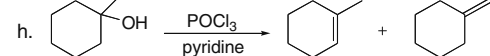


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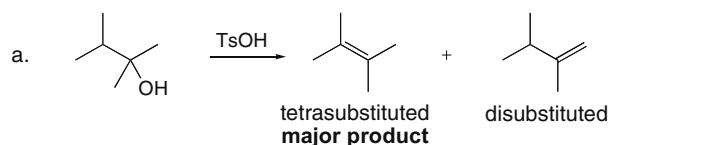
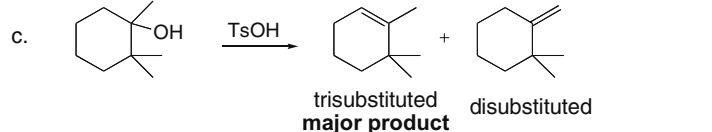
9.46

- a. $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH} \xrightarrow{\text{H}_2\text{SO}_4} \text{CH}_3\text{CH}=\text{CH}_2 + \text{H}_2\text{O}$
- b. $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH} \xrightarrow{\text{NaH}} \text{CH}_3\text{CH}_2\text{CH}_2\text{O}^- \text{Na}^+ + \text{H}_2$
- c. $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH} \xrightarrow[\text{ZnCl}_2]{\text{HCl}} \text{CH}_3\text{CH}_2\text{CH}_2\text{Cl} + \text{H}_2\text{O}$
- d. $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH} \xrightarrow{\text{HBr}} \text{CH}_3\text{CH}_2\text{CH}_2\text{Br} + \text{H}_2\text{O}$
- e. $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH} \xrightarrow[\text{pyridine}]{\text{SOCl}_2} \text{CH}_3\text{CH}_2\text{CH}_2\text{Cl}$
- f. $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH} \xrightarrow{\text{PBr}_3} \text{CH}_3\text{CH}_2\text{CH}_2\text{Br}$
- g. $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH} \xrightarrow[\text{pyridine}]{\text{TsCl}} \text{CH}_3\text{CH}_2\text{CH}_2\text{OTs}$
- h. $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH} \xrightarrow{[1] \text{ NaH}} \text{CH}_3\text{CH}_2\text{CH}_2\text{O}^- \text{Na}^+ \xrightarrow{[2] \text{ CH}_3\text{CH}_2\text{Br}} \text{CH}_3\text{CH}_2\text{CH}_2\text{OCH}_2\text{CH}_3$
- i. $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH} \xrightarrow{[1] \text{ TsCl}} \text{CH}_3\text{CH}_2\text{CH}_2\text{OTs} \xrightarrow{[2] \text{ NaSH}} \text{CH}_3\text{CH}_2\text{CH}_2\text{SH}$

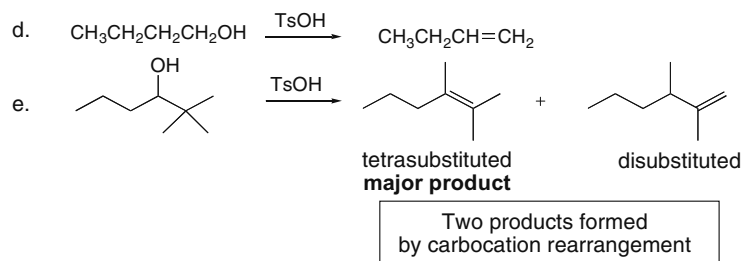
9.47

- a.  e. 
- b.  f. 
- c.  g. 
- d.  h. 

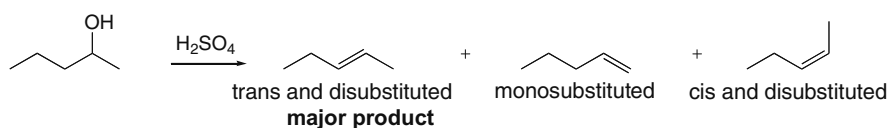
9.48 Dehydration follows the Zaitsev rule, so the more stable, more substituted alkene is the major product.

- a. 
- b. 
- c. 

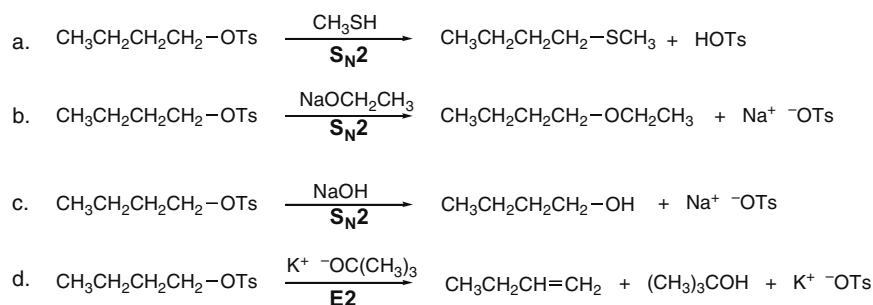
Alcohols, Ethers, and Epoxides 9-21



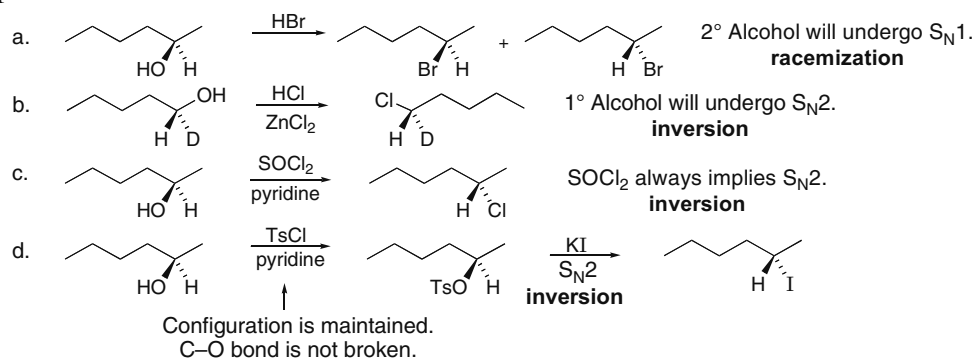
9.49 The most stable alkene is the major product.



9.50 OTs is a good leaving group and will easily be replaced by a nucleophile. Draw the products by substituting the nucleophile in the reagent for OTs in the starting material.

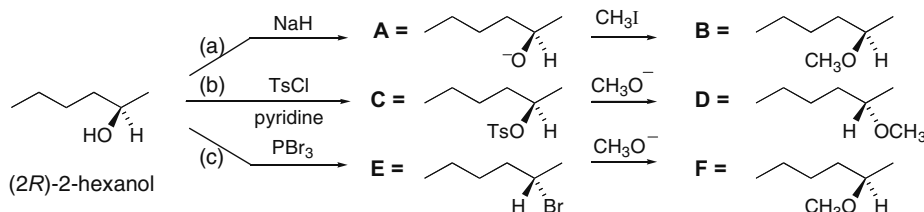


9.51



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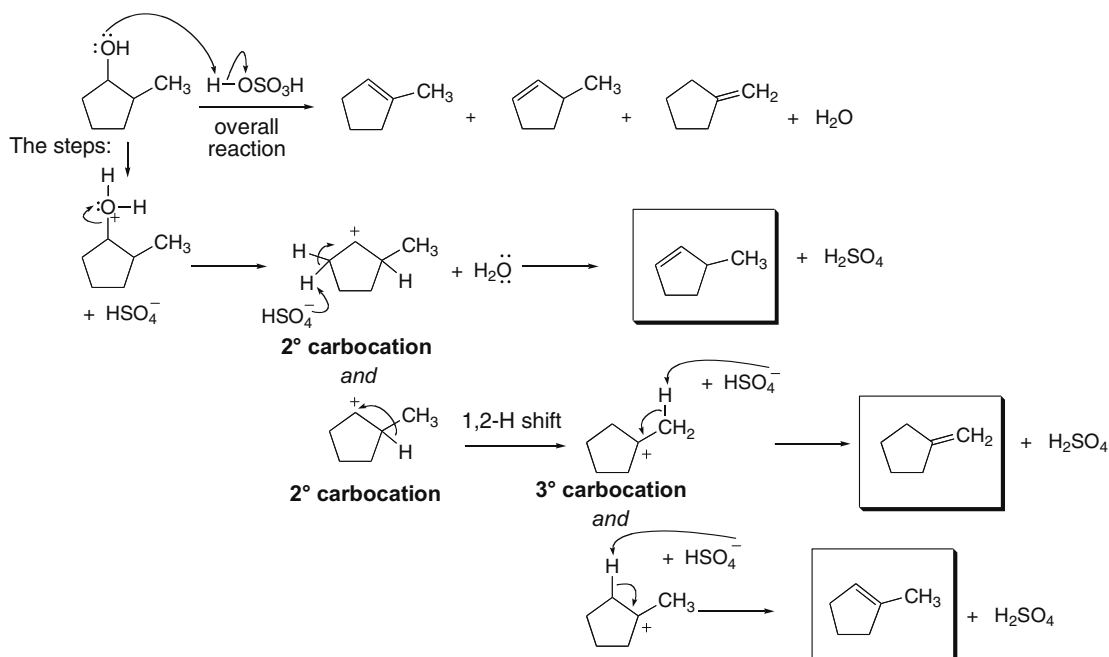
9.52



Routes (a) and (c) given identical products, labeled **B** and **F**.

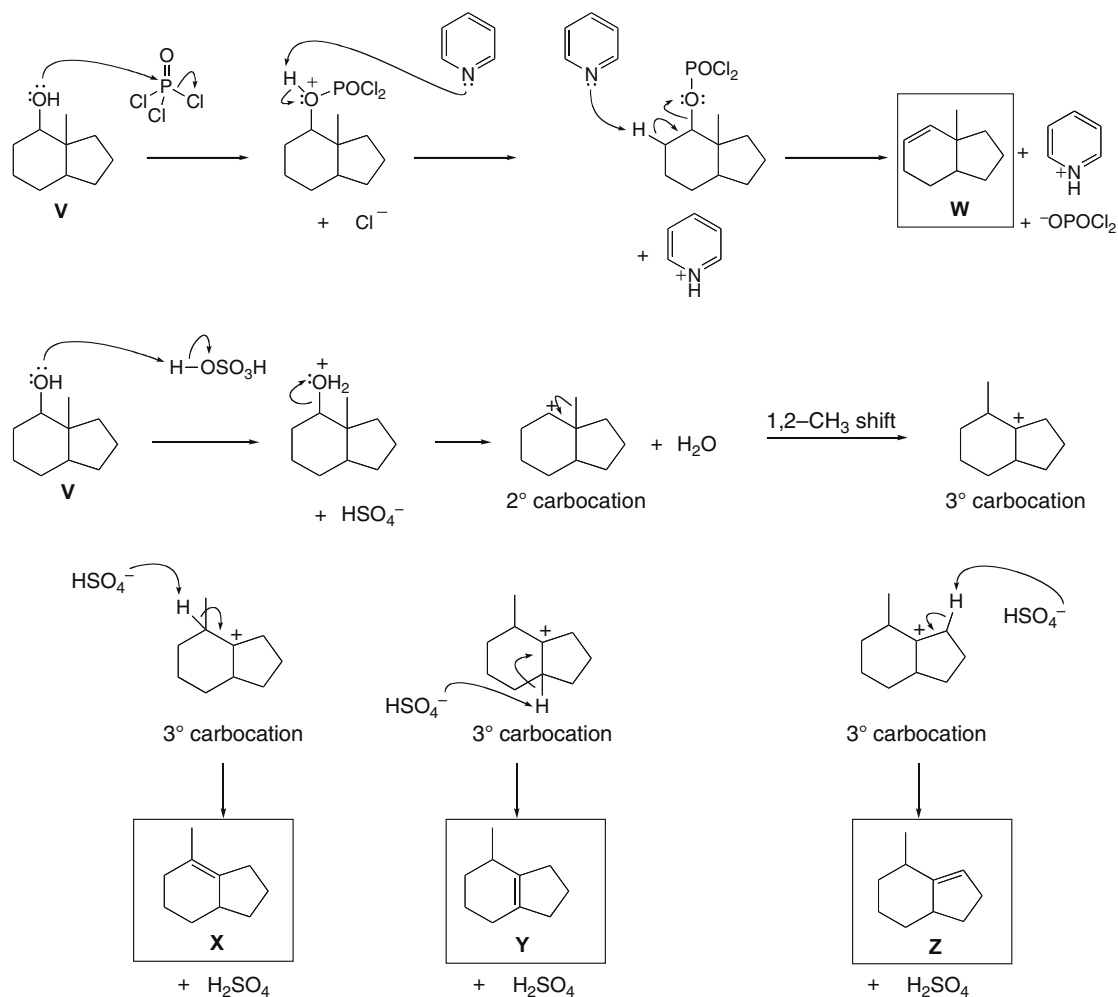
9.53 Acid-catalyzed dehydration follows an E1 mechanism for 2° and 3° ROH with an added step to make a good leaving group. The three steps are:

- [1] Protonate the oxygen to make a good leaving group.
- [2] Break the C–O bond to form a carbocation.
- [3] Remove a β hydrogen to form the π bond.



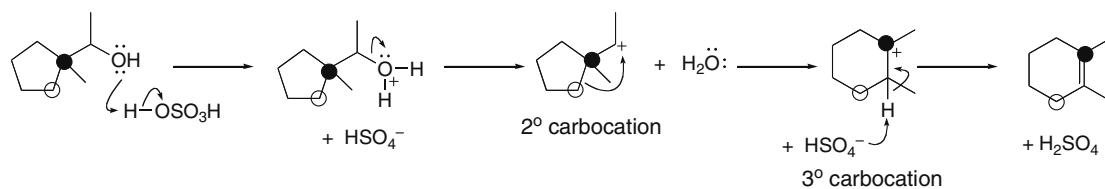
9.54 With POCl_3 (pyridine), elimination occurs by an E2 mechanism. Since only one carbon has a β hydrogen, only one product is formed. With H_2SO_4 , the mechanism of elimination is E1. A 2° carbocation rearranges to a 3° carbocation, which has three pathways for elimination.

Alcohols, Ethers, and Epoxides 9-23

**9.55** To draw the mechanism:

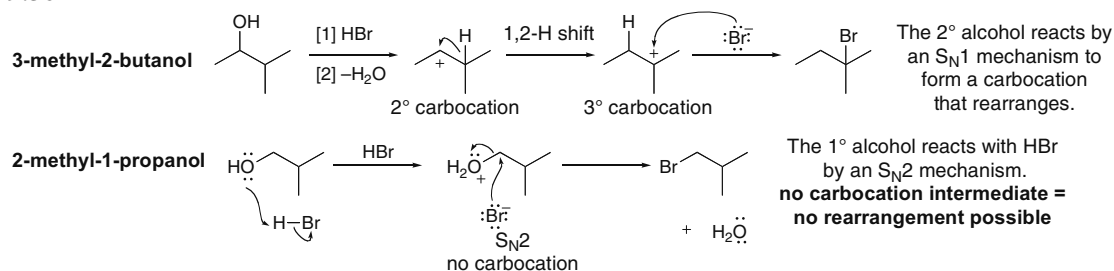
- [1] Protonate the oxygen to make a good leaving group.
- [2] Break the C–O bond to form a carbocation.
- [3] Look for possible rearrangements to make a more stable carbocation.
- [4] Remove a β hydrogen to form the π bond.

Dark and light circles are meant to show where the carbons in the starting material appear in the product.

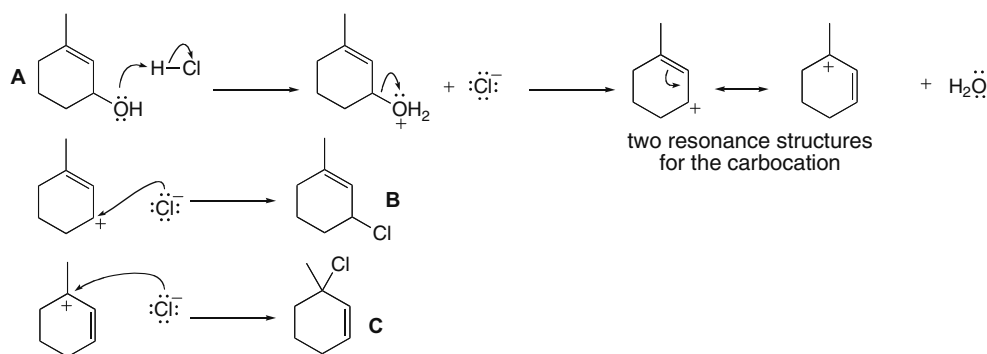


Chapter 9–24

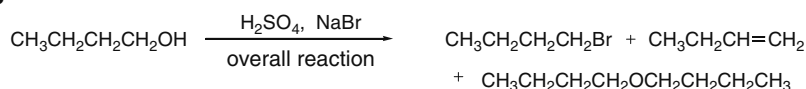
9.56



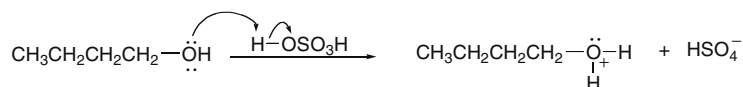
9.57



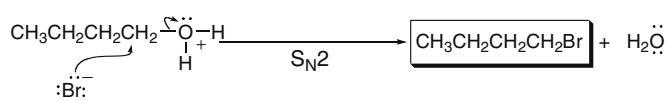
9.58



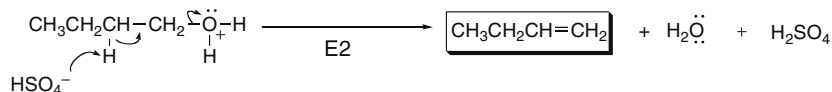
Step [1] for all products: Formation of a good leaving group



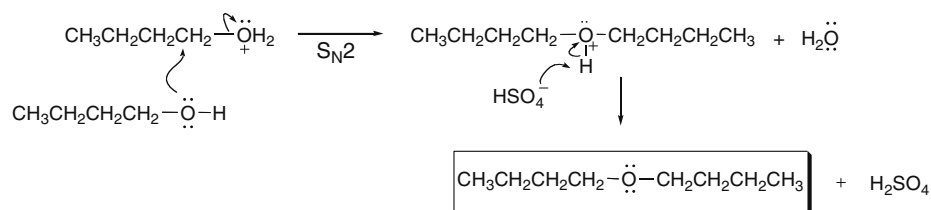
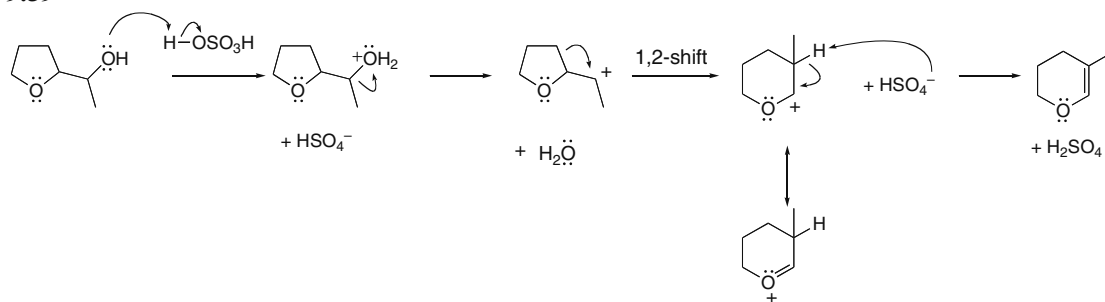
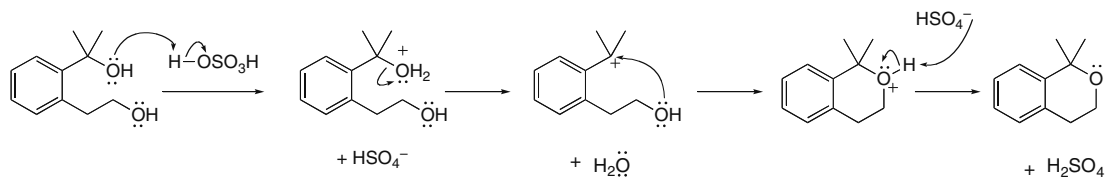
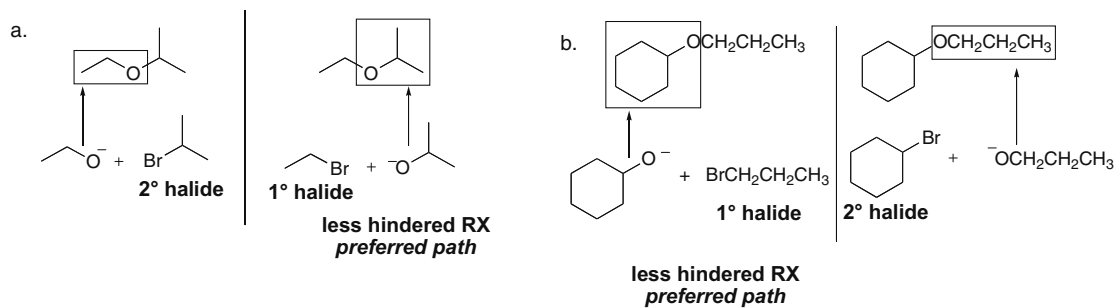
Formation of $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}$:



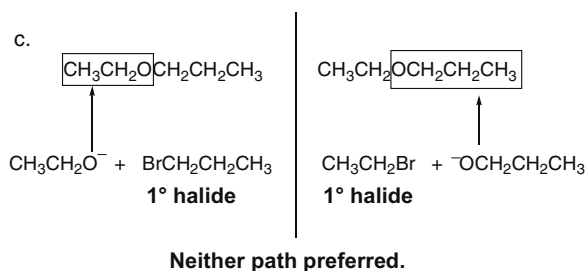
Formation of $\text{CH}_3\text{CH}_2\text{CH}=\text{CH}_2$:



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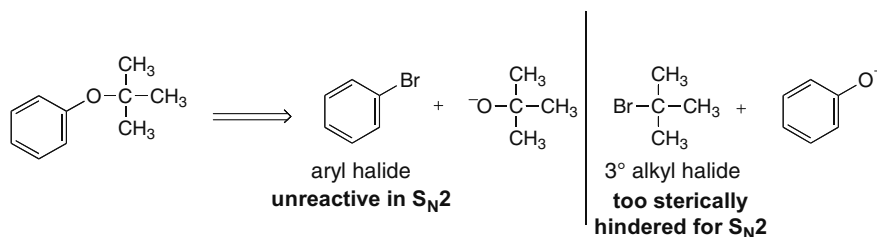
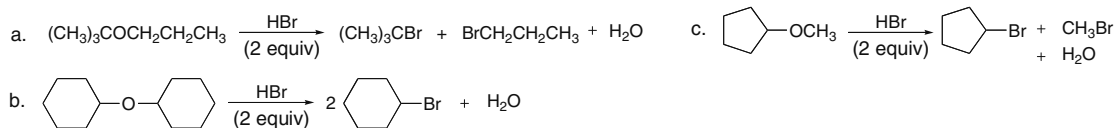
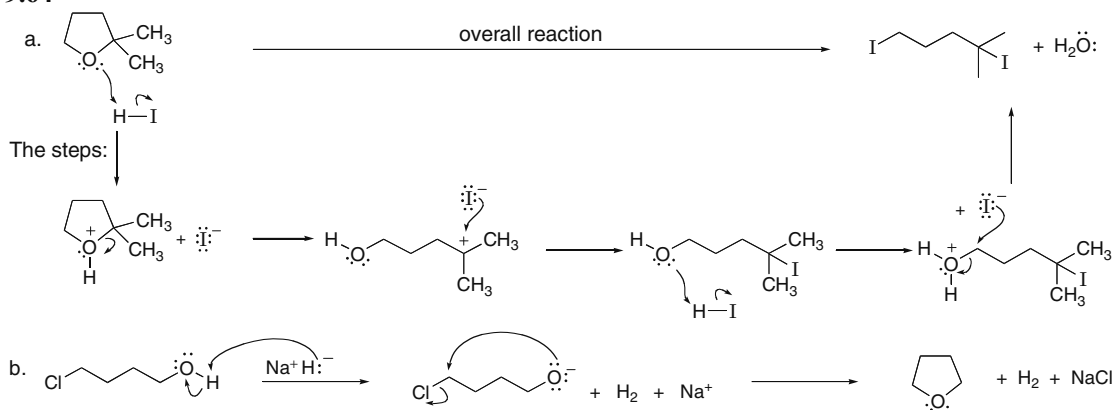
Ether formation (from the protonated alcohol):**9.59****9.60****9.61**

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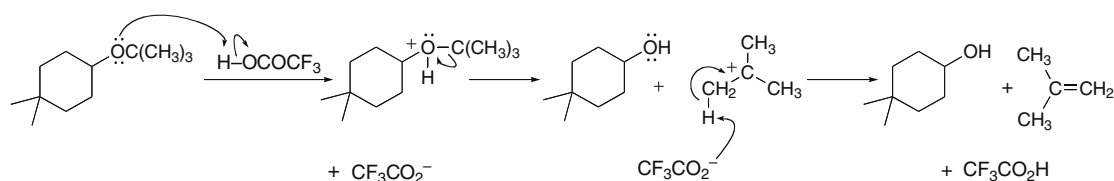
9.62 A tertiary halide is too hindered and an aryl halide too unreactive to undergo a Williamson ether synthesis.

Two possible sets of starting materials:

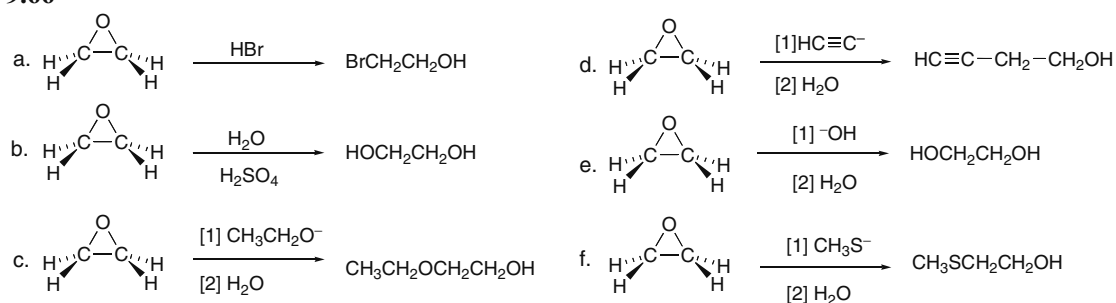
**9.63****9.64**

Alcohols, Ethers, and Epoxides 9-27

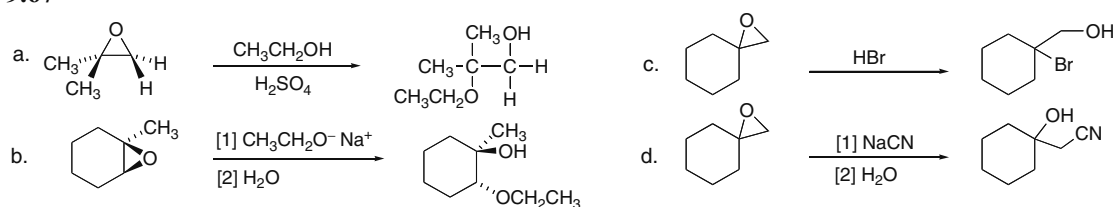
9.65



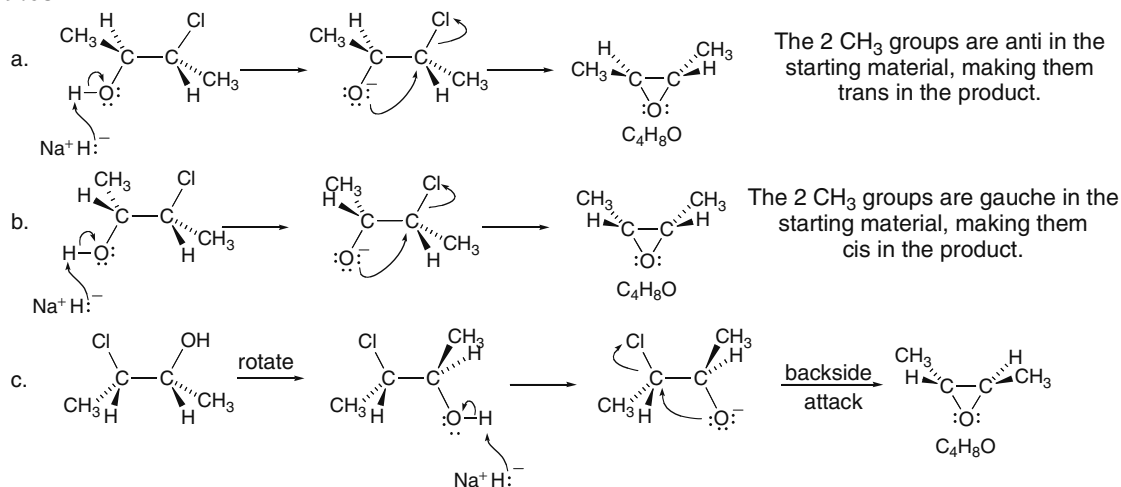
9.66



9.67

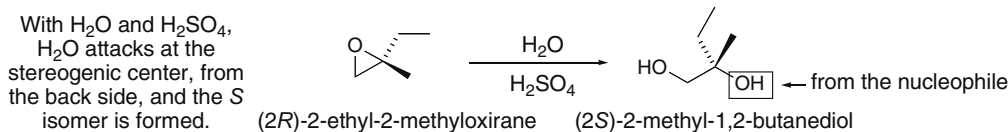
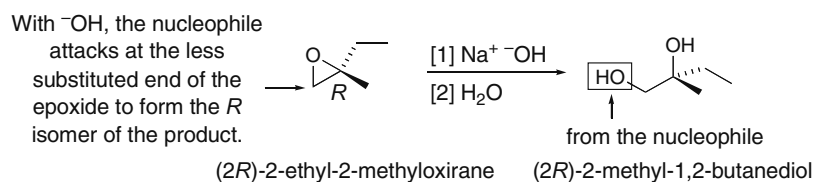
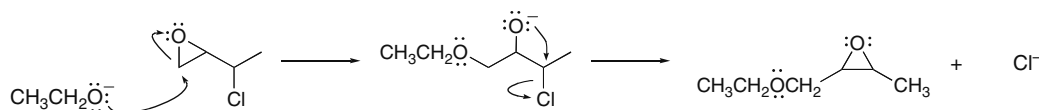
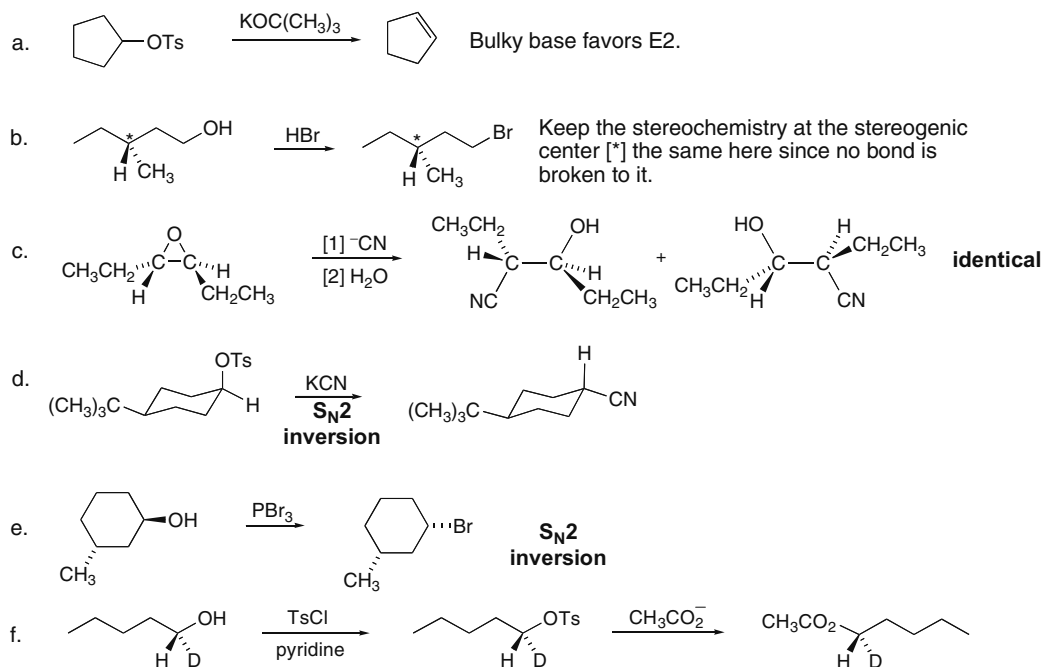


9.68

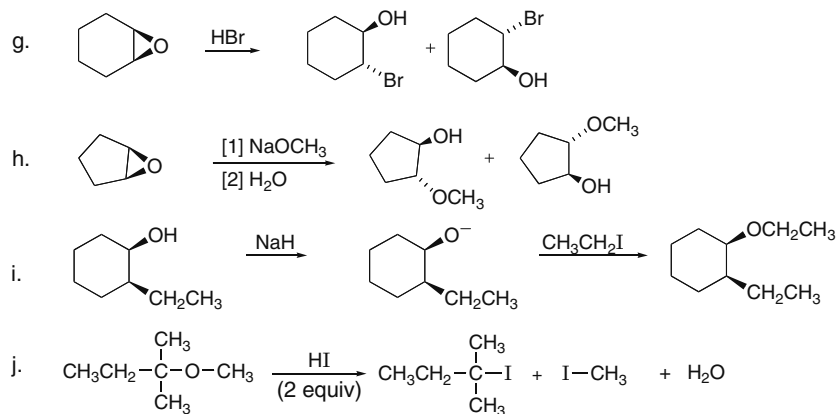


Chapter 9–28

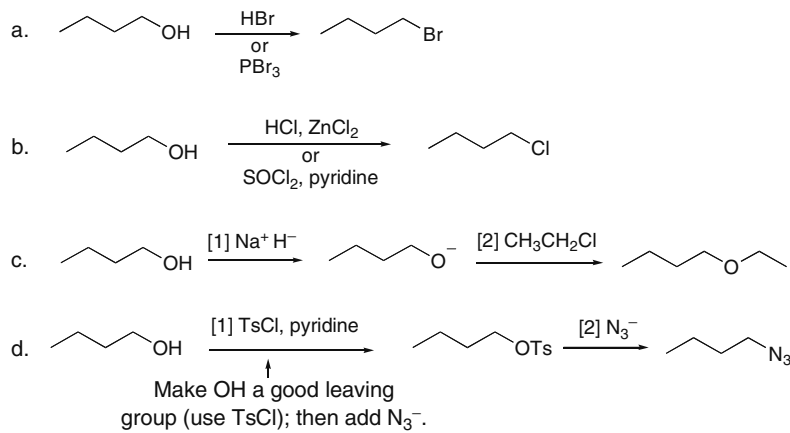
9.69 First, use the names to draw the structures of the starting material and both products. Because the product has two OH groups, one OH must come from the epoxide oxygen, and one must come from the nucleophile, either OH^- or H_2O .

**9.70****9.71**

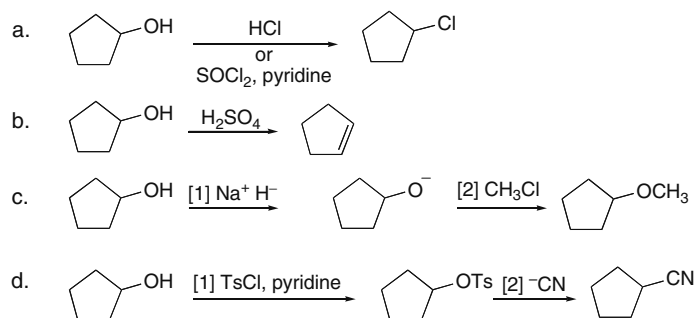
Alcohols, Ethers, and Epoxides 9-29



9.72



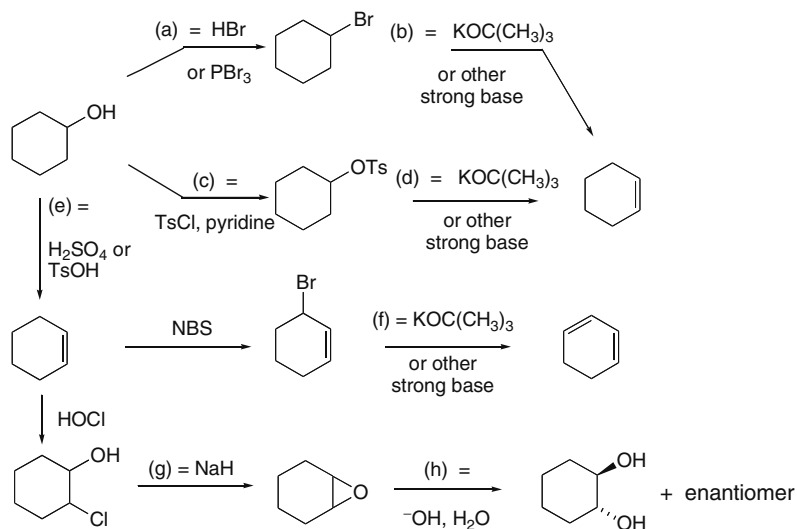
9.73



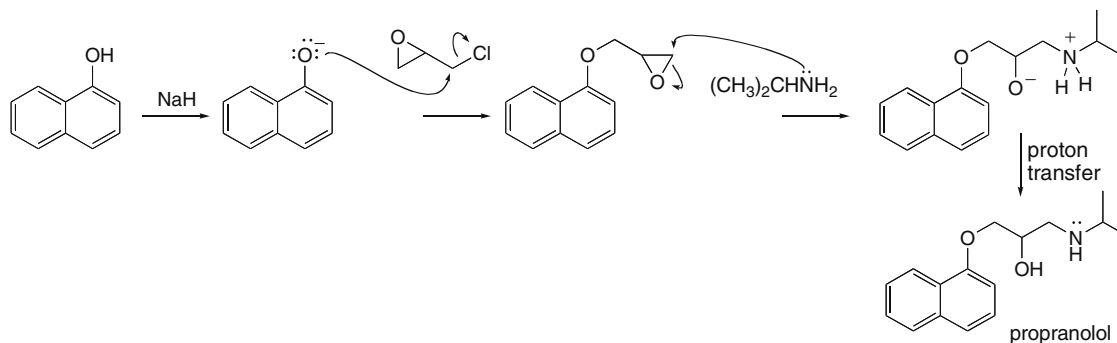
Make OH a good leaving group (use TsCl); then add ⁻CN.

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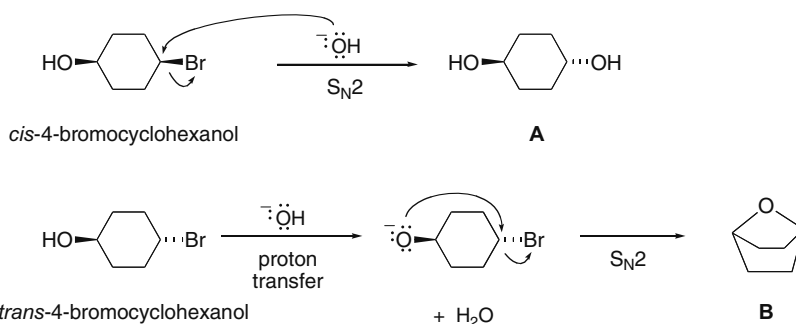
9.74



9.75

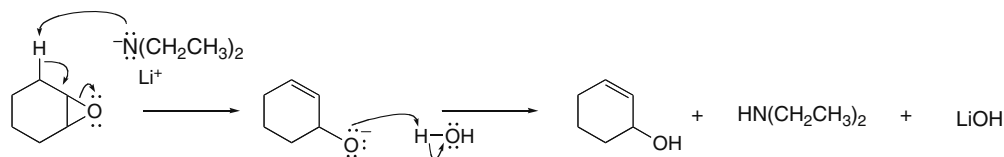


9.76 With the cis isomer, OH^- acts as a nucleophile to displace Br^- from the back side, forming a trans diol (**A**). With the trans isomer, the two functional groups are arranged in a manner that allows an intramolecular $\text{S}_{\text{N}}2$. OH^- removes a proton to form an alkoxide, which can then displace Br^- by intramolecular backside attack to afford an ether (**B**). Such a reaction is not possible with the cis isomer because the nucleophile and leaving group are on the same side.

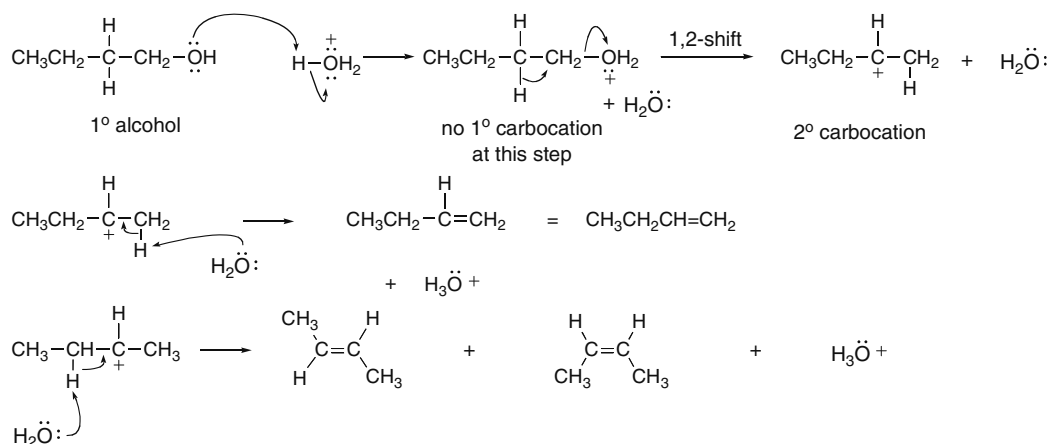


Alcohols, Ethers, and Epoxides 9-31

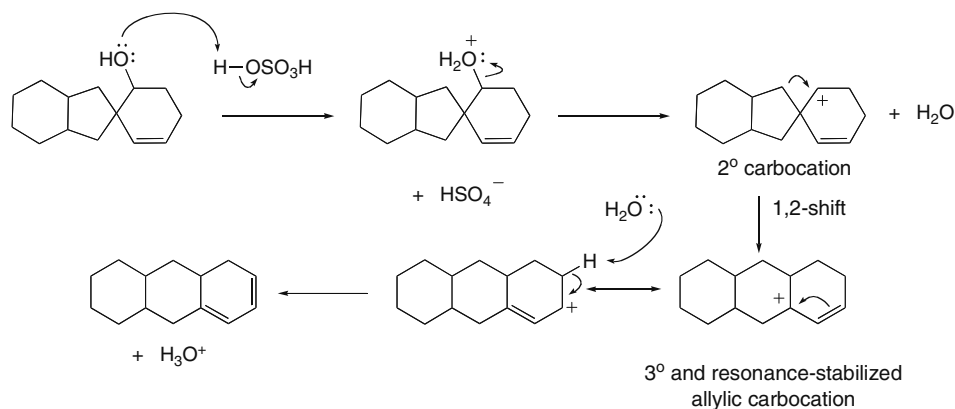
9.77 If the base is not bulky, it can react as a nucleophile and open the epoxide ring. The bulky base cannot act as a nucleophile, and will only remove the proton.



9.78 First form the 2° carbocation. Then lose a proton to form each product.

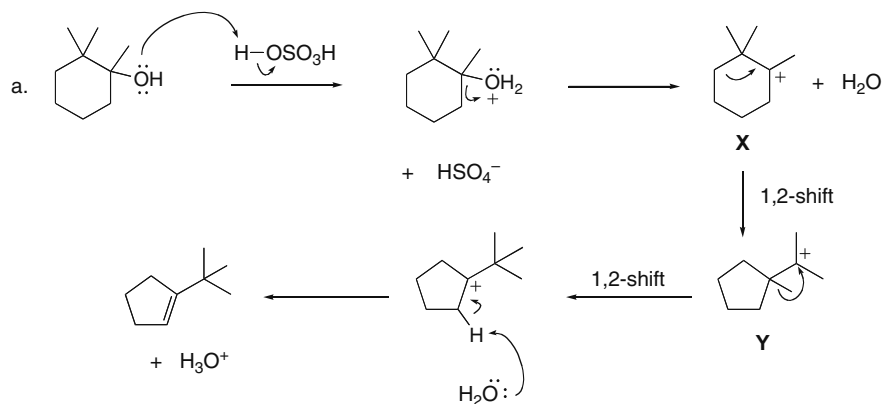


9.79

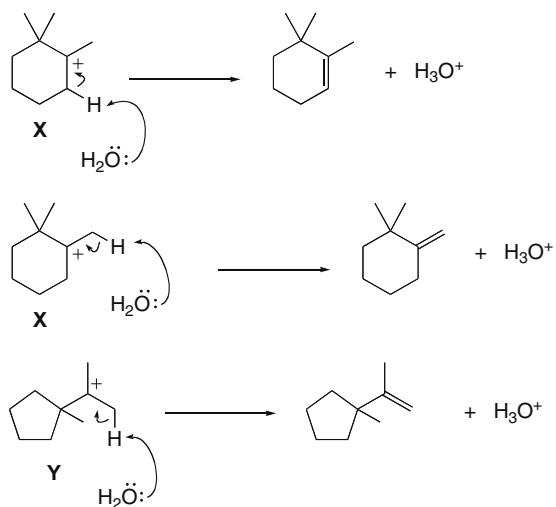


Chapter 9–32

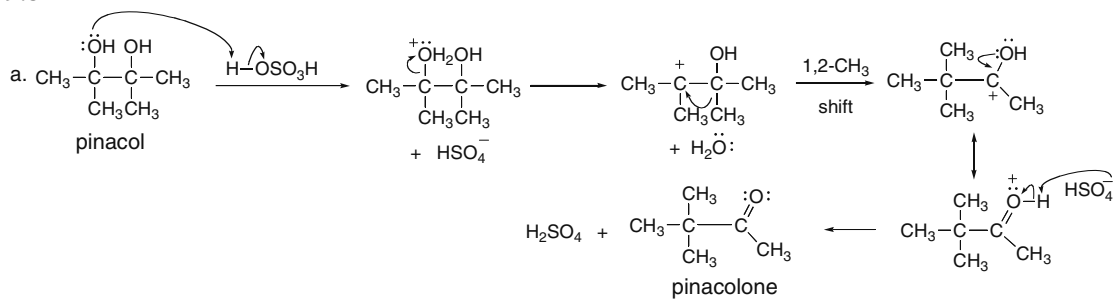
9.80



b. Other elimination products can form from carbocations X and Y.

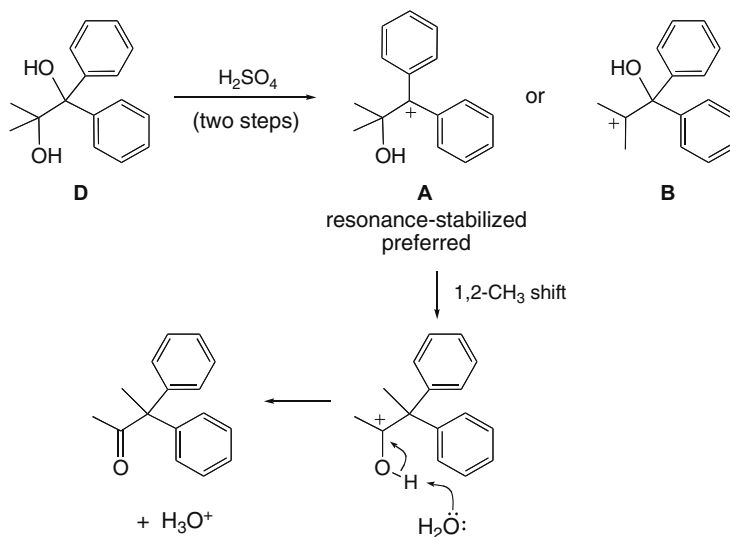


9.81

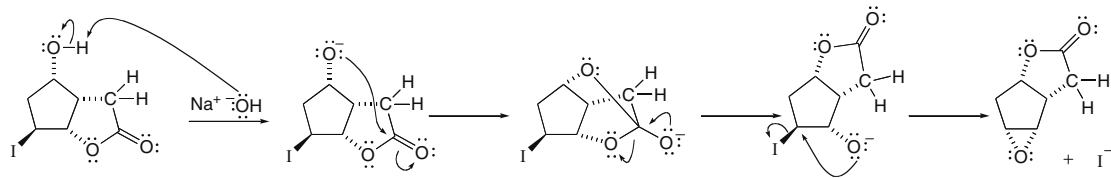


Alcohols, Ethers, and Epoxides 9-33

- b. Two different carbocations can form. The carbocation with the (+) charge adjacent to the benzene rings (**A**) is more stable, so it is preferred.

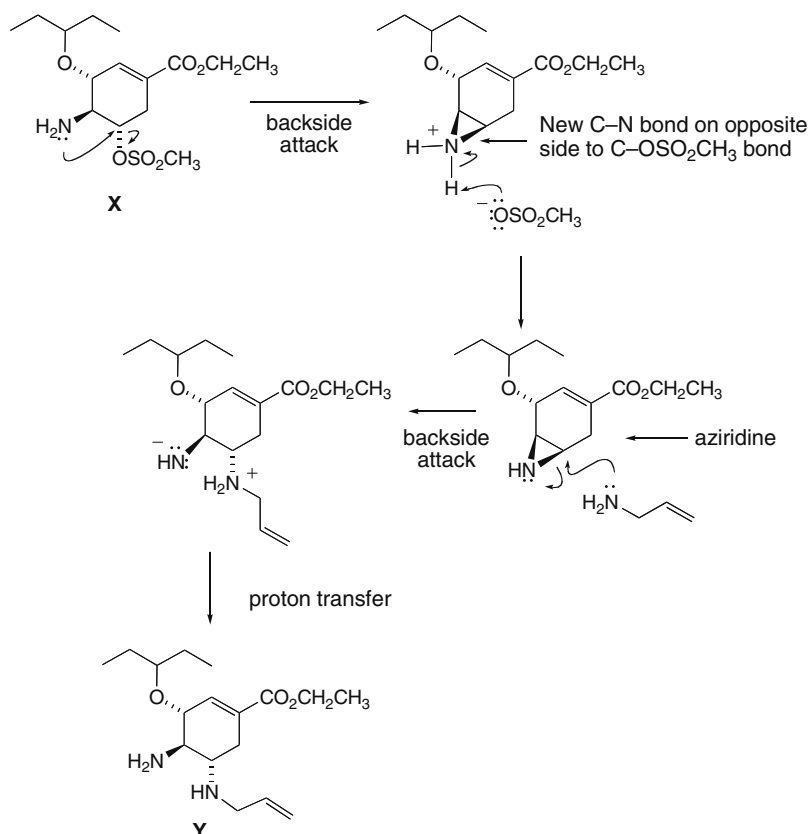


9.82



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9.83 The conversion of **X** to **Y** requires two operations. **X** contains both a nucleophile (NH_2) and a leaving group (OSO_2CH_3), so an intramolecular $\text{S}_{\text{N}}2$ reaction forms an aziridine. Since the aziridine is strained, the amine nucleophile ($\text{CH}_2=\text{CHCH}_2\text{NH}_2$) opens the ring by backside attack, resulting in the trans stereochemistry of the two N's on the six-membered ring.



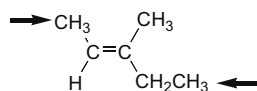
Chapter 10 Alkenes

Chapter Review

General facts about alkenes

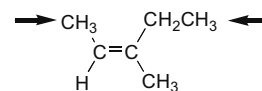
- Alkenes contain a carbon-carbon double bond consisting of a stronger σ bond and a weaker π bond. Each carbon is sp^2 hybridized and trigonal planar (10.1).
- Alkenes are named using the suffix **-ene** (10.3).
- Alkenes with different groups on each end of the double bond exist as a pair of diastereomers, identified by the prefixes *E* and *Z* (10.3B).

Two higher priority groups on
opposite sides



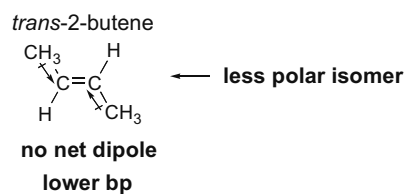
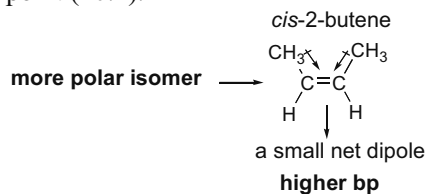
E isomer
(2*E*)-3-methyl-2-pentene

Two higher priority groups on
the **same** side



Z isomer
(2*Z*)-3-methyl-2-pentene

- Alkenes have weak intermolecular forces, giving them low mp's and bp's, and making them water insoluble. A *cis* alkene is more polar than a *trans* alkene, giving it a slightly higher boiling point (10.4).

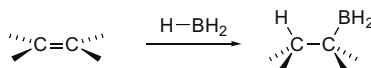


- Since a π bond is electron rich and much weaker than a σ bond, alkenes undergo addition reactions with electrophiles (10.8).

Stereochemistry of alkene addition reactions (10.8)

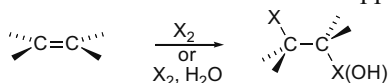
A reagent XY adds to a double bond in one of three different ways:

- Syn addition**—X and Y add from the same side.



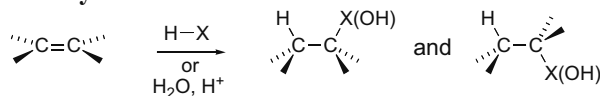
- Syn addition occurs in **hydroboration**.

- Anti addition**—X and Y add from opposite sides.



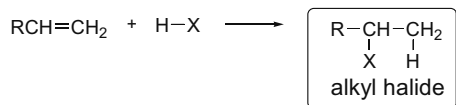
- Anti addition occurs in **halogenation** and **halohydrin formation**.

- Both syn and anti addition** occur when carbocations are intermediates.

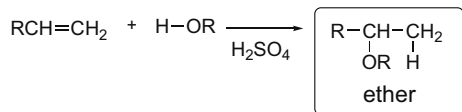
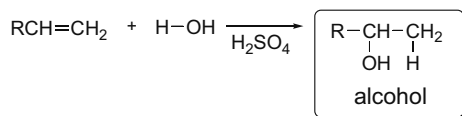


- Syn and anti addition occur in **hydrohalogenation** and **hydration**.

Chapter 10-2

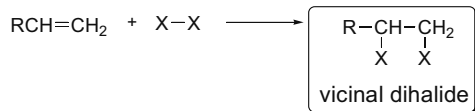
Addition reactions of alkenes**[1] Hydrohalogenation**—Addition of HX (X = Cl, Br, I) (10.9–10.11)

- The mechanism has two steps.
- Carbocations are formed as intermediates.
- Carbocation rearrangements are possible.
- Markovnikov's rule is followed. H bonds to the less substituted C to form the more stable carbocation.
- Syn and anti addition occur.

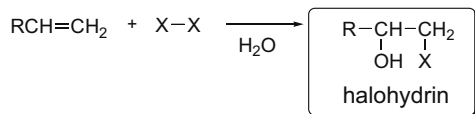
[2] Hydration and related reactions—Addition of H₂O or ROH (10.12)

For both reactions:

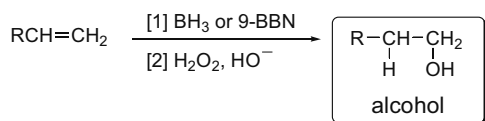
- The mechanism has three steps.
- Carbocations are formed as intermediates.
- Carbocation rearrangements are possible.
- Markovnikov's rule is followed. H bonds to the less substituted C to form the more stable carbocation.
- Syn and anti addition occur.

[3] Halogenation—Addition of X₂ (X = Cl or Br) (10.13–10.14)

- The mechanism has two steps.
- Bridged halonium ions are formed as intermediates.
- No rearrangements occur.
- Anti addition occurs.

[4] Halohydrin formation—Addition of OH and X (X = Cl, Br) (10.15)

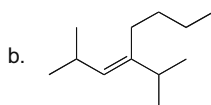
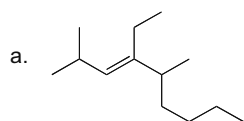
- The mechanism has three steps.
- Bridged halonium ions are formed as intermediates.
- No rearrangements occur.
- X bonds to the less substituted C.
- Anti addition occurs.
- NBS in DMSO and H₂O adds Br and OH in the same fashion.

[5] Hydroboration-oxidation—Addition of H₂O (10.16)

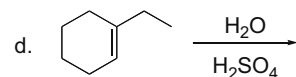
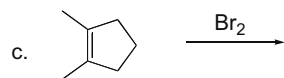
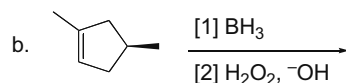
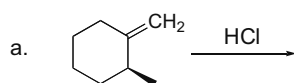
- Hydroboration has a one-step mechanism.
- No rearrangements occur.
- OH bonds to the less substituted C.
- Syn addition of H₂O results.

Practice Test on Chapter Review

1. Give the IUPAC name for the following compounds.



2. Draw the organic products formed in the following reactions. Draw all stereogenic centers using wedges and dashes.



3. Fill in the table with the stereochemistry observed in the reaction of an alkene with each reagent. Choose from syn, anti, or both syn and anti.

Reagent	Stereochemistry
a. [1] 9-BBN; [2] H ₂ O ₂ , ⁻ OH	
b. H ₂ O, H ₂ SO ₄	
c. Cl ₂ , H ₂ O	
d. HI	
e. Br ₂	

Chapter 10–4

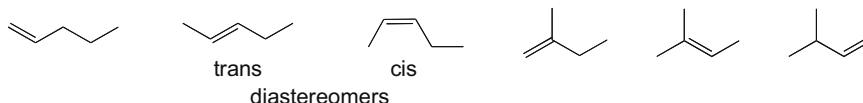
4. a. In which of the following reactions are carbocation rearrangements are observed?
1. hydrohalogenation
 2. halohydrin formation
 3. hydroboration–oxidation
 4. Carbocation rearrangements are observed in reactions (1) and (2).
 5. Carbocation rearrangements are observed in reactions (1), (2), and (3).
- b. Which of the following products are formed when HCl is added to 3-methyl-1-pentene?
1. 2-chloro-2-methylpentane
 2. 3-chloro-3-methylpentane
 3. 1-chloro-3-methylpentane
 4. Both (1) and (2) are formed.
 5. Products (1), (2), and (3) are all formed.

Answers to Practice Test

1. a. (3*E*)-4-ethyl-2,5-dimethyl-3-nonene
b. (3*E*)-4-isopropyl-2-methyl-3-octene
- 2.
- a.
- b.
- c.
- d.
3. a. syn
b. both
c. anti
d. both
e. anti
4. a. 1
b. 2

Answers to Problems

10.1

Six alkenes of molecular formula C_5H_{10} :

10.2 To determine the number of degrees of unsaturation:

- [1] Calculate the maximum number of H's ($2n + 2$).
- [2] Subtract the actual number of H's from the maximum number.
- [3] Divide by two.

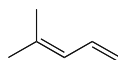
Alkenes 10-5

- a. C_2H_2
 [1] maximum number of H's = $2n + 2 = 2(2) + 2 = 6$
 [2] subtract actual from maximum = $6 - 2 = 4$
 [3] divide by two = $4/2 = 2$ **degrees of unsaturation**
- b. C_6H_6
 [1] maximum number of H's = $2n + 2 = 2(6) + 2 = 14$
 [2] subtract actual from maximum = $14 - 6 = 8$
 [3] divide by two = $8/2 = 4$ **degrees of unsaturation**
- c. C_8H_{18}
 [1] maximum number of H's = $2n + 2 = 2(8) + 2 = 18$
 [2] subtract actual from maximum = $18 - 18 = 0$
 [3] divide by two = $0/2 = 0$ **degrees of unsaturation**
- d. C_7H_8O
 Ignore the O.
 [1] maximum number of H's = $2n + 2 = 2(7) + 2 = 16$
 [2] subtract actual from maximum = $16 - 8 = 8$
 [3] divide by two = $8/2 = 4$ **degrees of unsaturation**
- e. $C_7H_{11}Br$
 Because of Br, add one more H ($11 + 1$ H = 12 H's).
 [1] maximum number of H's = $2n + 2 = 2(7) + 2 = 16$
 [2] subtract actual from maximum = $16 - 12 = 4$
 [3] divide by two = $4/2 = 2$ **degrees of unsaturation**
- f. C_5H_9N
 Because of N, subtract one H ($9 - 1$ H = 8 H's).
 [1] maximum number of H's = $2n + 2 = 2(5) + 2 = 12$
 [2] subtract actual from maximum = $12 - 8 = 4$
 [3] divide by two = $4/2 = 2$ **degrees of unsaturation**

10.3

One possibility for C_6H_{10} :

- a. a compound that has 2
- π
- bonds



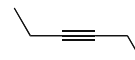
- c. a compound with 2 rings



- b. a compound that has 1 ring and 1
- π
- bond



- d. a compound with 1 triple bond

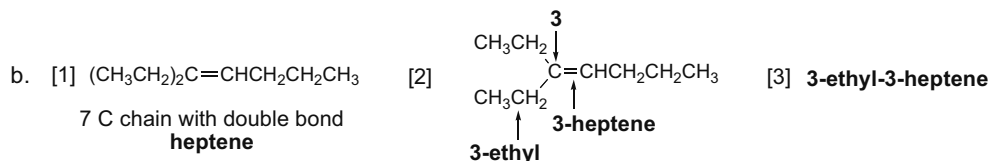
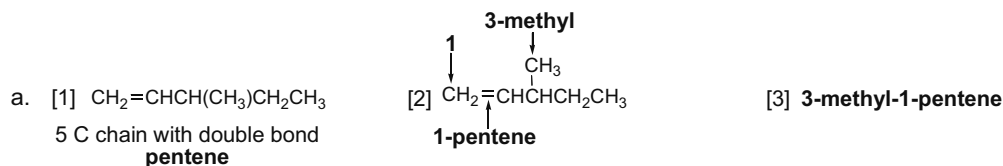


10.4 To name an alkene:

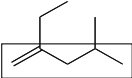
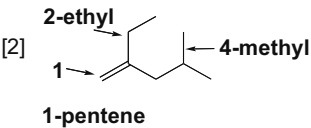
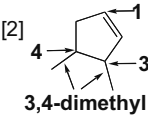
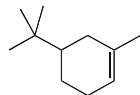
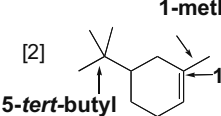
- [1] Find the longest chain that contains the double bond. Change the ending from **-ane** to **-ene**.
- [2] Number the chain to give the double bond the lower number. The alkene is named by the first number.
- [3] Apply all other rules of nomenclature.

To name a cycloalkene:

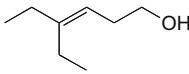
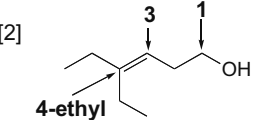
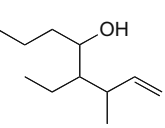
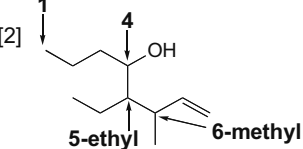
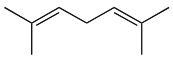
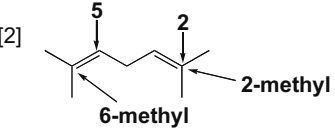
- [1] When a double bond is located in a ring, it is always located between C1 and C2. Omit the "1" in the name. Change the ending from **-ane** to **-ene**.
- [2] Number the ring clockwise or counterclockwise to give the first substituent the lower number.
- [3] Apply all other rules of nomenclature.



Chapter 10–6

- c. [1]  [2]  [3] **2-ethyl-4-methyl-1-pentene**
 5 C chain with double bond
pentene
- d. [1]  [2]  [3] **3,4-dimethylcyclopentene**
 5 C ring with a double bond
cyclopentene
- e. [1]  [2]  [3] **5-tert-butyl-1-methylcyclohexene**
 6 C ring with a double bond
cyclohexene

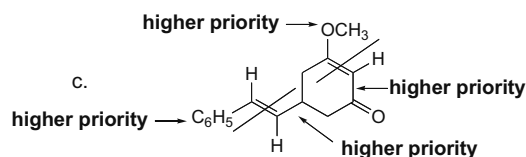
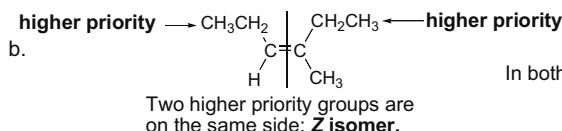
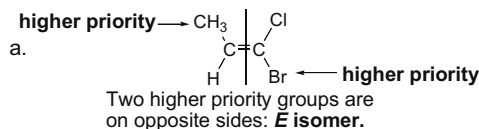
10.5 Use the rules from Answer 10.4 to name the compounds. Enols are named to give the OH the lower number. Compounds with two C=C's are named with the suffix **-adiene**.

- a. [1]  [2]  [3] **4-ethyl-3-hexen-1-ol**
 6 C chain with double bond
hexene
- b. [1]  [2]  [3] **5-ethyl-6-methyl-7-octen-4-ol**
 8 C chain with double bond
octene
- c. [1]  [2]  [3] **2,6-dimethyl-2,5-heptadiene**
 7 C chain with two double bonds
heptadiene

10.6 To label an alkene as *E* or *Z*:

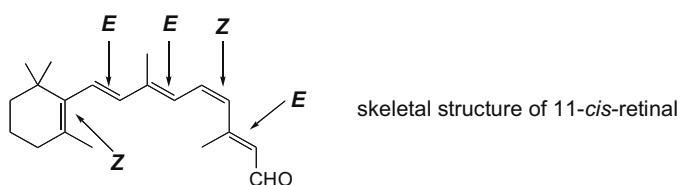
- [1] **Assign priorities** to the two substituents **on each end** using the rules for *R,S* nomenclature.
 [2] **Assign *E* or *Z*** depending on the location of the two higher priority groups.
- The *E* prefix is used when the two higher priority groups are on **opposite sides**.
 - The *Z* prefix is used when the two higher priority groups are on the **same side** of the double bond.

Alkenes 10-7



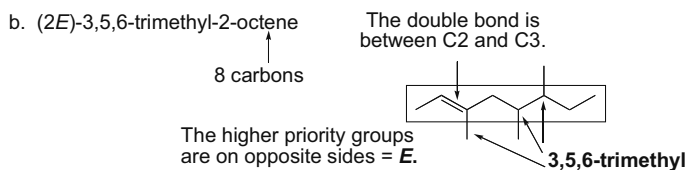
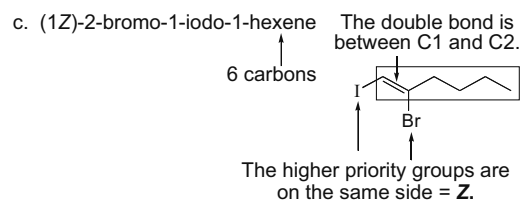
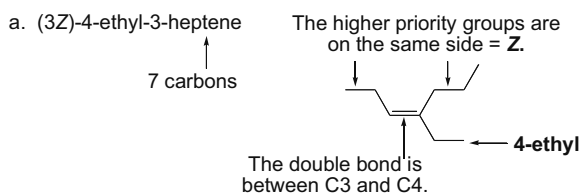
In both double bonds, the two higher priority groups are on opposite sides: **E isomers**.

10.7

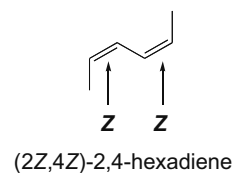
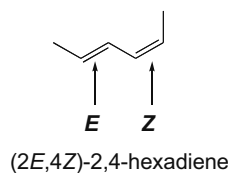
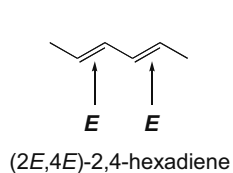


10.8 To work backwards from a name to a structure:

- [1] Find the parent name and functional group and draw, remembering that the double bond is between C1 and C2 for cycloalkenes.
- [2] Add the substituents to the appropriate carbons.



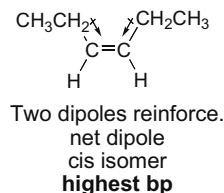
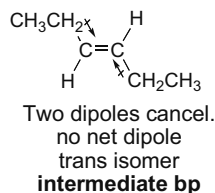
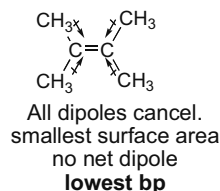
10.9 Draw all of the stereoisomers and then use the rules from Answer 10.6 to name each diene.



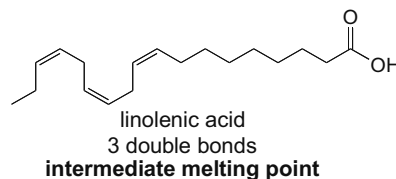
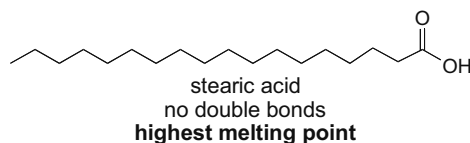
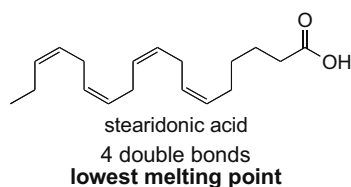
Chapter 10-8

10.10 To rank the isomers by increasing boiling point:

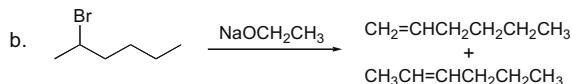
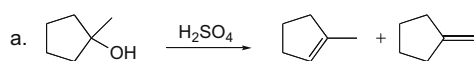
Look for polarity differences: *small net dipoles* make an alkene more polar, giving it a higher boiling point than an alkene with *no net dipole*. Cis isomers have a higher boiling point than their trans isomers.



10.11 Increasing number of double bonds = decreasing melting point.



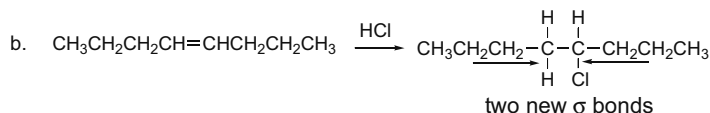
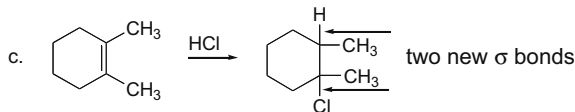
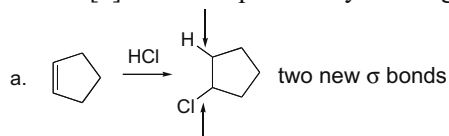
10.12



10.13 To draw the products of an addition reaction:

[1] Locate the two bonds that will be broken in the reaction. Always break the π bond.

[2] Draw the product by forming two new σ bonds.

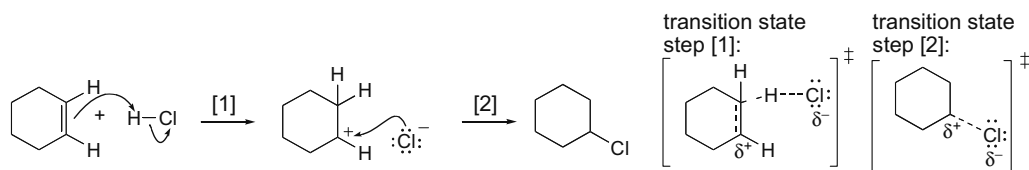


10.14 Addition reactions of HX occur in two steps:

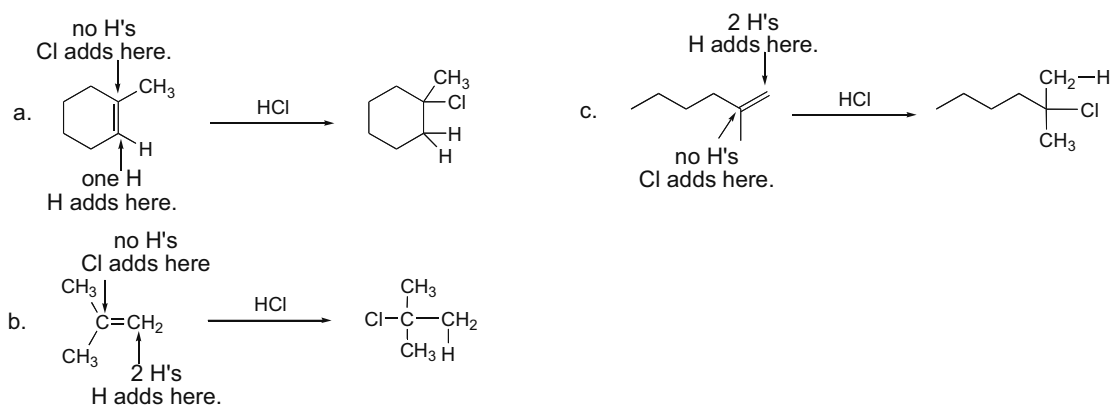
[1] The double bond attacks the H atom of HX to form a carbocation.

[2] X^- attacks the carbocation to form a C-X bond.

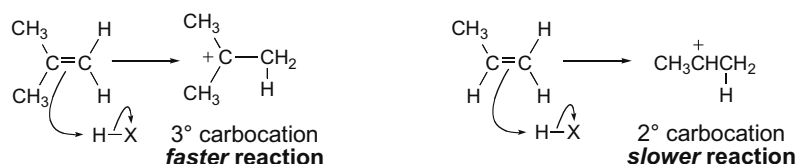
Alkenes 10-9



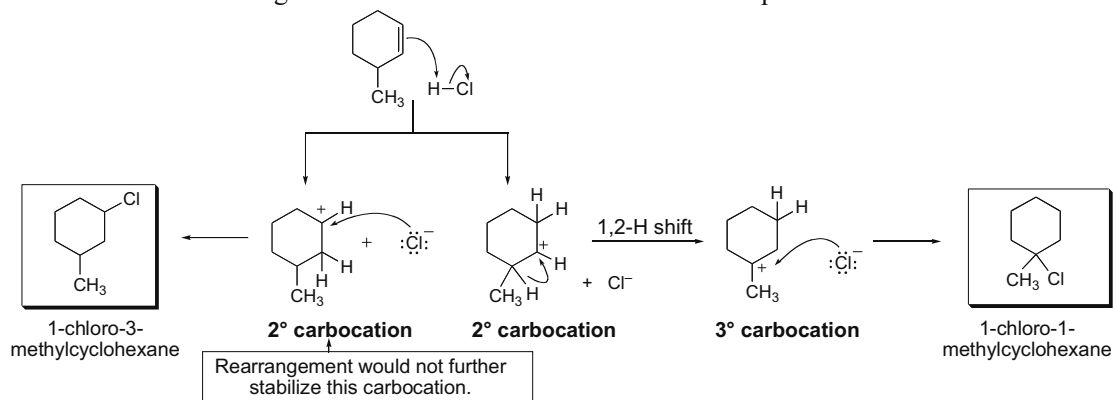
10.15 Addition to alkenes follows Markovnikov's rule: When HX adds to an unsymmetrical alkene, the H bonds to the C that has more H's to begin with.



10.16 To determine which alkene will react faster, draw the carbocation that forms in the rate-determining step. The more stable, more substituted the carbocation, the lower the E_a to form it and the faster the reaction.



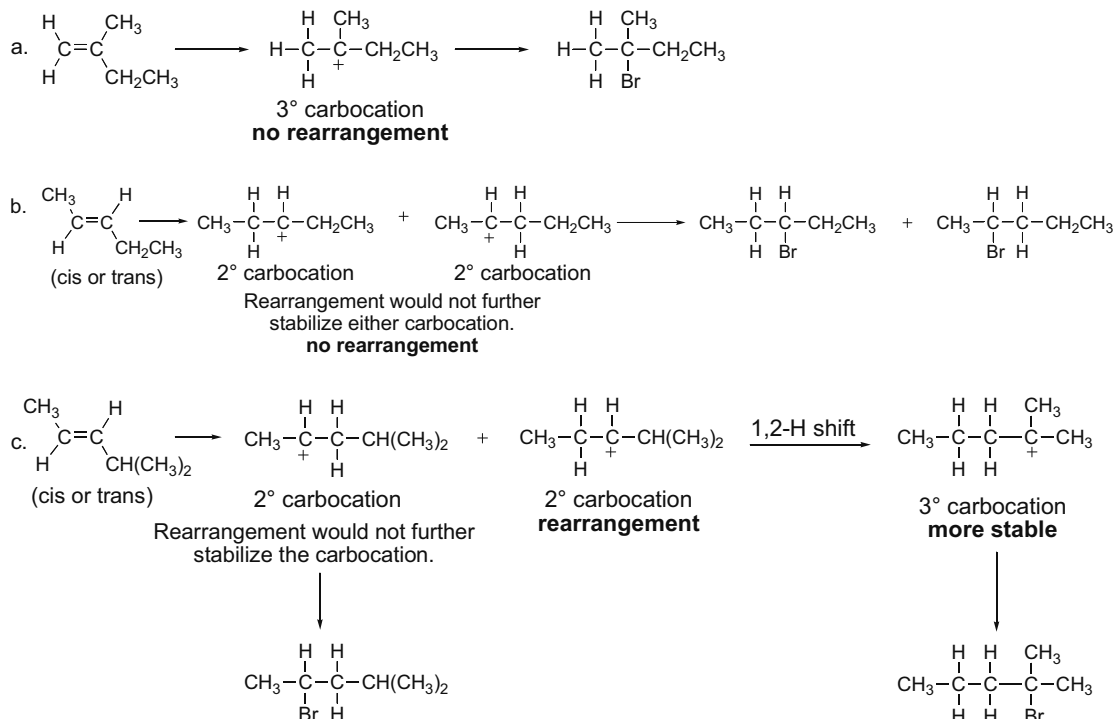
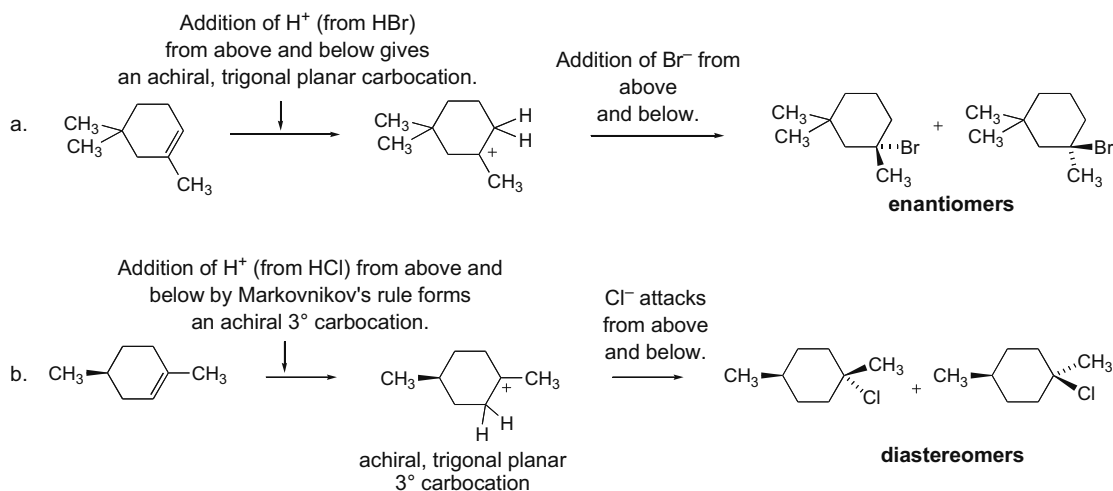
10.17 Look for rearrangements of a carbocation intermediate to explain these results.



Chapter 10-10

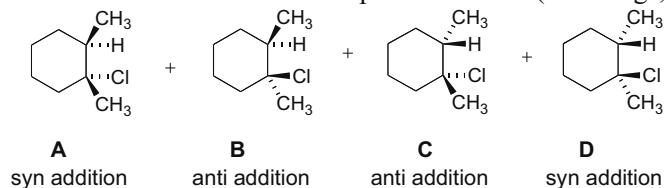
10.18 Addition of HX to alkenes involves the formation of carbocation intermediates.

Rearrangement of the carbocation will occur if it forms a more stable carbocation.

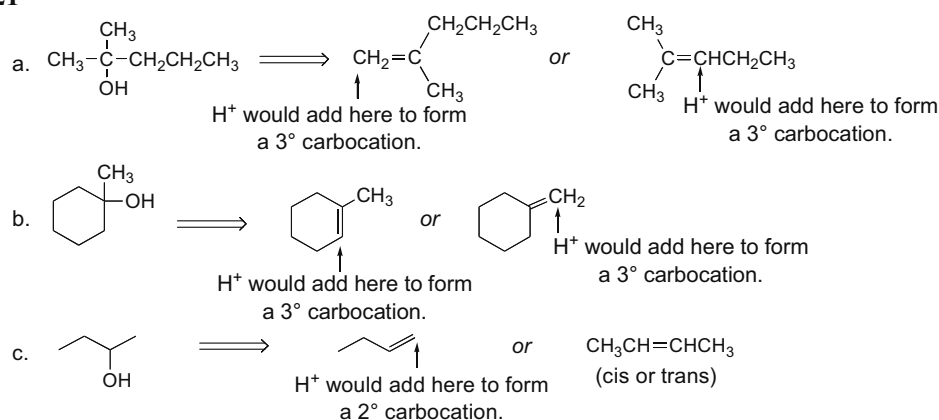
**10.19** To draw the products, remember that addition of HX proceeds via a carbocation intermediate.

Alkenes 10-11

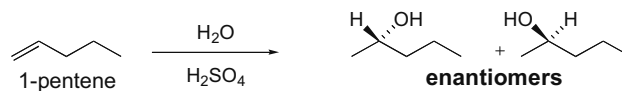
10.20 The product of syn addition will have H and Cl both up or down (both on wedges or both dashes), while the product of anti addition will have one up and one down (one wedge, one dash).



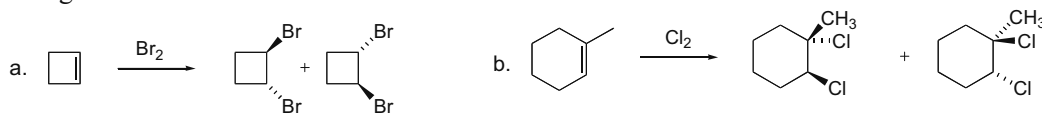
10.21



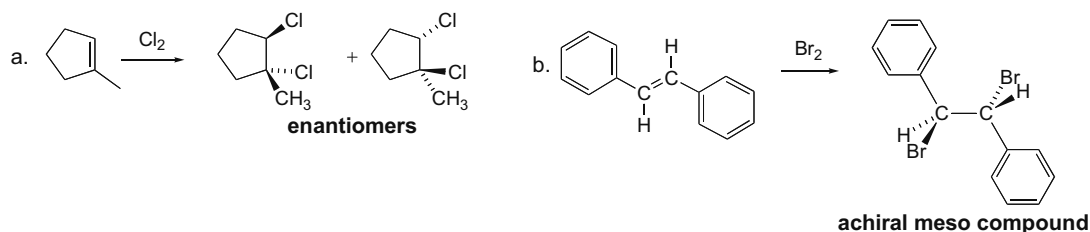
10.22



10.23 Halogenation of an alkene adds two elements of X in an anti fashion.



10.24 To draw the products of halogenation of an alkene, remember that the halogen adds to both ends of the double bond but only anti addition occurs.



c. **diastereomers**

[1] Addition of X^+ to the alkene to form a bridged halonium ion
[2] Nucleophilic attack by X^-



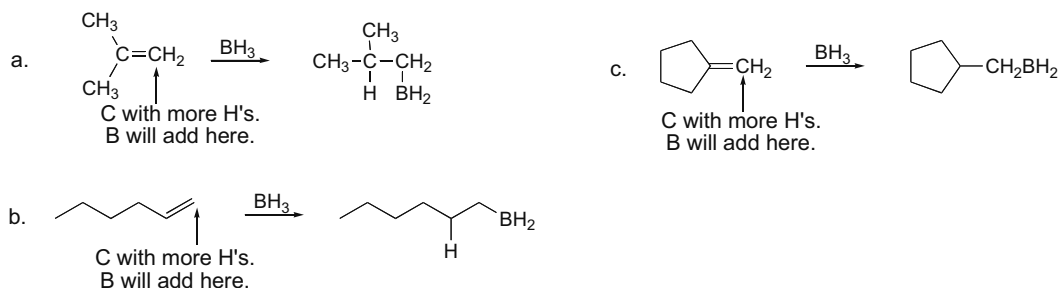
a. b.

Cl bonds to the carbon with more H's to begin with.

a. $(\text{CH}_3)_2\ddot{\text{S}}:$ $\begin{array}{c} \text{H} \\ | \\ \text{H}-\text{B}-\text{S}^+ \\ | \quad | \\ \text{H} \quad \text{CH}_3 \end{array}$ b. $(\text{CH}_3\text{CH}_2)_3\text{N}:$ $\begin{array}{c} \text{H} \quad \text{CH}_2\text{CH}_3 \\ | \quad | \\ \text{H}-\text{B}-\text{N}^+ \\ | \quad | \\ \text{H} \quad \text{CH}_2\text{CH}_3 \end{array}$ c. $(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2)_3\text{P}:$ $\begin{array}{c} \text{H} \quad \text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 \\ | \quad | \\ \text{H}-\text{B}-\text{P}^+ \\ | \quad | \\ \text{H} \quad \text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3 \end{array}$

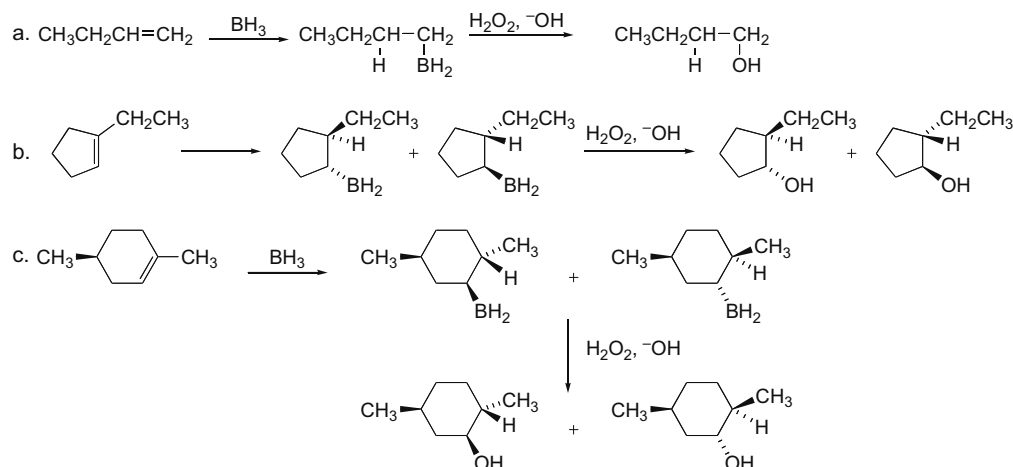
Alkenes 10-13

10.28 In hydroboration the boron atom is the electrophile and becomes bonded to the carbon atom that had more H's to begin with.

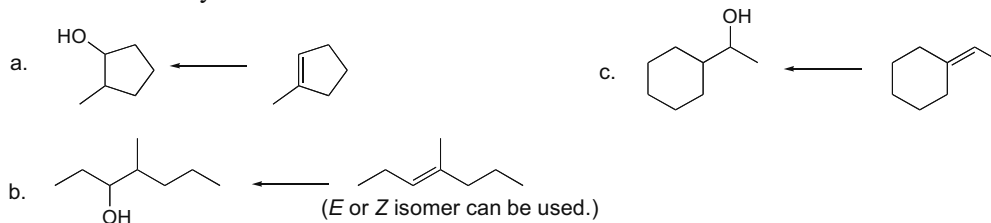


10.29 The hydroboration-oxidation reaction occurs in two steps:

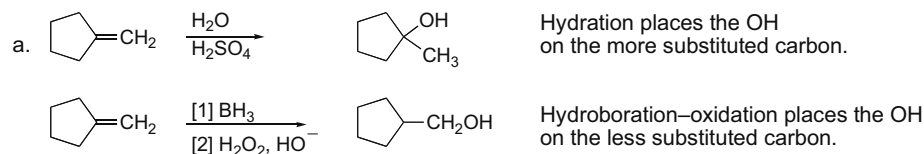
- [1] Syn addition of BH_3 , with the boron on the less substituted carbon atom
 [2] OH replaces the BH_2 with retention of configuration.



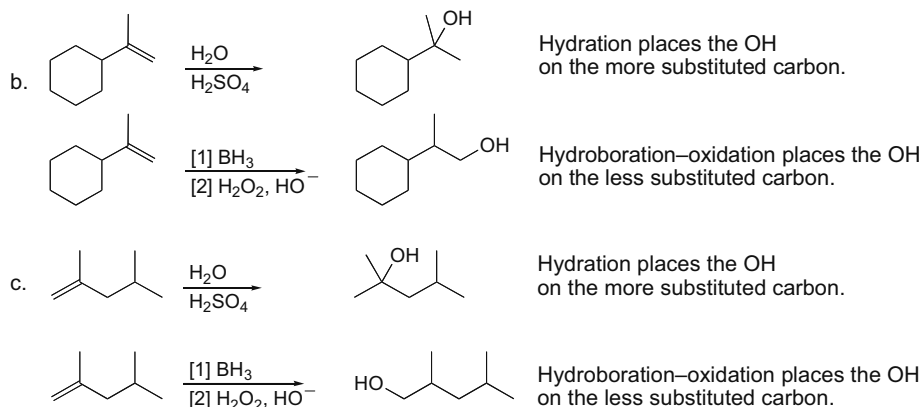
10.30 Remember that hydroboration results in addition of OH on the less substituted C.



10.31

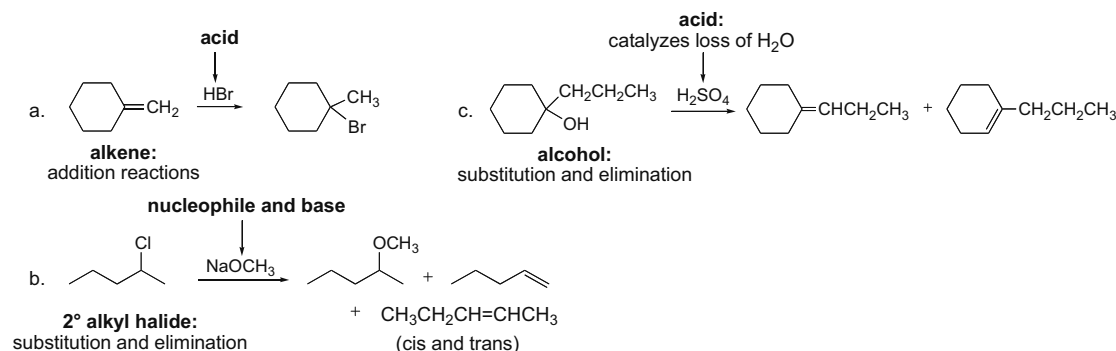


Chapter 10–14



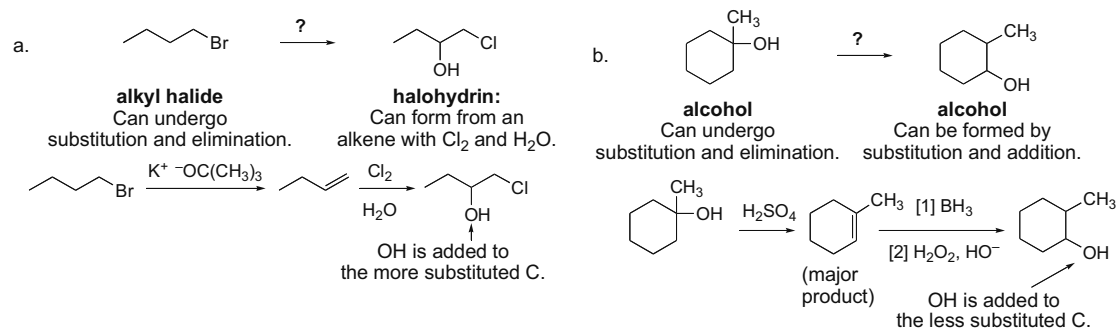
10.32 There are always two steps in this kind of question:

- [1] **Identify the functional group and decide what types of reactions it undergoes** (e.g., substitution, elimination, or addition).
- [2] **Look at the reagent and determine if it is an electrophile, nucleophile, acid, or base.**



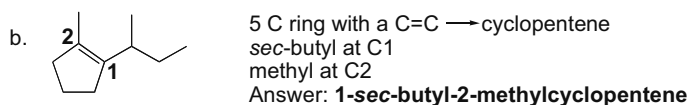
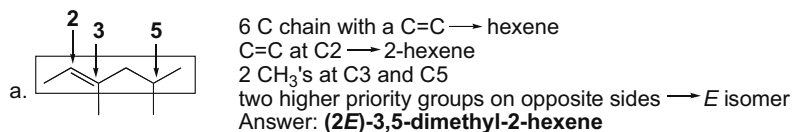
10.33 To devise a synthesis:

- [1] Look at the starting material and decide what reactions it can undergo.
- [2] Look at the product and decide what reactions could make it.

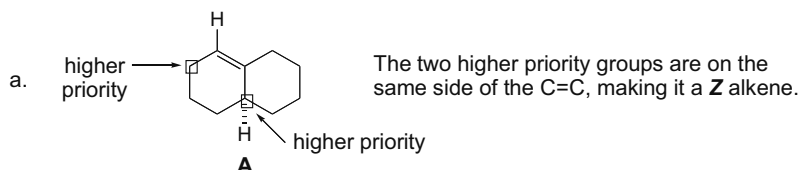


Alkenes 10-15

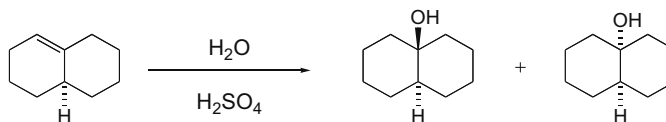
10.34 Convert each ball-and-stick model to a skeletal structure and then name the molecule.



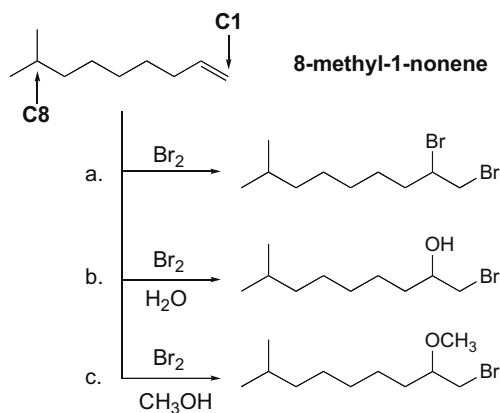
10.35



b. Add H₂O in a Markovnikov fashion to form two products.



10.36



Chapter 10–16

10.37 Use the directions from Answer 10.2 to calculate degrees of unsaturation.

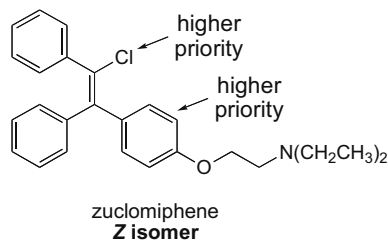
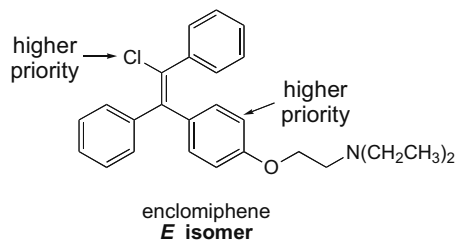
- a. C_3H_4
 [1] maximum number of H's = $2n + 2 = 2(3) + 2 = 8$
 [2] subtract actual from maximum = $8 - 4 = 4$
 [3] divide by 2 = $4/2 = 2$ **degrees of unsaturation**
- b. C_6H_8
 [1] maximum number of H's = $2n + 2 = 2(6) + 2 = 14$
 [2] subtract actual from maximum = $14 - 8 = 6$
 [3] divide by 2 = $6/2 = 3$ **degrees of unsaturation**
- c. $C_{40}H_{56}$
 [1] maximum number of H's = $2n + 2 = 2(40) + 2 = 82$
 [2] subtract actual from maximum = $82 - 56 = 26$
 [3] divide by 2 = $26/2 = 13$ **degrees of unsaturation**
- d. C_8H_8O
 Ignore the O.
 [1] maximum number of H's = $2n + 2 = 2(8) + 2 = 18$
 [2] subtract actual from maximum = $18 - 8 = 10$
 [3] divide by 2 = $10/2 = 5$ **degrees of unsaturation**
- e. $C_{10}H_{16}O_2$
 Ignore both O's.
 [1] maximum number of H's = $2n + 2 = 2(10) + 2 = 22$
 [2] subtract actual from maximum = $22 - 16 = 6$
 [3] divide by 2 = $6/2 = 3$ **degrees of unsaturation**
- f. C_8H_9Br
 Because of Br, add one H ($9 + 1 = 10$ H's).
 [1] maximum number of H's = $2n + 2 = 2(8) + 2 = 18$
 [2] subtract actual from maximum = $18 - 10 = 8$
 [3] divide by 2 = $8/2 = 4$ **degrees of unsaturation**
- g. C_8H_9ClO
 Ignore the O; count Cl as one more H ($9 + 1 = 10$ H's).
 [1] maximum number of H's = $2n + 2 = 2(8) + 2 = 18$
 [2] subtract actual from maximum = $18 - 10 = 8$
 [3] divide by 2 = $8/2 = 4$ **degrees of unsaturation**
- h. C_7H_9Br
 Because of Br, add one H ($9 + 1 = 10$ H's).
 [1] maximum number of H's = $2n + 2 = 2(7) + 2 = 16$
 [2] subtract actual from maximum = $16 - 10 = 6$
 [3] divide by 2 = $6/2 = 3$ **degrees of unsaturation**
- i. $C_7H_{11}N$
 Because of N, subtract one H ($11 - 1 = 10$ H's).
 [1] maximum number of H's = $2n + 2 = 2(7) + 2 = 16$
 [2] subtract actual from maximum = $16 - 10 = 6$
 [3] divide by 2 = $6/2 = 3$ **degrees of unsaturation**
- j. C_4H_8BrN
 Because of Br, add one H, but subtract one for N ($8 + 1 - 1 = 8$ H's).
 [1] maximum number of H's = $2n + 2 = 2(4) + 2 = 10$
 [2] subtract actual from maximum = $10 - 8 = 2$
 [3] divide by 2 = $2/2 = 1$ **degree of unsaturation**

10.38 First determine the number of degrees of unsaturation in the compound. Then decide which combinations of rings and π bonds could exist.

- $C_{10}H_{14}$
 [1] maximum number of H's = $2n + 2 = 2(10) + 2 = 22$
 [2] subtract actual from maximum = $22 - 14 = 8$
 [3] divide by two = $8/2 = 4$ **degrees of unsaturation**

possibilities:
 4 π bonds
 3 π bonds + 1 ring
 2 π bonds + 2 rings
 1 π bond + 3 rings
 4 rings

10.39 The statement is incorrect because when naming isomers with more than two groups on a double bond, one must use an *E,Z* label, rather than a *cis, trans* label.



Alkenes 10-17

10.40 Name the alkenes using the rules in Answers 10.4 and 10.6.

- a. $\text{CH}_2=\text{CHCH}_2\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}_3$
 6 C chain with a double bond = **hexene**
 $\text{CH}_2=\text{CHCH}_2\text{CH}(\text{CH}_3)\text{CH}_2\text{CH}_3$
 1-hexene 4-methyl
4-methyl-1-hexene
- b.
 8 C chain with a double bond = **octene**
 2-methyl 5-ethyl
 2-octene
5-ethyl-2-methyl-2-octene
- c.
 5 C chain with a double bond = **pentene**
 2-isopropyl 4-methyl
 1-pentene
2-isopropyl-4-methyl-1-pentene
- d.
 6 C ring with a double bond = **cyclohexene**
 1-ethyl 5-isopropyl
1-ethyl-5-isopropylcyclohexene
- e.
 7 C chain with a double bond = **heptene**
 4-isopropyl 3-ol
 4-heptene
E double bond (higher priority groups on opposite sides with bold bonds)
(4E)-4-isopropyl-4-hepten-3-ol
- f.
 6 C ring with a double bond = **cyclohexene**
 2-cyclohexene 5-sec-butyl
 1-ol
5-sec-butyl-2-cyclohexenol

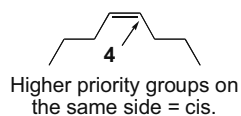
10.41 Use the directions from Answer 10.8.

- a.
 a. **(3E)-4-ethyl-3-heptene**
 7 carbons
 4-ethyl
 3
 Higher priority groups on opposite sides = **E**.
- b.
 b. **3,3-dimethylcyclopentene**
 5 carbon ring
 3,3-dimethyl

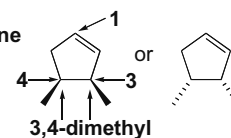
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c. *cis*-4-octene

8 carbons

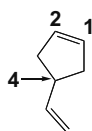
f. *cis*-3,4-dimethylcyclopentene

5 carbon ring

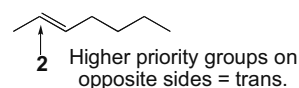


d. 4-vinylcyclopentene

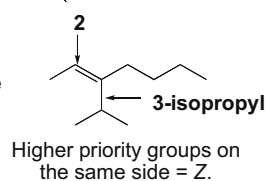
5 carbon ring

g. *trans*-2-heptene

7 carbons

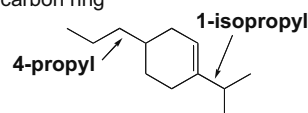
e. (2*Z*)-3-isopropyl-2-heptene

7 carbons



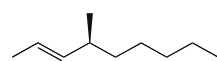
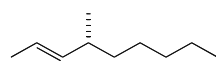
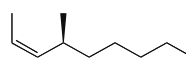
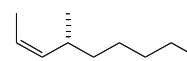
h. 1-isopropyl-4-propylcyclohexene

6 carbon ring

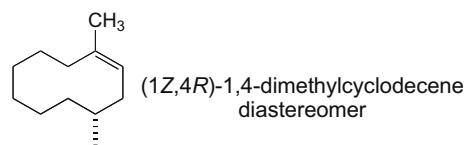
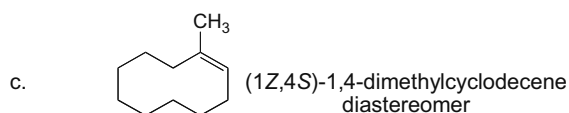
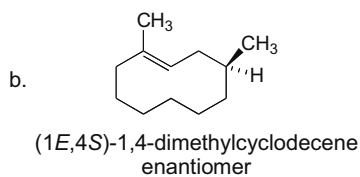
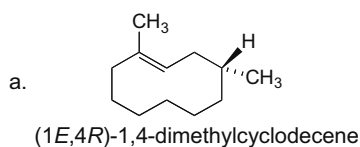


10.42

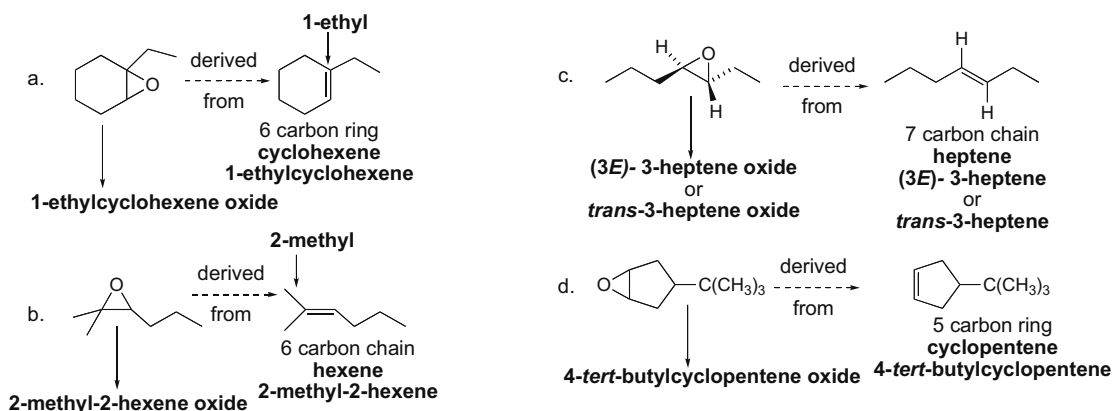
a.

(2*E*,4*S*)-4-methyl-2-nonene**A**(2*E*,4*R*)-4-methyl-2-nonene**B**(2*Z*,4*S*)-4-methyl-2-nonene**C**(2*Z*,4*R*)-4-methyl-2-nonene**D**b. **A** and **B** are enantiomers. **C** and **D** are enantiomers.c. Pairs of diastereomers: **A** and **C**, **A** and **D**, **B** and **C**, **B** and **D**.

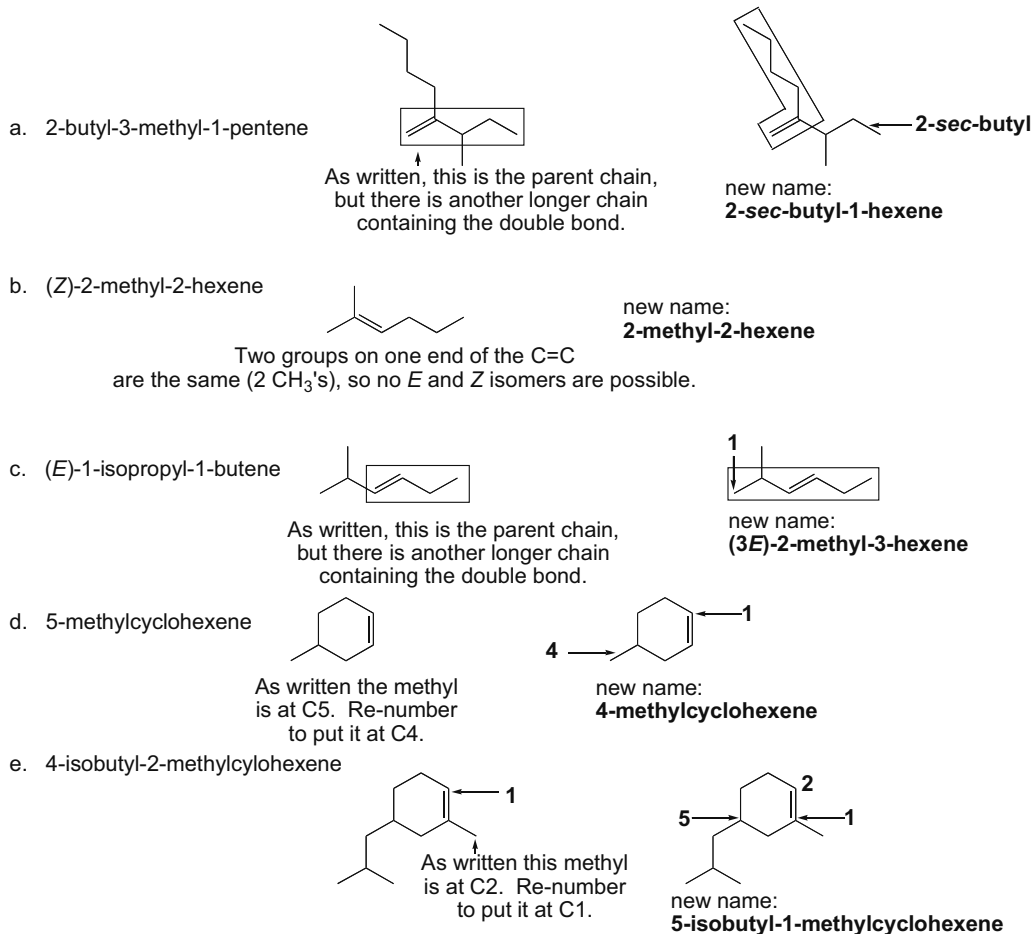
10.43



10.44 Name the alkene from which the epoxide can be derived and add the word *oxide*.

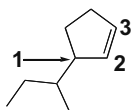


10.45

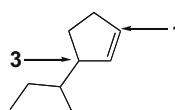


Chapter 10–20

- f. 1-sec-butyl-2-cyclopentene

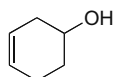


This has the double bond between C2 and C3. Cycloalkenes must have the double bond between C1 and C2. Re-number.

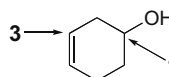


new name:
3-sec-butylcyclopentene

- g. 1-cyclohexen-4-ol

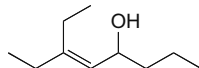


The numbering is incorrect. When a compound contains both a double bond and an OH group, number the C skeleton to give the OH group the lower number.

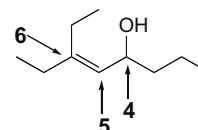


3-cyclohexenol (The "1" can be omitted.)

- h. 3-ethyl-3-octen-5-ol

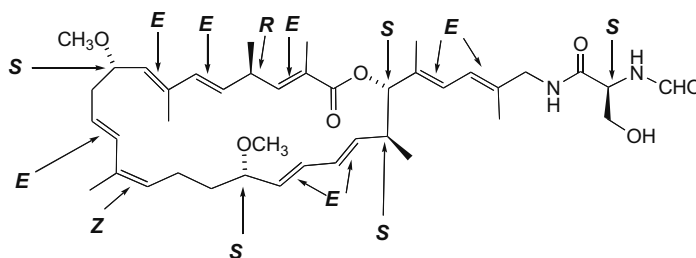


The numbering is incorrect. When a compound contains both a double bond and an OH group, number the C skeleton to give the OH group the lower number.

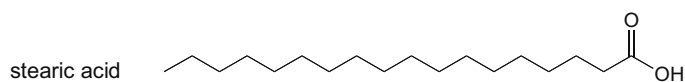


6-ethyl-5-octen-4-ol

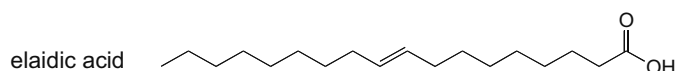
10.46 a, b. *E,Z*, and *R,S* designations are shown.



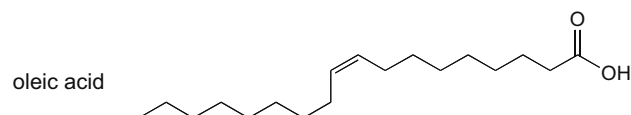
- c. Nine double bonds that can be *E* or *Z*
 Six tetrahedral stereogenic centers
 Maximum possible number of stereoisomers = 2^{15}

10.47

highest melting point
no double bonds



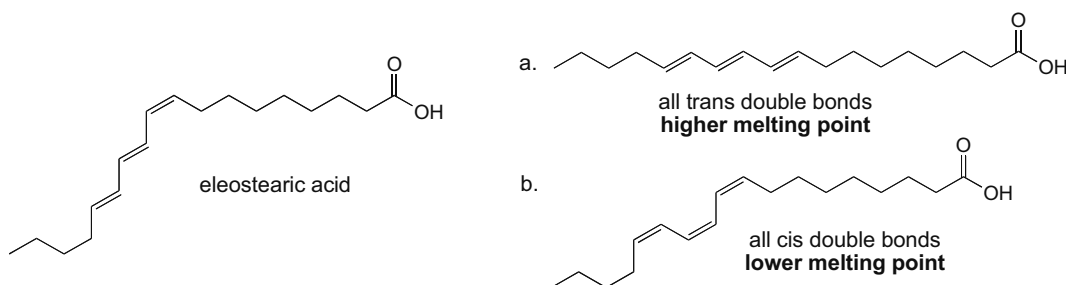
intermediate melting point
one *E* double bond



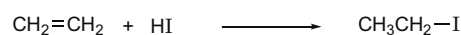
lowest melting point
one *Z* double bond

Alkenes 10-21

10.48



10.49 The more negative the ΔH° , the larger the K_{eq} assuming entropy changes are comparable. Calculate the ΔH° for each reaction and compare.



[1] Bonds broken

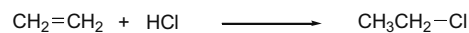
	ΔH° (kJ/mol)
C-C π bond	+ 267
H-I	+ 297
Total	+ 564 kJ/mol

[2] Bonds formed

	ΔH° (kJ/mol)
$\text{CH}_2\text{ICH}_2-\text{H}$	- 410
C-I	- 222
Total	- 632 kJ/mol

[3] Overall $\Delta H^\circ =$

sum in Step [1]
+ sum in Step [2]
+ 564 kJ/mol
- 632 kJ/mol
- 68 kJ/mol



[1] Bonds broken

	ΔH° (kJ/mol)
C-C π bond	+ 267
H-Cl	+ 431
Total	+ 698 kJ/mol

[2] Bonds formed

	ΔH° (kJ/mol)
$\text{CH}_2\text{ClCH}_2-\text{H}$	- 410
C-Cl	- 339
Total	- 749 kJ/mol

[3] Overall $\Delta H^\circ =$

sum in Step [1]
+ sum in Step [2]
+ 698 kJ/mol
- 749 kJ/mol
- 51 kJ/mol

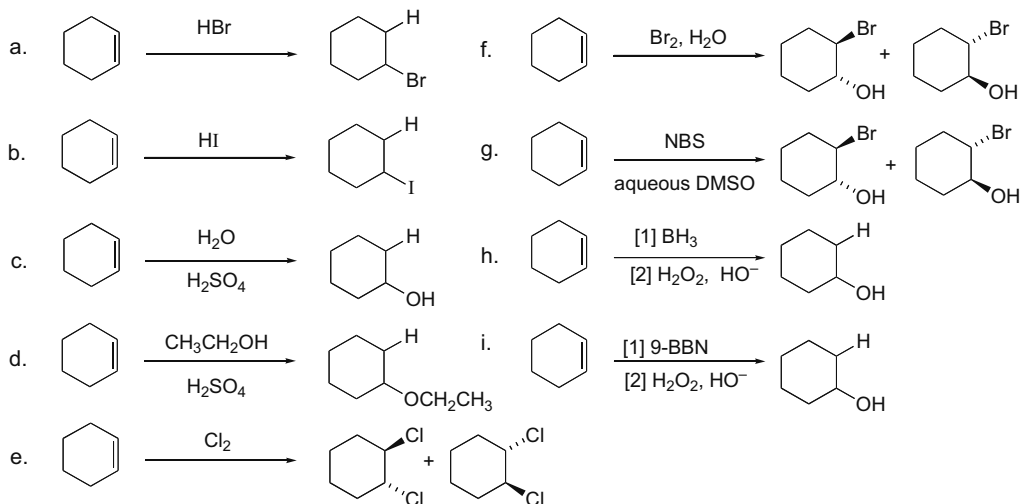
Compare the ΔH° :

Addition of HI: **-68 kJ/mol** = more negative ΔH° , larger K_{eq}

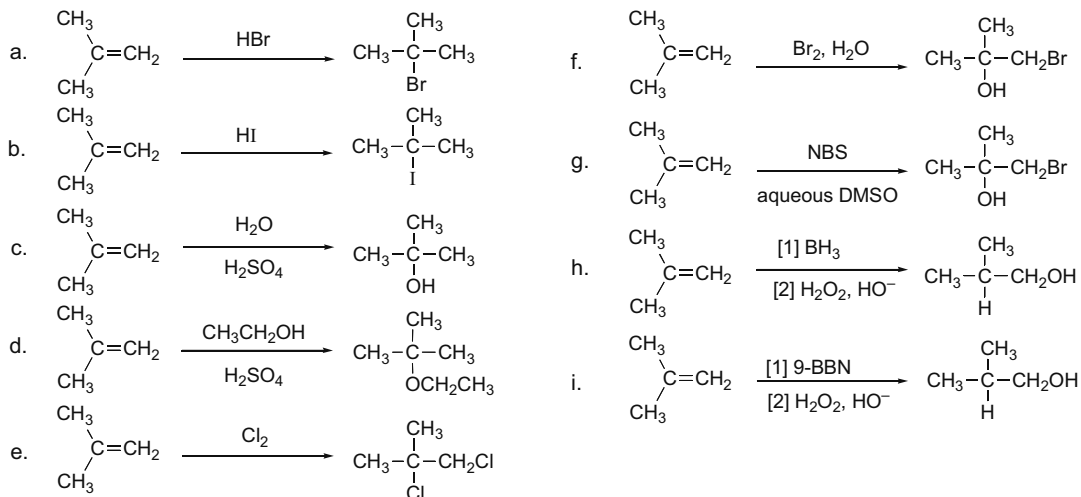
Addition of HCl: **-51 kJ/mol**

Chapter 10-22

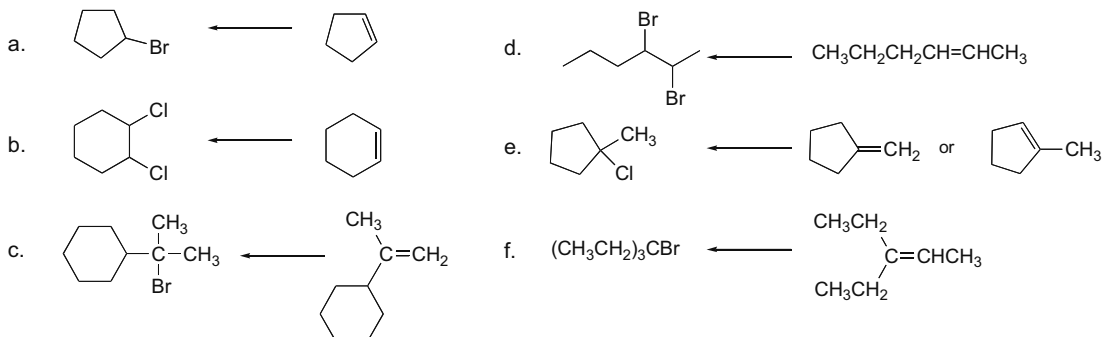
10.50



10.51

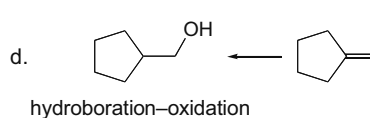
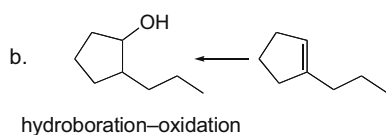
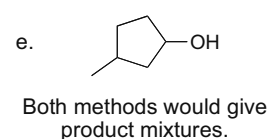
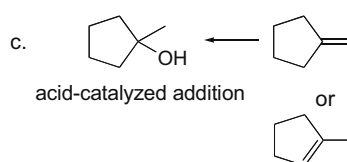
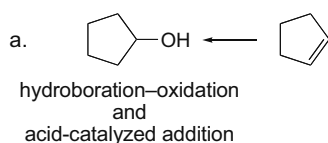
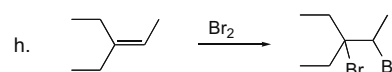
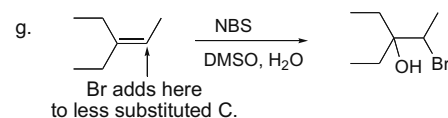
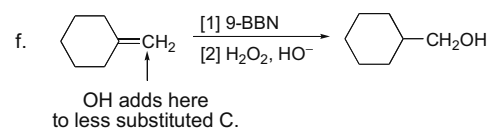
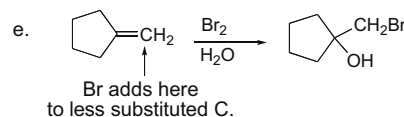
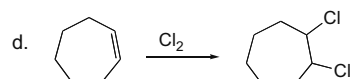
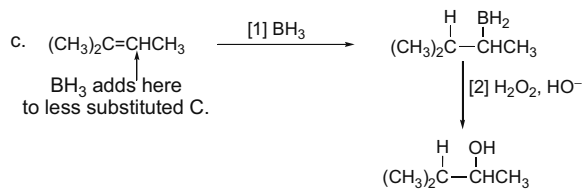
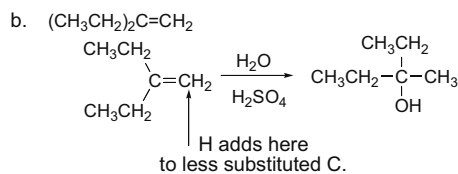
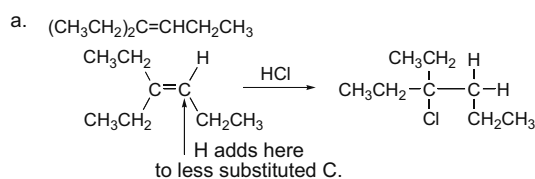
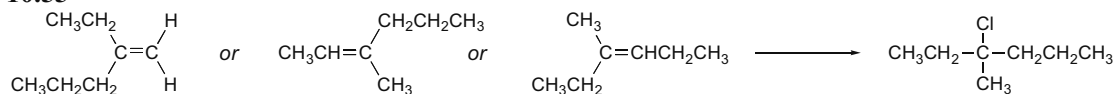


10.52



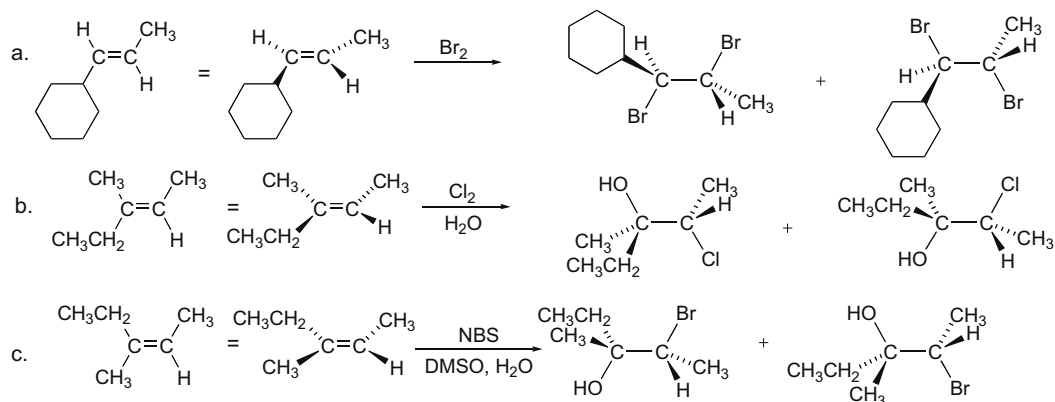
Alkenes 10-23

10.53 Hydroboration–oxidation results in addition of an OH group on the less substituted carbon, whereas acid-catalyzed addition of H₂O results in the addition of an OH group on the more substituted carbon.

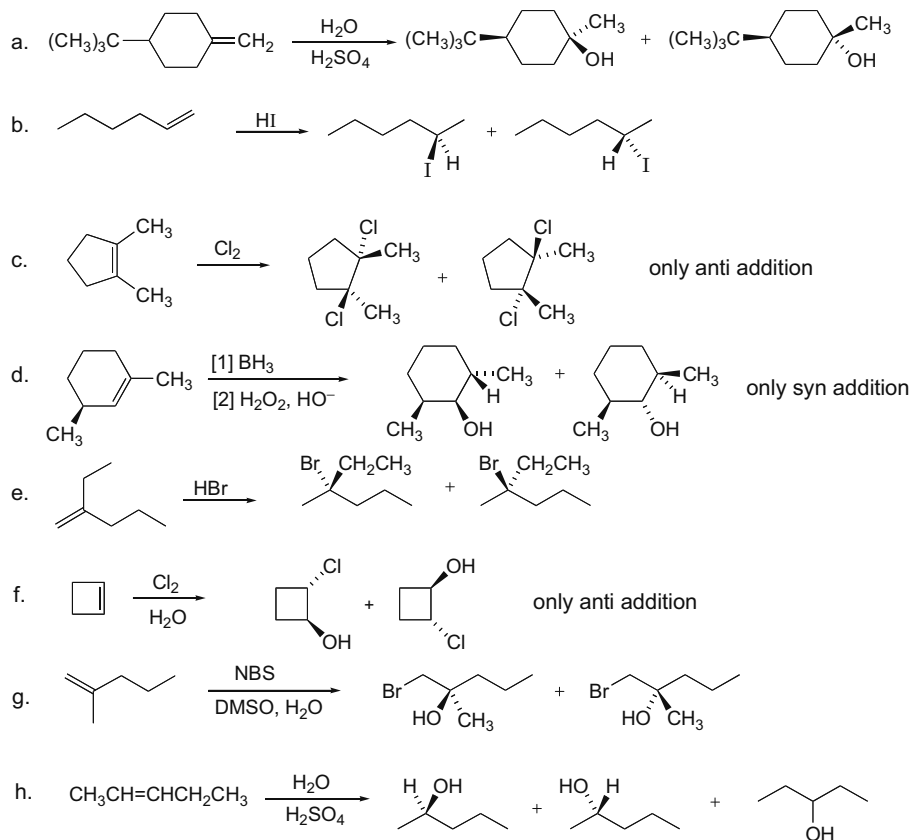
**10.54****10.55**

Chapter 10-24

10.56

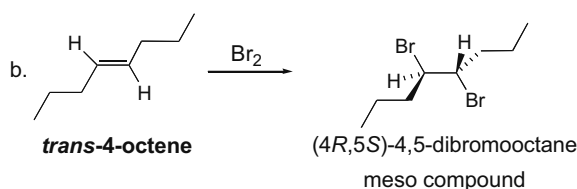
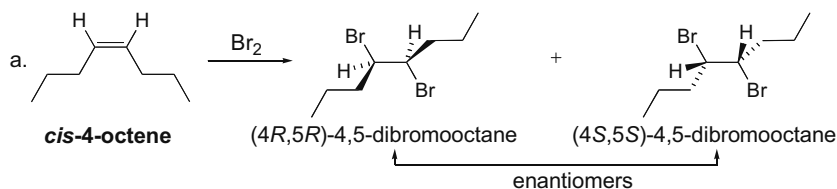
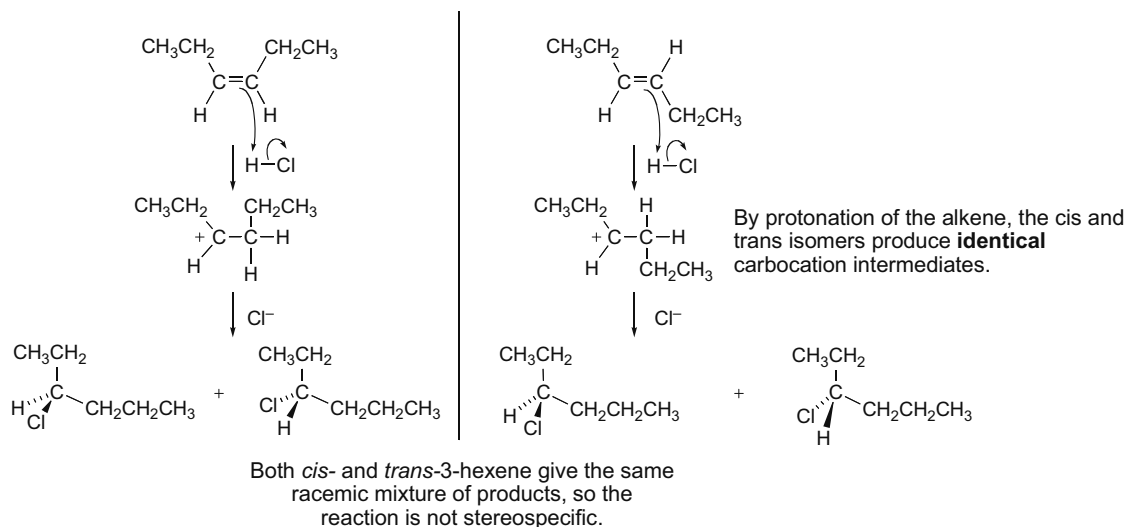
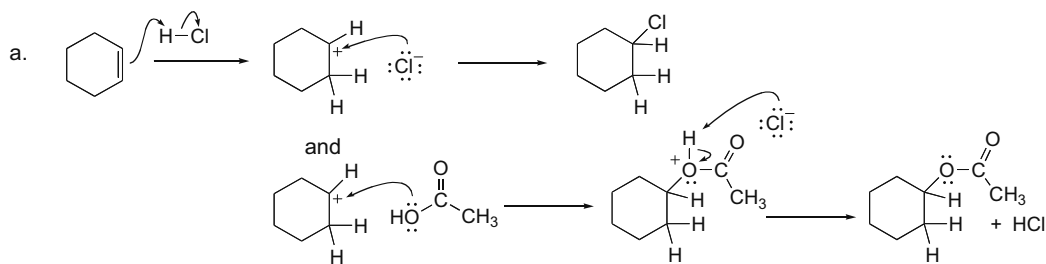


10.57

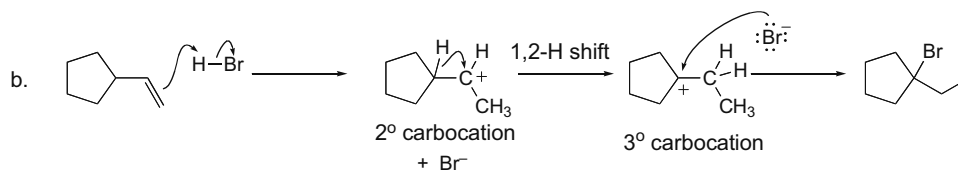


Alkenes 10-25

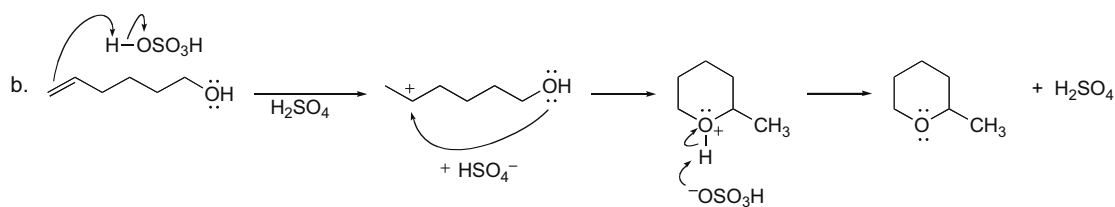
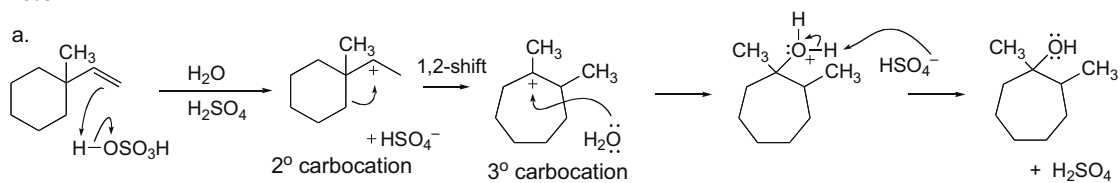
- 10.58** Draw each reaction. (a) The *cis* isomer of 4-octene gives two enantiomers on addition of Br₂.
 (b) The *trans* isomer gives a meso compound.

**10.59****10.60**

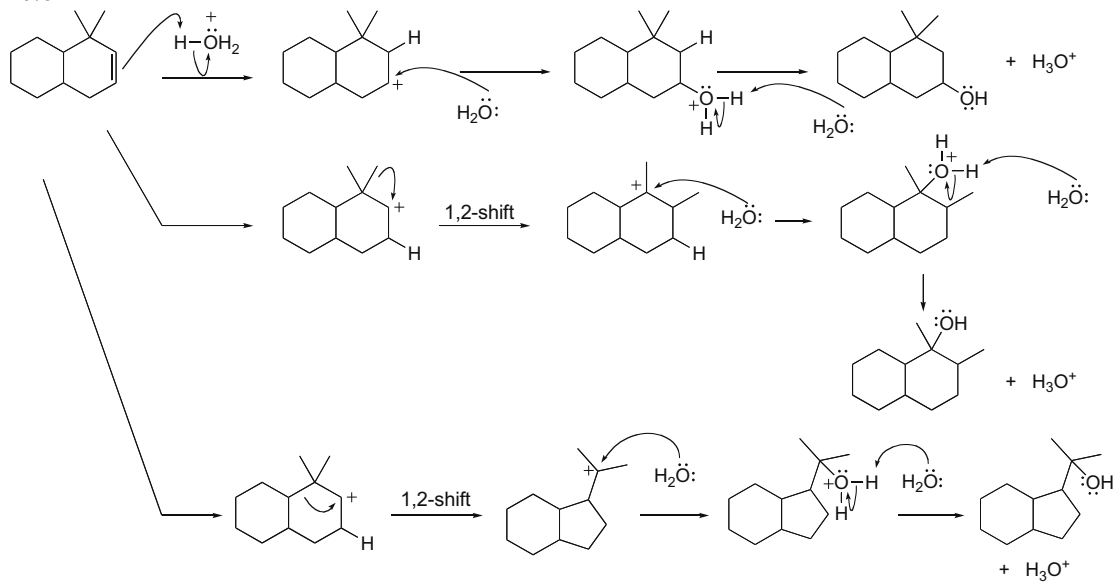
Chapter 10-26



10.61

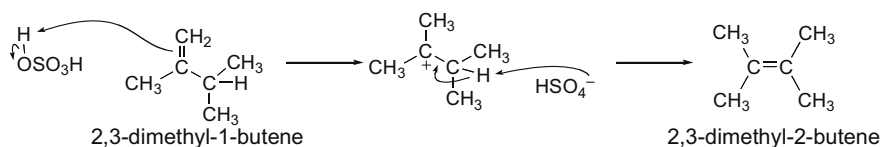


10.62

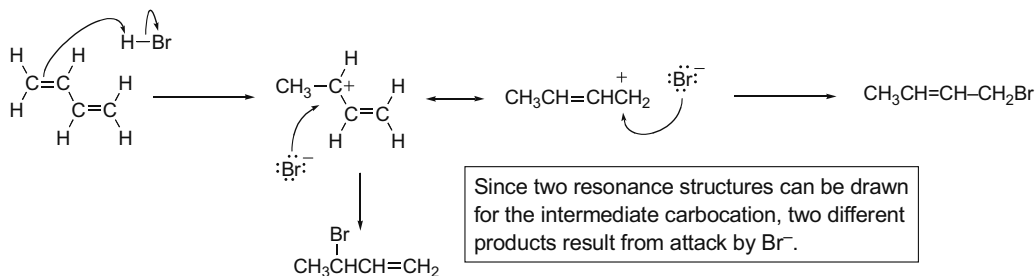


Alkenes 10-27

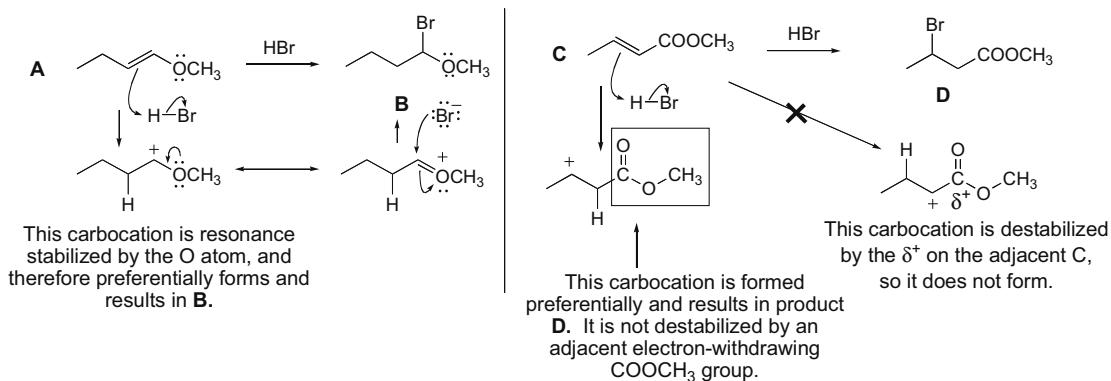
10.63 The isomerization reaction occurs by protonation and deprotonation.



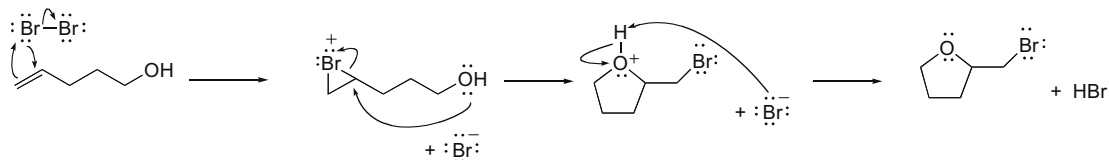
10.64



10.65

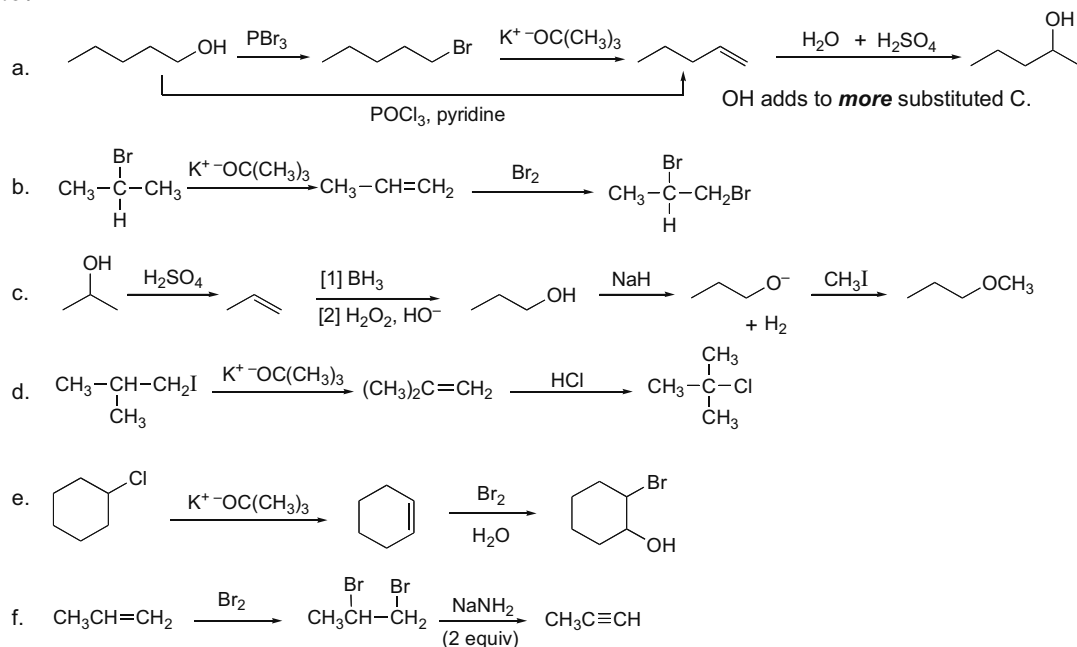


10.66

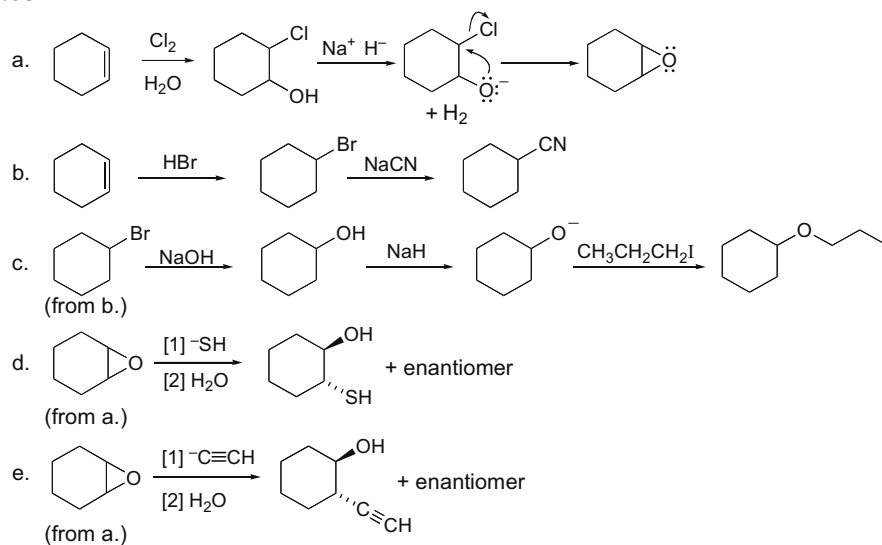


Chapter 10–28

10.67

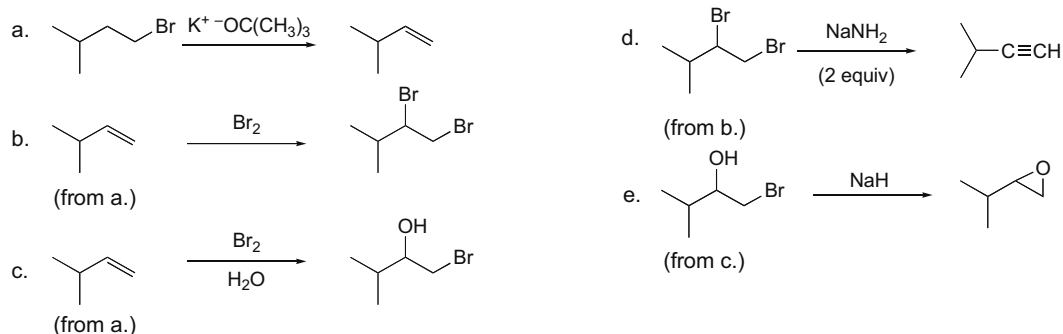


10.68

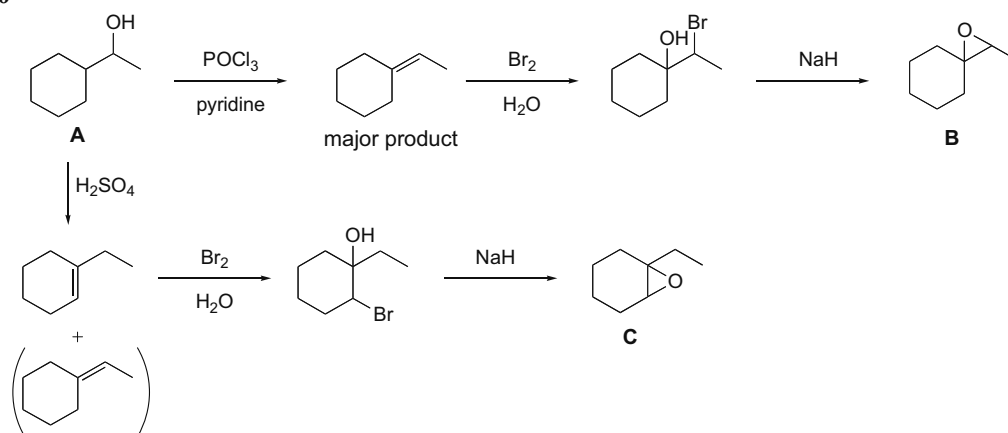


Alkenes 10-29

10.69



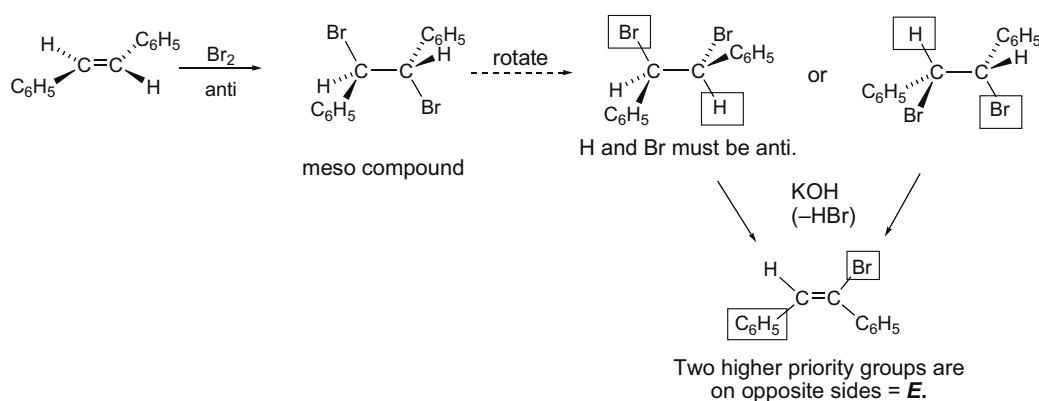
10.70



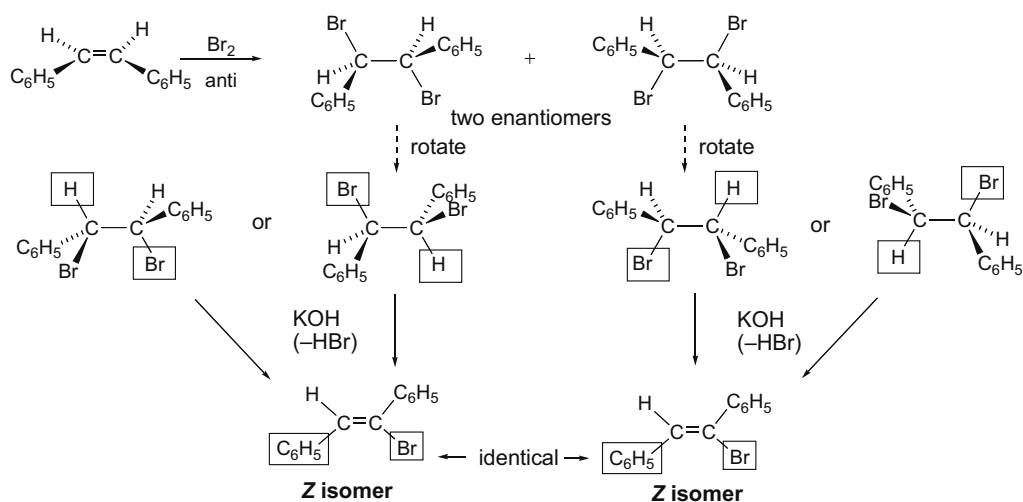
10.71 Having two rings joined together as in **A** and **B** creates a very rigid ring system and constrains bond angles. Evidently the bond angles around the C=C in **A** are close enough to the trigonal planar bond angle of 120° so that **A** is stable. With **B**, however, the C=C is located at a carbon shared by both rings and the bond angles around the C=C deviate greatly from the desired angle, so that **B** is not a stable compound.

Chapter 10–30

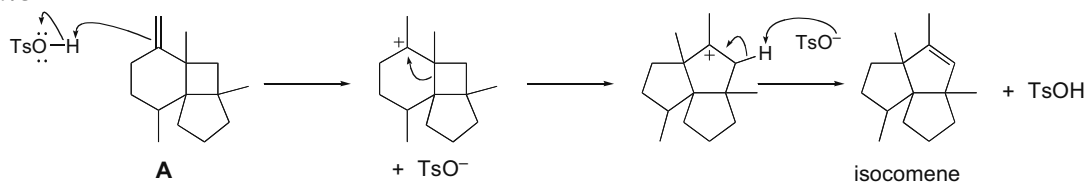
- 10.72** a. Br_2 adds in an anti fashion to form a meso dibromide. Rotate around the C–C bond to place H and Br anti periplanar in the second step. HBr can be eliminated in two ways, but both give the same product.



- b. Br_2 addition forms two enantiomers. Anti periplanar elimination of H and Br gives the same alkene from both compounds.

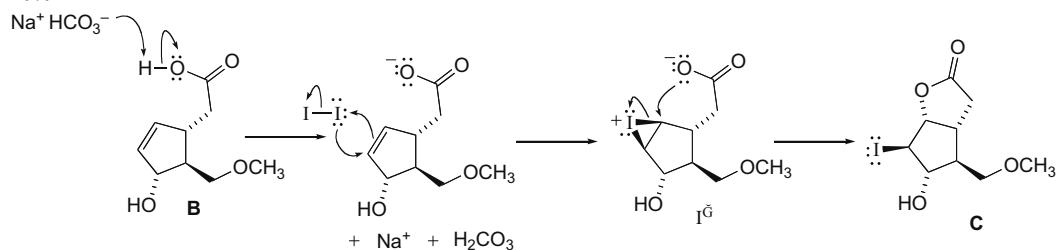


- c. The products in (a) and (b) are diastereomers.

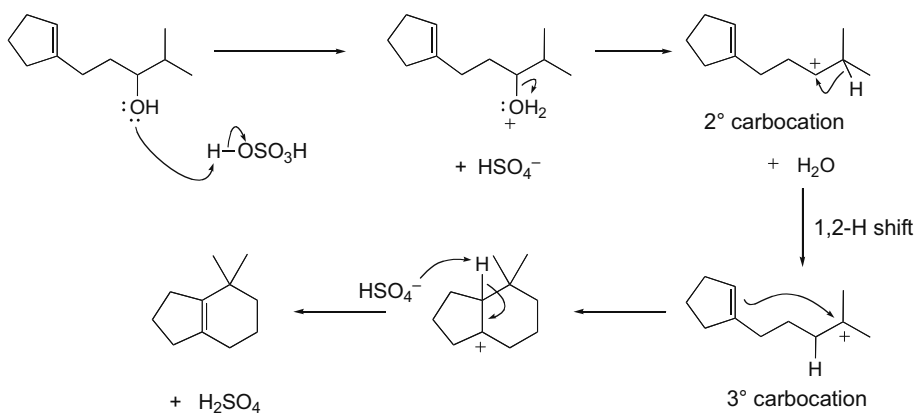
10.73

Alkenes 10-31

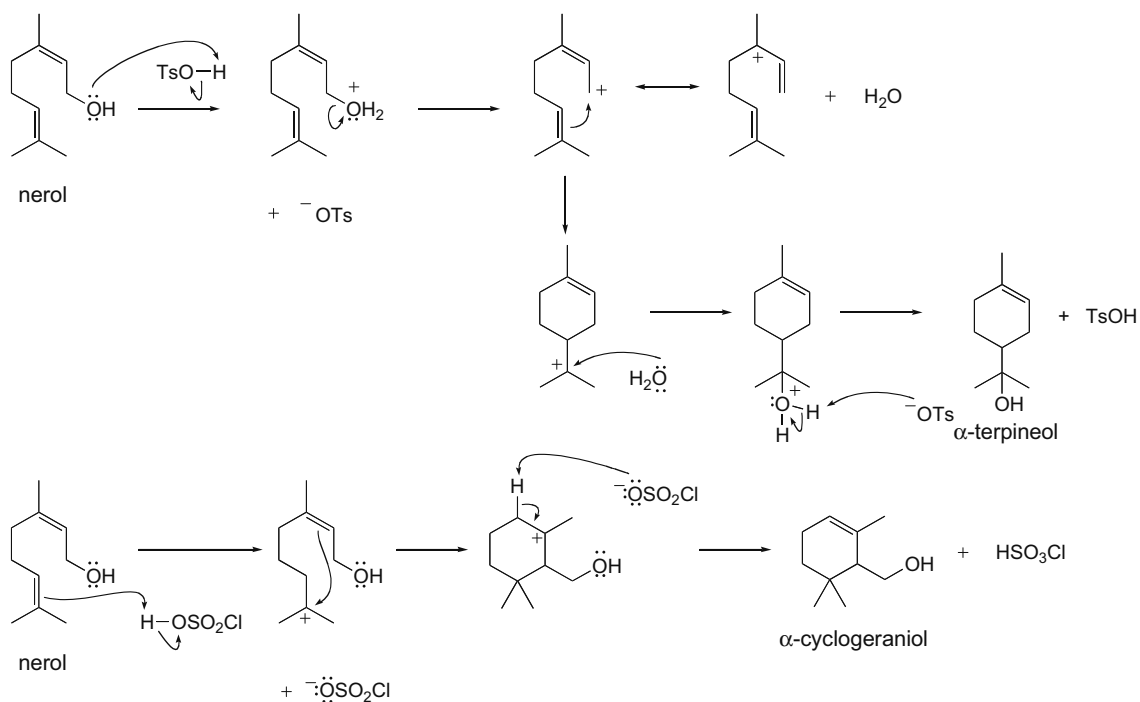
10.74



10.75

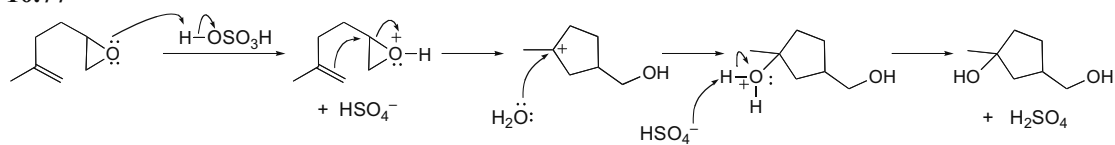


10.76



Chapter 10-32

10.77

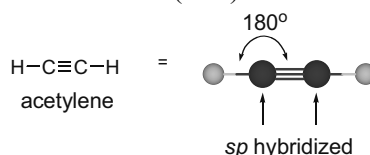


Chapter 11 Alkynes

Chapter Review

General facts about alkynes

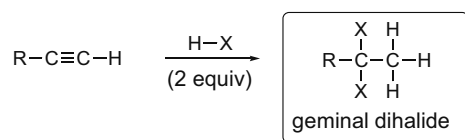
- Alkynes contain a carbon-carbon triple bond consisting of a strong σ bond and two weak π bonds. Each carbon is sp hybridized and linear (11.1).



- Alkynes are named using the suffix **-yne** (11.2).
- Alkynes have weak intermolecular forces, giving them low mp's and low bp's, and making them water insoluble (11.3).
- Since its weaker π bonds make an alkyne electron rich, alkynes undergo addition reactions with electrophiles (11.6).

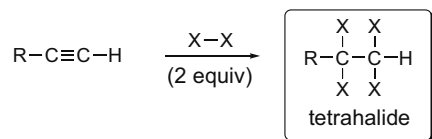
Addition reactions of alkynes

[1] Hydrohalogenation—Addition of HX (X = Cl, Br, or I) (11.7)



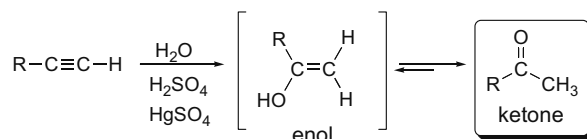
- Markovnikov's rule is followed. H bonds to the less substituted C in order to form the more stable carbocation.

[2] Halogenation—Addition of X_2 (X = Cl or Br) (11.8)



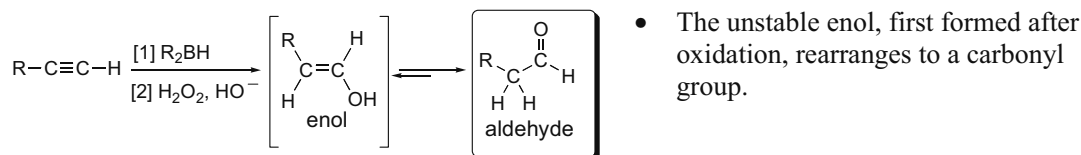
- Bridged halonium ions are formed as intermediates.
- Anti addition of X_2 occurs.

[3] Hydration—Addition of H_2O (11.9)



- Markovnikov's rule is followed. H bonds to the less substituted C in order to form the more stable carbocation.
- The unstable enol that is first formed rearranges to a carbonyl group.

Chapter 11-2

[4] Hydroboration-oxidation—Addition of H₂O (11.10)**Reactions involving acetylide anions**

[1] Formation of acetylide anions from terminal alkynes (11.6B)



[2] Reaction of acetylide anions with alkyl halides (11.11A)

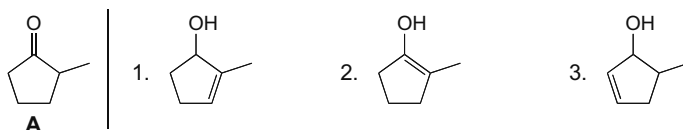


[3] Reaction of acetylide anions with epoxides (11.11B)

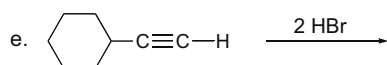
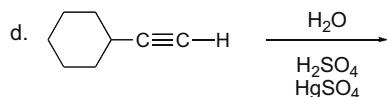
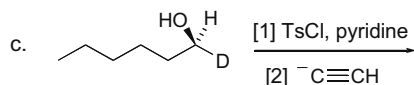
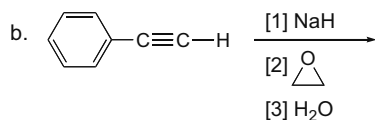
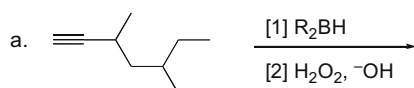


Practice Test on Chapter Review

1. Draw the structure for the compound with the following IUPAC name: 5-*tert*-butyl-6,6-dimethyl-3-nonyne.
2. a. Which of the following compounds is an enol tautomer of compound **A**?

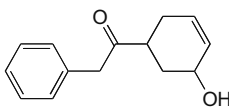


4. **A** can be a tautomer of both compounds (1) and (2).
 5. **A** can be a tautomer of compounds (1), (2), and (3).
- b. Which of the following bases is strong enough to deprotonate $\text{CH}_3\text{C}\equiv\text{CH}$ (propyne, $\text{p}K_{\text{a}} = 25$)? The $\text{p}K_{\text{a}}$'s of the conjugate acids of the bases are given in parentheses.
1. CH_3Li ($\text{p}K_{\text{a}} = 50$)
 2. NaOCH_3 ($\text{p}K_{\text{a}} = 15.5$)
 3. NaOCOCH_3 ($\text{p}K_{\text{a}} = 4.8$)
 4. The bases in (1) and (2) are both strong enough.
 5. The bases in (1), (2), and (3) are all strong enough.
3. Draw the organic products formed in the following reactions.

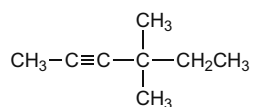


Chapter 11-4

4. Draw two different enol tautomers for the following compound.

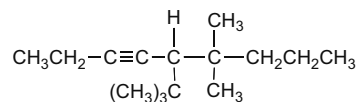


5. What acetylide anion and alkyl halide are needed to make the following alkyne?



Answers to Practice Test

1.

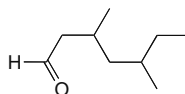


2. a. 2

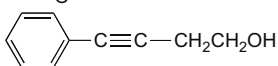
b. 1

3.

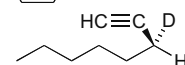
a.



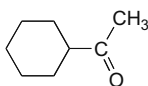
b.



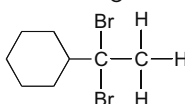
c.



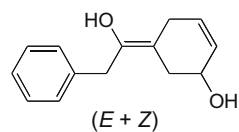
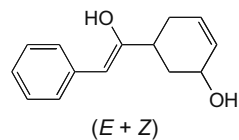
d.



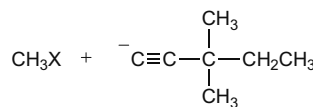
e.



4.

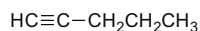


5.

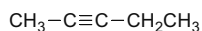


Answers to Problems

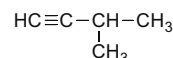
- 11.1** • An **internal alkyne** has the triple bond somewhere in the *middle* of the carbon chain.
 • A **terminal alkyne** has the triple bond at the *end* of the carbon chain.



terminal alkyne

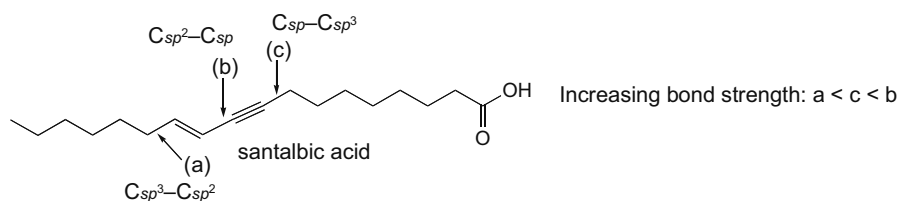


internal alkyne



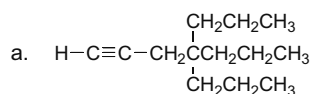
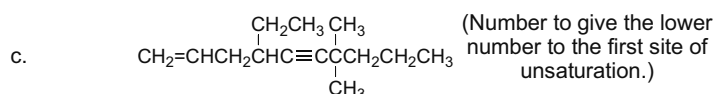
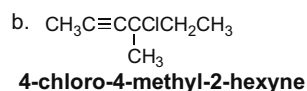
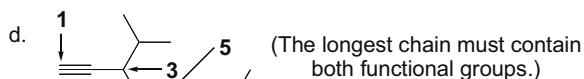
terminal alkyne

11.2



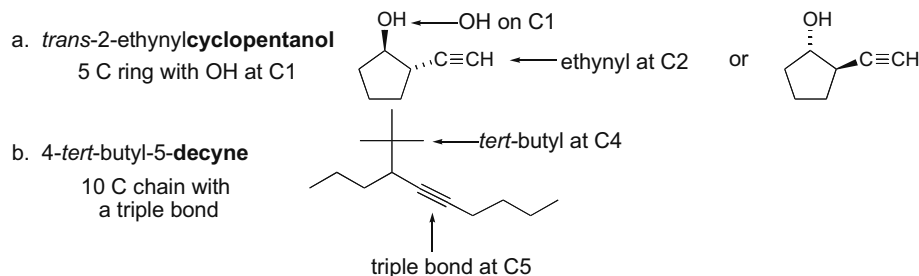
11.3 To name an alkyne:

- [1] Find the longest chain that contains both atoms of the triple bond, change the *-ane* ending of the parent name to *-yne*, and number the chain to give the first carbon of the triple bond the lower number.
- [2] Name all substituents following the other rules of nomenclature.

**4,4-dipropyl-1-heptyne****4-ethyl-7,7-dimethyl-1-decen-5-yne****4-chloro-4-methyl-2-hexyne****3-isopropyl-1,5-octadiyne**

11.4 To work backwards from a name to a structure:

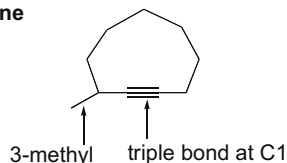
- [1] Find the parent name and the functional group.
- [2] Add the substituents to the appropriate carbon.



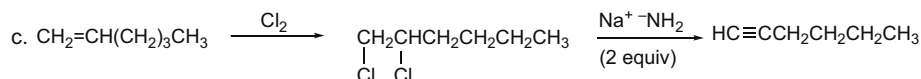
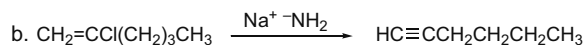
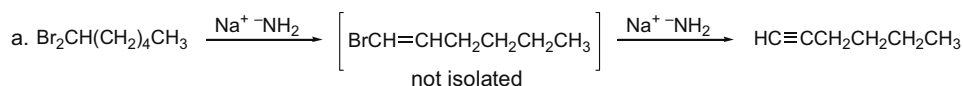
Chapter 11-6

c. 3-methylcyclononyne

9 C ring with a triple bond at C1



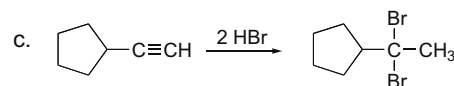
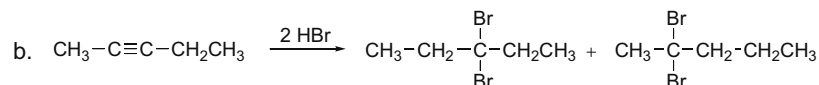
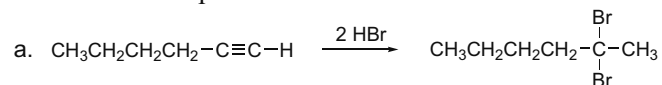
11.5 Two factors cause the boiling point increase. The linear sp hybridized C's of the alkyne allow for more van der Waals attraction between alkyne molecules. Also, since a triple bond is more polarizable than a double bond, this increases the van der Waals forces between two molecules as well.

11.6 To convert an alkene to an alkyne:[1] Make a vicinal dihalide from the alkene by addition of X_2 .[2] Add base to remove two equivalents of HX and form the alkyne.

11.7 Acetylene has a pK_a of 25, so **bases having a conjugate acid with a pK_a above 25** will be able to deprotonate it.

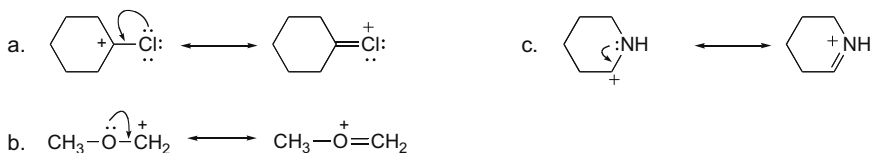
a. CH_3NH^- [$pK_a(\text{CH}_3\text{NH}_2) = 40$] $pK_a > 25 = \text{Can deprotonate acetylene.}$ b. CO_3^{2-} [$pK_a(\text{HCO}_3^-) = 10.2$] $pK_a < 25 = \text{Cannot deprotonate acetylene.}$ c. $\text{CH}_2=\text{CH}^-$ [$pK_a(\text{CH}_2=\text{CH}_2) = 44$] $pK_a > 25 = \text{Can deprotonate acetylene.}$ d. $(\text{CH}_3)_3\text{CO}^-$ [$pK_a[(\text{CH}_3)_3\text{COH}] = 18$] $pK_a < 25 = \text{Cannot deprotonate acetylene.}$ **11.8** To draw the products of reactions with HX :

- Add two moles of HX to the triple bond, following Markovnikov's rule.
- Both X 's end up on the more substituted C.

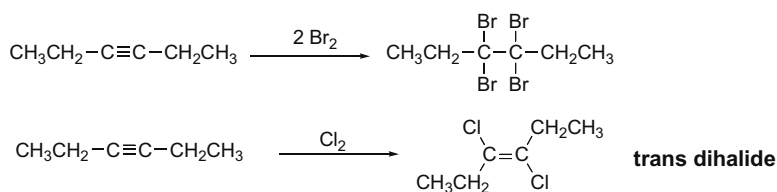


Alkynes 11-7

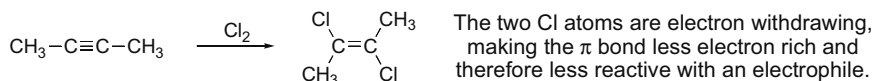
11.9



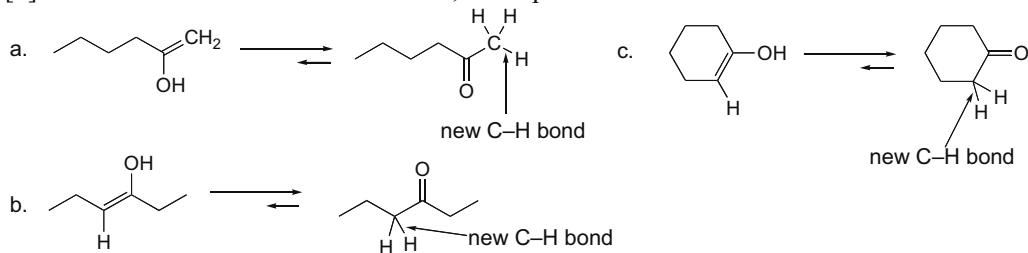
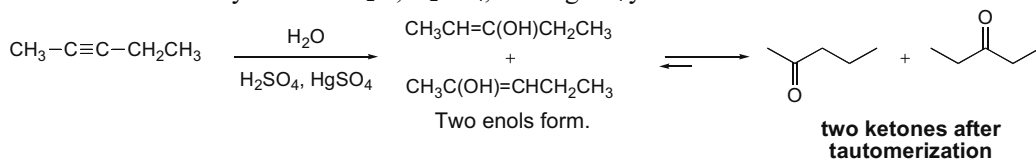
11.10 Addition of one equivalent of X_2 to alkynes forms trans dihalides.
Addition of two equivalents of X_2 to alkynes forms tetrahalides.



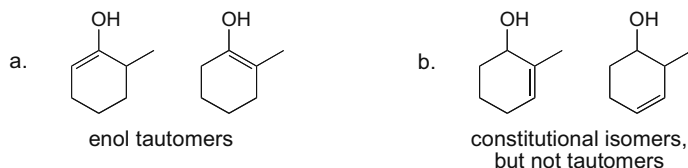
11.11

**11.12 To draw the keto form of each enol:**

- [1] Change the C–OH to a C=O at one end of the double bond.
[2] At the other end of the double bond, add a proton.

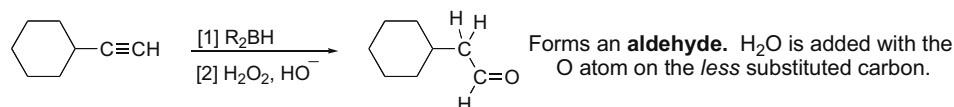
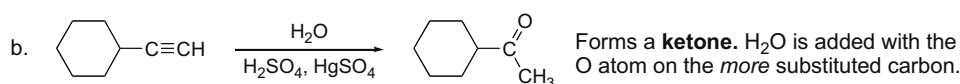
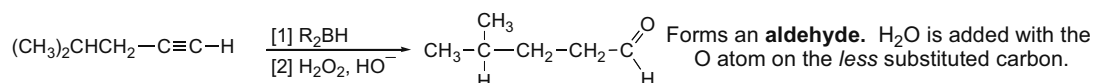
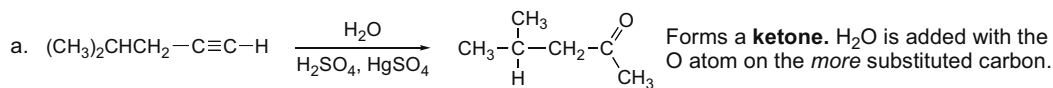
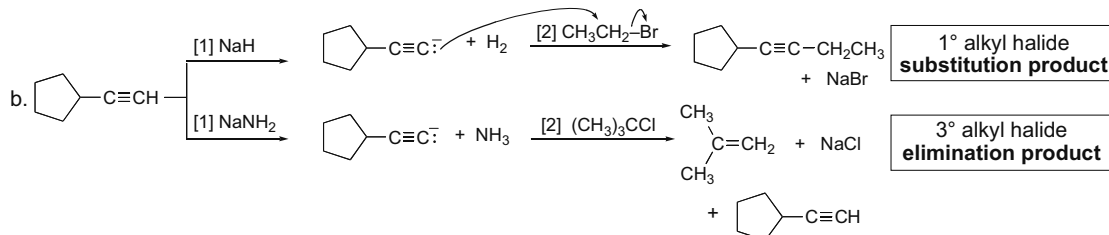
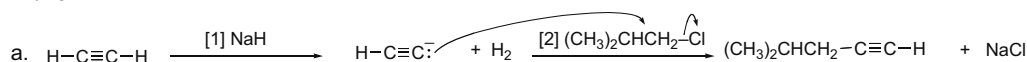
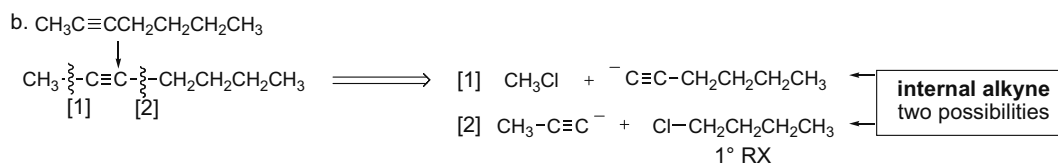
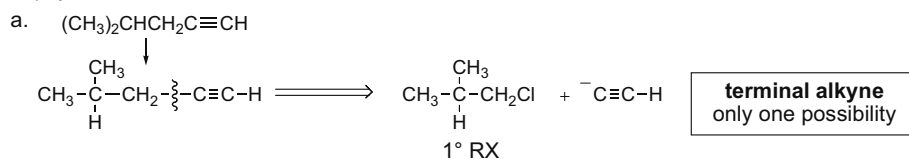
**11.13** The treatment of alkynes with H_2O , H_2SO_4 , and HgSO_4 yields ketones.

11.14

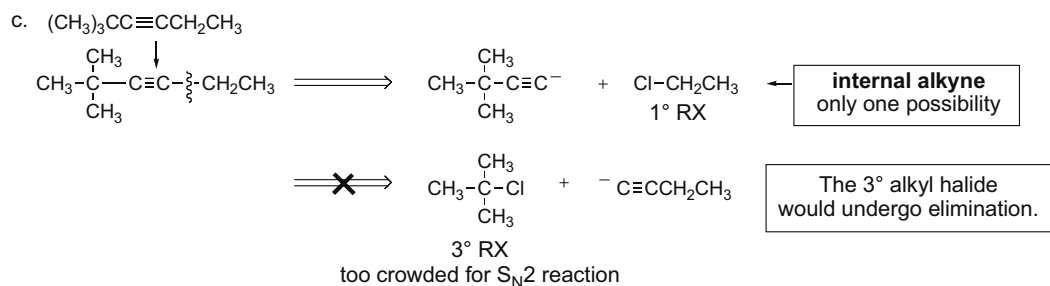


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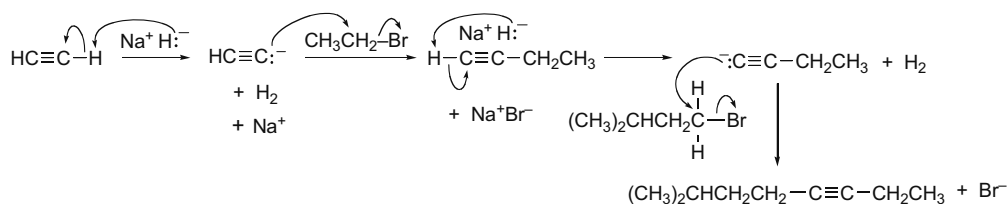
11.15 Reaction with H_2O , H_2SO_4 , and HgSO_4 adds the oxygen to the *more* substituted carbon.
 Reaction with [1] R_2BH , [2] H_2O_2 , HO^- adds the oxygen to the *less* substituted carbon.

**11.16****11.17**

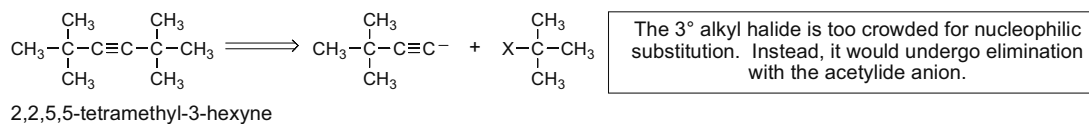
Alkynes 11-9



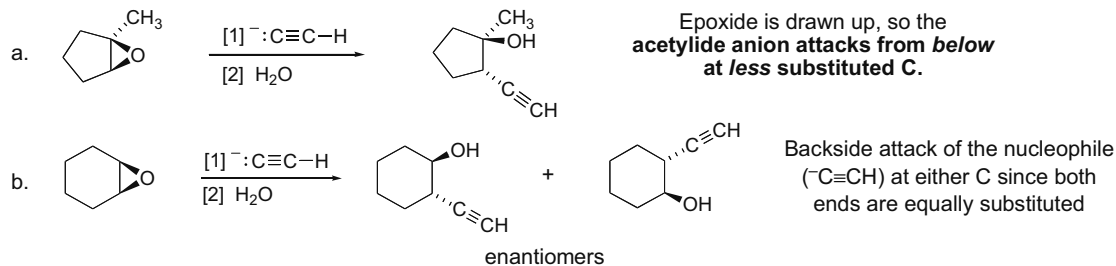
11.18



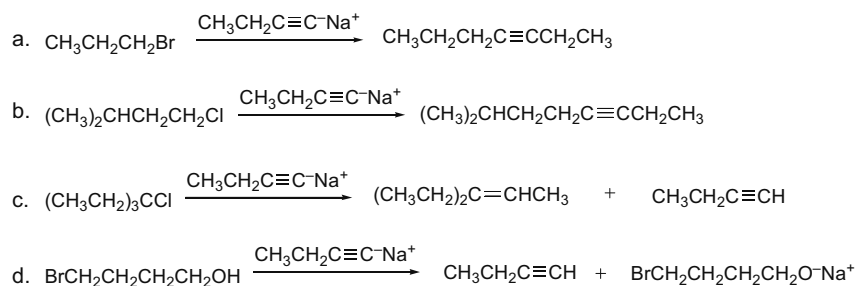
11.19



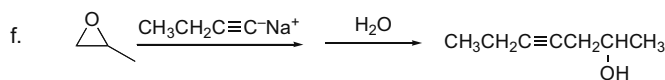
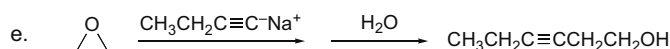
11.20



11.21

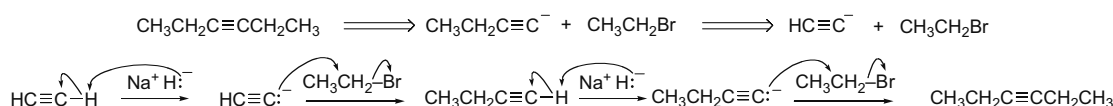
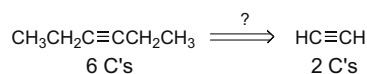


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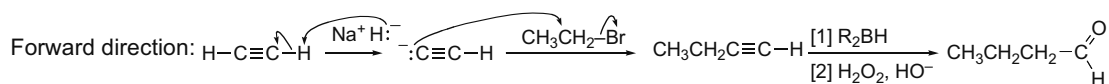
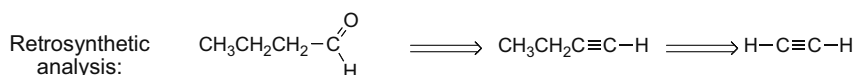
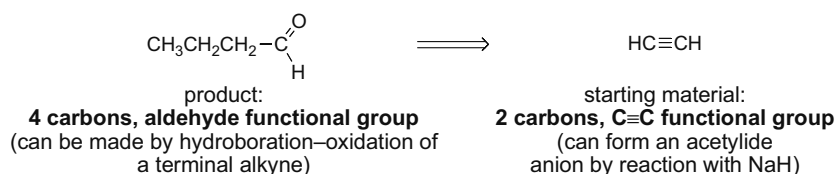


11.22 To use a retrosynthetic analysis:

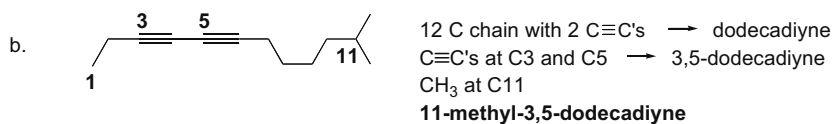
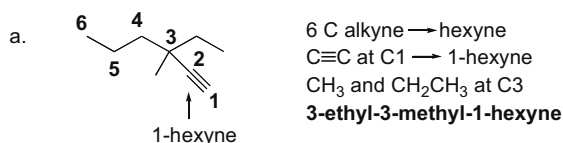
- [1] **Count the number of carbon atoms** in the starting material and product.
- [2] **Look at the functional groups** in the starting material and product.
 - Determine what types of reactions can form the product.
 - Determine what types of reactions the starting material can undergo.
- [3] **Work backwards** from the product to make the starting material.
- [4] Write out the synthesis in the synthetic direction.



11.23

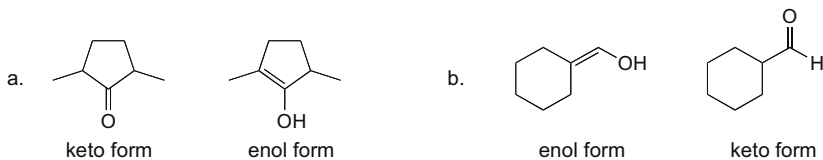


11.24

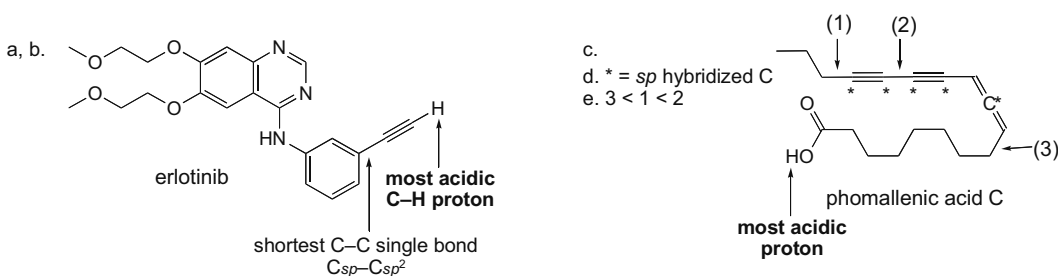


Alkynes 11–11

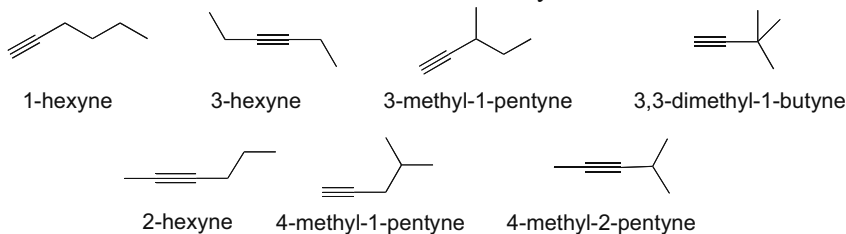
11.25



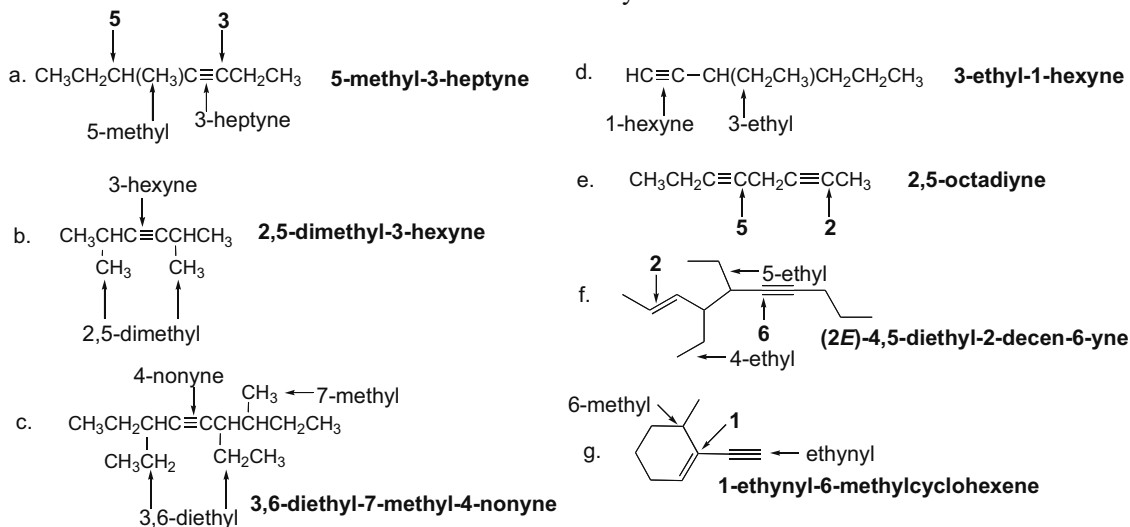
11.26



11.27 Use the rules from Answer 11.3 to name the alkynes.



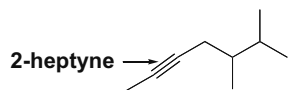
11.28 Use the rules from Answer 11.3 to name the alkynes.



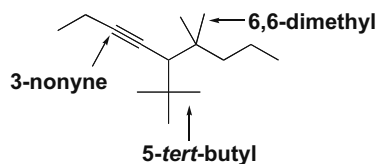
Chapter 11–12

11.29 Use the directions from Answer 11.4 to draw each structure.

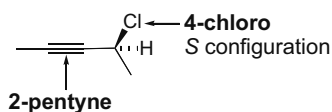
a. 5,6-dimethyl-2-heptyne



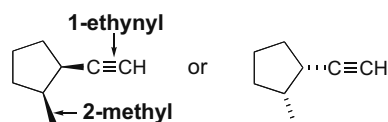
b. 5-*tert*-butyl-6,6-dimethyl-3-nonyne



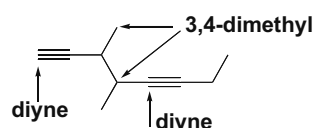
c. (4*S*)-4-chloro-2-pentyne



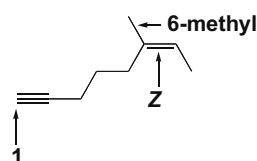
d. *cis*-1-ethynyl-2-methylcyclopentane



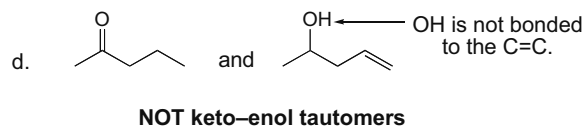
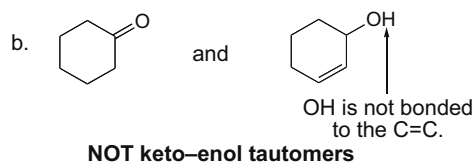
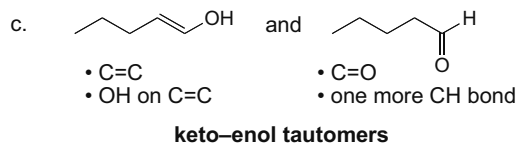
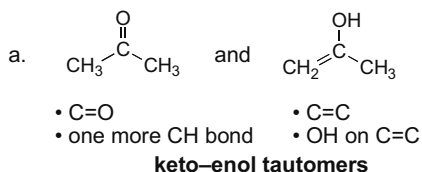
e. 3,4-dimethyl-1,5-octadiyne



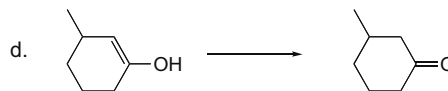
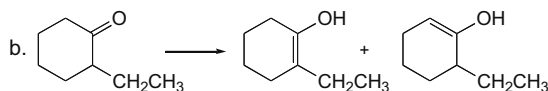
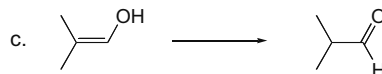
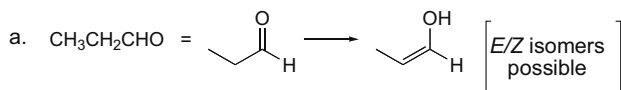
f. (6*Z*)-6-methyl-6-octen-1-yne



11.30 Keto–enol tautomers are constitutional isomers in equilibrium that differ in the location of a double bond and a hydrogen. The OH in an enol must be bonded to a C=C.

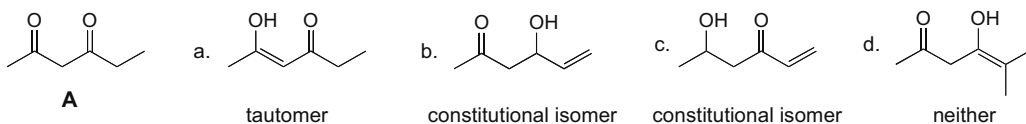


11.31 To draw the enol form of each keto form: [1] Change the C=O to a C–OH. [2] Change one single C–C bond to a double bond, making sure the OH group is bonded to the C=C. Use the directions from Answer 11.12 to draw each keto form.

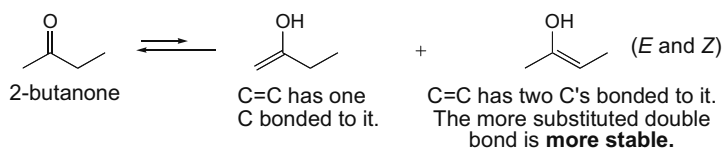


Alkynes 11-13

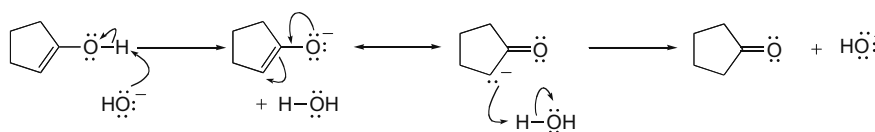
11.32 Tautomers are constitutional isomers that are in equilibrium and differ in the location of a double bond and a hydrogen atom.



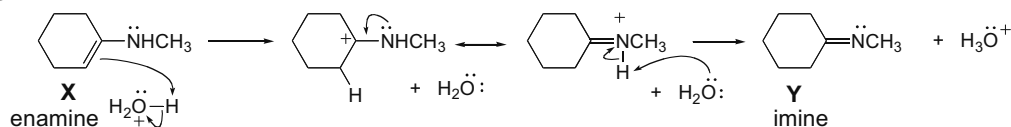
11.33



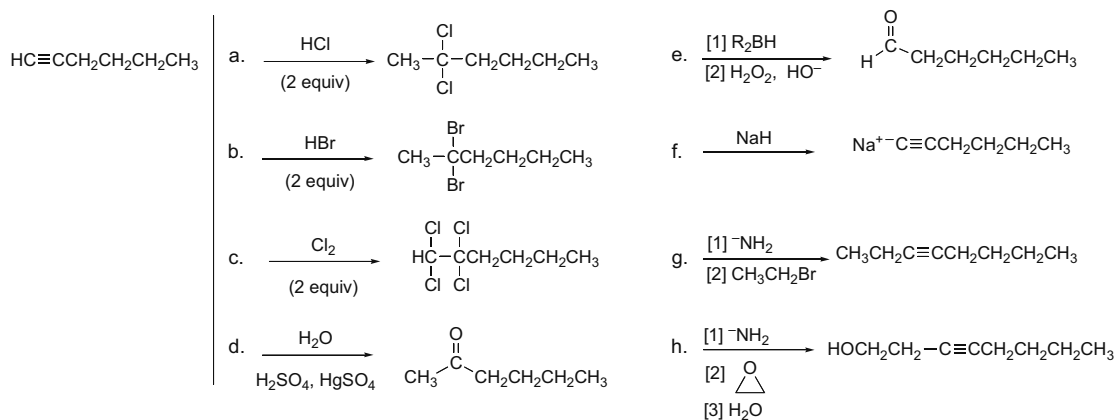
11.34



11.35

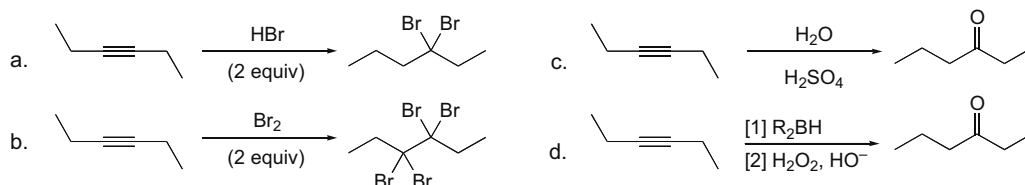


11.36

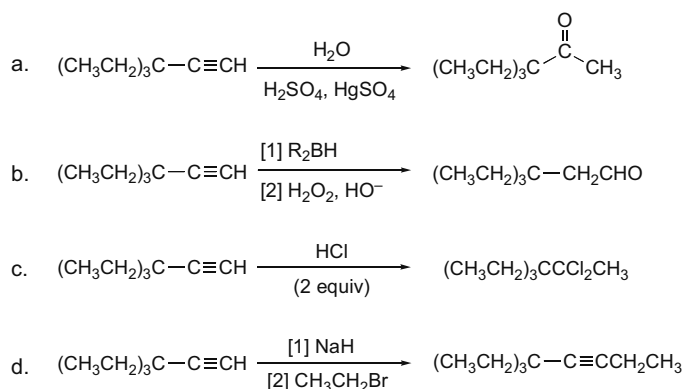


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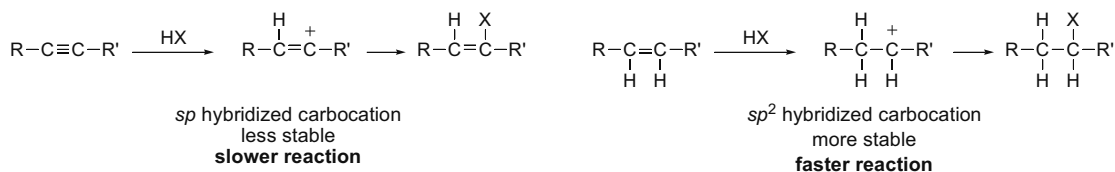
11.37



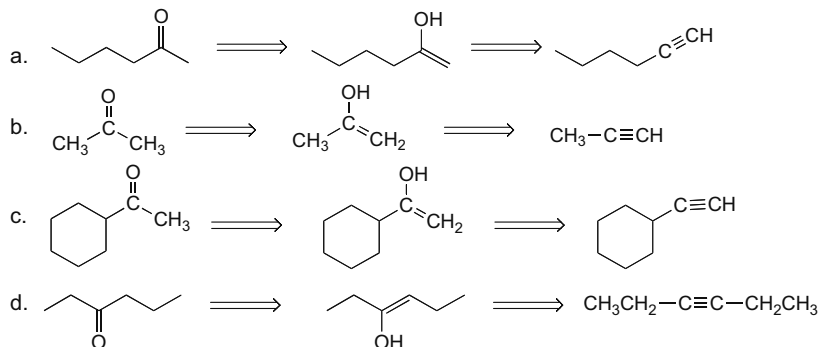
11.38



11.39 Reaction rate (which is determined by E_a) and enthalpy (ΔH°) are not related. More exothermic reactions are not necessarily faster. Since the addition of HX to an alkene forms a more stable carbocation in an endothermic, rate-determining step, this carbocation is formed faster by the Hammond postulate.

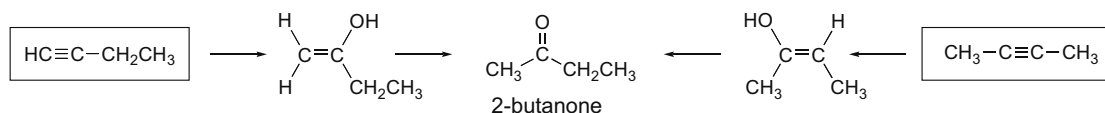


11.40

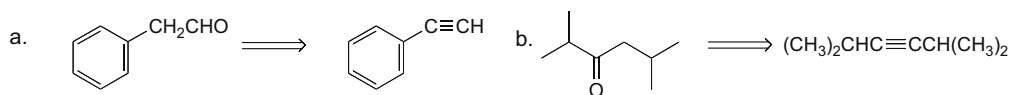


Alkynes 11–15

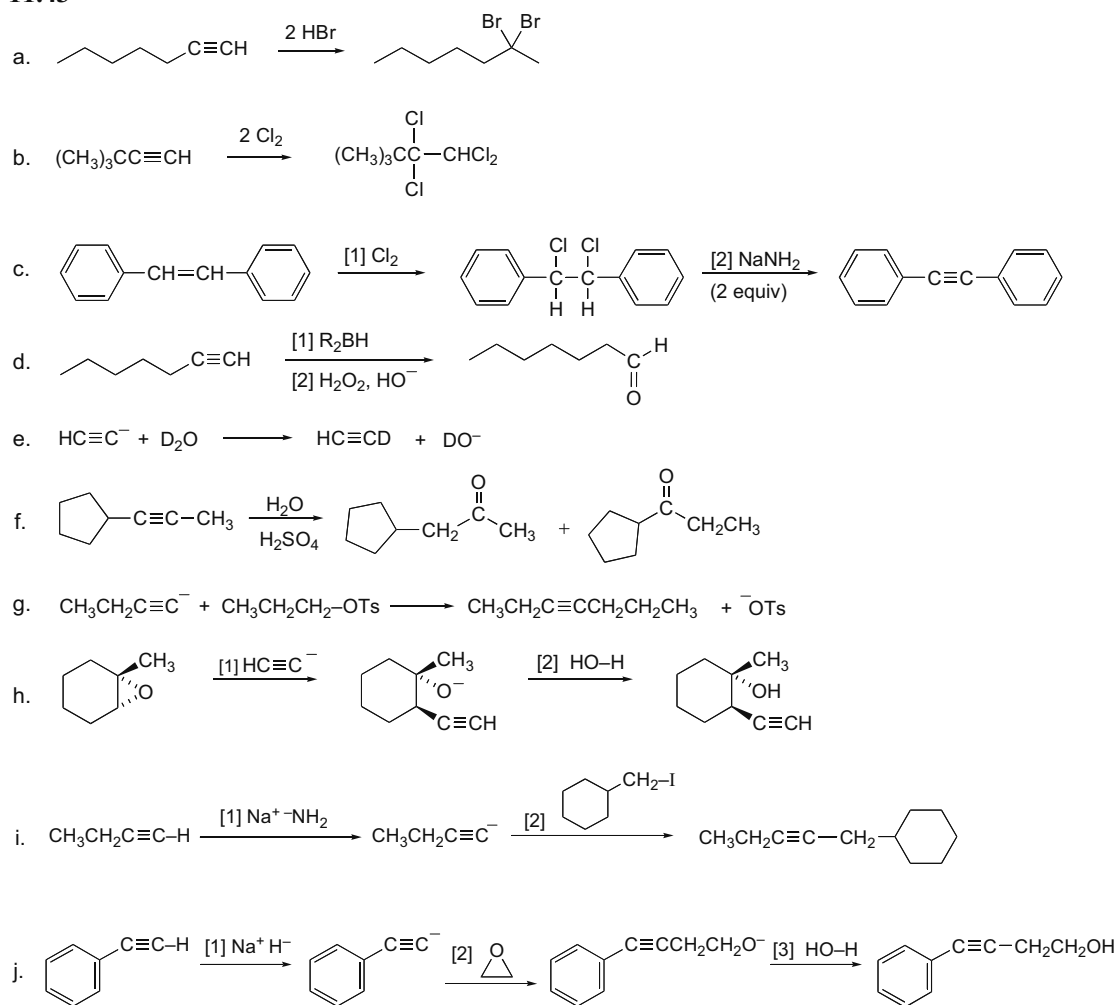
11.41 To determine what two alkynes could yield the given ketone, work backwards by drawing the enols and then the alkynes.



11.42

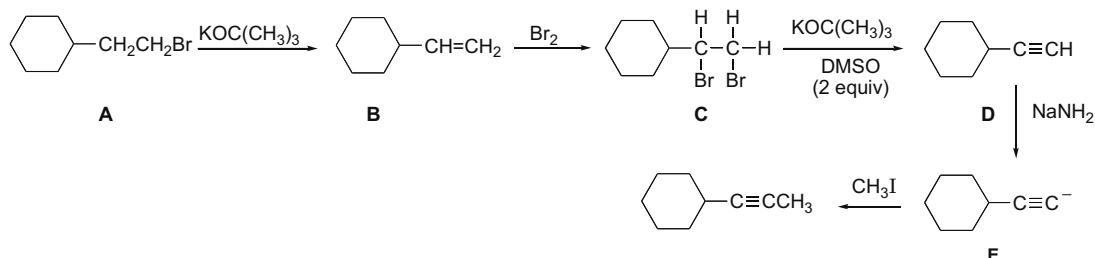


11.43

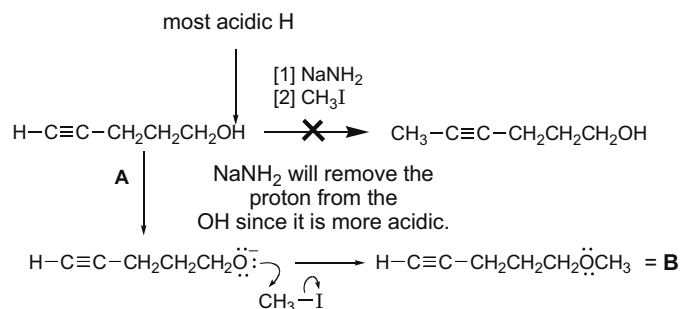


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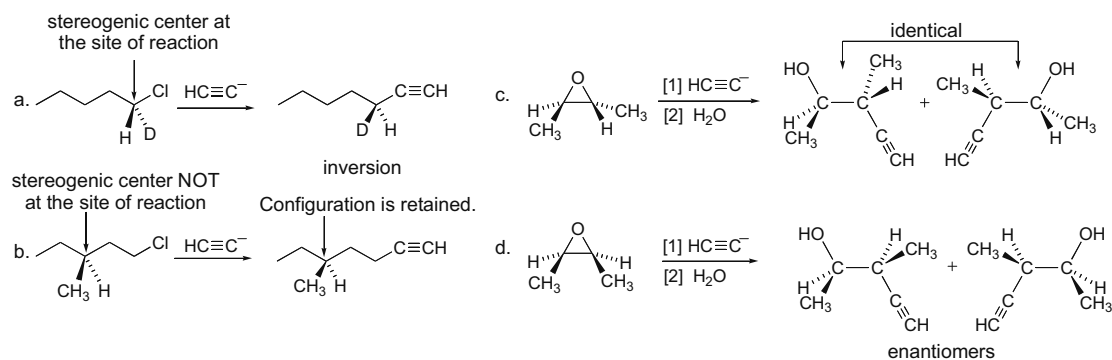
11.44



11.45

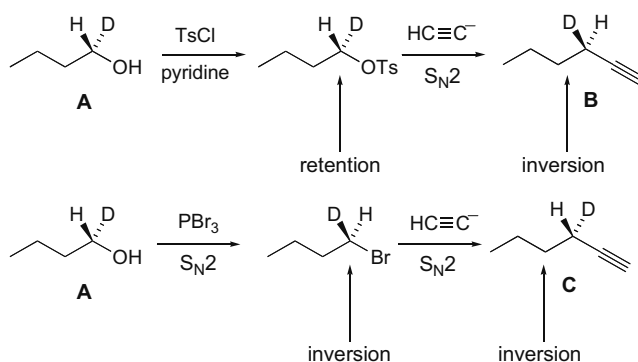


11.46

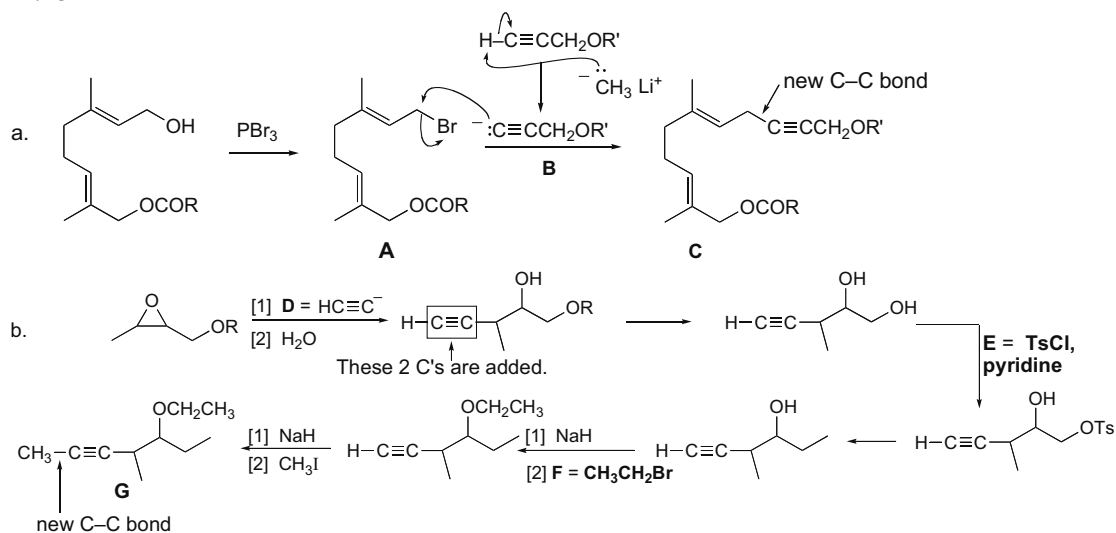


Alkynes 11-17

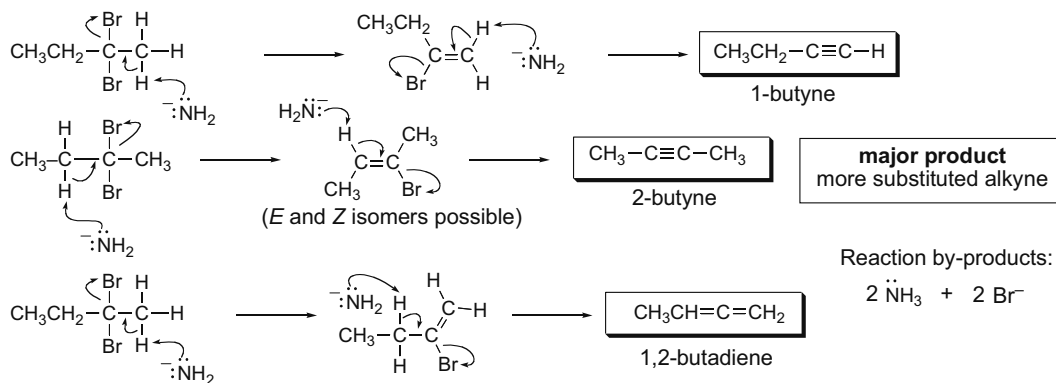
11.47



11.48

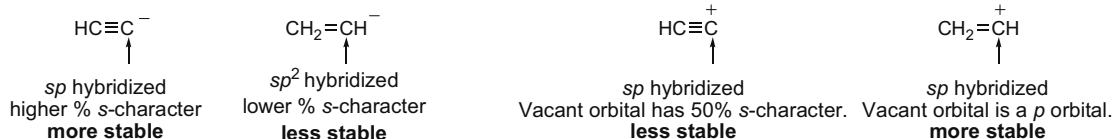
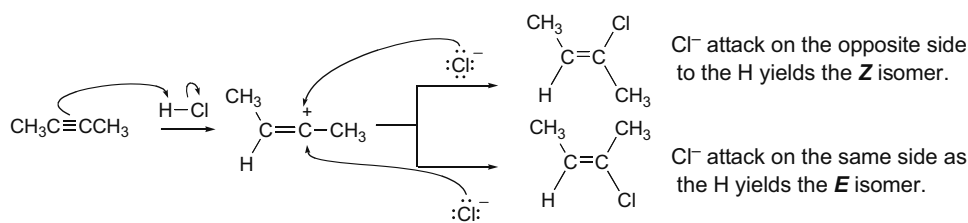
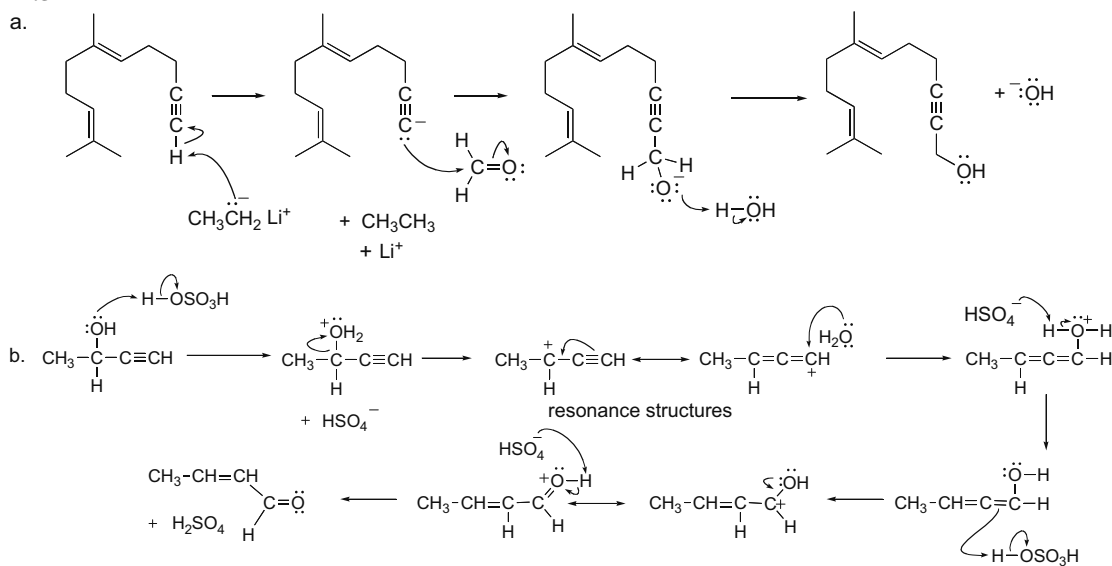


11.49



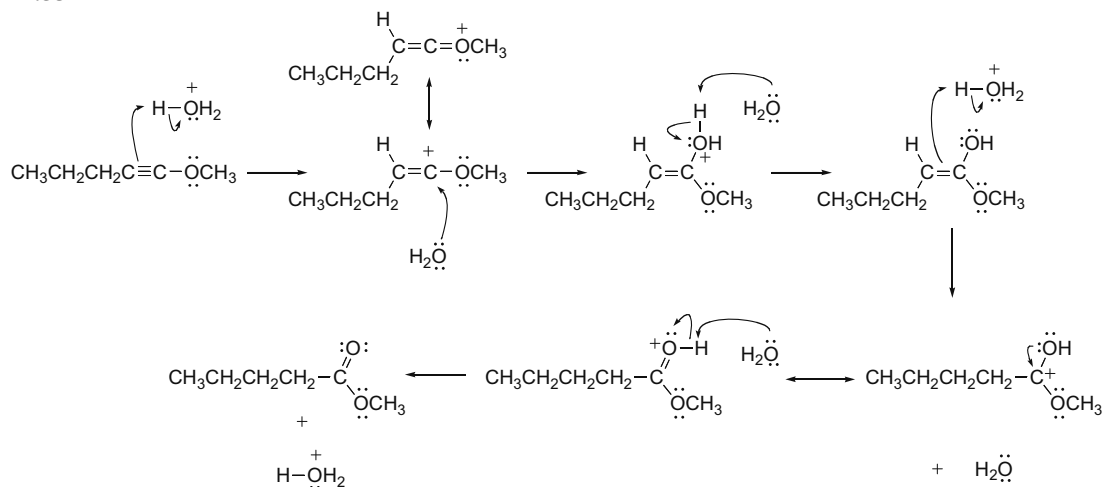
Chapter 11–18

11.50 A carbanion is more stable when its lone pair is in an orbital with a higher percentage of the smaller s orbital. A carbocation is more stable when its positive charge is due to a vacant orbital with a lower percentage of the smaller s orbital. In $\text{HC}\equiv\text{C}^+$, the positively charged C uses two p orbitals to form two π bonds. If the σ bond is formed using an sp hybrid orbital, the second hybrid orbital would have to remain vacant, a highly unstable situation.

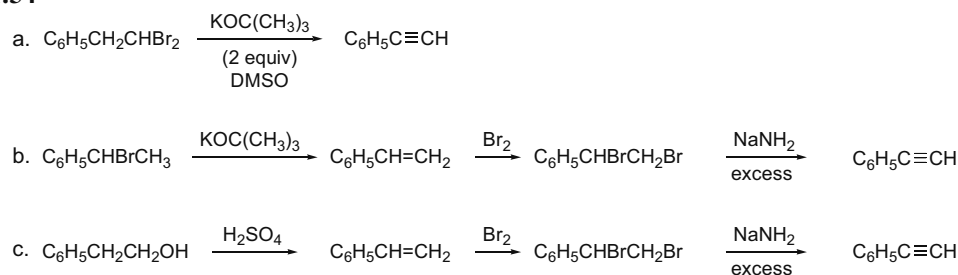
**11.51****11.52**

Alkynes 11-19

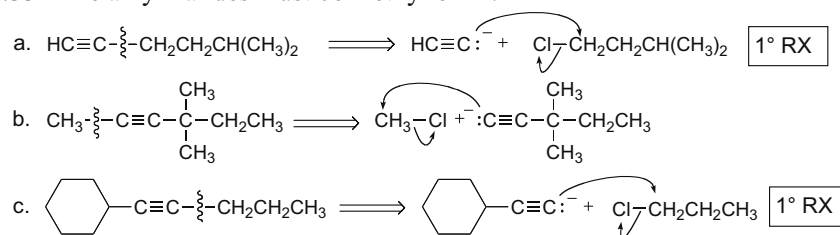
11.53



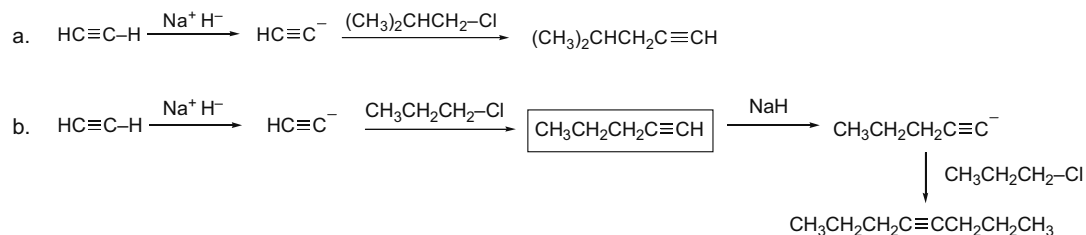
11.54



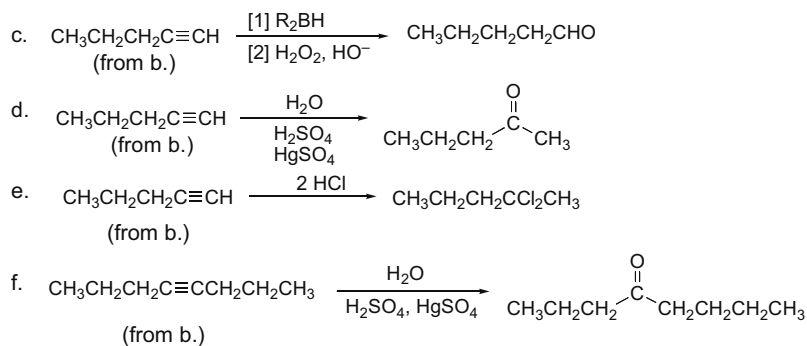
11.55 The alkyl halides must be methyl or 1°.



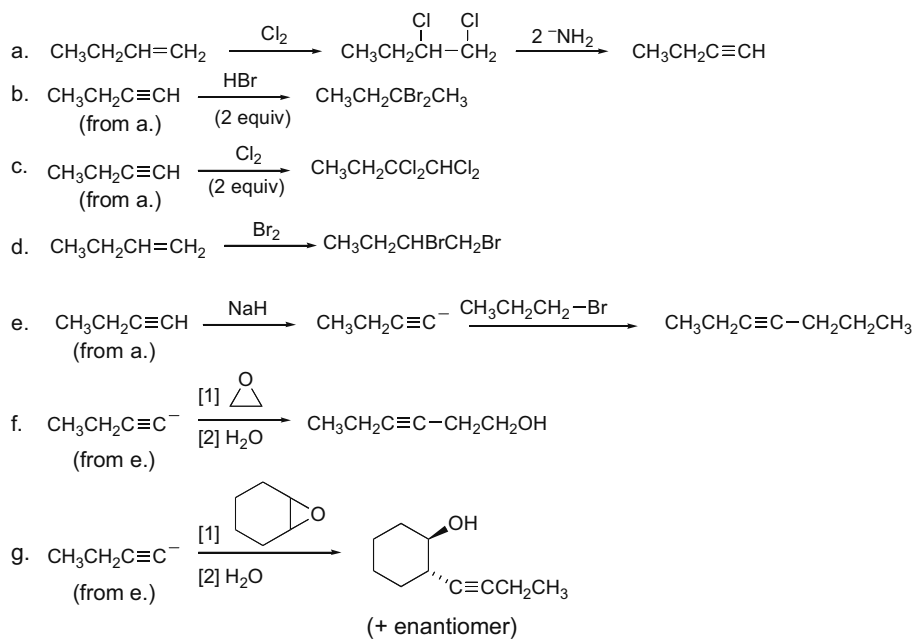
11.56



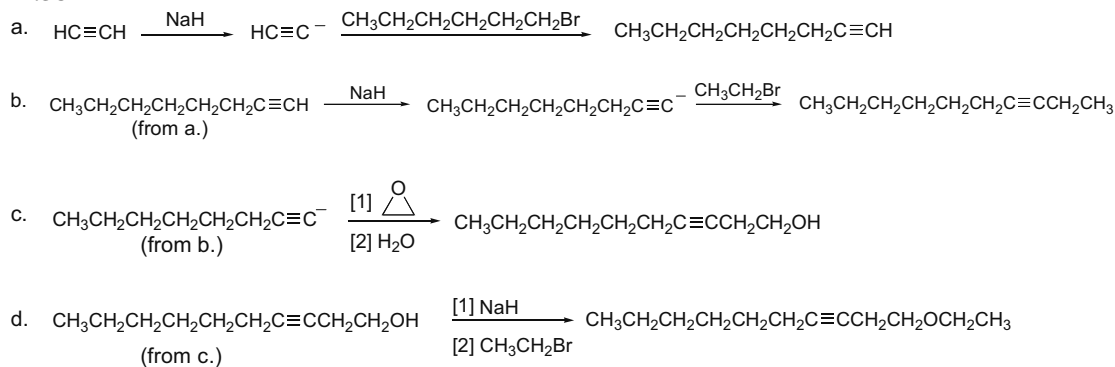
Chapter 11–20



11.57

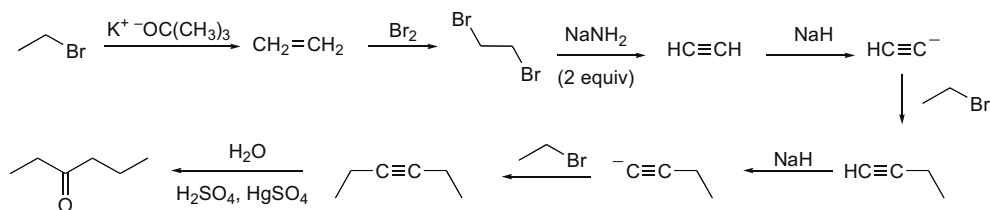


11.58

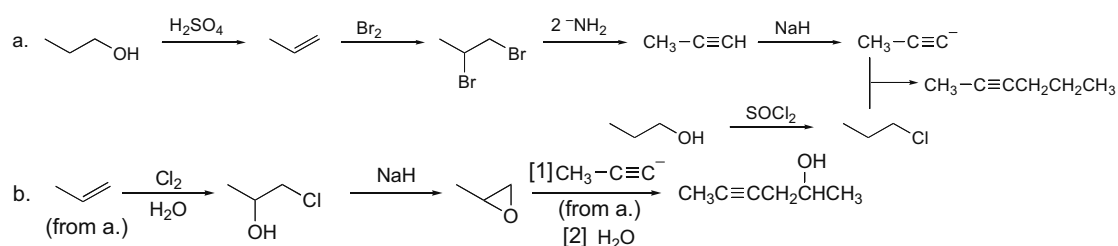


Alkynes 11-21

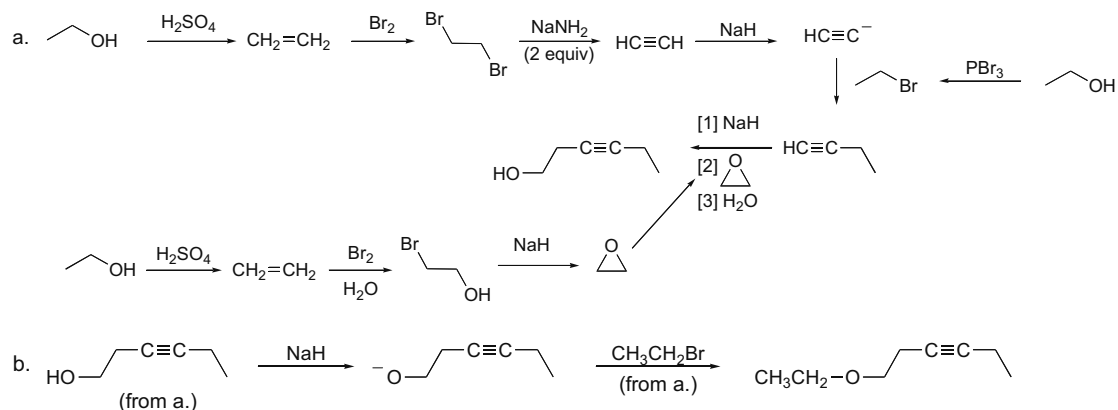
11.59



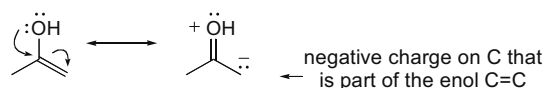
11.60



11.61



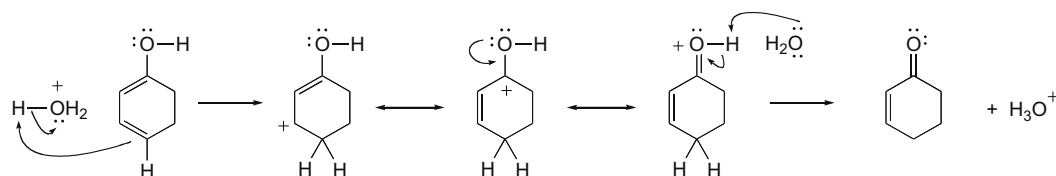
11.62 Two resonance structures can be drawn for an enol.



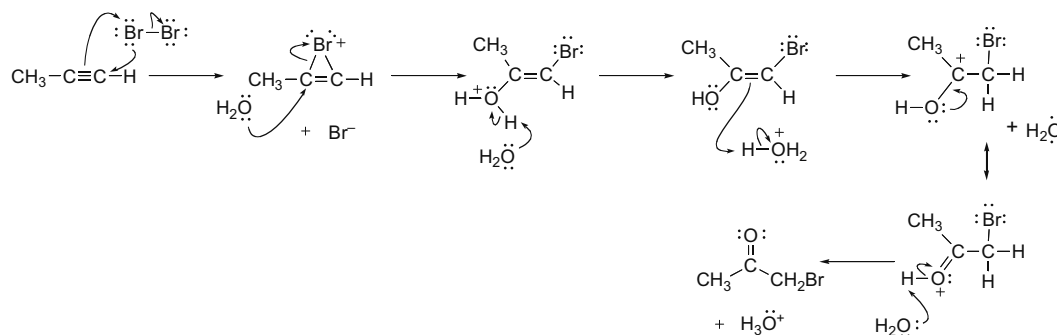
Since the second resonance structure places an electron pair (and therefore a negative charge) on an enol carbon, this makes the C=C more nucleophilic than the C=C of an alkene for which no additional resonance forms can be drawn. Thus, the OH group donates electron density to the C=C by a resonance effect.

Chapter 11-22

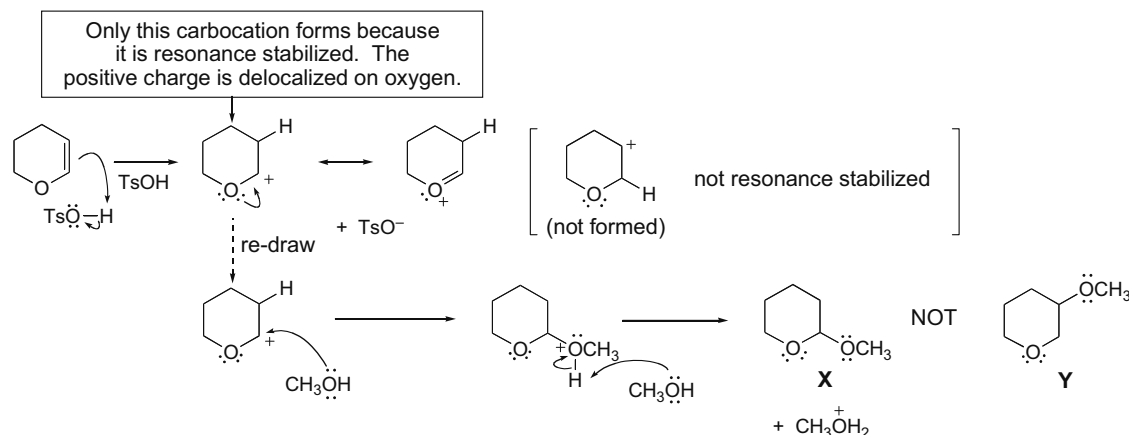
11.63



11.64

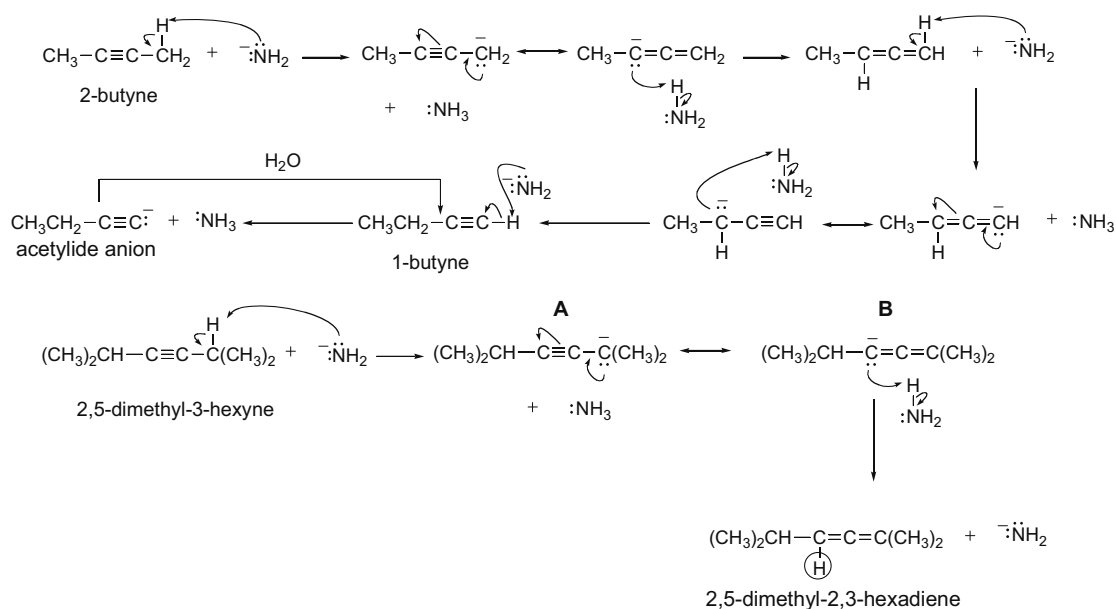


11.65



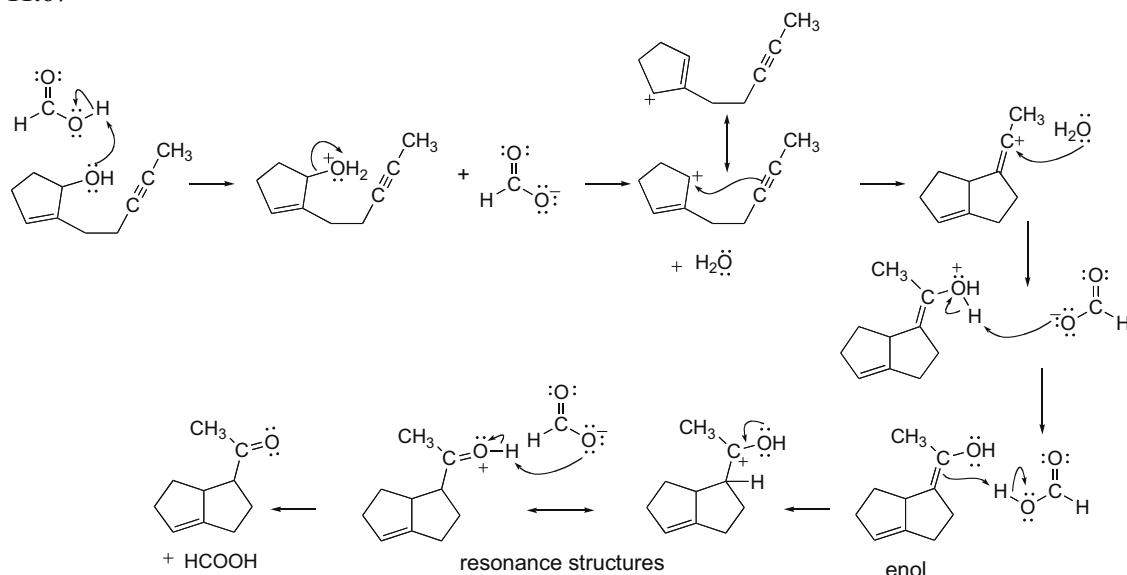
- 11.66** A more stable internal alkyne can be isomerized to a less stable terminal alkyne under these reaction conditions because when $\text{CH}_3\text{CH}_2\text{C}\equiv\text{CH}$ is first formed, it contains an sp hybridized C-H bond, which is more acidic than any proton in $\text{CH}_3-\text{C}\equiv\text{C}-\text{CH}_3$. Under the reaction conditions, this proton is removed with base. Formation of the resulting acetylide anion drives the equilibrium to favor its formation. Protonation of this acetylide anion gives the less stable terminal alkyne.

Alkynes 11-23



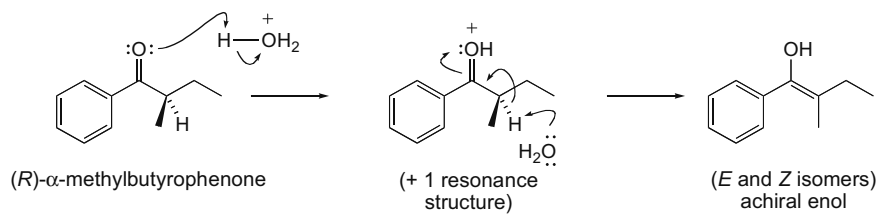
In this case the reaction stops with formation of 2,5-dimethyl-2,3-hexadiene because a terminal alkyne (with an acidic sp hybridized C-H bond) is not formed. Removal of the circled H in the diene re-forms the anion shown in resonance structures **A** and **B**.

11.67

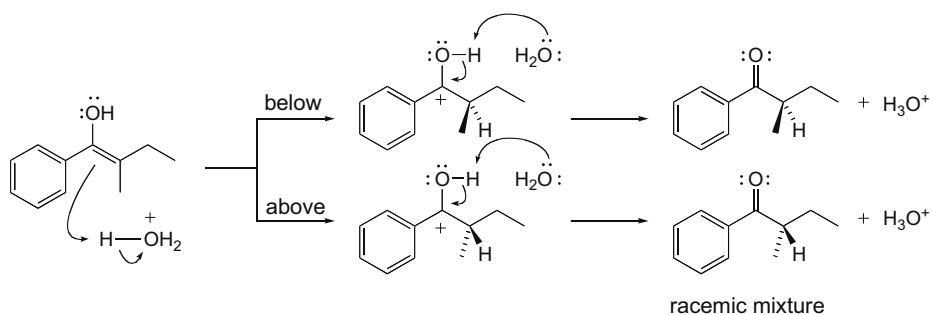


Chapter 11-24

11.68 In the presence of acid, (*R*)- α -methylbutyrophenone enolizes to form an achiral enol.



The achiral enol can then be protonated from above or below the plane to form a racemic mixture that is optically inactive.

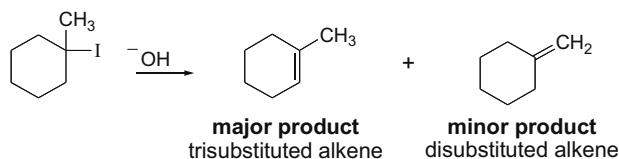


Chapter 12 Oxidation and Reduction

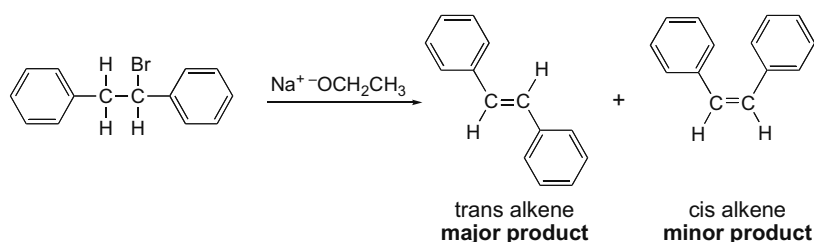
Chapter Review

Summary: Terms that describe reaction selectivity

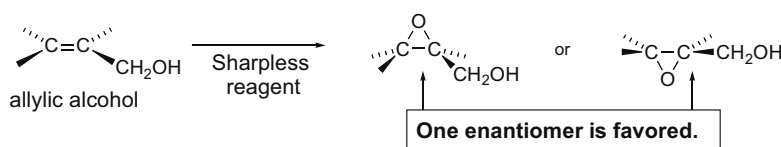
- A **regioselective reaction** forms predominately or exclusively one constitutional isomer (Section 8.5).



- A **stereoselective reaction** forms predominately or exclusively one stereoisomer (Section 8.5).



- An **enantioselective reaction** forms predominately or exclusively one enantiomer (Section 12.15).



Definitions of oxidation and reduction

Oxidation reactions result in:

- an increase in the number of C–Z bonds, *or*
- a decrease in the number of C–H bonds.

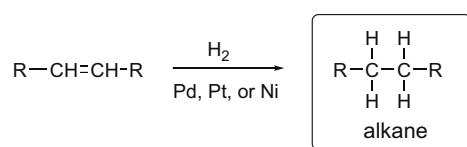
Reduction reactions result in:

- a decrease in the number of C–Z bonds, *or*
- an increase in the number of C–H bonds.

[Z = an element more electronegative than C]

Reduction reactions

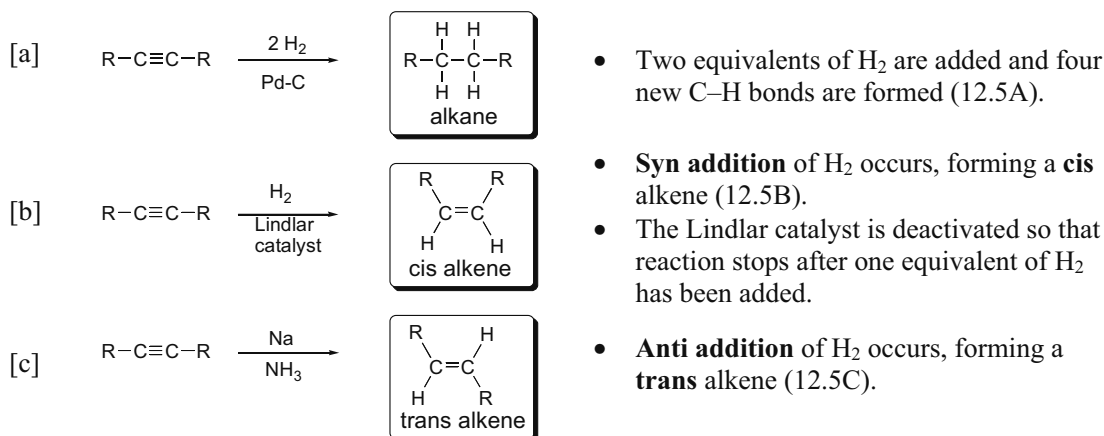
[1] Reduction of alkenes—Catalytic hydrogenation (12.3)



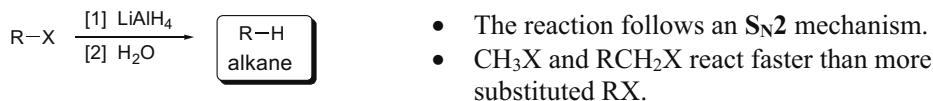
- Syn addition** of H₂ occurs.
- Increasing alkyl substitution on the C=C decreases the rate of reaction.

Chapter 12-2

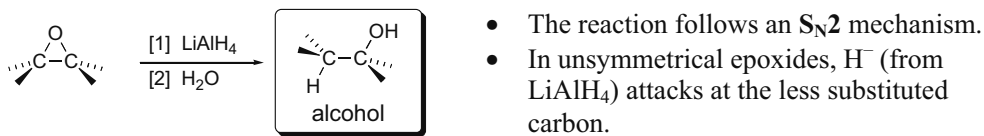
[2] Reduction of alkynes



[3] Reduction of alkyl halides (12.6)

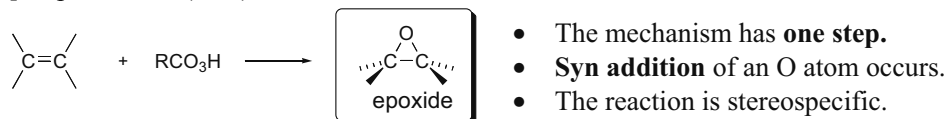


[4] Reduction of epoxides (12.6)

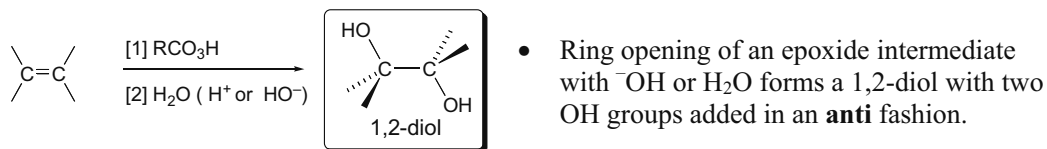
**Oxidation reactions**

[1] Oxidation of alkenes

[a] Epoxidation (12.8)

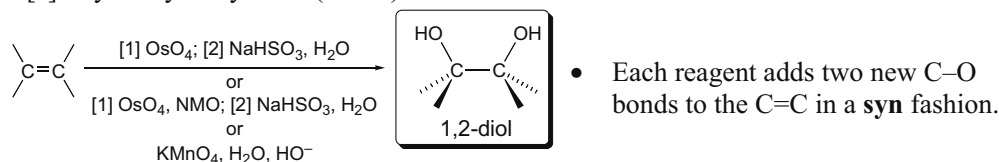


[b] Anti dihydroxylation (12.9A)

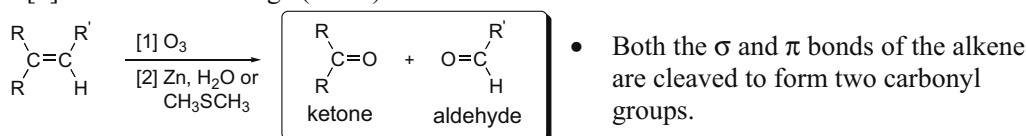


Oxidation and Reduction 12-3

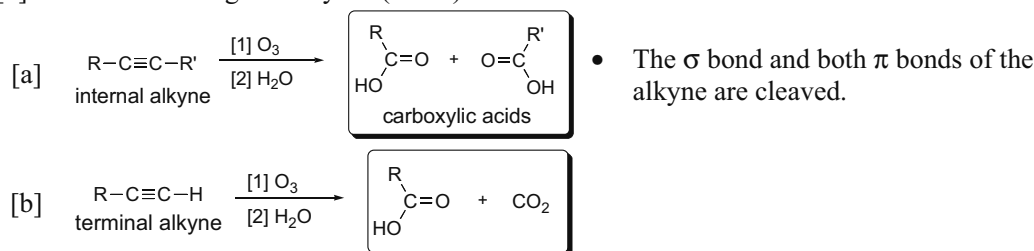
[c] Syn dihydroxylation (12.9B)



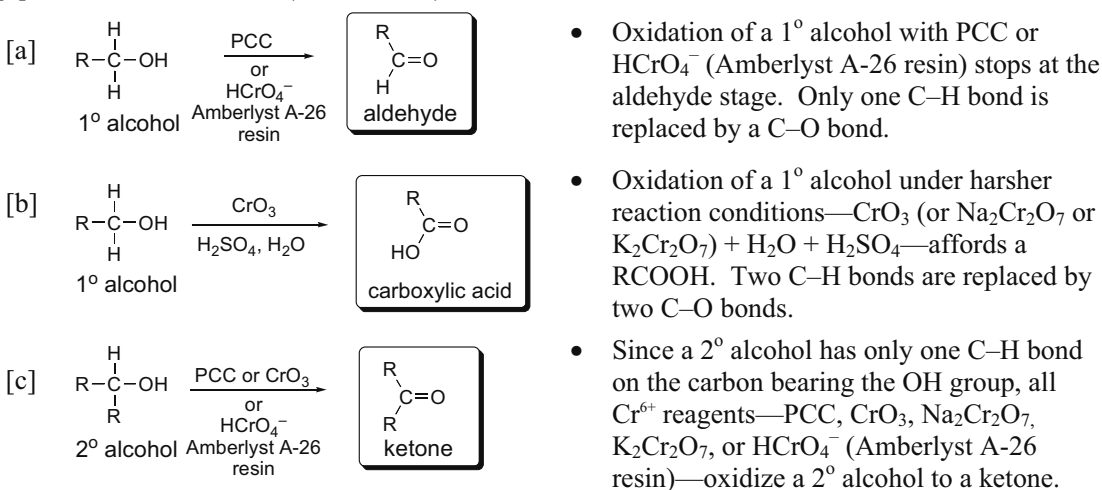
[d] Oxidative cleavage (12.10)



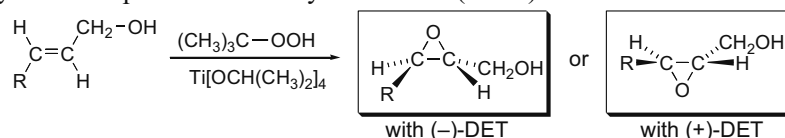
[2] Oxidative cleavage of alkynes (12.11)



[3] Oxidation of alcohols (12.12, 12.13)



[4] Asymmetric epoxidation of allylic alcohols (12.15)



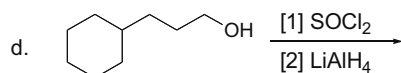
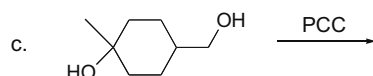
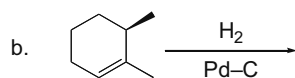
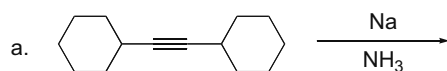
Chapter 12-4

Practice Test on Chapter Review

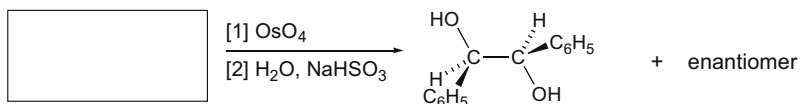
- 1.a. Compound **X** has a molecular formula of C_9H_{12} and contains no triple bonds. **X** is hydrogenated to a compound of molecular formula C_9H_{14} with excess H_2 and a palladium catalyst. What can be said about **X**?
1. **X** has four rings.
 2. **X** has three rings and one double bond.
 3. **X** has two rings and two double bonds.
 4. **X** has one ring and three double bonds.
 5. **X** has four double bonds.
- b. Syn addition to an alkene occurs exclusively with which reagents?
1. OsO_4
 2. $KMnO_4$, H_2O , ^-OH
 3. mCPBA, then H_2O , ^-OH
 4. Both reagents (1) and (2) give syn addition exclusively.
 5. Reagents (1), (2), and (3) give syn addition exclusively.
- c. Which of the following reagents adds to an alkene exclusively in an anti fashion?
1. Br_2
 2. H_2 , Pd-C
 3. BH_3 , then H_2O_2 , ^-OH
 4. Reagents (1) and (2) both add in an anti fashion.
 5. Reagents (1), (2), and (3) all add in an anti fashion.
2. Label each statement as True (T) or False (F).
- a. PCC oxidizes 1° alcohols to aldehydes.
 - b. CrO_3 oxidizes 2° alcohols to ketones.
 - c. Treatment of 2-hexyne with Na in NH_3 forms *cis*-2-hexene.
 - d. Reduction of propene oxide with $LiAlH_4$ forms 1-propanol.
 - e. Ozonolysis of 2-methyl-2-octene forms one ketone and one aldehyde.
 - f. mCPBA is an oxidizing agent that converts alkenes to trans diols.
 - g. 1-Octen-5-yne reacts with H_2 and Pd-C, but does not react with H_2 and Lindlar catalyst.
 - h. Treatment of cyclohexene with OsO_4 affords an optically inactive product mixture that contains two enantiomers.
3. Label each reagent as an oxidizing agent, reducing agent, or neither.
- a. O_3
 - b. $LiAlH_4$
 - c. mCPBA
 - d. H_2O , H_2SO_4
 - e. PCC
 - f. Na, NH_3

Oxidation and Reduction 12–5

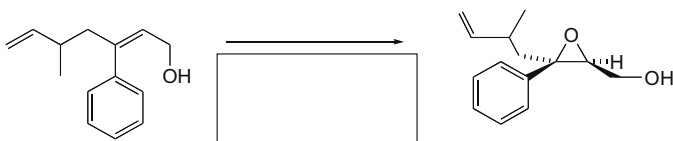
4. Draw the organic products formed in each reaction and indicate stereochemistry when necessary.



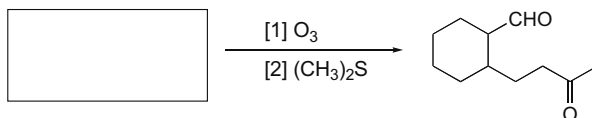
5. a. Fill in the appropriate starting material (including any needed stereochemistry) in the following reaction.



b. Fill in the appropriate reagent in the following reaction.



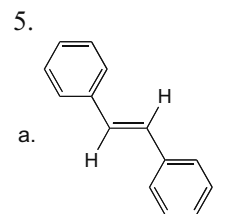
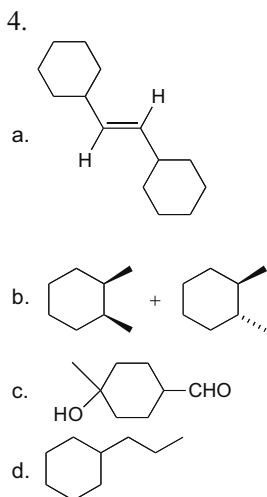
c. What starting material is needed for the following reaction?



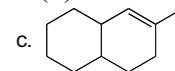
Chapter 12–6

Answers to Practice Test

- 1.a. 2
b. 4
c. 1
- 2.a. T
b. T
c. F
d. F
e. T
f. F
g. F
h. F
- 3.a. oxidizing
b. reducing
c. oxidizing
d. neither
e. oxidizing
f. reducing



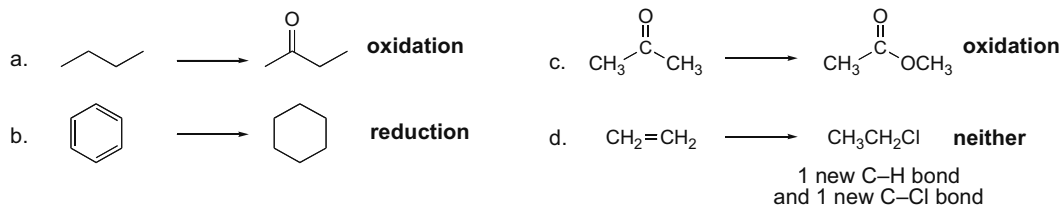
b. Sharpless reagent
(+)-DET



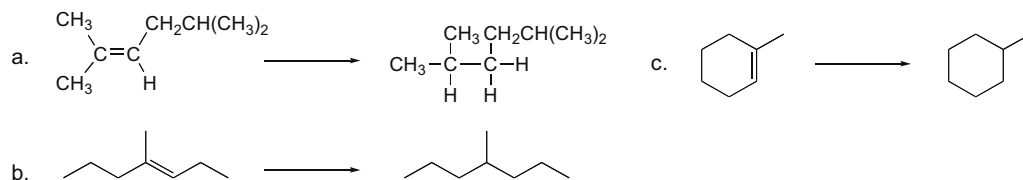
Chapter 12: Answers to Problems

12.1 Oxidation results in an *increase* in the number of C–Z bonds (usually C–O bonds) or a *decrease* in the number of C–H bonds.

Reduction results in a *decrease* in the number of C–Z bonds (usually C–O bonds) or an *increase* in the number of C–H bonds.

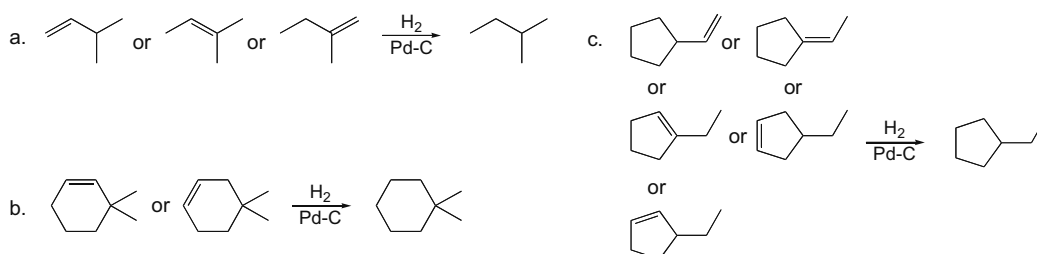


12.2 Hydrogenation is the addition of hydrogen. When alkenes are hydrogenated, they are *reduced* by the addition of H₂ to the π bond. To draw the alkane product, add a H to each C of the double bond.

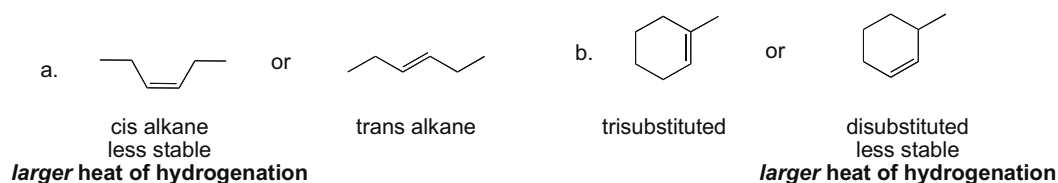


Oxidation and Reduction 12-7

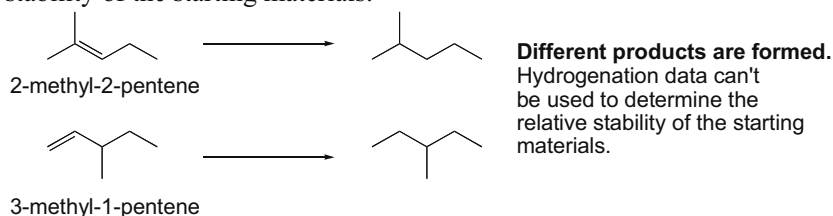
12.3 Draw the alkenes that form each alkane when hydrogenated.



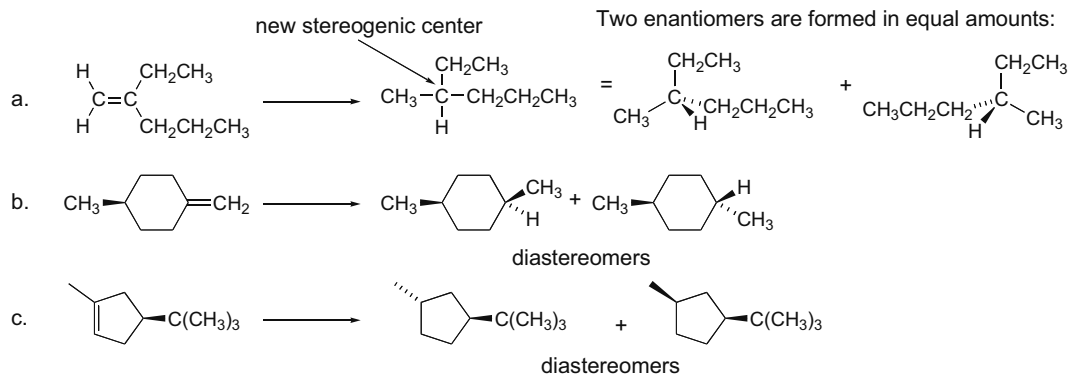
12.4 Cis alkenes are less stable than trans alkenes, so they have larger heats of hydrogenation. Increasing alkyl substitution increases the stability of a C=C, thus decreasing the heat of hydrogenation.



12.5 Hydrogenation products must be identical to use hydrogenation data to evaluate the relative stability of the starting materials.



12.6

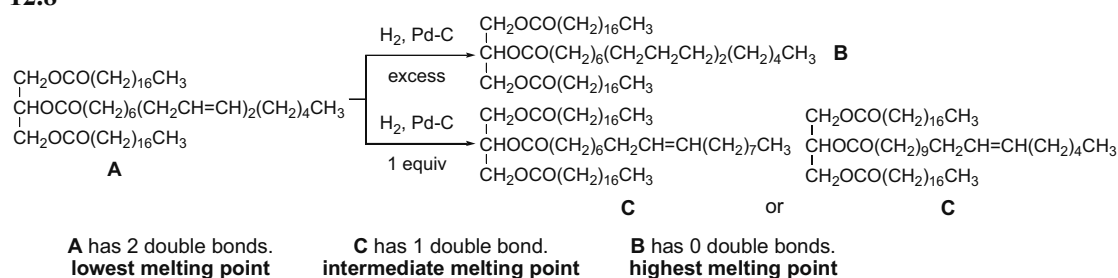


Chapter 12-8

12.7

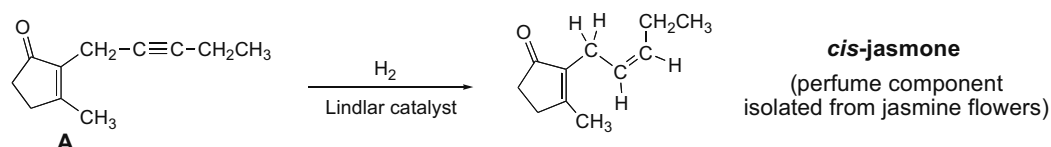
Compound	Molecular formula before hydrogenation	Molecular formula after hydrogenation	Number of rings	Number of π bonds
A	$C_{10}H_{12}$	$C_{10}H_{16}$	3	2
B	C_4H_8	C_4H_{10}	0	1
C	C_6H_8	C_6H_{12}	1	2

12.8

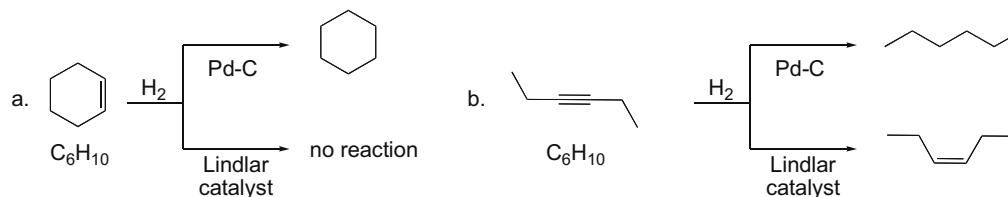


12.9 Hydrogenation of $\text{HC}\equiv\text{CCH}_2\text{CH}_2\text{CH}_3$ and $\text{CH}_3\text{C}\equiv\text{CCH}_2\text{CH}_3$ yields the same compound. The heat of hydrogenation is larger for $\text{HC}\equiv\text{CCH}_2\text{CH}_2\text{CH}_3$ than for $\text{CH}_3\text{C}\equiv\text{CCH}_2\text{CH}_3$ because internal alkynes are more stable (lower in energy) than terminal alkynes.

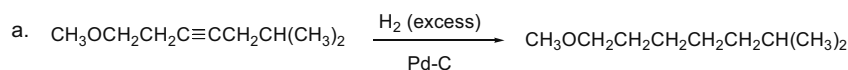
12.10



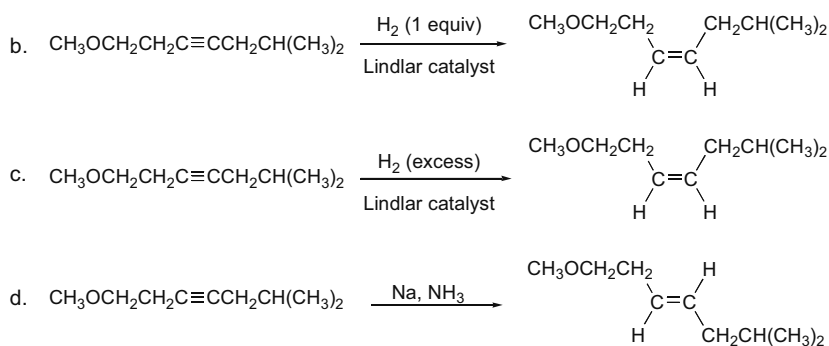
12.11 In the presence of Pd-C, H_2 adds to alkenes and alkynes to form alkanes. In the presence of the Lindlar catalyst, only alkynes react with H_2 to form cis alkenes.



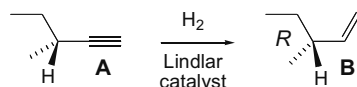
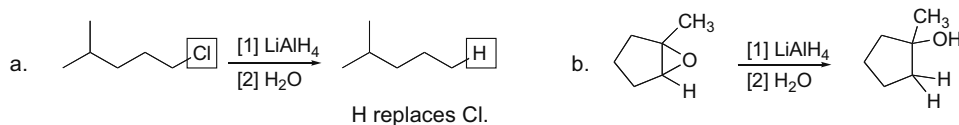
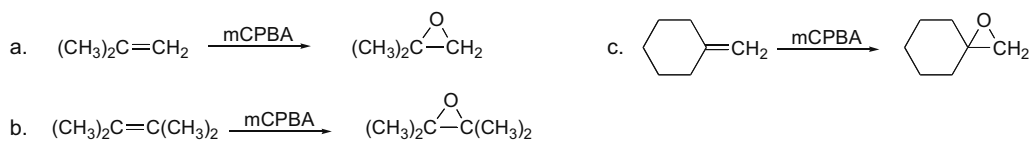
12.12 Use the directions from Answer 12.11.



Oxidation and Reduction 12-9

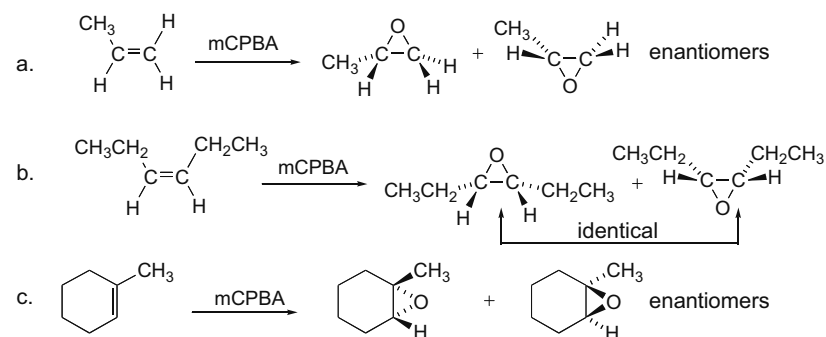


12.13

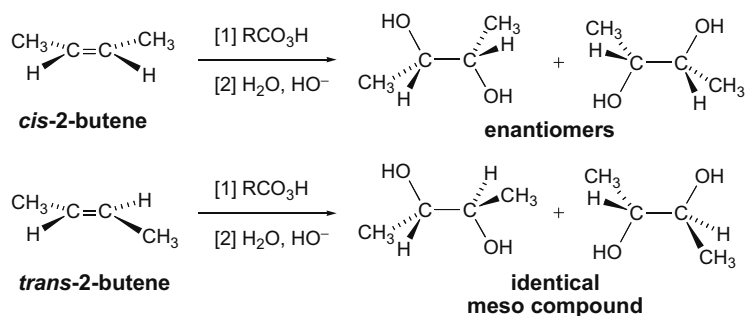
12.14 LiAlH_4 reduces alkyl halides to alkanes and epoxides to alcohols.12.15 To draw the product, add an O atom across the π bond of the $\text{C}=\text{C}$.

12.16 For epoxidation reactions:

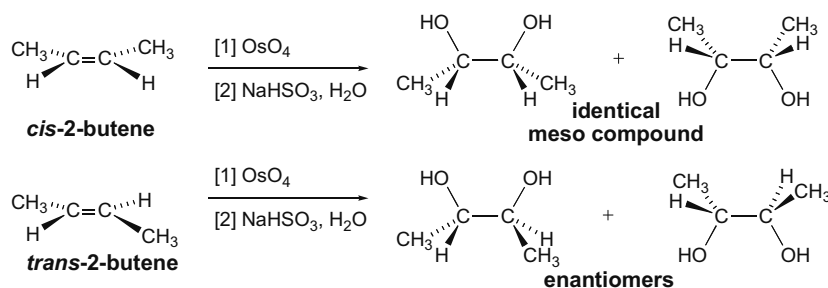
- There are two possible products: O adds from above and below the double bond.
- Substituents on the $\text{C}=\text{C}$ retain their original configuration in the products.



12.17 Treatment of an alkene with a peroxyacid followed by H_2O , HO^- adds two hydroxy groups in an **anti** fashion. *cis*-2-Butene and *trans*-2-butene yield different products of dihydroxylation. *cis*-2-Butene gives a mixture of two enantiomers and *trans*-2-butene gives a meso compound. The reaction is stereospecific because two stereoisomeric starting materials give different products that are also stereoisomers of each other.

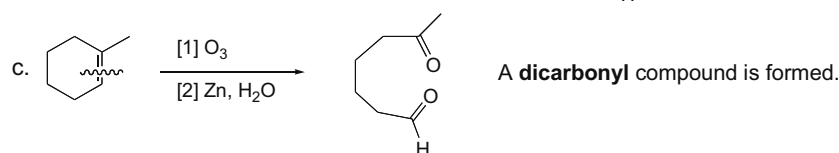
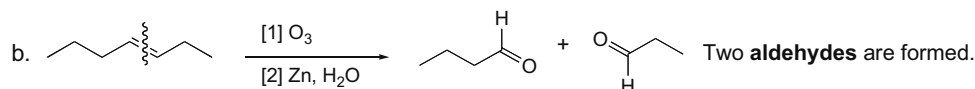


12.18 Treatment of an alkene with OsO_4 adds two hydroxy groups in a **syn** fashion. *cis*-2-Butene and *trans*-2-butene yield different stereoisomers in this dihydroxylation, so the reaction is stereospecific.



- Locate all the π bonds in the molecule.
- Replace all C=C's with *two* C=O's.

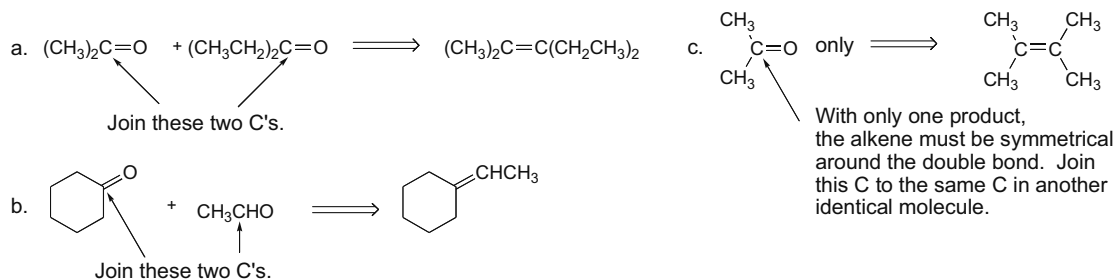
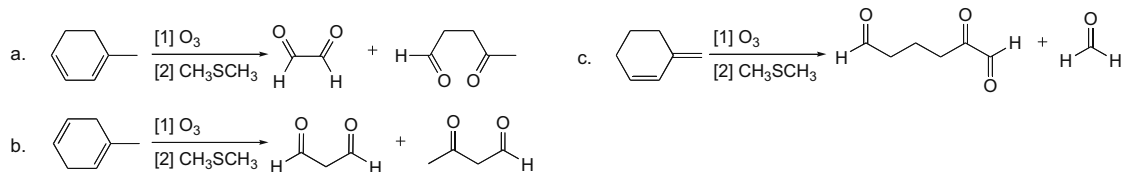
a. $(\text{CH}_3)_2\text{C}=\text{CHCH}_2\text{CH}_2\text{CH}_2\text{CH}_3 \xrightarrow[\text{[2] Zn, H}_2\text{O}]{\text{[1] O}_3} (\text{CH}_3)_2\text{C}=\text{O} + \text{O}=\text{CHCH}_2\text{CH}_2\text{CH}_2\text{CH}_3$
ketone aldehyde
One **ketone** and one **aldehyde** are formed.



Oxidation and Reduction 12-11

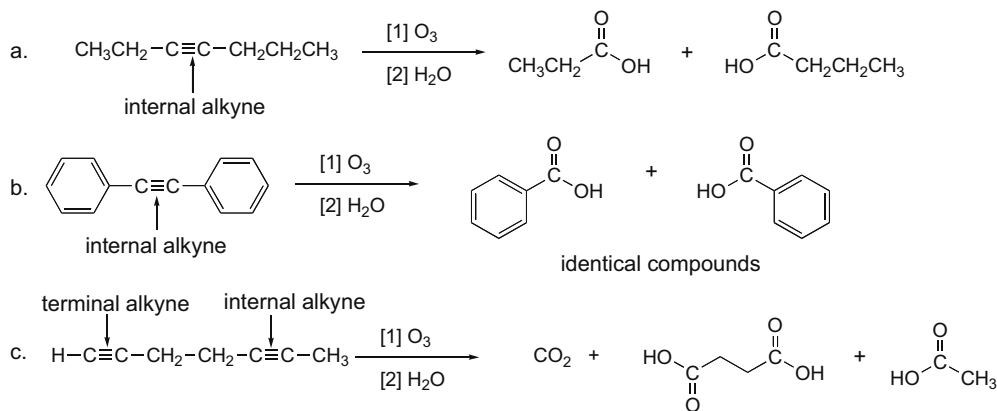
12.20 To find the alkene that yields the oxidative cleavage products:

- **Find the two carbonyl groups** in the products.
- **Join the two carbonyl carbons** together with a double bond. This is the double bond that was broken during ozonolysis.

**12.21**

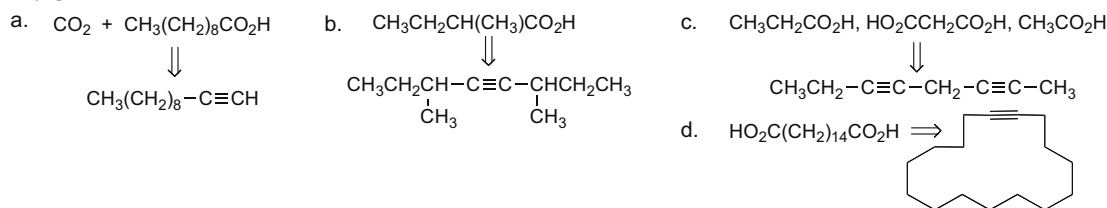
12.22 To draw the products of oxidative cleavage of alkynes:

- **Locate the triple bond.**
- For internal alkynes, **convert the *sp* hybridized C to COOH.**
- For terminal alkynes, the ***sp* hybridized C-H becomes CO₂.**

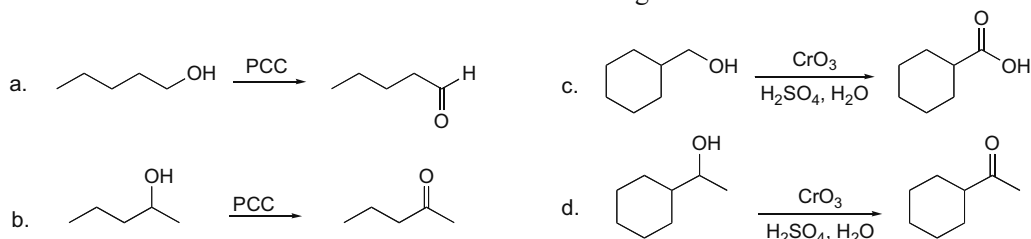


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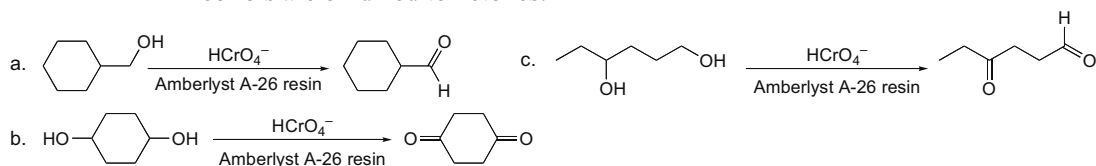
12.23

12.24 For the **oxidation of alcohols**, remember:

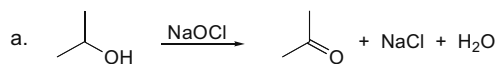
- **1° Alcohols** are oxidized to aldehydes with PCC.
- **1° Alcohols** are oxidized to carboxylic acids with oxidizing agents like CrO_3 or $\text{Na}_2\text{Cr}_2\text{O}_7$.
- **2° Alcohols** are oxidized to ketones with all Cr^{6+} reagents.

12.25 Upon treatment with HCrO_4^- –Amberlyst A-26 resin:

- **1° Alcohols** are oxidized to aldehydes.
- **2° Alcohols** are oxidized to ketones.



12.26

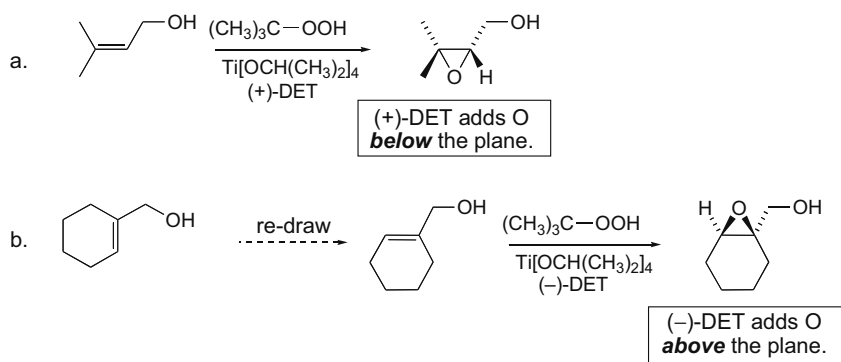
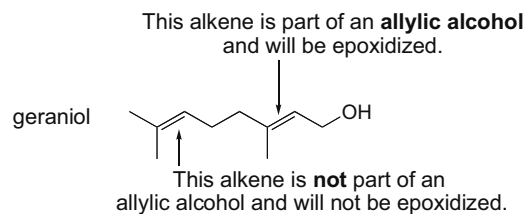
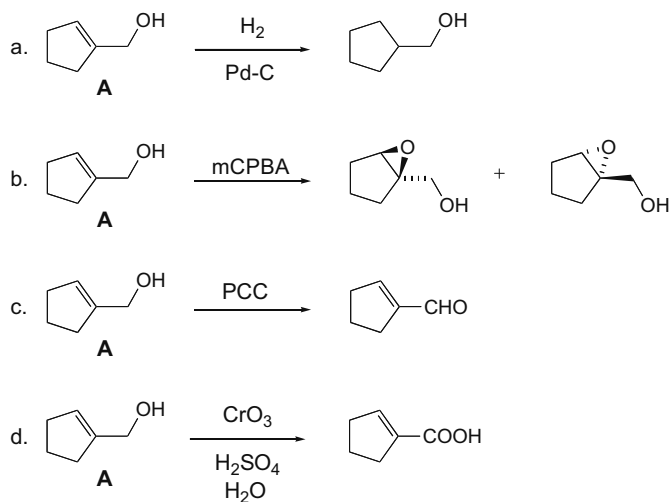


The by-products of the reaction with sodium hypochlorite are water and table salt (NaCl), as opposed to the by-products with HCrO_4^- –Amberlyst A-26 resin, which contain carcinogenic Cr^{3+} metal.

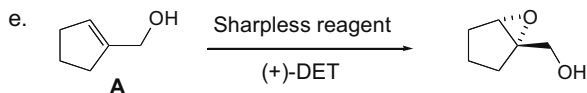
- b. Oxidation with NaOCl has at least two advantages over oxidation with CrO_3 , H_2SO_4 and H_2O . Since no Cr^{6+} is used as oxidant, there are no Cr by-products that must be disposed of. Also, CrO_3 oxidation is carried out in corrosive inorganic acids (H_2SO_4) and oxidation with NaOCl avoids this.

12.27 To draw the products of a **Sharpless epoxidation**:

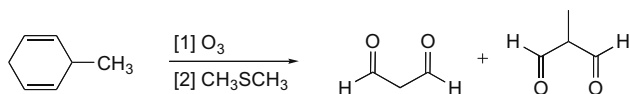
- With the C=C horizontal, draw the allylic alcohol with the OH on the **top right** of the alkene.
- Add the new oxygen **above** the plane if (–)-DET is used and **below** the plane if (+)-DET is used.

**12.28** Sharpless epoxidation needs an *allylic alcohol* as the starting material. Alkenes with no allylic OH group will not undergo reaction with the Sharpless reagent.**12.29**

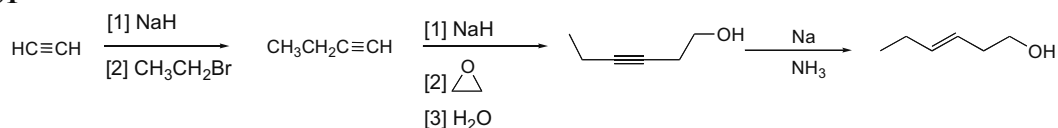
Chapter 12–14



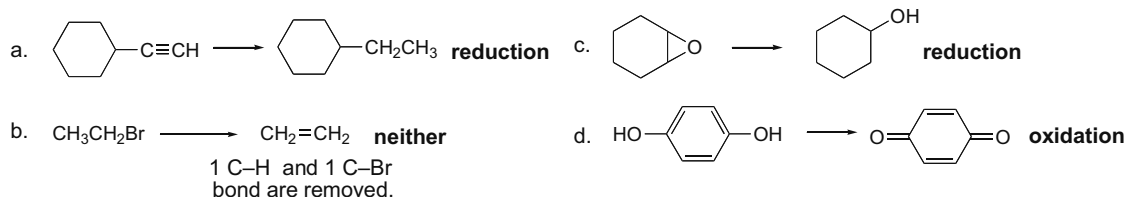
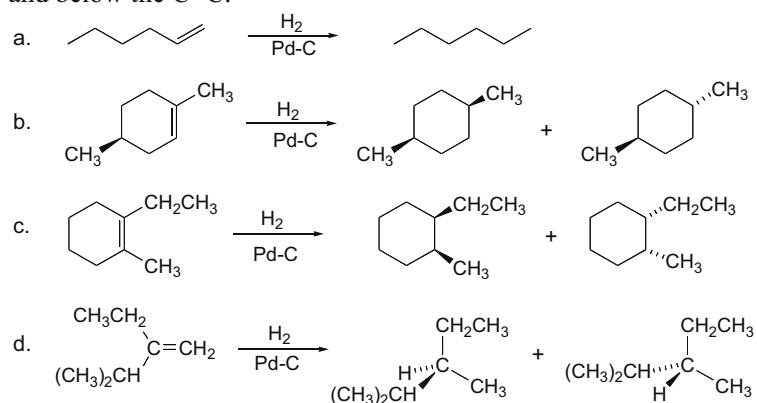
12.30



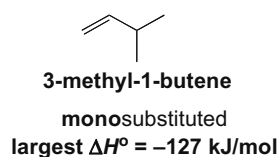
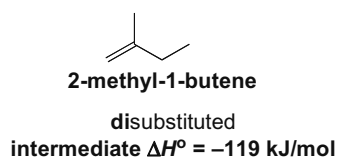
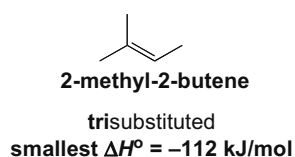
12.31



12.32 Use the rules from Answer 12.1.

12.33 Use the principles from Answer 12.2 and draw the products of syn addition of H₂ from above and below the C=C.

12.34 Increasing alkyl substitution increases alkene stability, thus decreasing the heat of hydrogenation.



Oxidation and Reduction 12-15

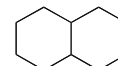
12.35

A possible structure:

- a. Compound **A**: molecular formula C_5H_8 ; hydrogenated to C_5H_{10} .
2 degrees of unsaturation, 1 is hydrogenated.

1 ring and 1 π bond

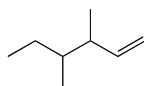
- b. Compound **B**: molecular formula $C_{10}H_{16}$; hydrogenated to $C_{10}H_{18}$.
3 degrees of unsaturation, 1 is hydrogenated.

2 rings and 1 π bond

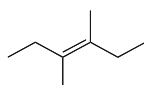
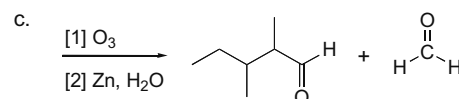
- c. Compound **C**: molecular formula C_8H_8 ; hydrogenated to C_8H_{16} .
5 degrees of unsaturation, 4 are hydrogenated.

1 ring and 4 π bonds

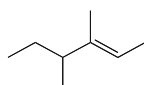
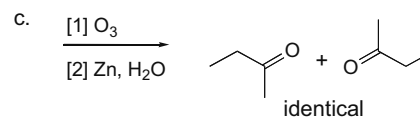
12.36

**A**

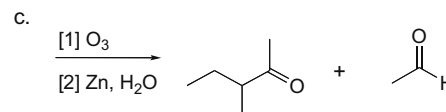
- a. **monosubstituted**
largest heat of hydrogenation
b. **fastest** reaction rate

**B**

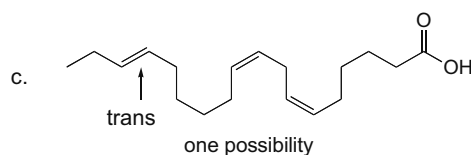
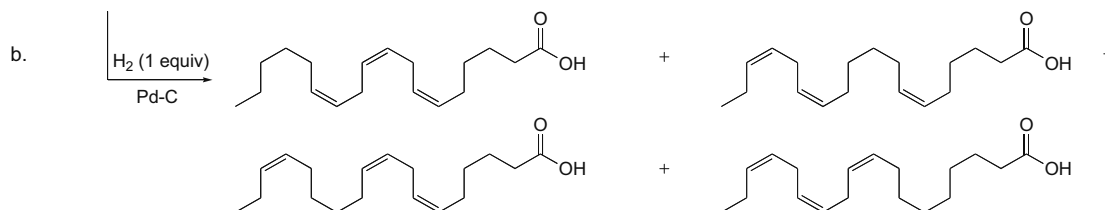
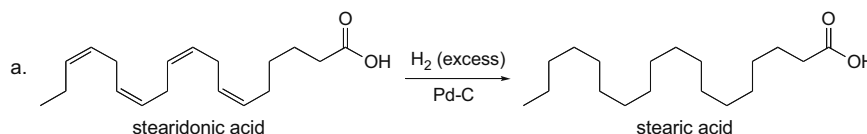
- a. **tetrasubstituted**
smallest heat of hydrogenation
b. **slowest** reaction rate

**C**

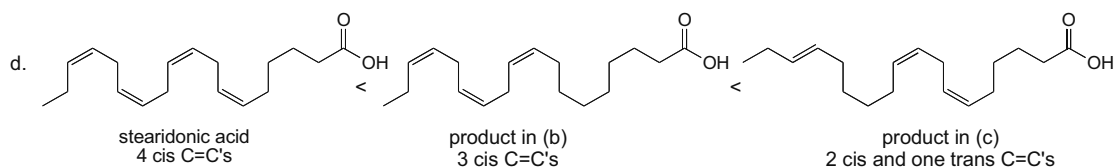
- a. **trisubstituted**
intermediate heat of hydrogenation
b. **intermediate** reaction rate



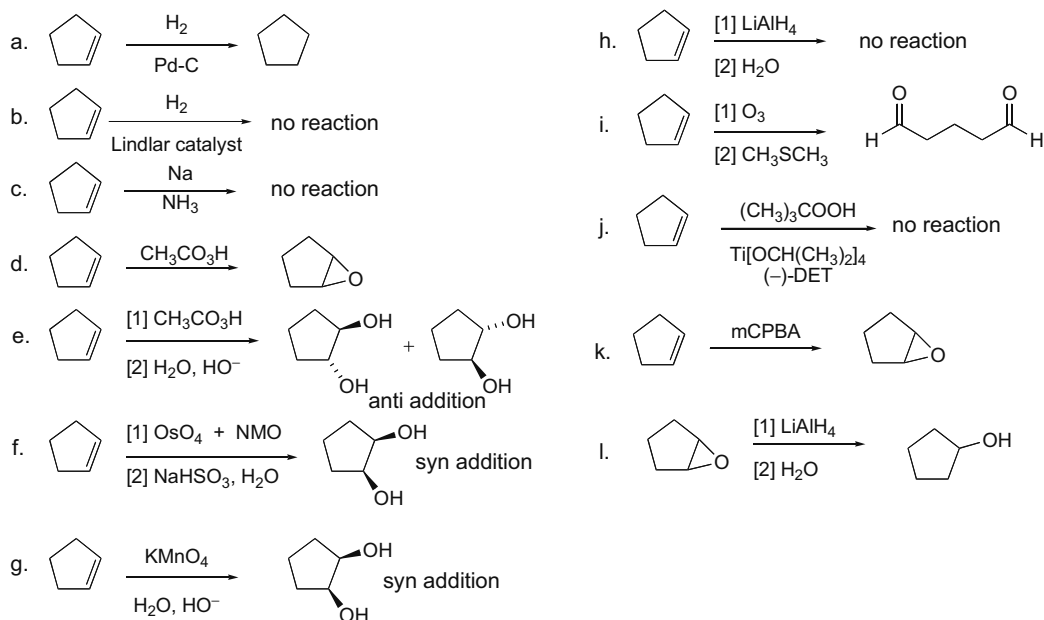
12.37



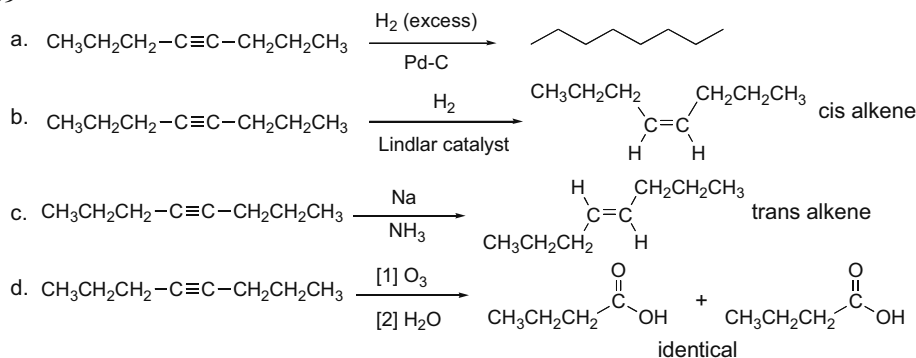
Chapter 12–16



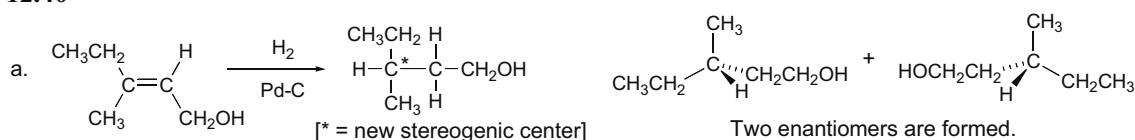
12.38



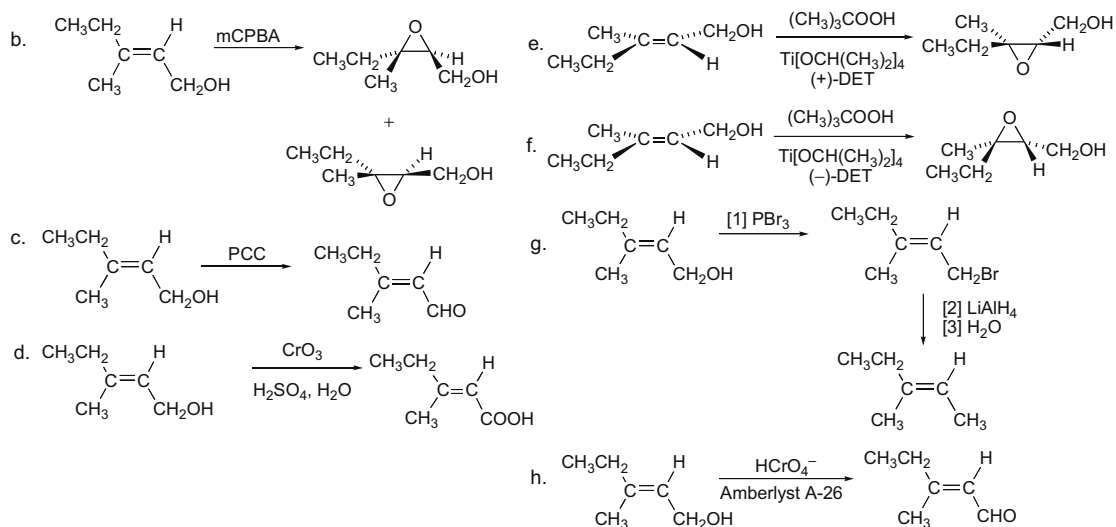
12.39



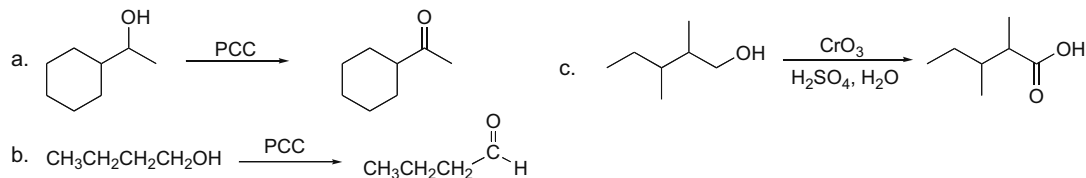
12.40



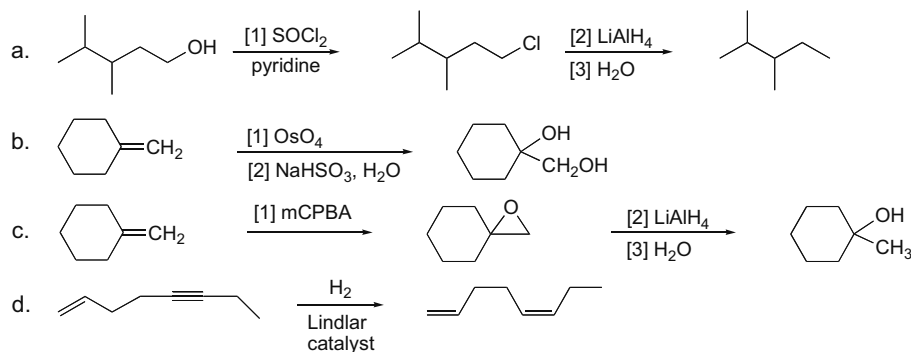
Oxidation and Reduction 12-17



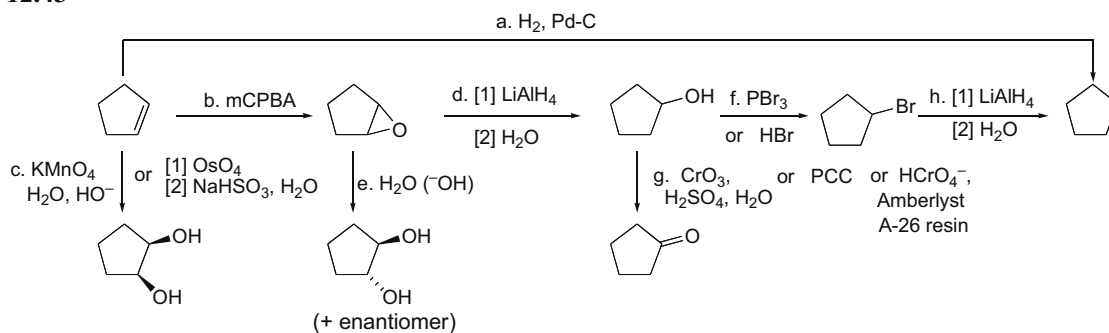
12.41



12.42

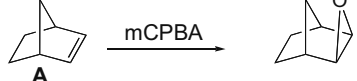


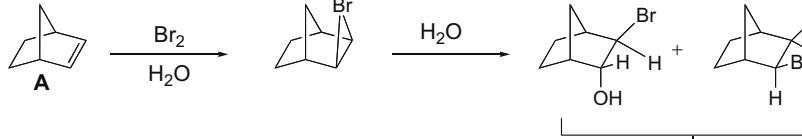
12.43



2-methyl-2-pentanol

2-methyl-2-pentene

a.  C1=CC2CCC1C2 + O=C1C=CC(=O)C=C1 >> C12CCC1C2O

b.  C1=CC2CCC1C2 + Br2 + H2O >> C12CCC1C2Br + OH
C12CCC1C2Br + OH >> C12CCC1C2O + HBr

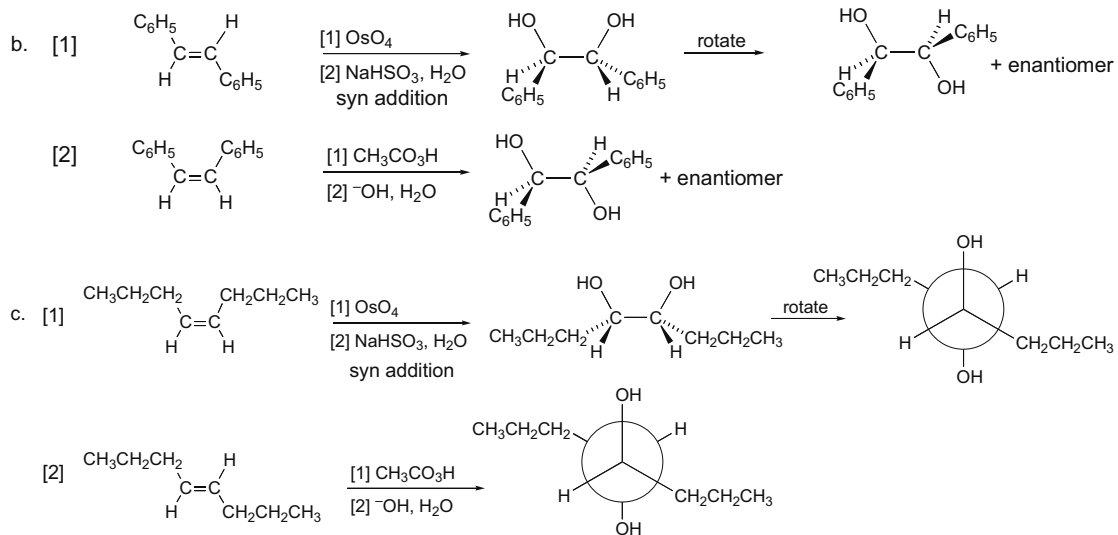
Since the OH of the bromohydrin is down, the resulting epoxide must also be down.

a. [1] $(\text{CH}_3)_2\text{CH}-\text{C}=\text{C}-\text{CH}(\text{CH}_3)_2$ $\xrightarrow[\text{[2] NaHSO}_3, \text{H}_2\text{O}]{\text{[1] OsO}_4}$ $(\text{CH}_3)_2\text{CH}-\text{C}(\text{OH})_2-\text{CH}(\text{CH}_3)_2$

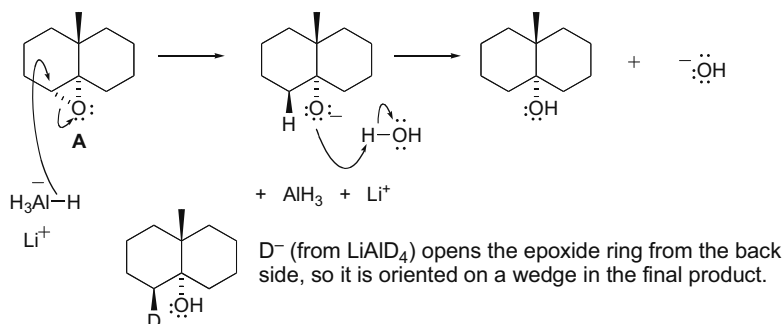
[2] $(\text{CH}_3)_2\text{CH}-\text{C}=\text{C}-\text{CH}(\text{CH}_3)_2$ $\xrightarrow[\text{[2] } ^-\text{OH}, \text{H}_2\text{O}]{\text{[1] CH}_3\text{CO}_3\text{H}}$ $(\text{CH}_3)_2\text{CH}-\text{C}(\text{OH})_2-\text{CH}(\text{CH}_3)_2$ rotate $\rightarrow$ $(\text{CH}_3)_2\text{CH}-\text{C}(\text{OH})_2-\text{CH}(\text{CH}_3)_2$

anti addition

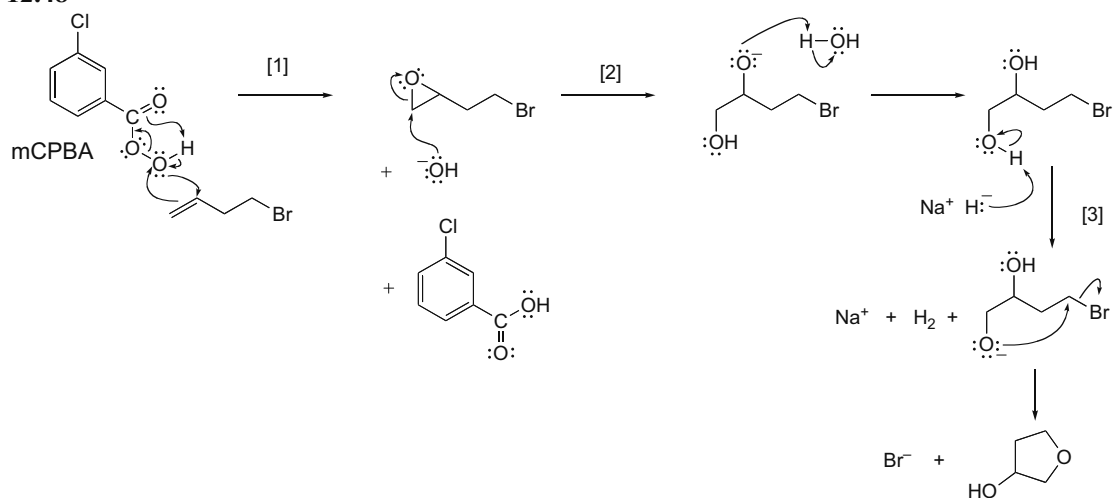
Oxidation and Reduction 12-19



12.47

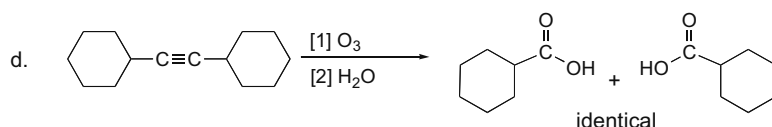
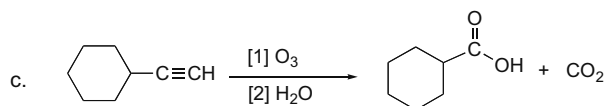
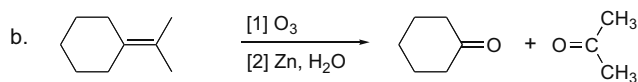
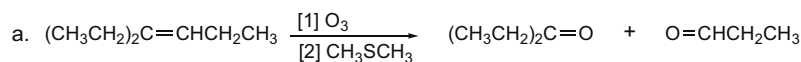


12.48

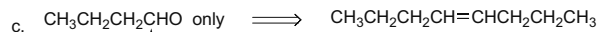
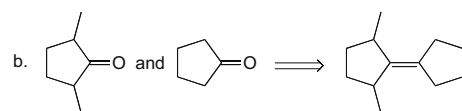
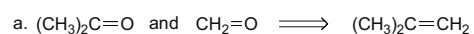


Chapter 12-20

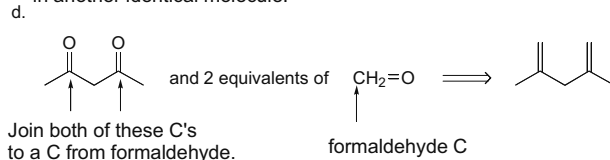
12.49 Use the directions from Answer 12.19.



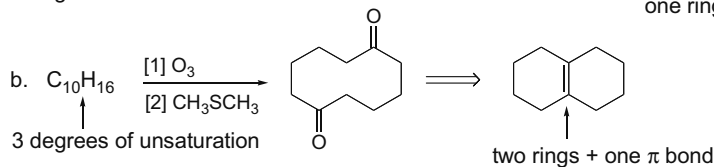
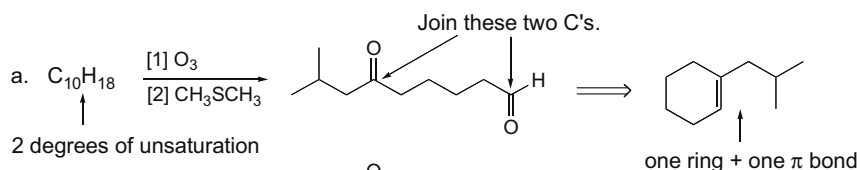
12.50



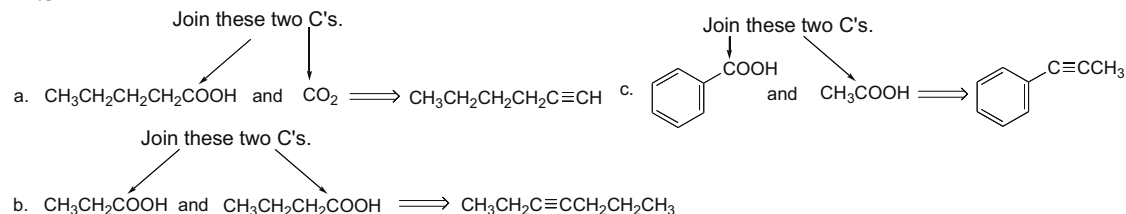
Join this C to the same C in another identical molecule.



12.51 Use the directions from Answer 12.20.

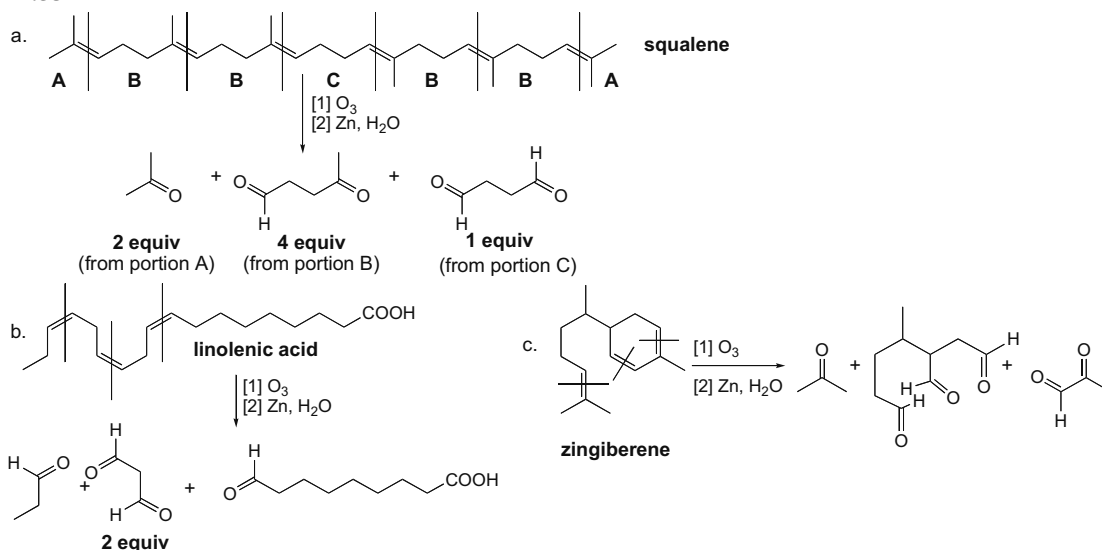


12.52

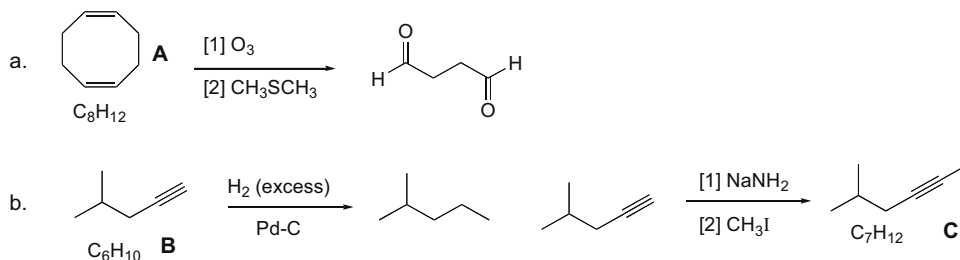


Oxidation and Reduction 12-21

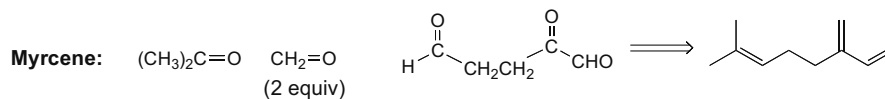
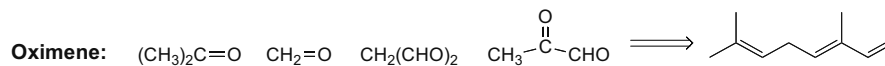
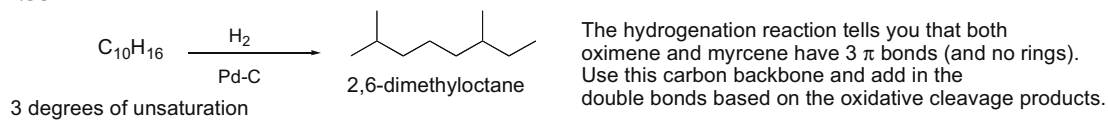
12.53



12.54

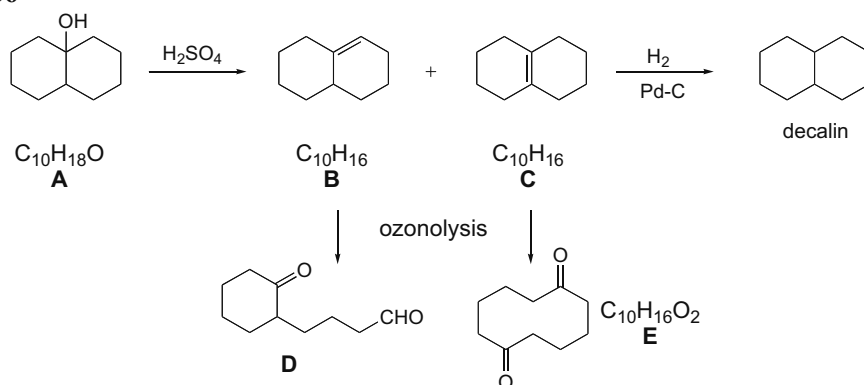


12.55

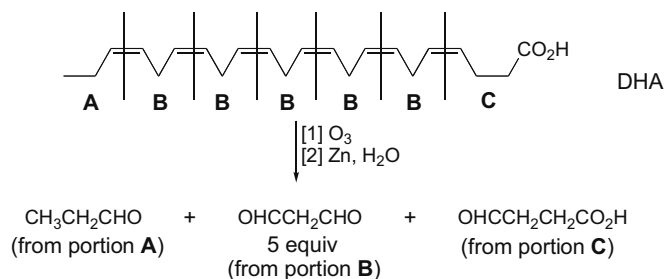


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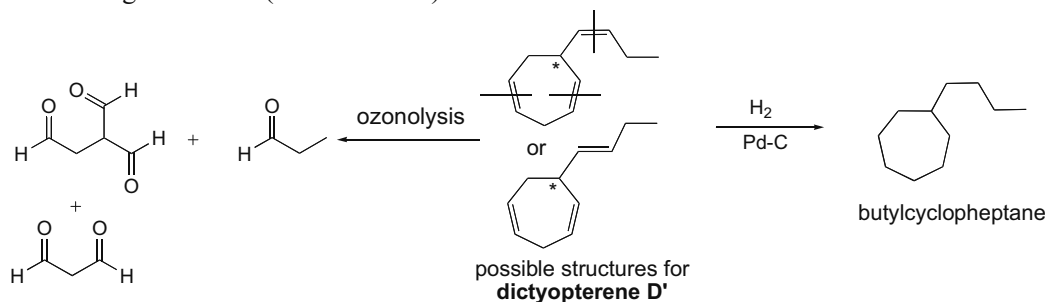
12.56



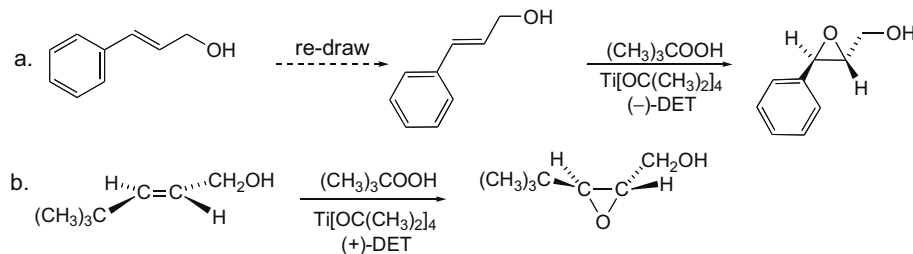
12.57 Since hydrogenation of DHA forms $\text{CH}_3(\text{CH}_2)_{20}\text{COOH}$, DHA is a 22-carbon fatty acid. The ozonolysis products show where the double bonds are located.



12.58 The stereogenic center (labeled with *) in both structures can be *R* or *S*.

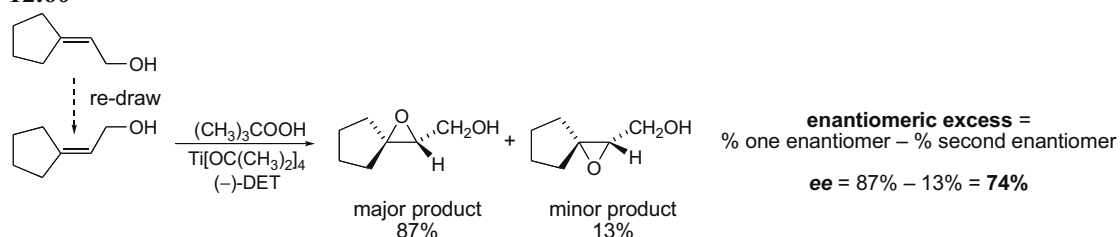


12.59

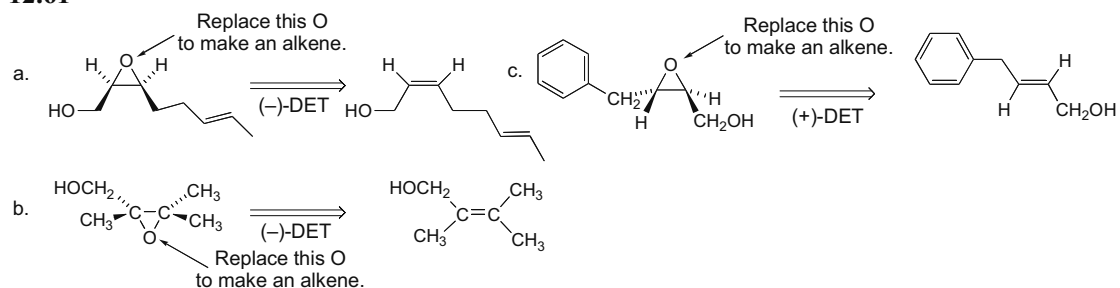


Oxidation and Reduction 12-23

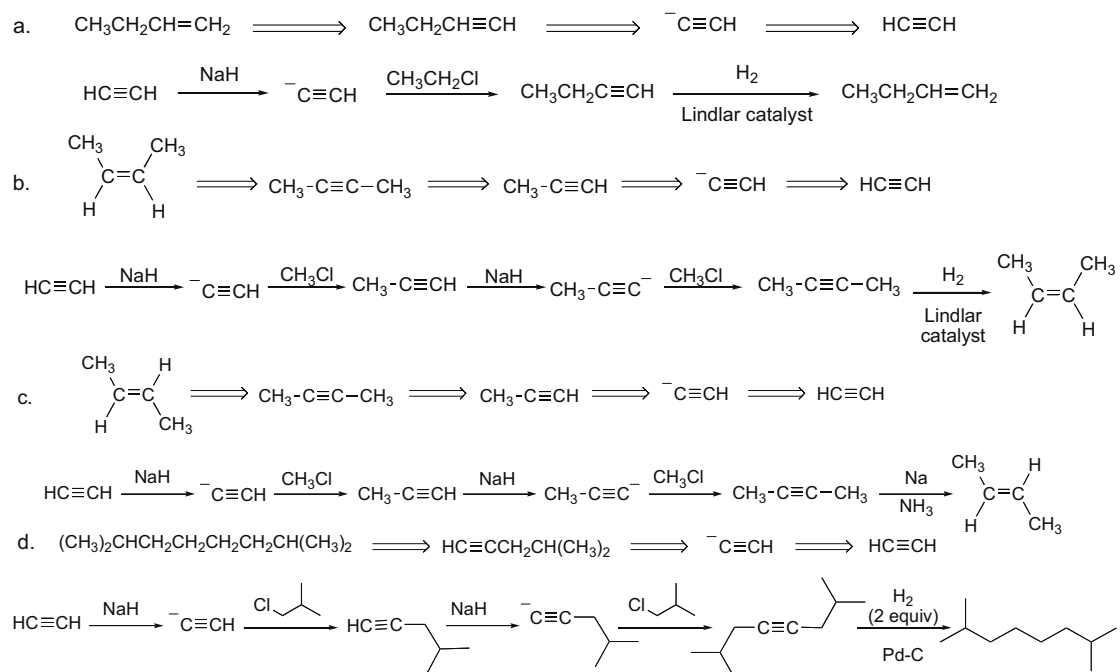
12.60



12.61

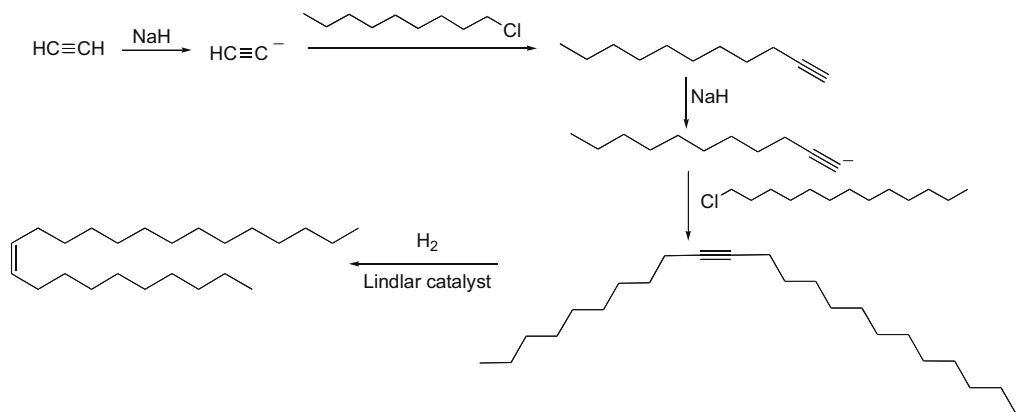


12.62 Use retrosynthetic analysis to devise a synthesis of each hydrocarbon from acetylene.

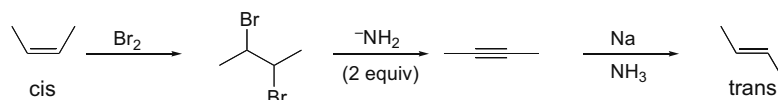


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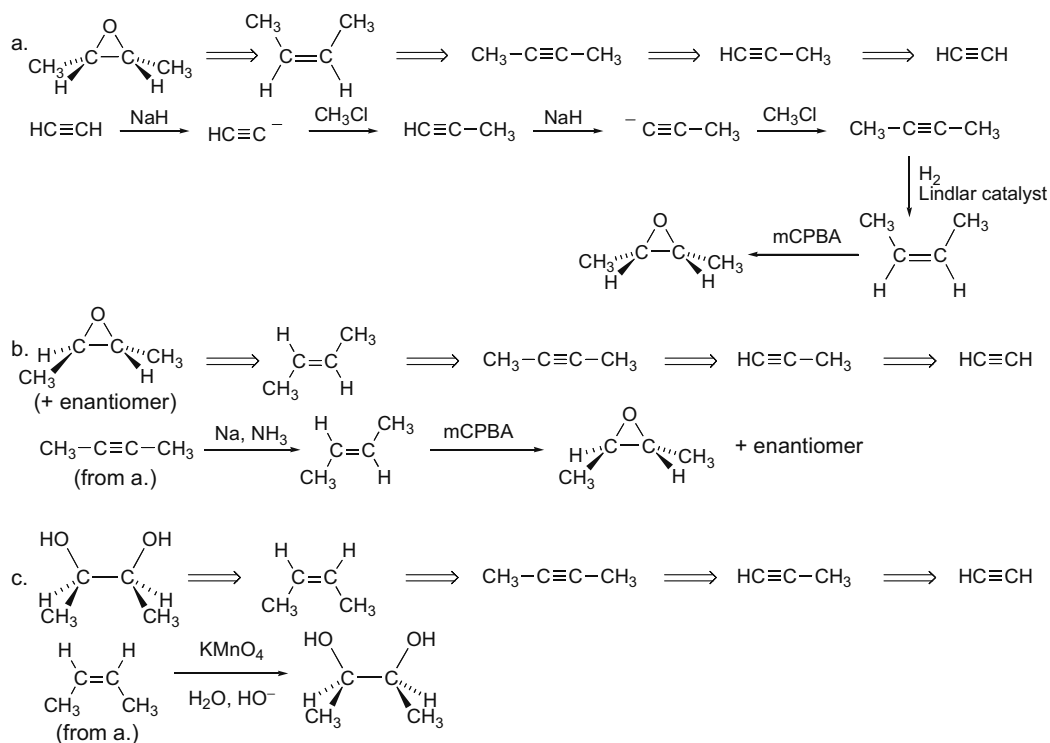
12.63



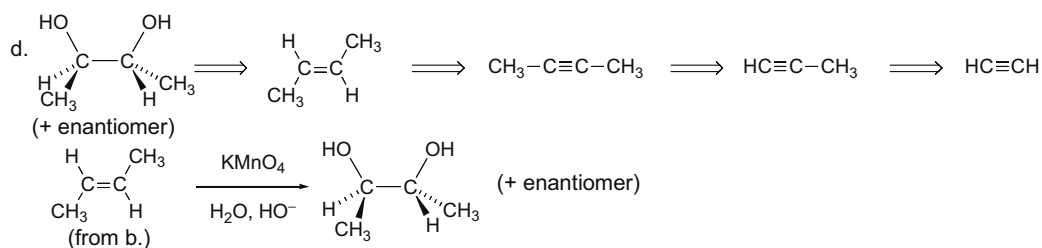
12.64



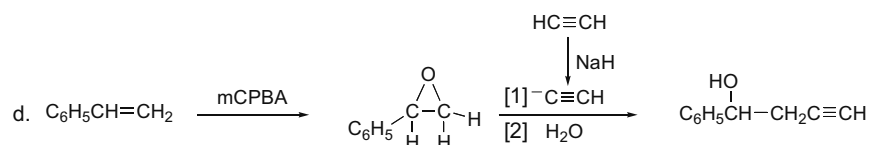
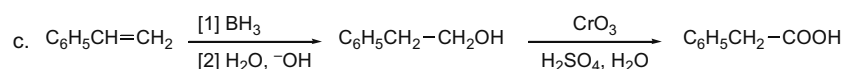
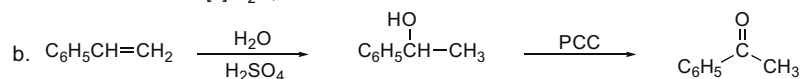
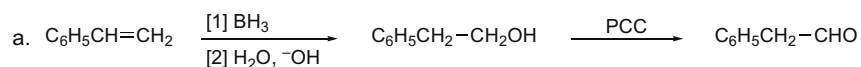
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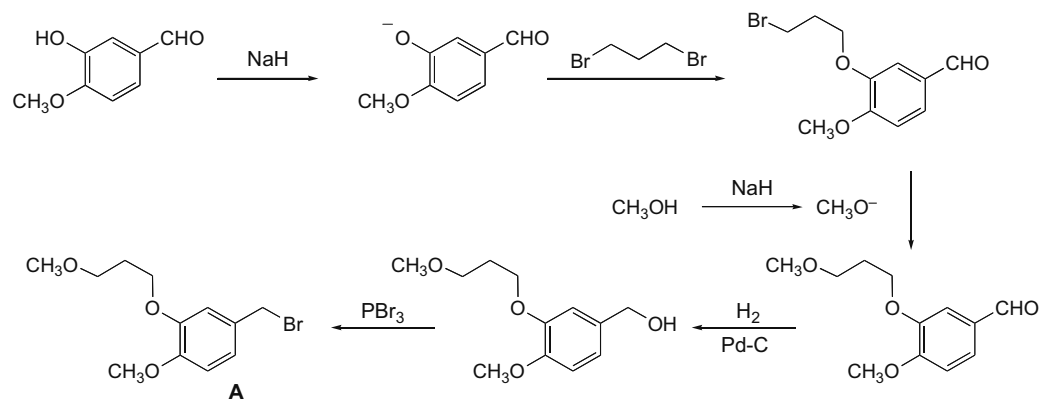
Oxidation and Reduction 12-25



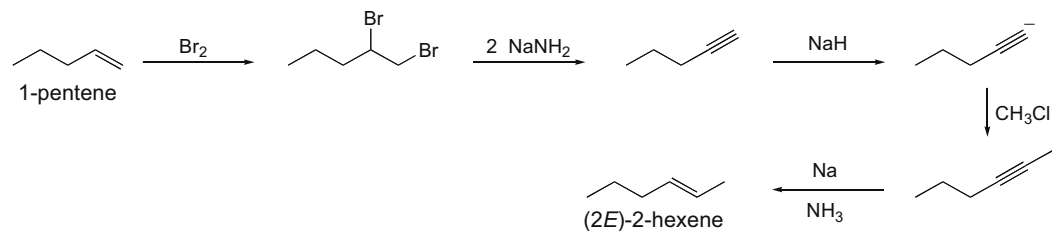
12.66



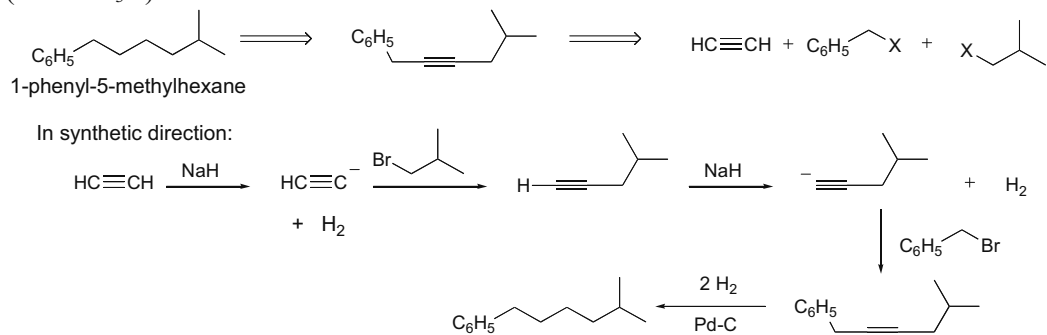
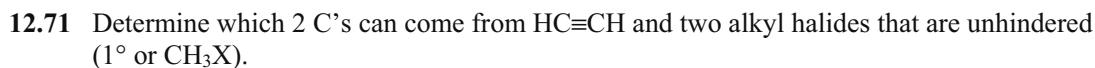
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12.68

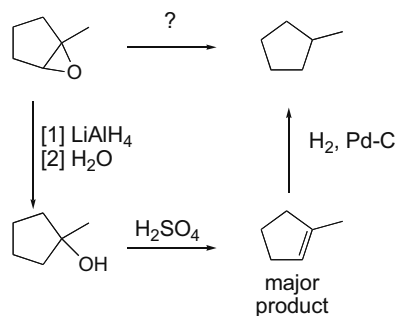


12.69

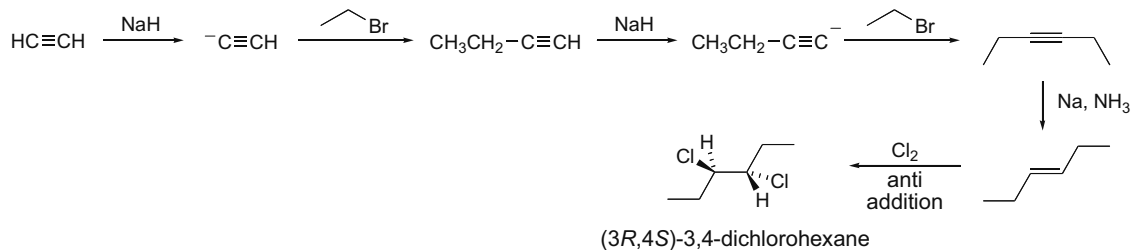


Oxidation and Reduction 12-27

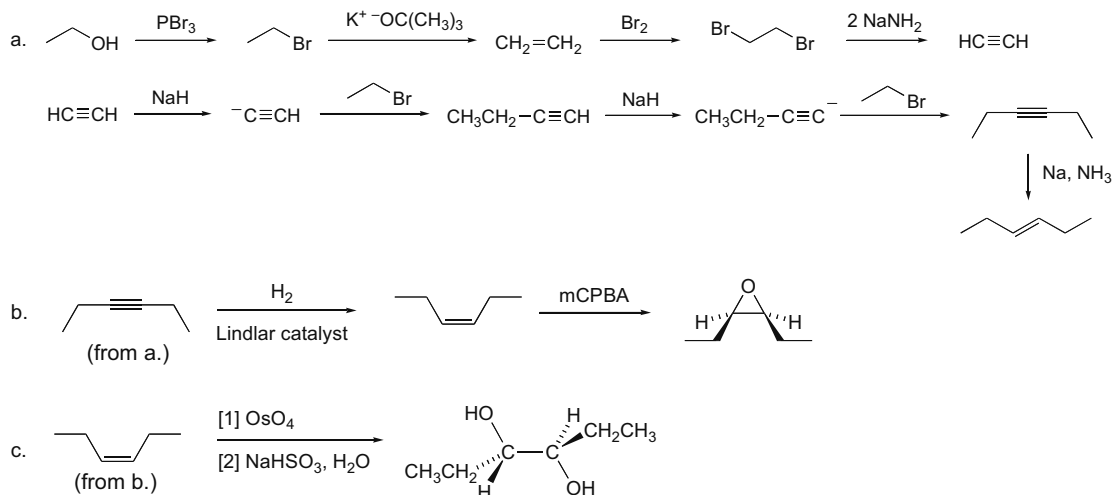
12.72



12.73

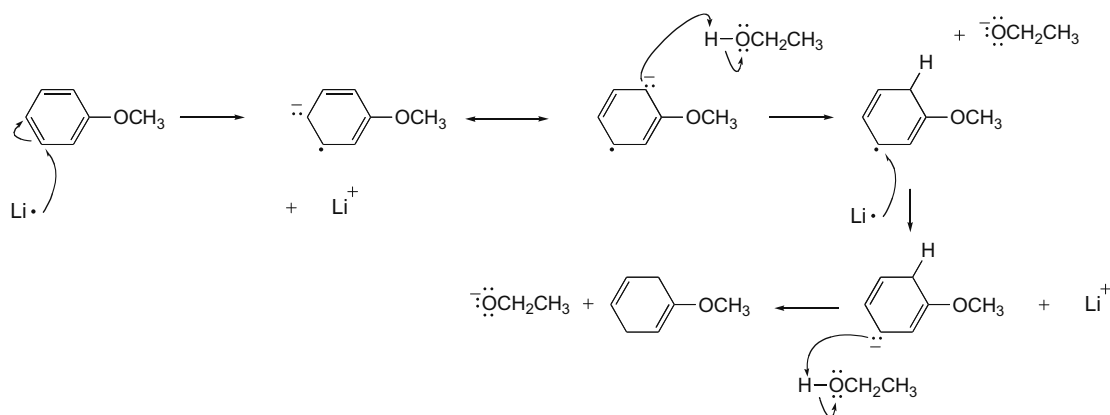


12.74

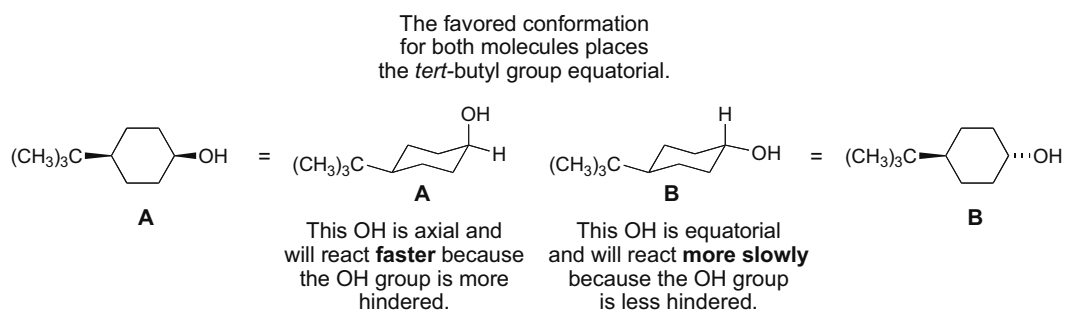


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12.75

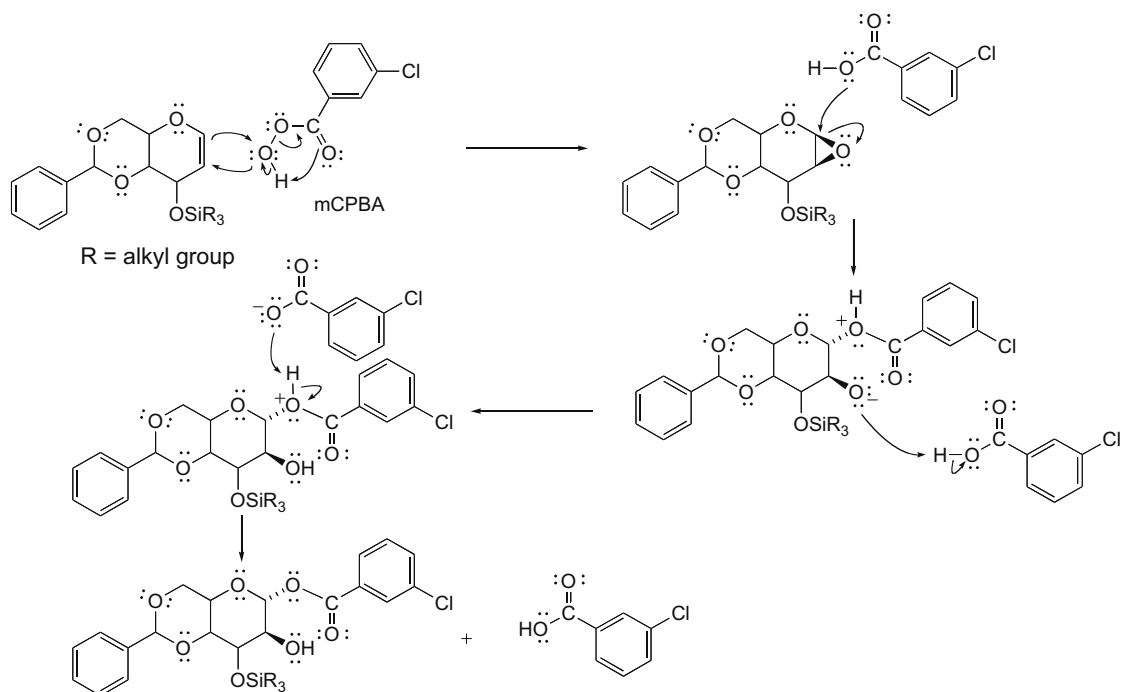


12.76

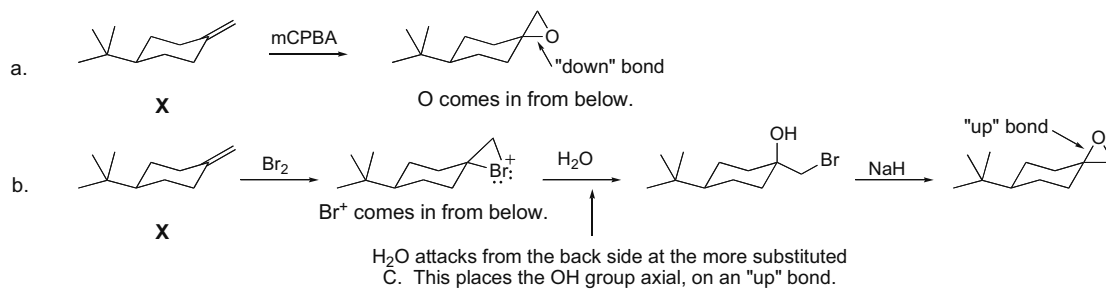


Oxidation and Reduction 12-29

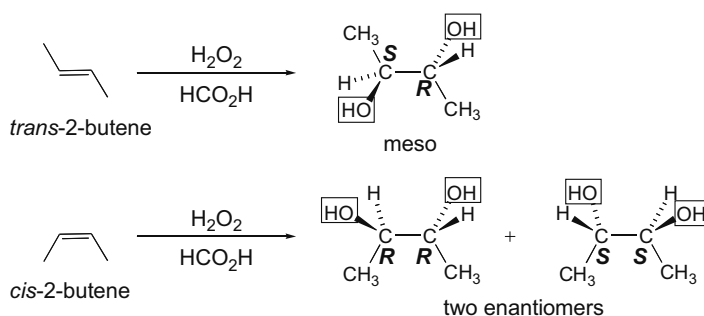
12.77



12.78

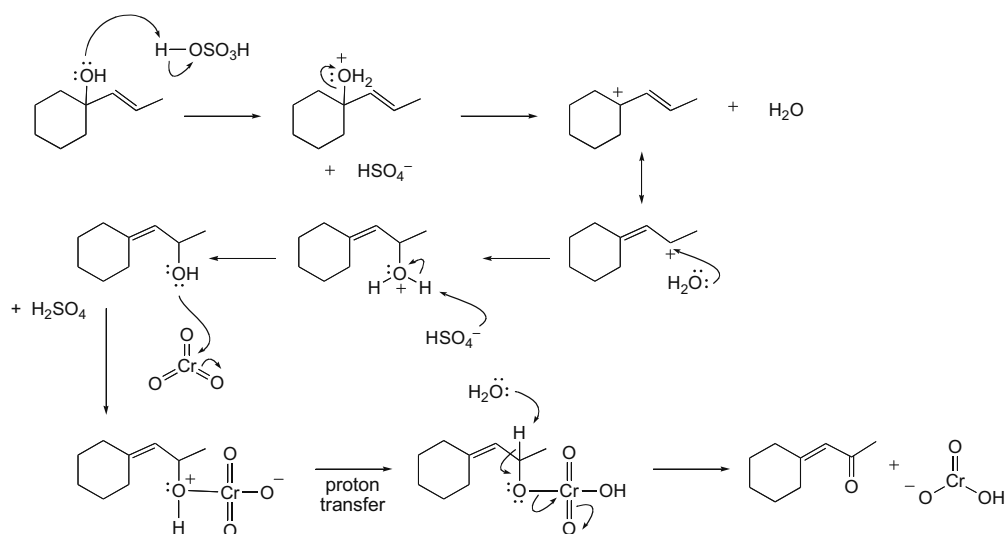


12.79 The two OH's are added to opposite faces of the C=C, so anti addition occurs.

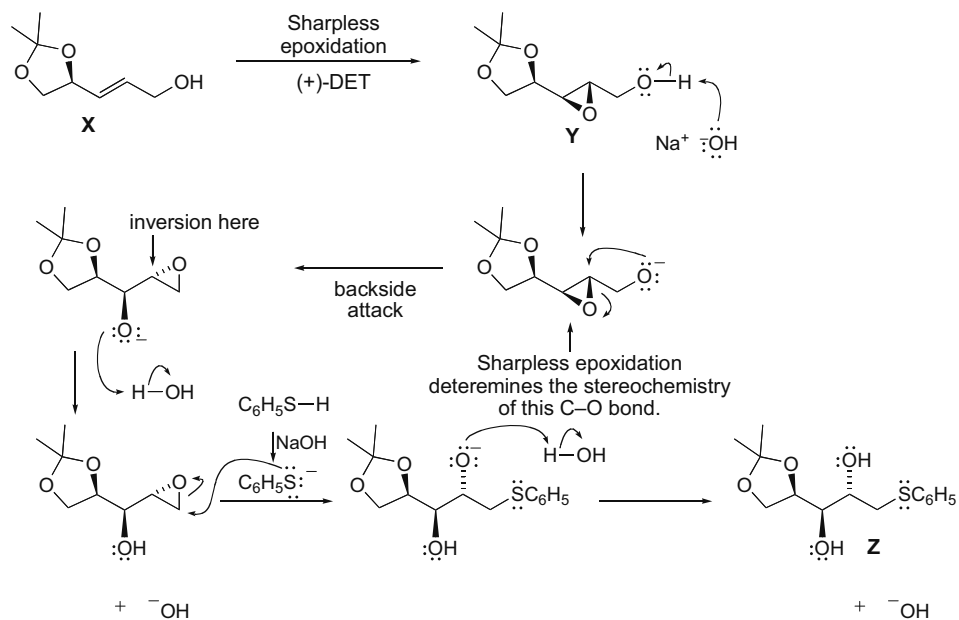


Chapter 12–30

12.80



12.81



Chapter 13 Mass Spectrometry and Infrared Spectroscopy

Chapter Review

Mass spectrometry (MS)

- Mass spectrometry measures the molecular weight of a compound (13.1A).
- The mass of the molecular ion (**M**) = the molecular weight of a compound. Except for isotope peaks at $M + 1$ and $M + 2$, the molecular ion has the highest mass in a mass spectrum (13.1A).
- The base peak is the tallest peak in a mass spectrum (13.1A).
- A compound with an odd number of N atoms gives an odd molecular ion. A compound with an even number of N atoms (including zero) gives an even molecular ion (13.1B).
- Organic chlorides show two peaks for the molecular ion (M and $M + 2$) in a 3:1 ratio (13.2).
- Organic bromides show two peaks for the molecular ion (M and $M + 2$) in a 1:1 ratio (13.2).
- The fragmentation of radical cations formed in a mass spectrometer gives lower molecular weight fragments, often characteristic of a functional group (13.3).
- High-resolution mass spectrometry gives the molecular formula of a compound (13.4A).

Electromagnetic radiation

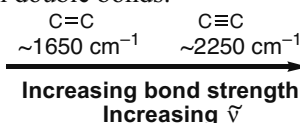
- The wavelength and frequency of electromagnetic radiation are *inversely* related by the following equations: $\lambda = c/\nu$ or $\nu = c/\lambda$ (13.5).
- The energy of a photon is proportional to its frequency; the higher the frequency the higher the energy: $E = h\nu$ (13.5).

Infrared spectroscopy (IR, 13.6 and 13.7)

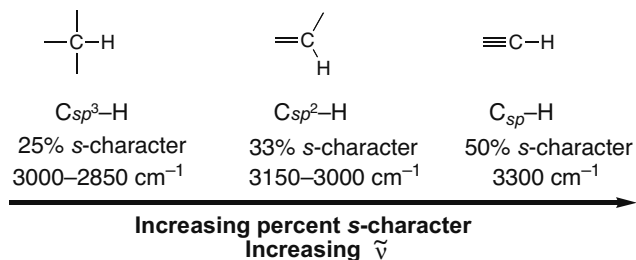
- Infrared spectroscopy identifies functional groups.
- IR absorptions are reported in wavenumbers:

$$\text{wavenumber} = \tilde{\nu} = 1/\lambda$$

- The functional group region from $4000\text{--}1500\text{ cm}^{-1}$ is the most useful region of an IR spectrum.
- C–H, O–H, and N–H bonds absorb at high frequency, $\geq 2500\text{ cm}^{-1}$.
- As bond strength increases, the wavenumber of an absorption increases; thus triple bonds absorb at higher wavenumber than double bonds.



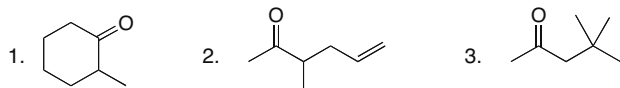
- The higher the percent *s*-character, the stronger the bond, and the higher the wavenumber of an IR absorption.



Chapter 13-2

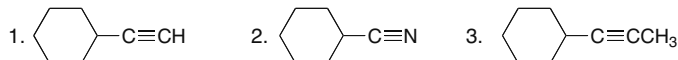
Practice Test on Chapter Review

1. a. Which compound has a molecular ion at 112 and a peak at 1720 cm^{-1} in its IR spectrum?



4. Compounds (1) and (2) both fit these criteria.
5. Compounds (1), (2), and (3) all fit these criteria.

b. Which of the following compounds has peaks at 3300 , 3000 , and 2250 cm^{-1} in its IR spectrum?

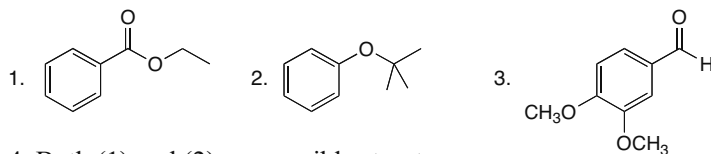


4. Compounds (1) and (2) have these peaks in their IR spectra.
5. Compounds (1), (2), and (3) all contain these peaks in their IR spectra.

c. What is the base peak in a mass spectrum?

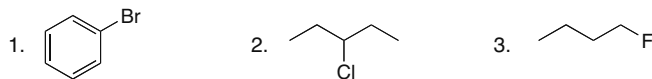
1. the peak due to the radical cation formed when a molecule loses an electron
2. the tallest peak in the mass spectrum
3. the peak due to the fragment with the largest m/z ratio
4. Both (1) and (2) describe the base peak.
5. Statements (1), (2), and (3) describe the base peak.

d. Which compounds are possible structures for a molecule that has a molecular ion at 150 in its mass spectrum?



4. Both (1) and (2) are possible structures.
5. Compounds (1), (2), and (3) are all possible structures.

e. Which compounds exhibit prominent $M+2$ peaks in their mass spectra?



4. Both (1) and (2) show $M+2$ peaks.
5. Compounds (1), (2), and (3) all show $M+2$ peaks.

Mass Spectrometry and Infrared Spectroscopy 13–3

2. Answer each question with the number that corresponds to one of the following regions of an IR spectrum.
1. 4000–2500 cm^{-1}
 2. 2500–2000 cm^{-1}
 3. 2000–1500 cm^{-1}
 4. < 1500 cm^{-1}
- a. This region is called the fingerprint region of an IR spectrum.
 - b. The OH group of 1-propanol absorbs in this region.
 - c. The C=N of $\text{C}_6\text{H}_5\text{CH}_2\text{CH}=\text{NCH}_3$ absorbs in this region.
 - d. An unsymmetrical $\text{C}\equiv\text{C}$ absorbs in this region.
 - e. An *sp* hybridized C–H bond absorbs in this region.
 - f. Ethyl benzoate ($\text{C}_6\text{H}_5\text{CO}_2\text{CH}_2\text{CH}_3$) absorbs in all regions of the IR except this one.
3. Answer True (T) or False (F).
- a. IR spectroscopy is useful for determining the molecular weight of a compound.
 - b. A C–H bond that absorbs at 3140 cm^{-1} is stronger than a C–H bond that absorbs at 2950 cm^{-1} .
 - c. A compound with a molecular ion at 109 contains a N atom.
 - d. A compound with a base peak at 57 must contain a N atom.
 - e. 2-Butyne shows an IR absorption at 2250 cm^{-1} .
 - f. 1-Propanol shows an IR absorption at 3200–3600 cm^{-1} .
 - g. An ether shows no IR absorptions at 3200–3600 or 1700 cm^{-1} .
 - h. In its mass spectrum, a compound that has a molecular ion with two peaks of approximately equal intensity at 124 and 126 contains chlorine.

Answers to Practice Test

1.a. 4	2.a. 4	3.a. F	e. F
b. 1	b. 1	b. T	f. T
c. 2	c. 3	c. T	g. T
d. 4	d. 2	d. F	h. F
e. 4	e. 1		
	f. 2		

Chapter 13–4

Answers to Problems

13.1 The molecular ion formed from each compound is equal to its molecular weight.

a. $\text{C}_3\text{H}_6\text{O}$ molecular weight = 58 molecular ion (m/z) = 58	b. $\text{C}_{10}\text{H}_{20}$ molecular weight = 140 molecular ion (m/z) = 140	c. $\text{C}_8\text{H}_8\text{O}_2$ molecular weight = 136 molecular ion (m/z) = 136	d. $\text{C}_{10}\text{H}_{15}\text{N}$ molecular weight = 149 molecular ion (m/z) = 149

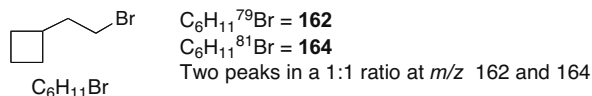
13.2 Some possible formulas for each molecular ion:

- Molecular ion at 72: C_5H_{12} , $\text{C}_4\text{H}_8\text{O}$, $\text{C}_3\text{H}_4\text{O}_2$
- Molecular ion at 100: C_8H_4 , C_7H_{16} , $\text{C}_6\text{H}_{12}\text{O}$, $\text{C}_5\text{H}_8\text{O}_2$
- Molecular ion at 73: $\text{C}_4\text{H}_{11}\text{N}$, $\text{C}_2\text{H}_7\text{N}_3$

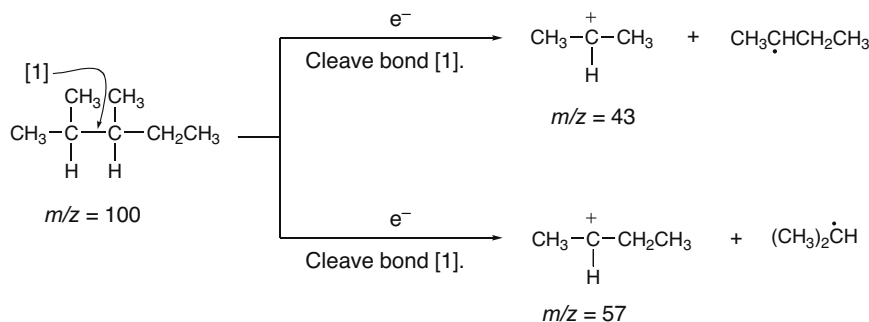
13.3 To calculate the molecular ions you would expect for compounds with Cl, calculate the molecular weight using each of the two most common isotopes of Cl (^{35}Cl and ^{37}Cl).

a. $\text{C}_4\text{H}_9^{35}\text{Cl}$ = 92 $\text{C}_4\text{H}_9^{37}\text{Cl}$ = 94 Two peaks in 3:1 ratio at m/z 92 and 94	c. $\text{C}_4\text{H}_{11}\text{N}$ = 73 One peak at m/z 73
b. $\text{C}_3\text{H}_7\text{F}$ = 62 One peak at m/z 62	d. $\text{C}_4\text{H}_4\text{N}_2$ = 80 One peak at m/z 80

13.4 Convert the ball-and-stick model to a skeletal structure and determine the molecular formula. Calculate the molecular weight using each of the two common isotopes for Br (^{79}Br and ^{81}Br).

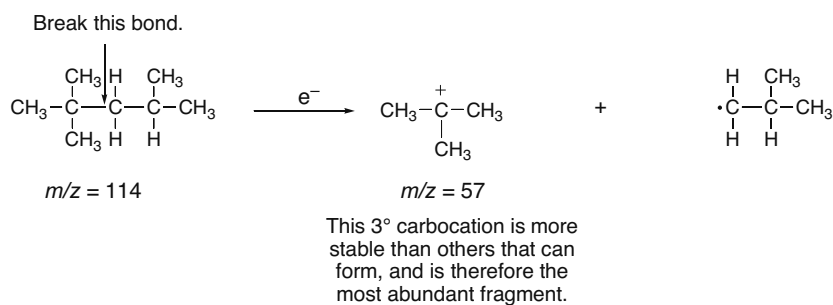


13.5 After calculating the mass of the molecular ion, draw the structure and determine which C–C bond is broken to form fragments of the appropriate mass-to-charge ratio.

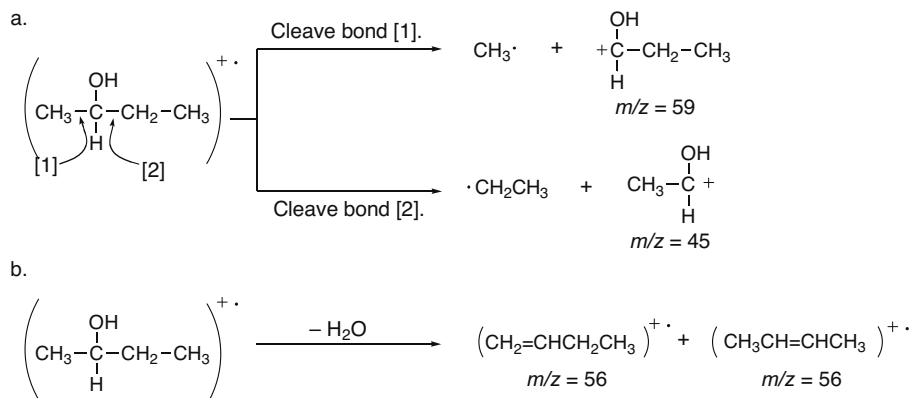


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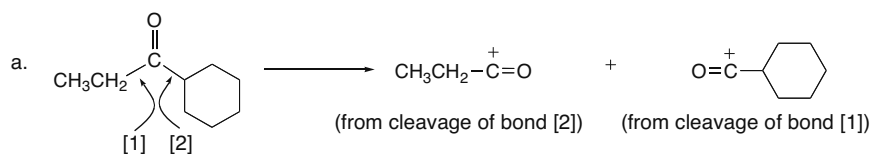
13.6



13.7



13.8



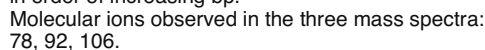
13.9 Use the exact mass values given in Table 13.1 to calculate the exact mass of each compound.

$\text{C}_7\text{H}_5\text{NO}_3$
mass: 151.0270

$\text{C}_8\text{H}_9\text{NO}_2$
mass: 151.0634
compound X

$\text{C}_{10}\text{H}_{17}\text{N}$
mass: 151.1362

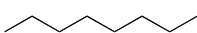
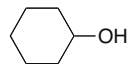
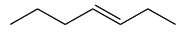
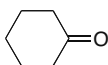
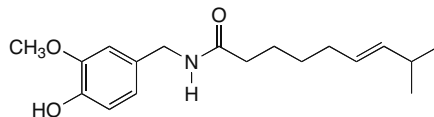
13.10

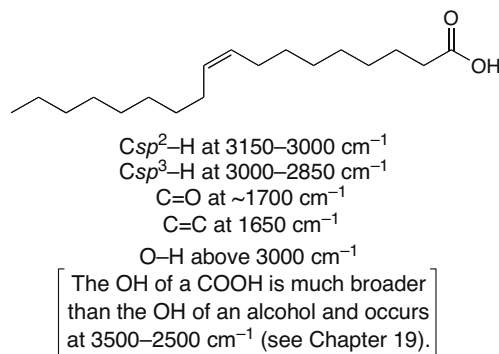


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Mass Spectrometry and Infrared Spectroscopy 13-7

13.18 All compounds show an absorption at $3000\text{--}2850\text{ cm}^{-1}$ due to the sp^3 hybridized C–H bonds. Additional peaks in the functional group region for each compound are shown.

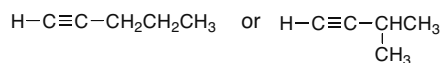
- a. 
no additional peaks
- b. 
O–H bond at $3600\text{--}3200\text{ cm}^{-1}$
- c. 
 $Csp^2\text{--H}$ at $3150\text{--}3000\text{ cm}^{-1}$
C=C bond at 1650 cm^{-1}
- d. 
C=O bond at $\sim 1700\text{ cm}^{-1}$
- e. 
O–H at $3600\text{--}3200\text{ cm}^{-1}$
N–H at $3500\text{--}3200\text{ cm}^{-1}$
 $Csp^2\text{--H}$ at $3150\text{--}3000\text{ cm}^{-1}$
C=O at $\sim 1700\text{ cm}^{-1}$
C=C at 1650 cm^{-1}
aromatic ring at $1600, 1500\text{ cm}^{-1}$

13.19

13.20 Possible structures are (a) $\text{CH}_3\text{COOCH}_2\text{CH}_3$ and (c) $\text{CH}_3\text{CH}_2\text{COOCH}_3$. Compounds (b) and (d) also have an OH group that would give a strong absorption at $\sim 3600\text{--}3200\text{ cm}^{-1}$, which is absent in the IR spectrum of X, thus excluding them as possibilities.

13.21

- a. Hydrocarbon with a molecular ion at $m/z = 68$
 IR absorptions at $3310\text{ cm}^{-1} = Csp\text{--H}$ bond
 $3000\text{--}2850\text{ cm}^{-1} = Csp^3\text{--H}$ bonds
 $2120\text{ cm}^{-1} = C\equiv C$ bond
 Molecular formula: C_5H_8

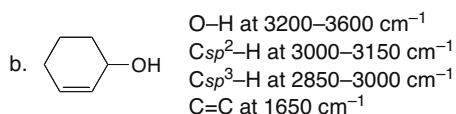
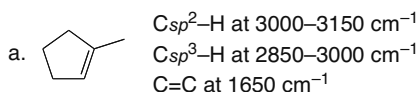


- b. Compound with C, H, and O with a molecular ion at $m/z = 60$
 IR absorptions at $3600\text{--}3200\text{ cm}^{-1} = \text{O--H}$ bond
 $3000\text{--}2850\text{ cm}^{-1} = Csp^3\text{--H}$ bonds
 Molecular formula: $\text{C}_3\text{H}_8\text{O}$

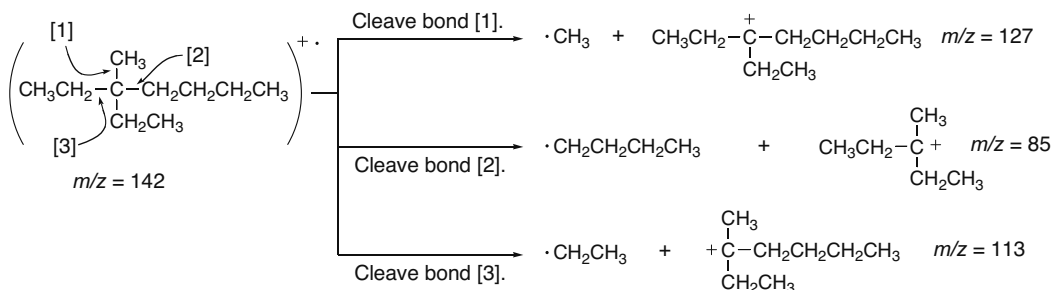


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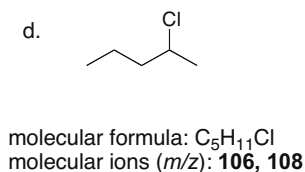
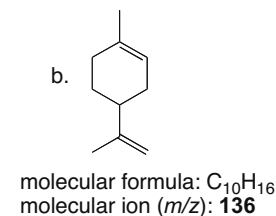
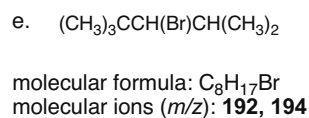
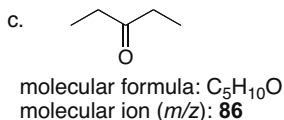
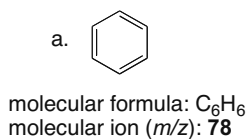
13.22



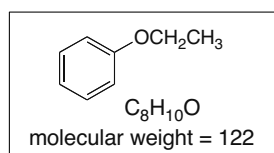
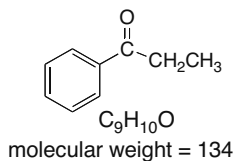
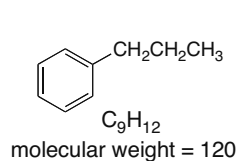
13.23



13.24



13.25



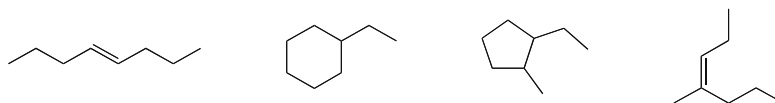
13.26 Examples are given for each molecular ion.

- molecular ion 102: C_8H_6 , $\text{C}_6\text{H}_{14}\text{O}$, $\text{C}_5\text{H}_{10}\text{O}_2$, $\text{C}_5\text{H}_{14}\text{N}_2$
- molecular ion 98: C_8H_2 , C_7H_{14} , $\text{C}_6\text{H}_{10}\text{O}$, $\text{C}_5\text{H}_6\text{O}_2$
- molecular ion 119: $\text{C}_8\text{H}_9\text{N}$, $\text{C}_6\text{H}_5\text{N}_3$
- molecular ion 74: C_6H_2 , $\text{C}_4\text{H}_{10}\text{O}$, $\text{C}_3\text{H}_6\text{O}_2$

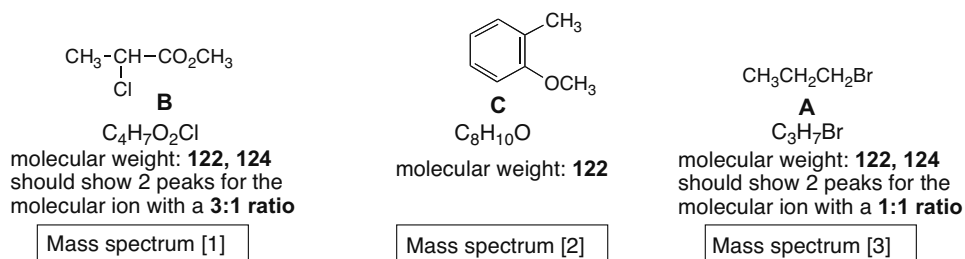
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13.27 Likely molecular formula, C_8H_{16} (one degree of unsaturation—one ring or one π bond).

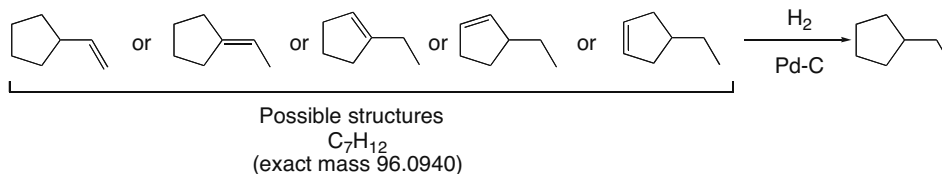
Four structures with $m/z = 112$



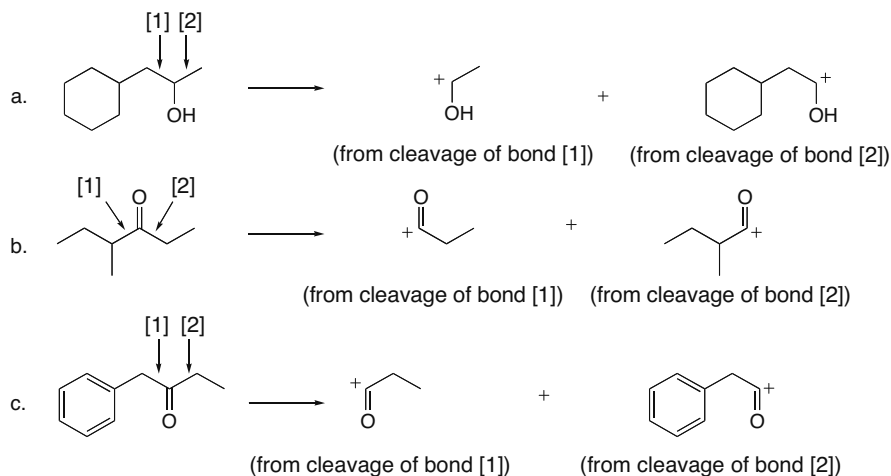
13.28



13.29

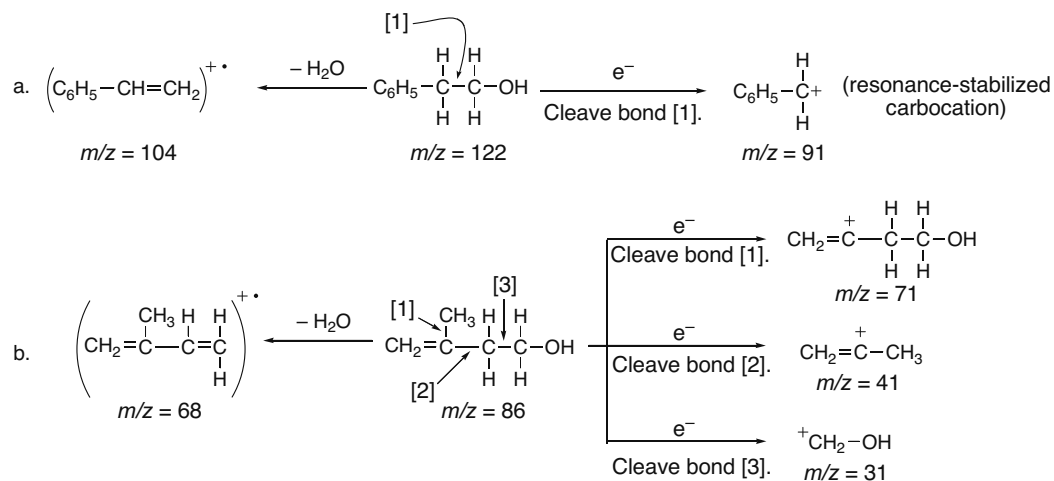


13.30

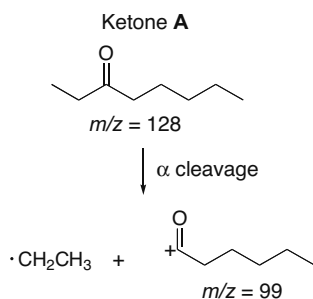


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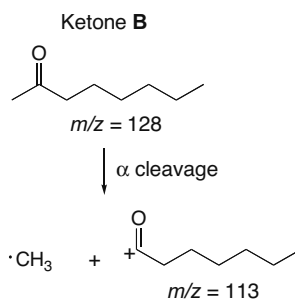
13.31



13.32



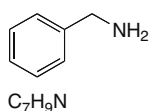
This is ketone **A** since α cleavage gives a fragment with m/z of 99.



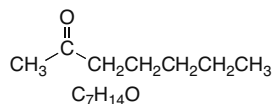
This is ketone **B** since α cleavage gives a fragment with m/z of 113.

13.33 One possible structure is drawn for each set of data:

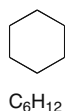
- a. A compound that contains a benzene ring and has a molecular ion at $m/z = 107$



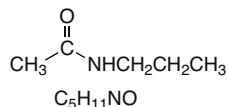
- c. A compound that contains a carbonyl group and gives a molecular ion at $m/z = 114$



- b. A hydrocarbon that contains only sp^3 hybridized carbons and a molecular ion at $m/z = 84$



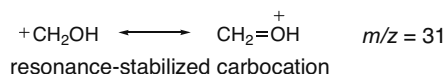
- d. A compound that contains C, H, N, and O and has an exact mass for the molecular ion at 101.0841

13.34 Use the values given in Table 13.1 to calculate the exact mass of each compound. $\text{C}_8\text{H}_{11}\text{NO}_2$ (exact mass 153.0790) is the correct molecular formula.

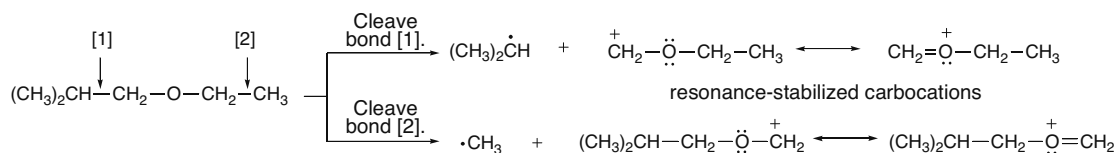
Mass Spectrometry and Infrared Spectroscopy 13–11

13.35 Two isomers such as $\text{CH}_2=\text{CHCH}_2\text{CH}_2\text{CH}_2\text{CH}_3$ and $(\text{CH}_3)_2\text{C}=\text{CHCH}_2\text{CH}_3$ have the same molecular formulas and therefore give the same exact mass, so they are not distinguishable by their exact mass spectra.

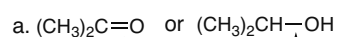
13.36 Alpha cleavage of a 1° alcohol (RCH_2OH) forms an alkyl radical ($\text{R}\bullet$) and a resonance-stabilized carbocation with $m/z = 31$.



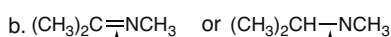
13.37 An ether fragments by α cleavage because the resulting carbocation is resonance stabilized.



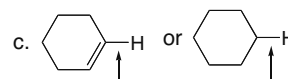
13.38



↑
stronger bond
higher $\tilde{\nu}$ absorption

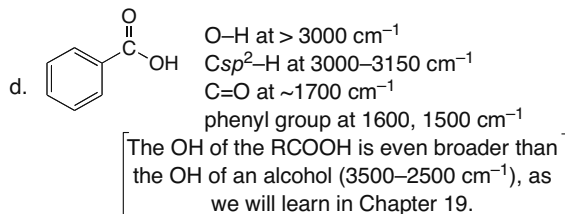
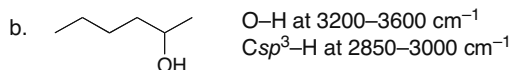
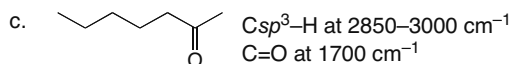
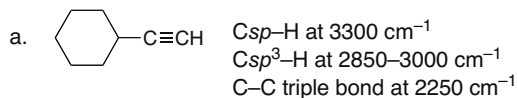


↑
stronger bond
higher $\tilde{\nu}$ absorption

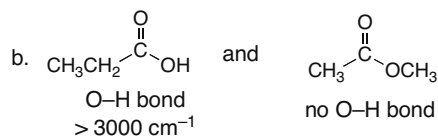
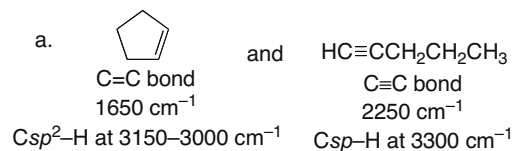


↑
stronger bond
higher $\tilde{\nu}$ absorption

13.39 Locate the functional groups in each compound. Use Table 13.2 to determine what IR absorptions each would have.

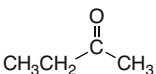
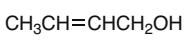
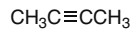
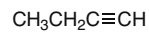
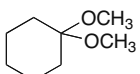
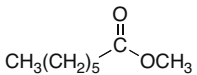
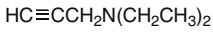
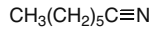


13.40

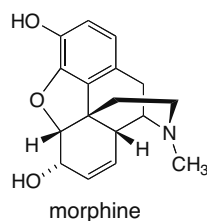


[See note on OH in Answer 13.39d.]

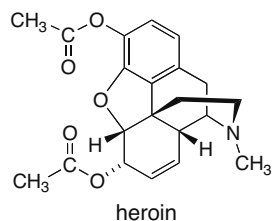
Chapter 13–12

- c.  and 
 C=O bond 1700 cm^{-1}
 O–H bond 3200–3600 cm^{-1}
 $\text{Csp}^2\text{–H}$ at 3150–3000 cm^{-1}
 C=C bond at 1650 cm^{-1}
- e.  and 
 no C≡C absorption due to symmetry
 Csp–H bond 3300 cm^{-1}
 C≡C bond at ~2250 cm^{-1}
- d.  and 
 no C=O bond
 C=O bond ~1700 cm^{-1}
- f.  and 
 Csp–H bond 3300 cm^{-1}

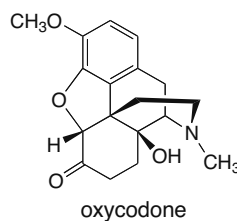
13.41 The IR absorptions above 1500 cm^{-1} are different for each of the narcotics.



- O–H bond at ~3200–3600 cm^{-1}
- no C=O bond

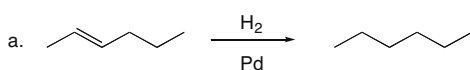


- C=O bond at ~1700 cm^{-1}
- no O–H bond

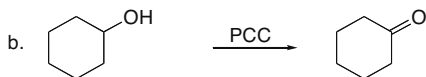


- C=O bond at ~1700 cm^{-1}
- O–H bond at ~3200–3600 cm^{-1}

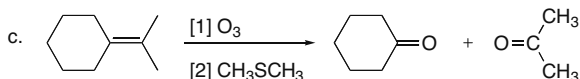
13.42 Look for a **change in functional groups** from starting material to product to see how IR could be used to determine when the reaction is complete.



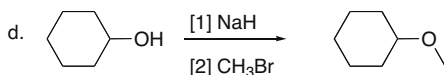
Loss of the C=C will be visible in the IR by disappearance of the peak at 1650 cm^{-1} .



Loss of the O–H group will be visible in the IR by disappearance of the peak at 3200–3600 cm^{-1} and appearance of the C=O at ~1700 cm^{-1} .



Loss of the C=C will be visible in the IR by disappearance of the peak at 1650 cm^{-1} and appearance of the C=O at ~1700 cm^{-1} .

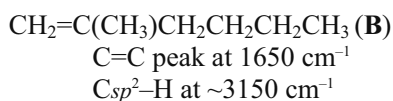


Loss of the O–H will be visible in the IR by disappearance of the peak at 3200–3600 cm^{-1} .

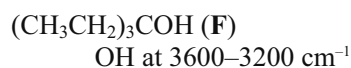
Mass Spectrometry and Infrared Spectroscopy 13-13

13.43 In addition to $C_{sp^3}-H$ at $\sim 3000-2850\text{ cm}^{-1}$:

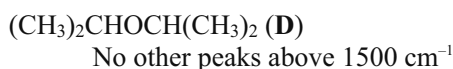
Spectrum [1]:



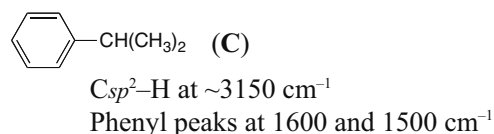
Spectrum [2]:



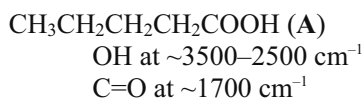
Spectrum [3]:



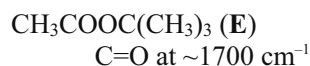
Spectrum [4]:



Spectrum [5]:



Spectrum [6]:

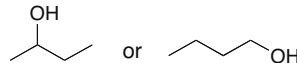


13.44

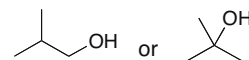
- a. Compound with a molecular ion at $m/z = 72$
 IR absorption at $1725\text{ cm}^{-1} = C=O$ bond
 Molecular formula: C_4H_8O



- c. Compound with a molecular ion at $m/z = 74$
 IR absorption at $3600-3200\text{ cm}^{-1} = O-H$ bond
 Molecular formula: $C_4H_{10}O$

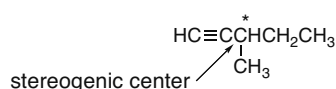


- b. Compound with a molecular ion at $m/z = 55$
 The odd molecular ion means an odd number of N's present. Molecular formula: C_3H_5N
 IR absorption at $2250\text{ cm}^{-1} = C\equiv N$ bond
 $CH_3CH_2C\equiv N$

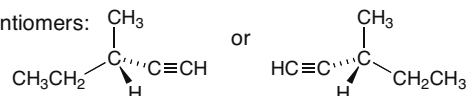


13.45

Chiral hydrocarbon with a molecular ion at $m/z = 82$
 Molecular formula: C_6H_{10}
 IR absorptions at $3300\text{ cm}^{-1} = C_{sp}-H$ bond
 $3000-2850\text{ cm}^{-1} = C_{sp^3}-H$ bonds
 $2250\text{ cm}^{-1} = C\equiv C$ bond

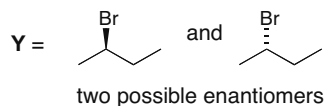


Two possible enantiomers:

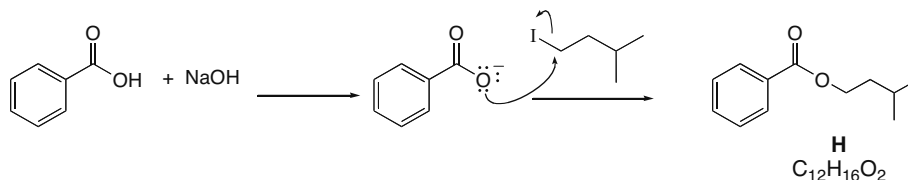
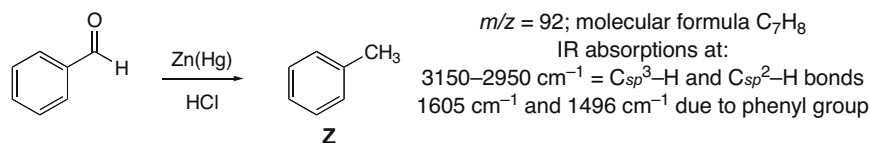
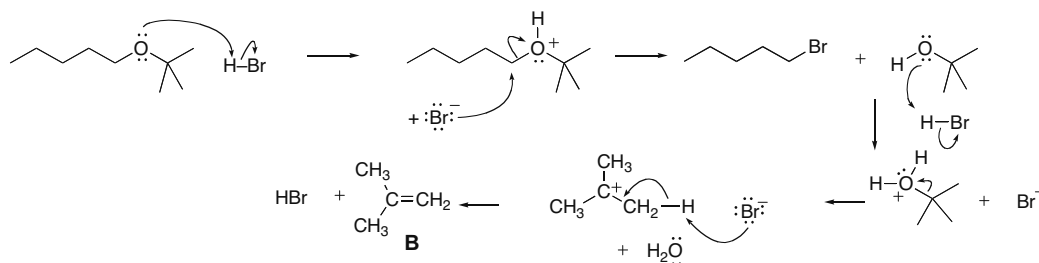


Chapter 13–14

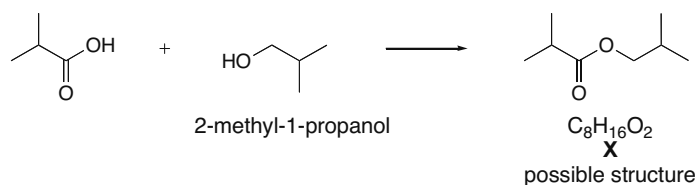
- 13.46** The chiral compound **Y** has a strong absorption at $2970\text{--}2840\text{ cm}^{-1}$ in its IR spectrum due to sp^3 hybridized C–H bonds. The two peaks of equal intensity at 136 and 138 indicate the presence of a Br atom. The molecular formula is $\text{C}_4\text{H}_9\text{Br}$. Only one constitutional isomer of this molecular formula has a stereogenic center:



- 13.47** The molecular ion of 192 suggests $\text{C}_{12}\text{H}_{16}\text{O}_2$ as a possible molecular formula. IR absorption at 1721 cm^{-1} is due to a $\text{C}=\text{O}$, and the absorptions around 3000 cm^{-1} are due to $\text{C}_{sp^2}\text{--H}$ and $\text{C}_{sp^3}\text{--H}$. The compound is an ester, formed in the following manner.

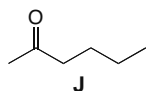
**13.48****13.49**

- 13.50** The molecular ion of 144 suggests $\text{C}_8\text{H}_{16}\text{O}_2$ as a possible molecular formula for **X**. The IR absorption at 1739 cm^{-1} is due to a $\text{C}=\text{O}$, and the absorptions at less than 3000 cm^{-1} are due to $\text{C}_{sp^3}\text{--H}$.



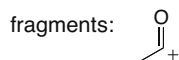
Mass Spectrometry and Infrared Spectroscopy 13–15

13.51

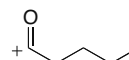


$\text{C}_5\text{H}_{10}\text{O}$
 $m/z = 100$

IR absorption at 2962 cm^{-1} = $\text{C}_{\text{sp}^3}\text{--H}$ bonds
 1718 cm^{-1} = C=O bond



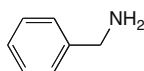
α cleavage product
 $m/z = 43$



α cleavage product
 $m/z = 85$

The fragment at $m/z = 57$ could be due to $(\text{C}_4\text{H}_9)^+$ or $(\text{C}_3\text{H}_5\text{O})^+$.

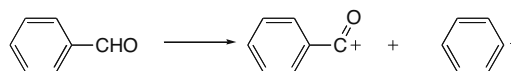
13.52



$\text{C}_7\text{H}_9\text{N}$
 $m/z = 107$

IR absorptions at 3373 and 3290 cm^{-1} = N--H
 3062 cm^{-1} = $\text{C}_{\text{sp}^2}\text{--H}$ bonds
 2920 cm^{-1} = $\text{C}_{\text{sp}^3}\text{--H}$ bonds
 1600 cm^{-1} = benzene ring

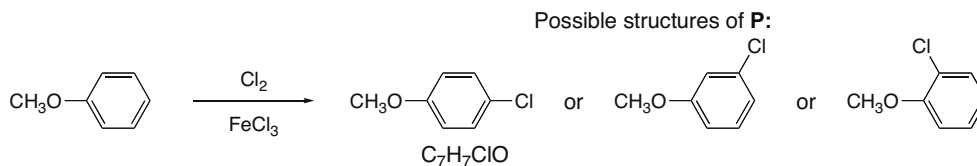
The odd molecular ion indicates the presence of a N atom.



$\text{C}_7\text{H}_6\text{O}$
 $m/z = 106$

IR absorption at 3068 cm^{-1} = $\text{C}_{\text{sp}^2}\text{--H}$ bonds on ring
 2850 cm^{-1} = $\text{C}_{\text{sp}^3}\text{--H}$ bond
 2820 cm^{-1} and 2736 cm^{-1} = C--H of RCHO (Appendix E)
 1703 cm^{-1} = C=O bond
 1600 cm^{-1} = aromatic ring

13.53

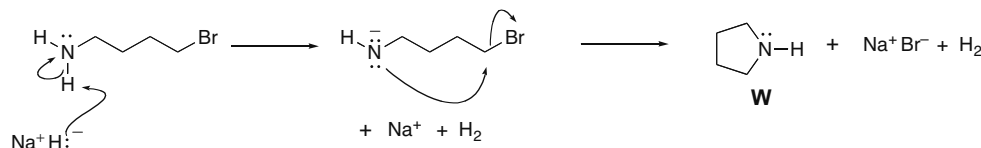


$m/z = 142, 144$

IR absorption at $3096\text{--}2837\text{ cm}^{-1}$ = $\text{C}_{\text{sp}^3}\text{--H}$ bonds and $\text{C}_{\text{sp}^2}\text{--H}$ bonds
 1582 cm^{-1} and 1494 cm^{-1} = benzene ring

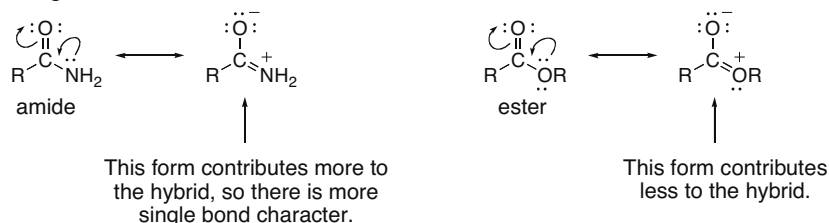
The peak at $M + 2$ shows the presence of Cl or Br. Since Cl_2 is a reactant, the compound presumably contains Cl.

13.54 The mass spectrum has a molecular ion at 71. The odd mass suggests the presence of an odd number of N atoms; likely formula, $\text{C}_4\text{H}_9\text{N}$. The IR absorption at $\sim 3300\text{ cm}^{-1}$ is due to N--H and the $3000\text{--}2850\text{ cm}^{-1}$ is due to sp^3 hybridized C--H bonds.



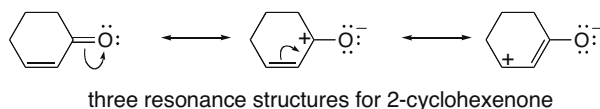
Chapter 13–16

- 13.55** Because the carbonyl absorption of an amide is at lower wavenumber than the carbonyl absorption of an ester, the C=O of the amide must be weaker and have more single bond character. This can be explained by resonance. Although both an ester and amide are resonance stabilized, the N atom of the amide is more basic, making it more willing to donate its electron pair.

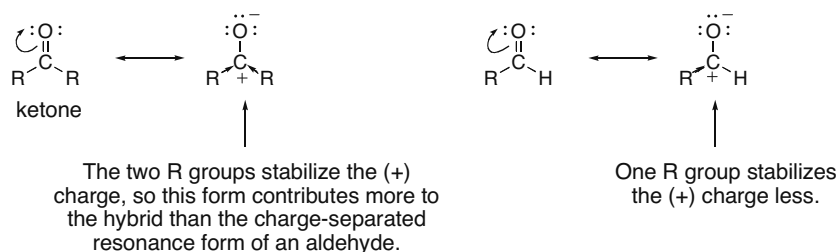


Since the amide carbonyl has more single bond character, the bond is weaker and it absorbs at lower wavenumber.

- 13.56** The α,β -unsaturated carbonyl compound has three resonance structures, two of which place a single bond between the C and O atoms. This means that the C–O bond has partial single bond character, making it weaker than a regular C=O bond, and moving the absorption to lower wavenumber.



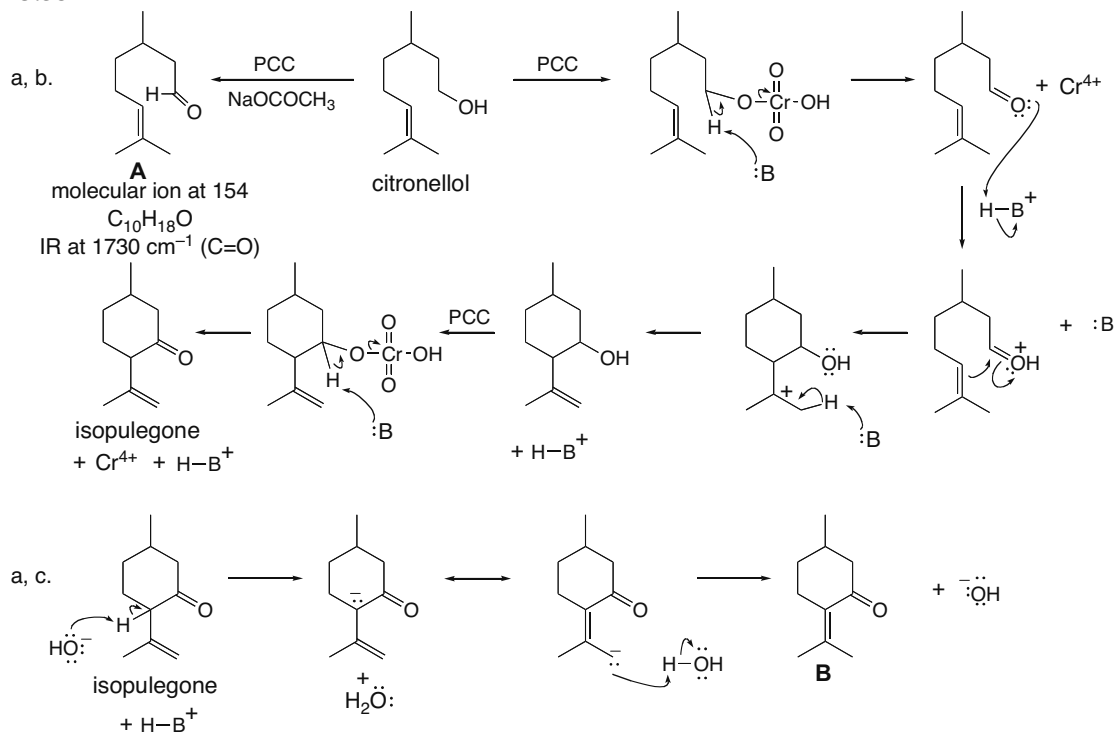
- 13.57** If a ketone carbonyl absorbs at lower wavenumber than an aldehyde carbonyl, the ketone carbonyl is weaker and has more single bond character. This can be explained by the fact that R groups are electron donating and stabilize an adjacent (+) charge.



As a result, the charge-separated resonance form of a ketone, which contains a C–O single bond, contributes more to the hybrid of a ketone, making the C=O weaker and shifting the absorption to lower wavenumber.

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13.58

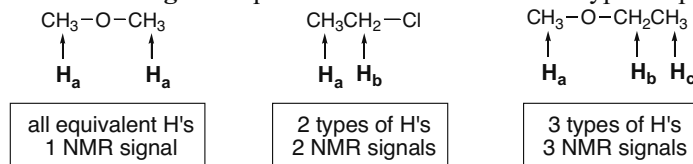


Chapter 14 Nuclear Magnetic Resonance Spectroscopy

Chapter Review

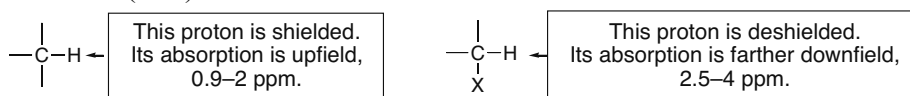
¹H NMR spectroscopy

[1] The **number of signals** equals the number of different types of protons (14.2).

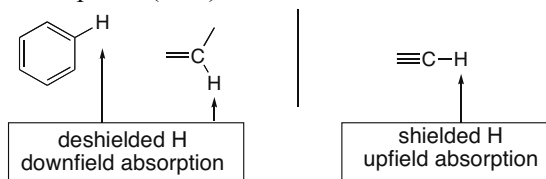


[2] The **position of a signal** (its chemical shift) is determined by shielding and deshielding effects.

- Shielding shifts an absorption upfield; deshielding shifts an absorption downfield.
- Electronegative atoms withdraw electron density, deshield a nucleus, and shift an absorption downfield (14.3).



- Loosely held π electrons can either shield or deshield a nucleus. Protons on benzene rings and double bonds are deshielded and absorb downfield, whereas protons on triple bonds are shielded and absorb upfield (14.4).



[3] The **area under an NMR signal** is proportional to the number of absorbing protons (14.5).

[4] **Spin-spin splitting** tells about nearby nonequivalent protons (14.6–14.8).

- Equivalent protons do not split each other's signals.
- A set of n nonequivalent protons on the same carbon or adjacent carbons split an NMR signal into $n + 1$ peaks.
- OH and NH protons do not cause splitting (14.9).
- When an absorbing proton has two sets of nearby nonequivalent protons that are equivalent to each other, use the $n + 1$ rule to determine splitting.
- When an absorbing proton has two sets of nearby nonequivalent protons that are not equivalent to each other, the number of peaks in the NMR signal = $(n + 1)(m + 1)$. In flexible alkyl chains, peak overlap often occurs, resulting in $n + m + 1$ peaks in an NMR signal.

¹³C NMR spectroscopy (14.11)

[1] The number of signals equals the number of different types of carbon atoms. All signals are single lines.

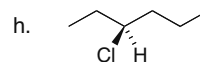
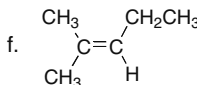
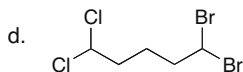
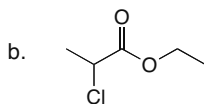
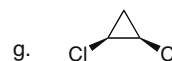
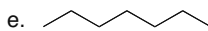
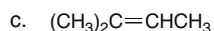
[2] The relative position of ¹³C signals is determined by shielding and deshielding effects.

- Carbons that are sp^3 hybridized are shielded and absorb upfield.
- Electronegative elements (N, O, and X) shift absorptions downfield.
- The carbons of alkenes and benzene rings absorb downfield.
- Carbonyl carbons are highly deshielded, and absorb farther downfield than other carbon types.

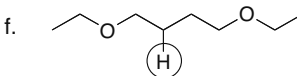
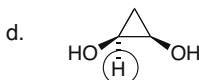
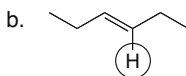
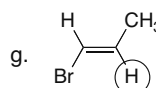
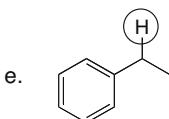
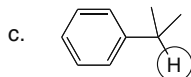
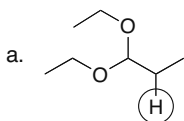
Chapter 14-2

Practice Test on Chapter Review

1. a. Which of the following statements is true about ^1H NMR absorptions?
1. A signal that occurs at 1800 Hz on a 300 MHz NMR spectrometer occurs at 3000 Hz on a 500 MHz NMR spectrometer.
 2. A signal that occurs at 3.3 ppm on a 60 MHz NMR absorbs at 198 Hz upfield from TMS.
 3. A signal that occurs at 600 Hz is downfield from a signal that occurs at 800 Hz.
 4. Statements (1) and (2) are both true.
 5. Statements (1), (2), and (3) are all true.
- b. Which of the following statements is true about ^1H NMR spectroscopy?
1. Electronegative elements shield a nucleus so an absorption shifts downfield.
 2. A triplet is due to a proton that has four adjacent nonequivalent protons.
 3. Circulating π electrons create a magnetic field that reinforces the applied field in the vicinity of the protons in benzene.
 4. Statements (1) and (2) are both true.
 5. Statements (1), (2), and (3) are all true.
2. How many different types of protons does each of the following molecules contain?

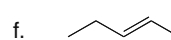
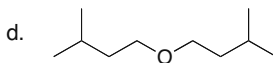
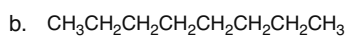
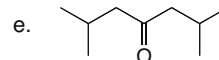
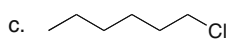
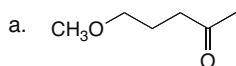


3. Into how many peaks will each of the circled protons be split in a proton NMR spectrum?

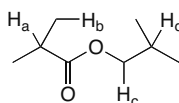


Nuclear Magnetic Resonance Spectroscopy 14-3

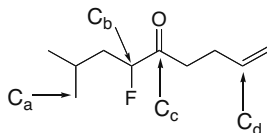
4. How many lines are presents in the ^{13}C NMR spectrum of each compound?



5. With reference to the ^1H NMR absorptions in the following compound, (a) which proton absorbs farthest upfield; (b) which proton absorbs farthest downfield?



6. With reference to the ^{13}C NMR absorptions in the following compound, (a) which carbon absorbs farthest downfield; (b) which carbon absorbs farthest upfield?



Answers to Practice Test

1. a. 1	2. a. 5	3. a. 8	4. a. 6	5. a. H_b	6. a. C_c
b. 3	b. 5	b. 3	b. 4	b. H_c	b. C_a
	c. 4	c. 7	c. 6		
	d. 5	d. 4	d. 4		
	e. 4	e. 4	e. 4		
	f. 5	f. 3	f. 5		
	g. 3	g. 8			
	h. 9				

Answers to Problems

14.1 Use the formula $\delta = [\text{observed chemical shift (Hz)} / \nu \text{ of the NMR (MHz)}]$ to calculate the chemical shifts.

a. CH_3 protons:
 $\delta = [1715 \text{ Hz}] / [500 \text{ MHz}]$
 $= 3.43 \text{ ppm}$

OH proton:
 $\delta = [1830 \text{ Hz}] / [500 \text{ MHz}]$
 $= 3.66 \text{ ppm}$

b. The positive direction of the δ scale is downfield from TMS. The CH_3 protons absorb upfield from the OH proton.

14.2 Calculate the chemical shifts as in Answer 14.1.

a. one signal:
 $\delta = [1017 \text{ Hz}] / [300 \text{ MHz}]$
 $= 3.39 \text{ ppm}$

second signal:
 $\delta = [1065 \text{ Hz}] / [300 \text{ MHz}]$
 $= 3.55 \text{ ppm}$

b. one signal:
 $3.39 = [x \text{ Hz}] / [500 \text{ MHz}]$
 $x = 1695 \text{ Hz}$

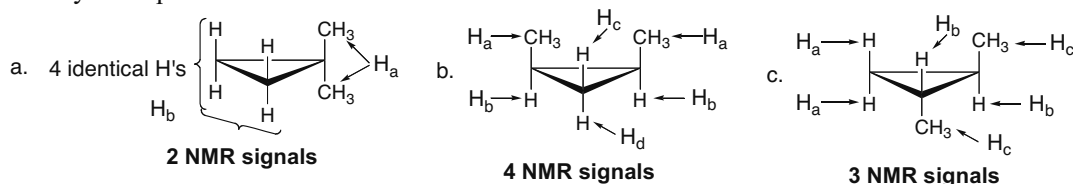
second signal:
 $3.55 = [x \text{ Hz}] / [500 \text{ MHz}]$
 $x = 1775 \text{ Hz}$

Chapter 14-4

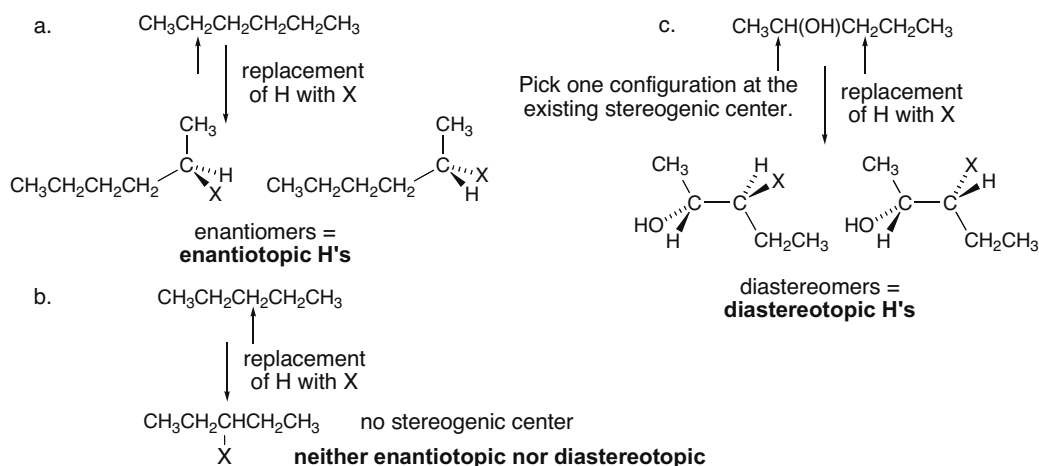
14.3 To determine if two H's are equivalent replace each by an atom X. If this yields the same compound or mirror images, the two H's are equivalent. Each kind of H will give one NMR signal.

a. CH_3CH_3 1 kind of H 1 NMR signal	c. $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_3$ 2 kinds of H's 2 NMR signals	e. $\text{CH}_3\text{CH}_2\text{CO}_2\text{CH}_2\text{CH}_3$ 4 kinds of H's 4 NMR signals	g. $\text{CH}_3(\text{CH}_2)_7\text{Cl}$ 8 kinds of H's 8 NMR signals
b. $\text{CH}_3\text{CH}_2\text{CH}_3$ 2 kinds of H's 2 NMR signals	d. $(\text{CH}_3)_2\text{CHCH}(\text{CH}_3)_2$ 2 kinds of H's 2 NMR signals	f. $\text{CH}_3\text{OCH}_2\text{CH}(\text{CH}_3)_2$ 4 kinds of H's 4 NMR signals	h. $\text{CH}_3\text{CH}_2\text{CH}_2\text{OH}$ 4 kinds of H's 4 NMR signals

14.4 Draw in all of the H's and compare them. If two H's are cis and trans to the same group, they are equivalent.



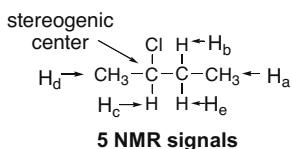
14.5 If replacement of H with X yields enantiomers, the protons are **enantiotopic**. If replacement of H with X yields diastereomers, the protons are **diastereotopic**. In general, if the compound has **one stereogenic center**, the protons in a CH_2 group are **diastereotopic**.



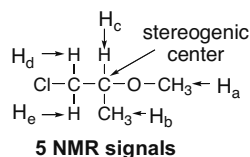
14.6 The two protons of a CH_2 group are different from each other if the compound has one stereogenic center. Replace one proton with X and compare the products.

Nuclear Magnetic Resonance Spectroscopy 14-5

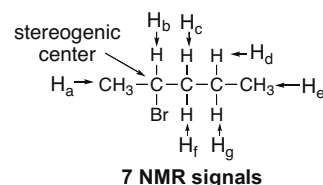
- a. The stereogenic center makes the H's in the CH_2 group diastereotopic and therefore different from each other.



b.



c.



- 14.7** Decreased electron density deshields a nucleus and the absorption goes downfield. Absorption also shifts downfield with increasing alkyl substitution.

- a. $\text{FCH}_2\text{CH}_2\text{CH}_2\text{Cl}$

F is more electronegative than Cl. The CH_2 group adjacent to the F is more deshielded and the H's will absorb farther downfield.

- c. $\text{CH}_3\text{OC}(\text{CH}_3)_3$

The CH_3 group bonded to the O atom will absorb farther downfield.

- b. $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{OCH}_3$

The CH_2 group adjacent to the O will absorb farther downfield because it is closer to the electronegative O atom.

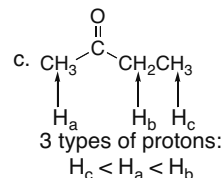
14.8

- a. $\text{ClCH}_2\text{CH}_2\text{CH}_2\text{Br}$

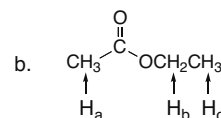
3 types of protons:
 $\text{H}_b < \text{H}_c < \text{H}_a$

- b. $\text{CH}_3\text{OCH}_2\text{OC}(\text{CH}_3)_3$

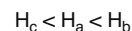
3 types of protons:
 $\text{H}_c < \text{H}_a < \text{H}_b$

**14.9**

- a. $\text{CH}_3\text{—C}\equiv\text{C—H}$ $\text{CH}_3\text{CH=CH}_2$ $\text{CH}_3\text{CH}_2\text{CH}_3$
- H_a H_b H_c
- H_c protons are shielded because they are bonded to an sp^3 C.
 H_a is shielded because it is bonded to an sp C.
 H_b protons are deshielded because they are bonded to an sp^2 C.



H_c protons are shielded because they are bonded to an sp^3 C.
 H_a protons are deshielded slightly because the CH_3 group is bonded to a C=O .
 H_b protons are deshielded because the CH_2 group is bonded to an O atom.



- 14.10** An integration ratio of 2:3 means that there are two types of hydrogens in the compound, and that the ratio of one type to another type is 2:3.

- a. $\text{CH}_3\text{CH}_2\text{Cl}$
2 types of H's
3:2 - YES

- b. $\text{CH}_3\text{CH}_2\text{CH}_3$
2 types of H's
6:2 or 3:1 - no

- c. $\text{CH}_3\text{CH}_2\text{OCH}_2\text{CH}_3$
2 types of H's
6:4 or 3:2 - YES

- d. $\text{CH}_3\text{OCH}_2\text{CH}_2\text{OCH}_3$
2 types of H's
6:4 or 3:2 - YES

Chapter 14-6

14.11 To determine how many protons give rise to each signal:

- Divide the total number of integration units by the total number of protons to find the number of units per H.
- Divide each integration value by this value and round to the nearest whole number.



total number of integration units = $14 + 12 + 44 = 70$ units

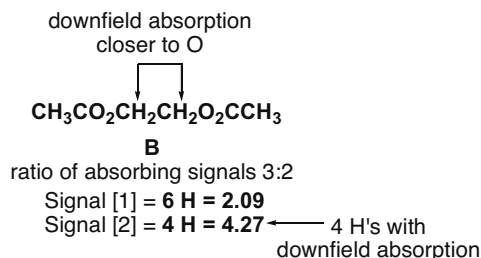
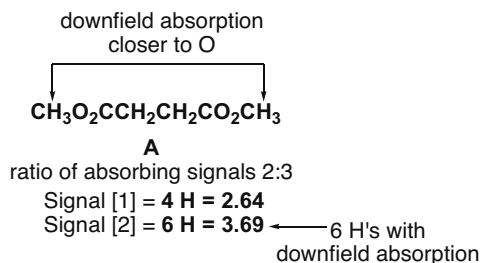
total number of protons = 14 H's

70 units/14 H's = **5 units per H**

Signal [A] = $14/5 = 3 \text{ H}$

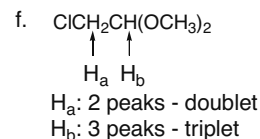
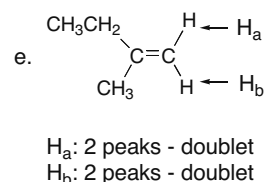
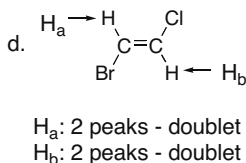
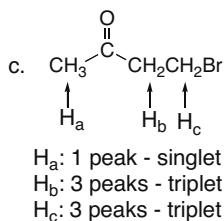
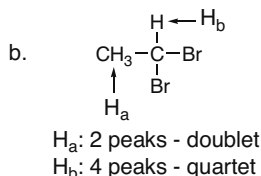
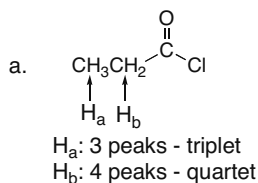
Signal [B] = $12/5 = 2 \text{ H}$

Signal [C] = $44/5 = 9 \text{ H}$

14.12

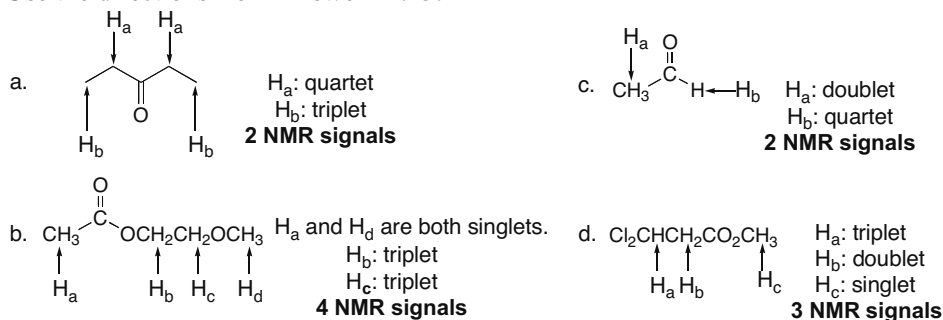
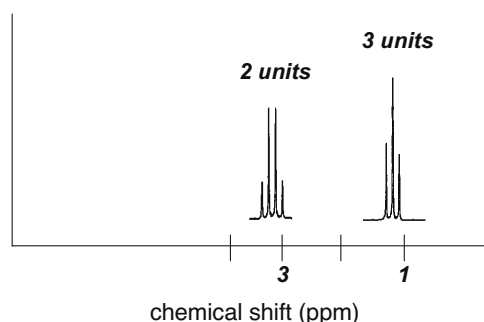
14.13 To determine the **splitting pattern** for a molecule:

- Determine the number of different kinds of protons.
- Nonequivalent protons on the same C or adjacent C's split each other.
- Apply the $n + 1$ rule.



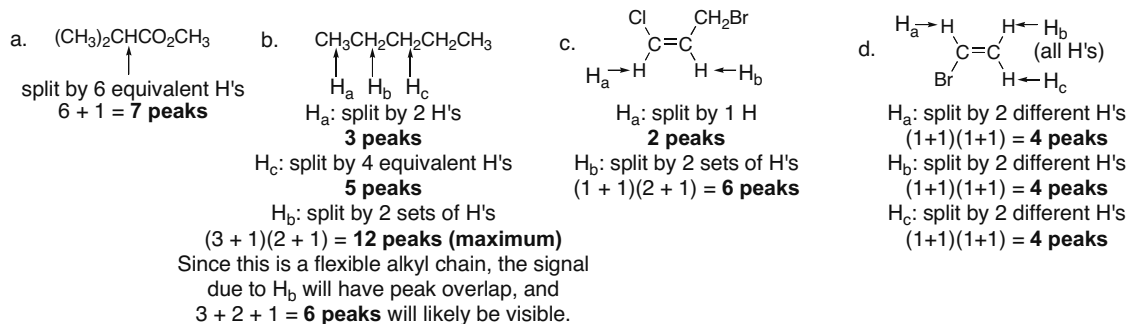
Nuclear Magnetic Resonance Spectroscopy 14-7

14.14 Use the directions from Answer 14.13.

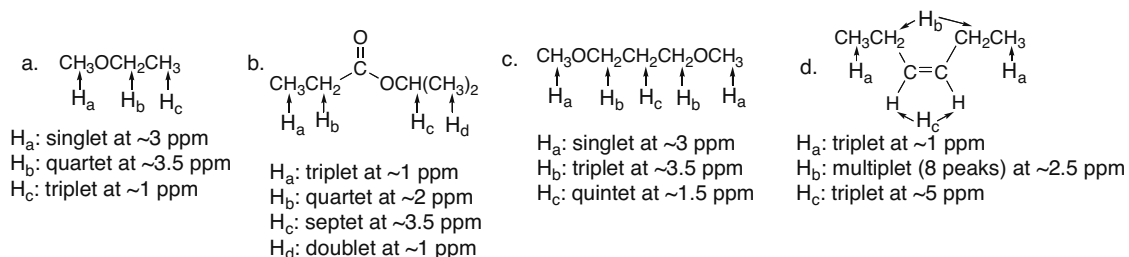
14.15 CH_3CH_2Cl 

There are two kinds of protons, and they can split each other. The CH_3 signal will be split by the CH_2 protons into $2 + 1 = 3$ peaks. It will be upfield from the CH_2 protons since it is farther from the Cl. The CH_2 signal will be split by the CH_3 protons into $3 + 1 = 4$ peaks. It will be downfield from the CH_3 protons since the CH_2 protons are closer to the Cl. The ratio of integration units will be 3:2.

14.16

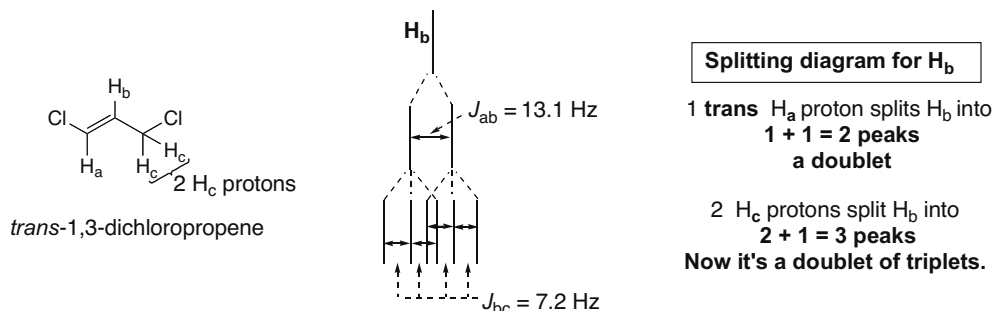


14.17

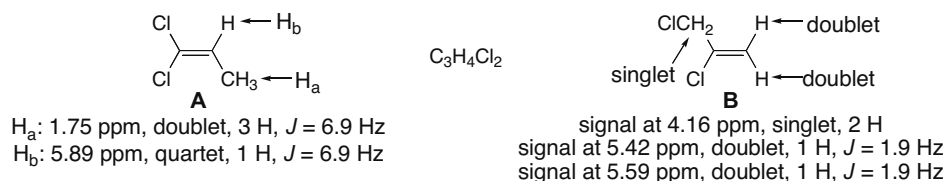


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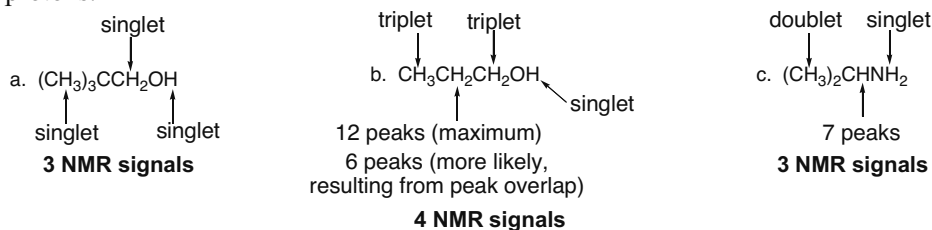
14.18



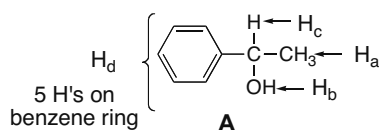
14.19



14.20 Remember that OH (or NH) protons do not split other signals, and are not split by adjacent protons.

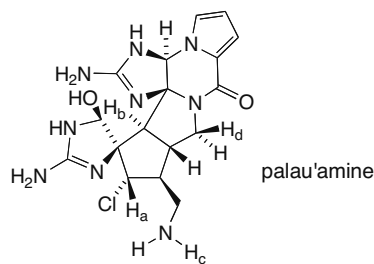


14.21



H_a : doublet at ~ 1.4 due to the CH_3 group, split into two peaks by one adjacent nonequivalent H (H_c).
 H_b : singlet at ~ 2.7 due to the OH group. OH protons are not split by nor do they split adjacent protons.
 H_c : quartet at ~ 4.7 due to the CH group, split into four peaks by the adjacent CH_3 group.
 H_d : Five protons on the benzene ring.

14.22



H_a : one adjacent nonequivalent H, so two peaks
 H_b : one adjacent nonequivalent H, so two peaks
 H_c : H_c is located on a N atom so there is no splitting and it appears as one peak.
 H_d : H_d has one nonequivalent H on the same carbon and one on an adjacent carbon, so it is split into $(1 + 1)(1 + 1) = 4$ peaks (a doublet of doublets).

Nuclear Magnetic Resonance Spectroscopy 14-9

14.23 Use these steps to propose a structure consistent with the molecular formula, IR, and NMR data.

- Calculate the **degrees of unsaturation**.
- Use the IR data to determine what types of **functional groups** are present.
- Determine the number of different **types of protons**.
- Calculate the **number of H's** giving rise to each signal.
- Analyze the **splitting pattern** and put the molecule together.
- Use the **chemical shift** information to check the structure.

- Molecular formula $C_7H_{14}O_2$

$$2n + 2 = 2(7) + 2 = 16$$

$$16 - 14 = 2/2 = 1 \text{ degree of unsaturation}$$

1 π bond or 1 ring

- IR peak at 1740 cm^{-1}

C=O absorption is around 1700 cm^{-1} (causes the degree of unsaturation).

No signal at $3200\text{--}3600 \text{ cm}^{-1}$ means there is no O-H bond.

- NMR data:

absorption	ppm	integration
singlet	1.2	26 -----> 26 units/3 units per H = 9 H's
triplet	1.3	10 -----> 10 units/3 units per H = 3 H's (probably a CH_3 group)
quartet	4.1	6 -----> 6 units/3 units per H = 2 H's (probably a CH_2 group)

- 3 kinds of H's

- number of H's per signal

total integration units: $26 + 10 + 6 = 42$ units

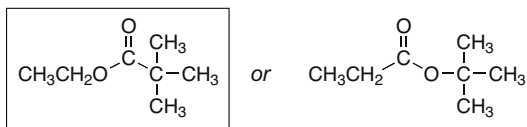
$42 \text{ units} / 14 \text{ H's} = 3 \text{ units per H}$

- look at the splitting pattern

The singlet (9 H) is likely from a *tert*-butyl group: $\begin{array}{c} CH_3 \\ | \\ -C-CH_3 \\ | \\ CH_3 \end{array}$

The CH_3 and CH_2 groups split each other: CH_3-CH_2-

- Join the pieces together.



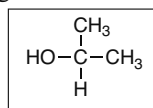
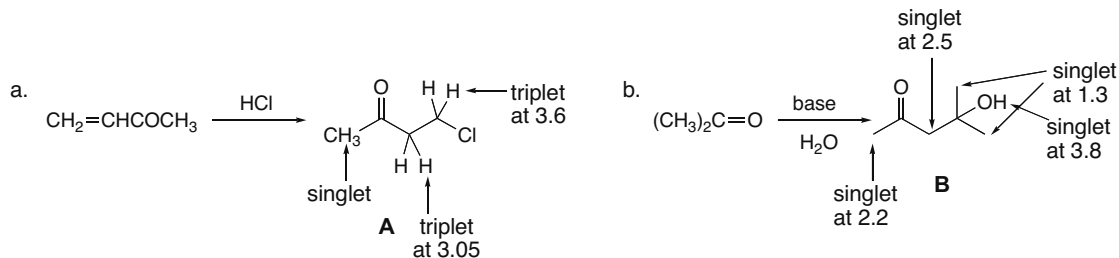
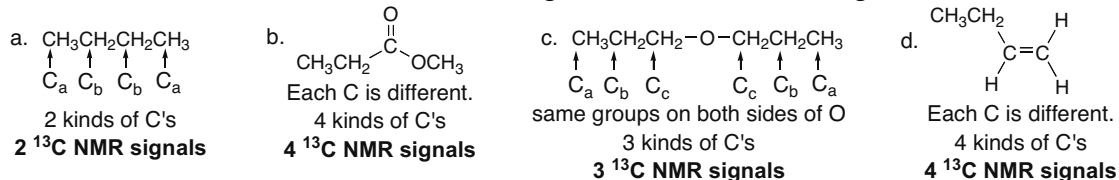
Pick this structure due to the chemical shift data.

The CH_2 group is shifted downfield (4 ppm), so it is close to the electron-withdrawing O.

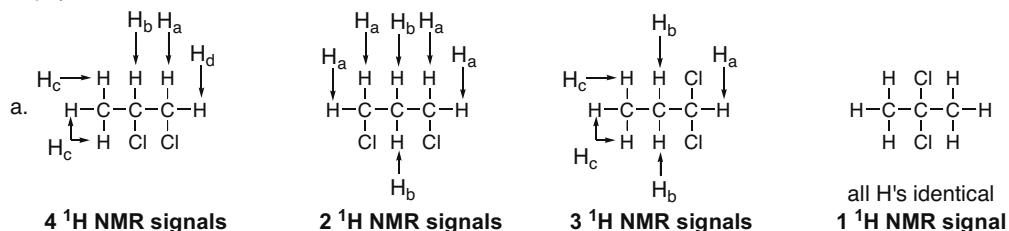
Chapter 14–10

14.24

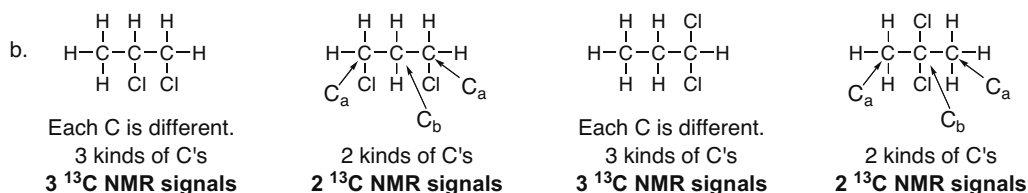
- Molecular formula: C_3H_8O ➤ Calculate degrees of unsaturation
 $2n + 2 = 2(3) + 2 = 8$
 $8 - 8 = 0$ **degrees of unsaturation**
 - IR peak at $3200\text{--}3600\text{ cm}^{-1}$ ➤ Peak at $3200\text{--}3600\text{ cm}^{-1}$ is due to an **O–H bond**.
 - NMR data:
 - doublet at ~ 1.2 (6 H)
 - singlet at ~ 2.2 (1 H)
 - septet at ~ 4 (1 H)
- 3 types of H's
 septet from 1 H ← split by 6 H's
 singlet from 1 H
 doublet from 6 H's ← split by 1 H
 from the O–H proton
- Put information together:

14.25 Identify each compound from the ^1H NMR data.14.26 Each different kind of carbon atom will give a different ^{13}C NMR signal.

14.27

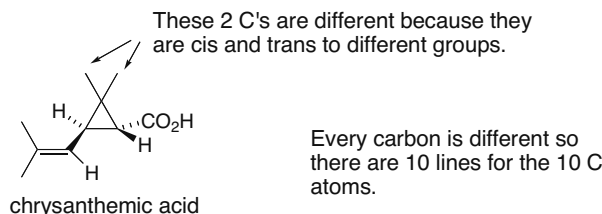


Nuclear Magnetic Resonance Spectroscopy 14-11

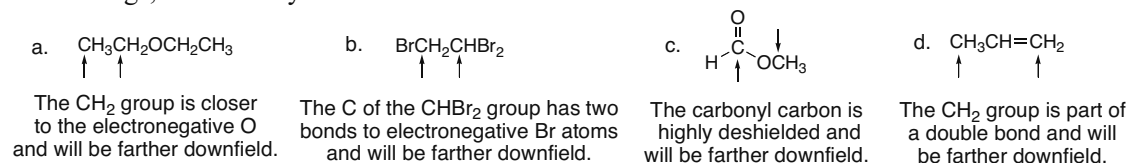


- c. Although the number of ^{13}C signals cannot be used to distinguish these isomers, each isomer exhibits a different number of signals in its ^1H NMR spectrum. As a result, the isomers are distinguishable by ^1H NMR spectroscopy.

14.28

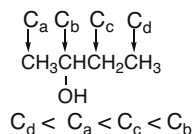


- 14.29 Electronegative elements shift absorptions downfield. The carbons of alkenes and benzene rings, and carbonyl carbons are also shifted downfield.

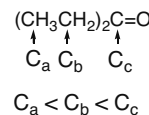


14.30

- a. In order of lowest to highest chemical shift:

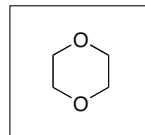


- b. In order of lowest to highest chemical shift:



14.31

- molecular formula $\text{C}_4\text{H}_8\text{O}_2$
 $2n + 2 = 2(4) + 2 = 10$
 $10 - 8 = 2/2 = 1$ **degree of unsaturation**
- no IR peaks at 3200–3600 or 1700 cm^{-1}
 no O–H or C=O
- ^1H NMR spectrum at 3.69 ppm
 only one kind of proton
- ^{13}C NMR spectrum at 67 ppm
 only one kind of carbon



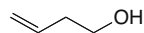
This structure satisfies all the data. One ring is one degree of unsaturation. All carbons and protons are identical.

Chapter 14–12

14.32

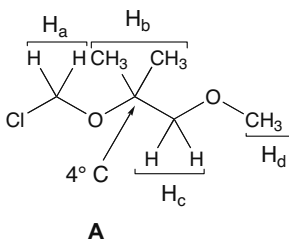


- molecular formula C_4H_8O
 $2n + 2 = 2(4) + 2 = 10$
 $10 - 8 = 2/2 = 1$ **degree of unsaturation**
- ^{13}C NMR signal at > 160 ppm due to $C=O$

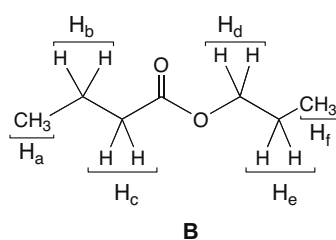


- molecular formula C_4H_8O
 $2n + 2 = 2(4) + 2 = 10$
 $10 - 8 = 2/2 = 1$ **degree of unsaturation**
- all ^{13}C NMR signals at < 160 ppm
 NO $C=O$

14.33

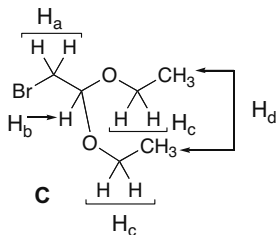


- a. 4 ^1H NMR signals
 b. 5 ^{13}C NMR signals (including the $4^\circ C$)

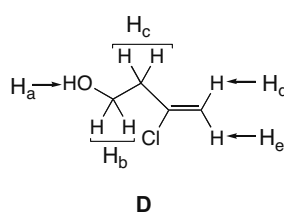


- a. 6 ^1H NMR signals
 b. 7 ^{13}C NMR signals (including the carbonyl C)

14.34



- a. 4 ^1H NMR signals
 b. H_a : 1 adjacent H, so 2 peaks
 H_b : 2 adjacent H's, so 3 peaks
 H_c : 3 adjacent H's, so 4 peaks
 H_d : 2 adjacent H's, so 3 peaks



- a. 5 ^1H NMR signals
 b. H_a : singlet
 H_b : 2 adjacent H's, so 3 peaks
 H_c : 2 adjacent H's, so 3 peaks
 H_d : 1 nonequivalent H on the same C, so 2 peaks
 H_e : 1 nonequivalent H on the same C, so 2 peaks

14.35 Use the directions from Answer 14.3.

- a. $(CH_3)_3CH$
2 kinds of H's

- b. $(CH_3)_3CC(CH_3)_3$
1 kind of H

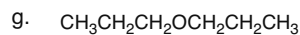
- c. $CH_3CH_2OCH_2CH_2CH_2CH_2CH_3$
7 kinds of H's

- d.
4 kinds of H's

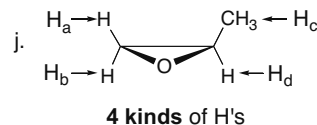
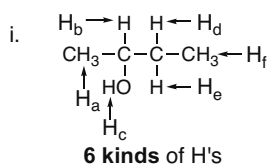
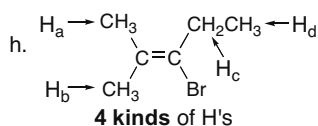
- e.
5 kinds of H's

- f.
3 kinds of H's

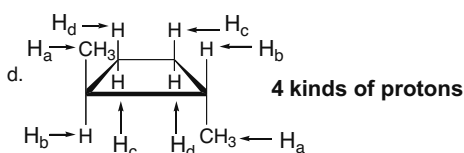
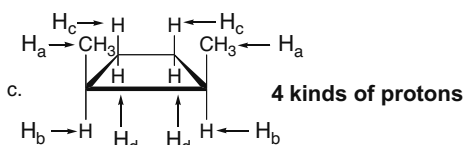
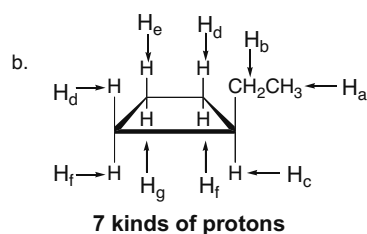
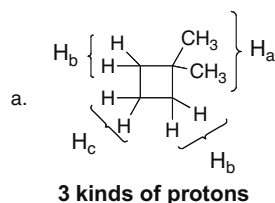
Nuclear Magnetic Resonance Spectroscopy 14-13



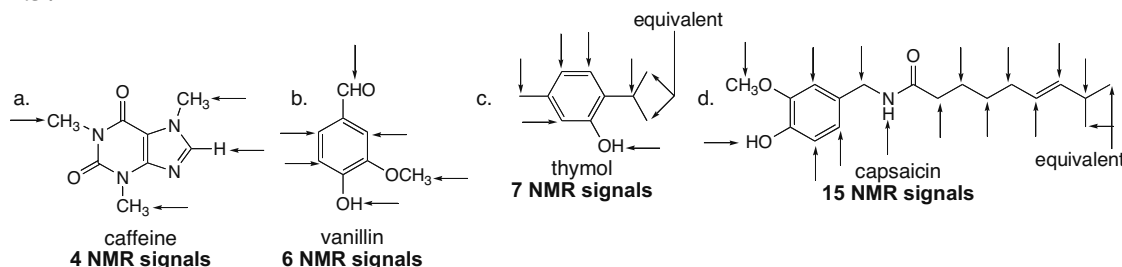
3 kinds of H's



14.36



14.37



14.38

$$\delta \text{ (in ppm)} = [\text{observed chemical shift (Hz)}] / \nu \text{ of the NMR (MHz)}$$

a. $2.5 = x \text{ Hz}/300 \text{ MHz}$

$x = 750 \text{ Hz}$

b. $\text{ppm} = 1200 \text{ Hz}/300 \text{ MHz}$

$= 4 \text{ ppm}$

c. $2.0 = x \text{ Hz}/300 \text{ MHz}$

$x = 600 \text{ Hz}$

14.39

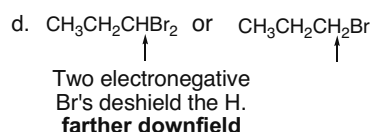
$2.16 = x \text{ Hz}/500 \text{ MHz}$

$x = 1080 \text{ Hz}$ (chemical shift of acetone in Hz)

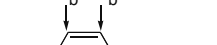
$1080 \text{ Hz} + 1570 \text{ Hz} = 2650 \text{ Hz}$

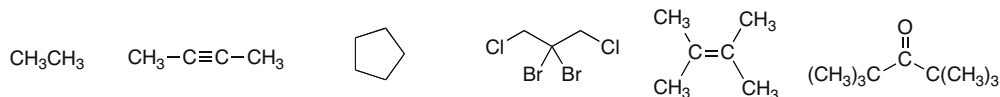
$2650 \text{ Hz}/500 \text{ MHz} = 5.3 \text{ ppm}$ (chemical shift of the CH_2Cl_2 signal)

14.40 Use the directions from Answer 14.7.



Signal of 13 units is from **1 H**.
Signal of 33 units is from **3 H's**.
Signal of 73 units is from **6 H's**.

c. 
 $H_a : H_b = 3 : 2$ $H_a : H_b = 3 : 1$
different ratio of peak areas

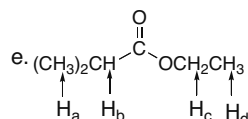


c.  CCc1ccccc1
 CH_3 protons split by 2 H's = **triplet**
 CH_2 protons split by 3 H's = **quartet**

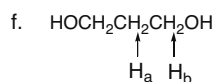
Nuclear Magnetic Resonance Spectroscopy 14–15



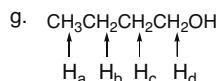
CH_2 protons split by 1 H = **doublet**
CH proton split by 2 H's = **triplet**



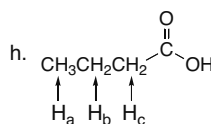
H_a protons split by 1 H = **doublet**
 H_b proton split by 6 H's = **septet**
 H_c protons split by 3 H's = **quartet**
 H_d protons split by 2 H's = **triplet**



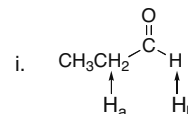
H_a protons split by 2 CH_2 groups = **quintet**
 H_b protons split by 2 H's = **triplet**



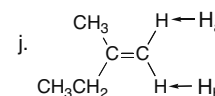
H_a protons split by 2 H's = **triplet**
 H_b protons split by $\text{CH}_3 + \text{CH}_2$ protons = **12 peaks** (maximum)
 H_c protons split by 2 different CH_2 groups = **9 peaks** (maximum)
 H_d protons split by 2 H's = **triplet**
Since H_b and H_c are located in a flexible alkyl chain, it is likely that peak overlap occurs, so that the following is observed: H_b (3 + 2 + 1 = 6 peaks), H_c (2 + 2 + 1 = 5 peaks).



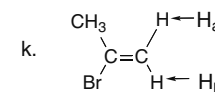
H_a protons split by 2 H's = **triplet**
 H_c protons split by 2 H's = **triplet**
 H_b protons split by $\text{CH}_3 + \text{CH}_2$ protons = **12 peaks** (maximum)
Since H_b is located in a flexible alkyl chain, it is likely that peak overlap occurs, so that only 3 + 2 + 1 = 6 peaks will be observed.



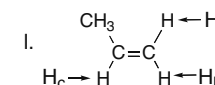
H_a : split by CH_3 group + H_b = **8 peaks** (maximum)
 H_b : split by 2 H's = **triplet**



H_a : split by 1 H = **doublet**
 H_b : split by 1 H = **doublet**

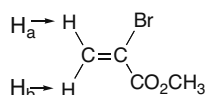


H_a : split by 1 H = **doublet**
 H_b : split by 1 H = **doublet**

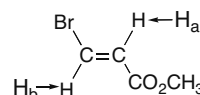


H_a : split by $\text{H}_b + \text{H}_c$ - **doublet of doublets** (4 peaks)
 H_b : split by $\text{H}_a + \text{H}_c$ - **doublet of doublets** (4 peaks)
 H_c : split by CH_3 , $\text{H}_a + \text{H}_b$ - **16 peaks**

14.45



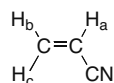
H_a : split by 1 H = **doublet**
 H_b : split by 1 H = **doublet**
 H_a and H_b are geminal.



H_a : split by 1 H = **doublet**
 H_b : split by 1 H = **doublet**
 H_a and H_b are trans.

Both compounds exhibit two doublets for the H's on the $\text{C}=\text{C}$, but the coupling constants (J_{geminal} and J_{trans}) are different. J_{geminal} is much smaller than J_{trans} (0–3 Hz versus 11–18 Hz).

14.46



$J_{ab} = 11.8 \text{ Hz}$
 $J_{bc} = 0.9 \text{ Hz}$
 $J_{ac} = 18 \text{ Hz}$

H_a : doublet of doublets at 5.7 ppm. Two large J values are seen for the H's cis ($J_{ab} = 11.8 \text{ Hz}$) and trans ($J_{ac} = 18 \text{ Hz}$) to H_a .

H_b : doublet of doublets at ~6.2 ppm. One large J value is seen for the cis H ($J_{ab} = 11.8 \text{ Hz}$). The geminal coupling ($J_{bc} = 0.9 \text{ Hz}$) is hard to see.

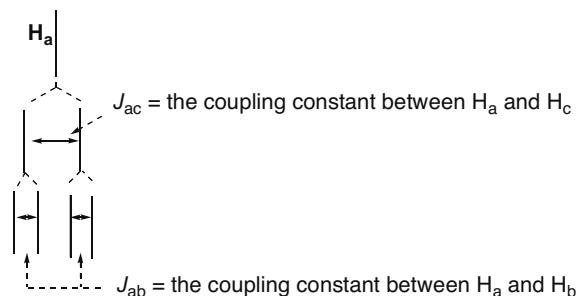
H_c : doublet of doublets at ~6.6 ppm. One large J value is seen for the trans H ($J_{ac} = 18 \text{ Hz}$). The geminal coupling ($J_{bc} = 0.9 \text{ Hz}$) is hard to see.

Chapter 14–16

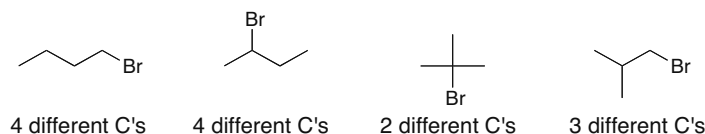
Splitting diagram for H_a

1 **trans** H_c proton splits H_a into
 $1 + 1 = 2$ peaks
 a doublet

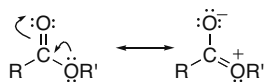
1 **cis** H_b proton splits H_a into
 $1 + 1 = 2$ peaks
 Now it's a doublet of doublets.



14.47

Four constitutional isomers of C_4H_9Br :14.48 Only two compounds in Problem 14.43 give one signal in their ^{13}C NMR spectrum:

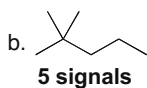
14.49



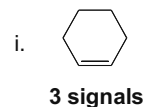
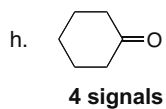
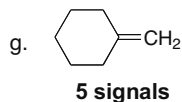
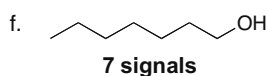
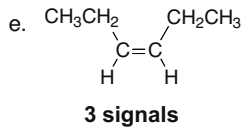
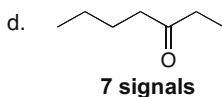
The O atom of an ester donates electron density, so the carbonyl carbon has less δ^+ , making it less deshielded than the carbonyl carbon of an aldehyde or ketone. Therefore, the carbonyl carbon of an aldehyde or ketone is more deshielded and absorbs farther downfield.

14.50

a. $HC(CH_3)_3$
 2 signals

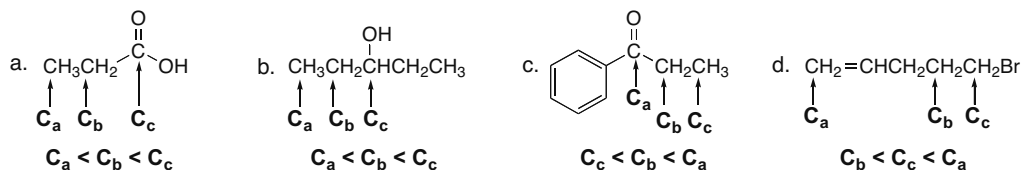


c. $CH_3OCH(CH_3)_2$
 3 signals

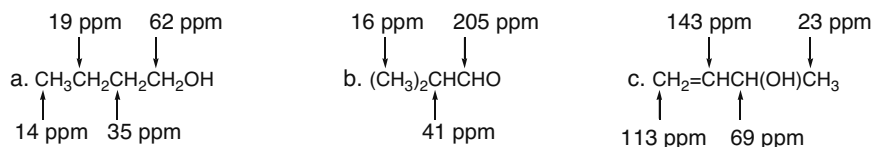


Nuclear Magnetic Resonance Spectroscopy 14–17

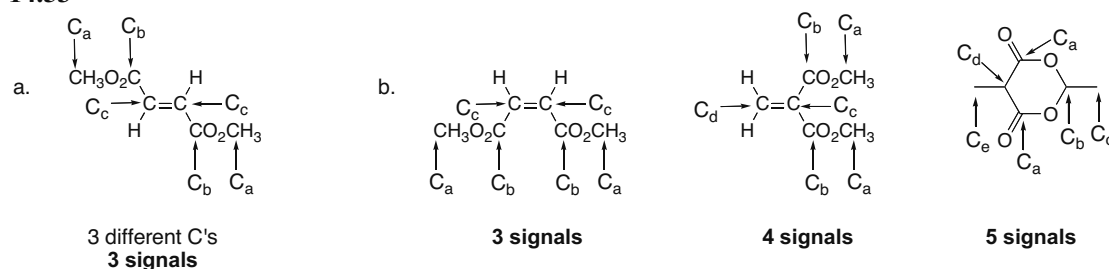
14.51



14.52

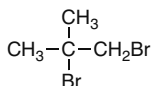


14.53

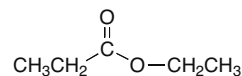


14.54 Use the directions from Answer 14.23.

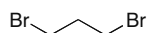
- a. $C_4H_8Br_2$: 0 degrees of unsaturation
IR peak at $3000\text{--}2850 \text{ cm}^{-1}$: $C_{sp^3}\text{--H}$ bonds
NMR: singlet at 1.87 ppm (6 H) (2 CH_3 groups)
singlet at 3.86 ppm (2 H) (CH_2 group)



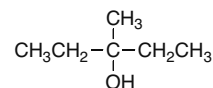
- c. $C_5H_{10}O_2$: 1 degree of unsaturation
IR peak at 1740 cm^{-1} : $C=O$
NMR: triplet at 1.15 ppm (3 H) (CH_3 split by 2 H's)
triplet at 1.25 ppm (3 H) (CH_3 split by 2 H's)
quartet at 2.30 ppm (2 H) (CH_2 split by 3 H's)
quartet at 4.72 ppm (2 H) (CH_2 split by 3 H's)



- b. $C_3H_6Br_2$: 0 degrees of unsaturation
IR peak at $3000\text{--}2850 \text{ cm}^{-1}$: $C_{sp^3}\text{--H}$ bonds
NMR: quintet at 2.4 ppm (split by 2 CH_2 groups)
triplet at 3.5 ppm (split by 2 H's)



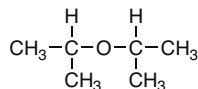
- d. $C_6H_{14}O$: 0 degrees of unsaturation
IR peak at $3600\text{--}3200 \text{ cm}^{-1}$: $O\text{--H}$
NMR: triplet at 0.8 ppm (6 H) (2 CH_3 groups split by CH_2 groups)
singlet at 1.0 ppm (3 H) (CH_3)
quartet at 1.5 ppm (4 H) (2 CH_2 groups split by CH_3 groups)
singlet at 1.6 ppm (1 H) ($O\text{--H}$ proton)



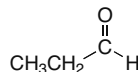
Chapter 14–18

e. $\text{C}_6\text{H}_{14}\text{O}$: 0 degrees of unsaturationIR peak at $3000\text{--}2850\text{ cm}^{-1}$: $\text{C}_{sp^3}\text{--H}$ bonds

NMR: doublet at 1.10 ppm (integration = 30 units)
 (from 12 H's)
 septet at 3.60 ppm (integration = 5 units)
 (from 2 H's)

f. $\text{C}_3\text{H}_6\text{O}$: 1 degree of unsaturationIR peak at 1730 cm^{-1} : C=O

NMR: triplet at 1.11 ppm
 multiplet at 2.46 ppm
 triplet at 9.79 ppm



14.55

Two isomers of $\text{C}_9\text{H}_{10}\text{O}$: 5 degrees of unsaturation (benzene ring likely)

Compound A:

IR absorption at 1742 cm^{-1} : C=O

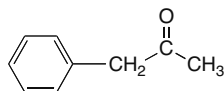
NMR data:

Absorptions:

singlet at 2.15 (3 H) (CH_3 group)singlet at 3.70 (2 H) (CH_2 group)

broad singlet at 7.20 (5 H)

(likely a monosubstituted benzene ring)



Compound B:

IR absorption at 1688 cm^{-1} : C=O

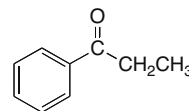
NMR data:

Absorptions:

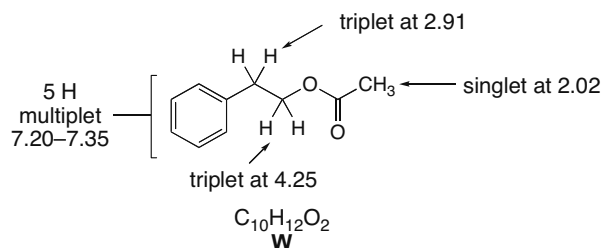
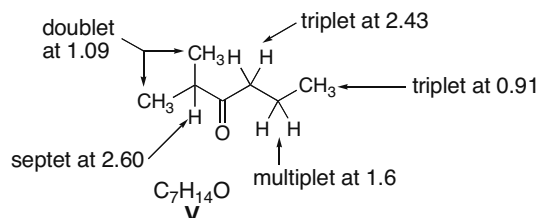
triplet at 1.22 (3 H) (CH_3 group split by 2 H's)quartet at 2.98 (2 H) (CH_2 group split by 3 H's)

multiplet at 7.28–7.95 (5 H)

(likely a monosubstituted benzene ring)



14.56 IR absorptions:

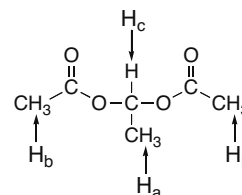
 $3088\text{--}2897\text{ cm}^{-1}$: sp^2 and sp^3 hybridized C–H 1740 cm^{-1} : C=O 1606 cm^{-1} : benzene ring14.57 IR absorption at 1713 cm^{-1} is due to C=O .

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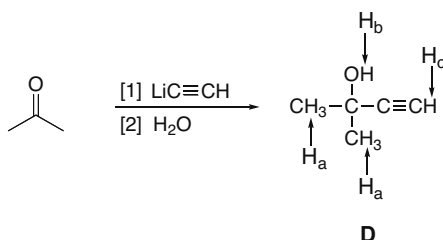
14.58

Compound C:**molecular ion** 146 (molecular formula $C_6H_{10}O_4$)**IR** absorption at 1762 cm^{-1} : **C=O** **^1H NMR** data:

Absorptions:

 H_a : doublet at 1.47 (3 H) (CH_3 group adjacent to CH) H_b : singlet at 2.07 (6 H) (2 CH_3 groups) H_c : quartet at 6.84 (1 H adjacent to CH_3)

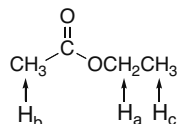
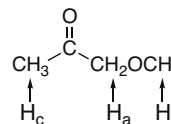
14.59

**Compound D:****molecular ion** 84 (molecular formula C_5H_8O)**IR** absorptions at $3600\text{--}3200\text{ cm}^{-1}$: OH 3303 cm^{-1} : $C_{sp}\text{--H}$ 2938 cm^{-1} : $C_{sp^3}\text{--H}$ 2120 cm^{-1} : $C\equiv C$ **^1H NMR** data:

Absorptions:

 H_a : singlet at 1.53 (6 H) (2 CH_3 groups) H_b : singlet at 2.37 (1 H) $\rightarrow$ alkynyl CH and OH H_c : singlet at 2.43 (1 H)

14.60

Compound E: **$C_4H_8O_2$:****1 degree of unsaturation****IR** absorption at 1743 cm^{-1} : **C=O****NMR** data:total integration units/# H's
(23 + 29 + 30)/8 = ~10 units per H H_a : quartet at 4.1 (23 units - **2 H**) H_b : singlet at 2.0 (29 units - **3 H**) H_c : triplet at 1.4 (30 units - **3 H**)**Compound F:** **$C_4H_8O_2$:****1 degree of unsaturation****IR** absorption at 1730 cm^{-1} : **C=O****NMR** data:total integration units/# H's
(18 + 30 + 31)/8 = ~10 units per H H_a : singlet at 4.1 (18 units - **2 H**) H_b : singlet at 3.4 (30 units - **3 H**) H_c : singlet at 2.1 (31 units - **3 H**)

Chapter 14–20

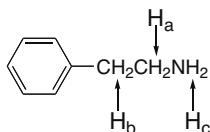
14.61

Compound H:**4 degrees of unsaturation**

IR absorptions at 3365 cm^{-1} : N–H
 3284 cm^{-1} : N–H
 3026 cm^{-1} : $\text{C}_{\text{sp}^2}\text{--H}$
 2932 cm^{-1} : $\text{C}_{\text{sp}^3}\text{--H}$
 1603 cm^{-1} : due to benzene
 1497 cm^{-1} : due to benzene

NMR data:

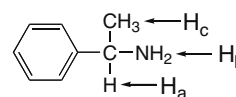
multiplet at 7.2–7.4 ppm, **5 H** on a benzene ring
 H_a : triplet at 2.9 ppm, **2 H**, split by 2 H's
 H_b : triplet at 2.8 ppm, **2 H**, split by 2 H's
 H_c : singlet at 1.1 ppm, **2 H**, no splitting (on NH_2)

**Compound I:****4 degrees of unsaturation**

IR absorptions at 3367 cm^{-1} : N–H
 3286 cm^{-1} : N–H
 3027 cm^{-1} : $\text{C}_{\text{sp}^2}\text{--H}$
 2962 cm^{-1} : $\text{C}_{\text{sp}^3}\text{--H}$
 1604 cm^{-1} : due to benzene
 1492 cm^{-1} : due to benzene

NMR data:

multiplet at 7.2–7.4 ppm, **5 H** on a benzene ring
 H_a : quartet at 4.1 ppm, **1 H**, split by 3 H's
 H_b : singlet at 1.45 ppm, **2 H**, no splitting (NH_2)
 H_c : doublet at 1.4 ppm, **3 H**, split by 1 H



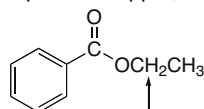
14.62

a. $\text{C}_9\text{H}_{10}\text{O}_2$:**5 degrees of unsaturation**

IR absorption at 1718 cm^{-1} : **C=O**

NMR data:

multiplet at 7.4–8.1 ppm, **5 H** on a benzene ring
quartet at 4.4 ppm, **2 H**, split by 3 H's
triplet at 1.3 ppm, **3 H**, split by 2 H's



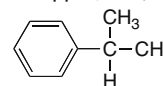
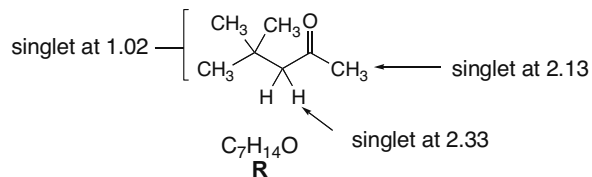
downfield due to the O atom

b. C_9H_{12} :**4 degrees of unsaturation**

IR absorption at $2850\text{--}3150\text{ cm}^{-1}$:

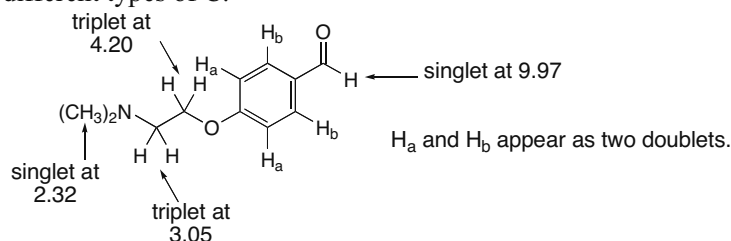
C–H bonds**NMR data:**

singlet at 7.1–7.4 ppm, **5 H**, benzene
septet at 2.8 ppm, **1 H**, split by 6 H's
doublet at 1.3 ppm, **6 H**, split by 1 H

14.63 IR absorption at 1717 cm^{-1} is due to a C=O.

Nuclear Magnetic Resonance Spectroscopy 14–21

- 14.64** IR absorption at 1730 cm^{-1} is due to a $\text{C}=\text{O}$. Eight lines in the ^{13}C NMR spectrum means there are eight different types of C.

**14.65**

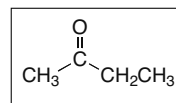
- a. Compound **J** has a molecular ion at 72: molecular formula $\text{C}_4\text{H}_8\text{O}$

1 degree of unsaturation

IR spectrum at 1710 cm^{-1} : $\text{C}=\text{O}$

^1H NMR data (ppm):

- 1.0 (triplet, 3 H), split by 2 H's
- 2.1 (singlet, 3 H)
- 2.4 (quartet, 2 H), split by 3 H's



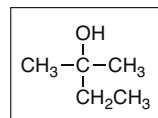
- b. Compound **K** has a molecular ion at 88: molecular formula $\text{C}_5\text{H}_{12}\text{O}$

0 degrees of unsaturation

IR spectrum at $3600\text{--}3200\text{ cm}^{-1}$: O-H bond

^1H NMR data (ppm):

- 0.9 (triplet, 3 H), split by 2 H's
- 1.2 (singlet, 6 H), due to 2 CH_3 groups
- 1.5 (quartet, 2 H), split by 3 H's
- 1.6 (singlet, 1 H), due to the OH proton

**14.66**

Compound **L** has a molecular ion at 90: molecular formula $\text{C}_4\text{H}_{10}\text{O}_2$

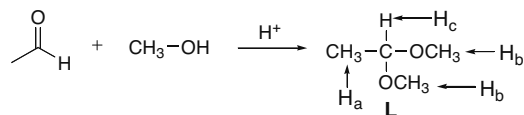
0 degrees of unsaturation

IR absorptions at 2992 and 2941 cm^{-1} : $\text{C}_{\text{sp}^3}\text{--H}$

^1H NMR data (ppm):

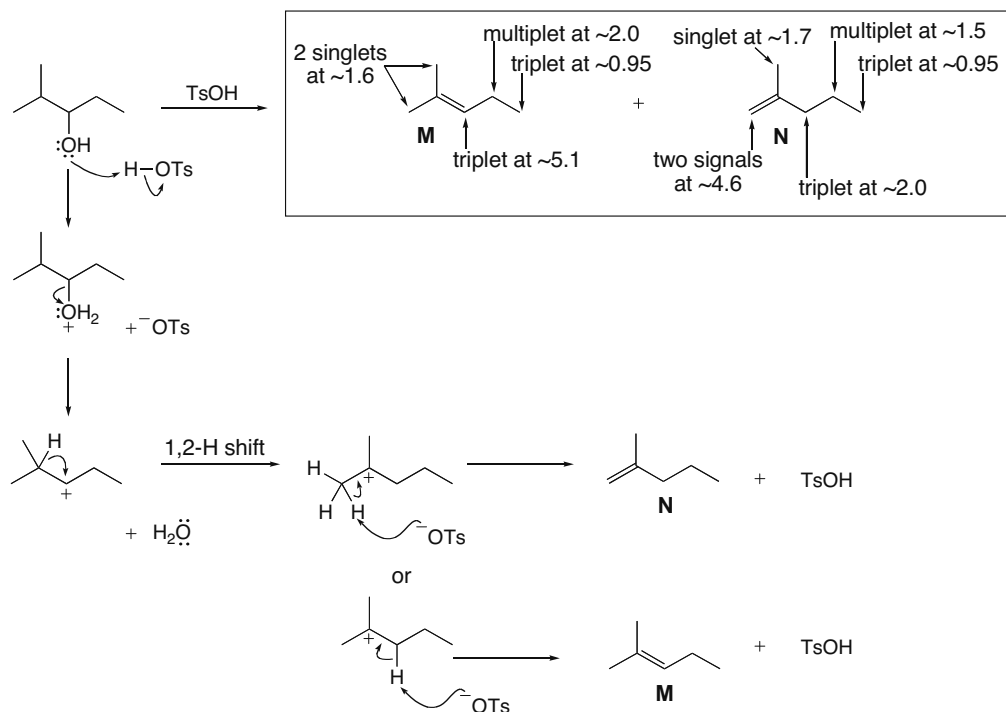
- H_a : 1.2 (doublet, 3 H), split by 1 H
- H_b : 3.3 (singlet, 6 H), due to 2 CH_3 groups
- H_c : 4.8 (quartet, 1 H), split by 3 adjacent H's

total integration units/# H's
(25 + 46 + 7)/10 = ~8 units per H



Chapter 14–22

14.67



14.68

Compound **O** has a molecular formula $\text{C}_{10}\text{H}_{12}\text{O}$.

5 degrees of unsaturation

IR absorption at 1687 cm^{-1}

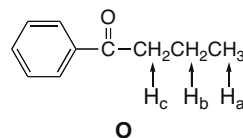
^1H NMR data (ppm):

H_a : 1.0 (triplet, 3 H), due to CH_3 group, split by 2 adjacent H's

H_b : 1.7 (sextet, 2 H), split by CH_3 and CH_2 groups

H_c : 2.9 (triplet, 2 H), split by 2 H's

7.4–8.0 (multiplet, 5 H), benzene ring



14.69

Compound **P** has a molecular formula $\text{C}_5\text{H}_9\text{ClO}_2$.

1 degree of unsaturation

^{13}C NMR shows 5 different C's, including a $\text{C}=\text{O}$.

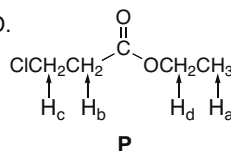
^1H NMR data (ppm):

H_a : 1.3 (triplet, 3 H), split by 2 H's

H_b : 2.8 (triplet, 2 H), split by 2 H's

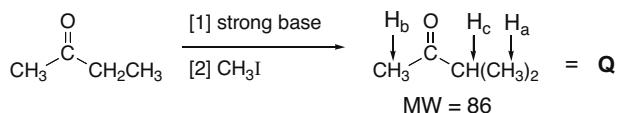
H_c : 3.7 (triplet, 2 H), split by 2 H's

H_d : 4.2 (quartet, 2 H), split by CH_3 group



Nuclear Magnetic Resonance Spectroscopy 14–23

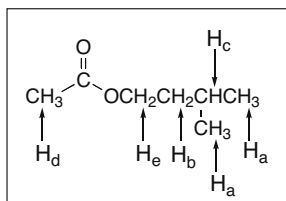
14.70

Compound Q: Molecular ion at 86.Molecular formula: $C_5H_{10}O$:**1 degree of unsaturation**IR absorption at $\sim 1700\text{ cm}^{-1}$: $C=O$ **NMR data:** H_a : doublet at 1.1 ppm, 2 CH_3 groups split by 1 H H_b : singlet at 2.1 ppm, CH_3 group H_c : septet at 2.6 ppm, 1 H split by 6 H's

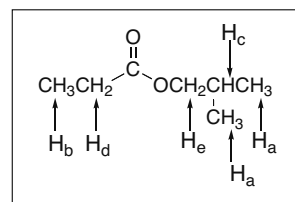
14.71

a. Compound **R**, the odor of banana: $C_7H_{14}O_2$ **1 degree of unsaturation** ^1H NMR (ppm):

H_a : 0.93 (doublet, 6 H)
 H_b : 1.52 (multiplet, 2 H)
 H_c : 1.69 (multiplet, 1 H)
 H_d : 2.04 (singlet, 3 H)
 H_e : 4.10 (triplet, 2 H)

b. Compound **S**, the odor of rum: $C_7H_{14}O_2$ **1 degree of unsaturation** ^1H NMR (ppm):

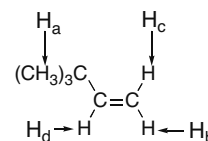
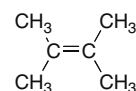
H_a : 0.94 (doublet, 6 H)
 H_b : 1.15 (triplet, 3 H)
 H_c : 1.91 (multiplet, 1 H)
 H_d : 2.33 (quartet, 2 H)
 H_e : 3.86 (doublet, 2 H)



14.72

 C_6H_{12} :**1 degree of unsaturation****T** ^1H NMR of **T** (ppm):

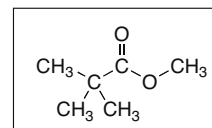
H_a : 1.01 (singlet, 9 H)
 H_b : 4.82 (doublet of doublets, 1 H, $J = 10, 1.7\text{ Hz}$)
 H_c : 4.93 (doublet of doublets, 1 H, $J = 18, 1.7\text{ Hz}$)
 H_d : 5.83 (doublet of doublets, 1 H, $J = 18, 10\text{ Hz}$)

**U** ^1H NMR of **U**: 1.60 (singlet) ppm.

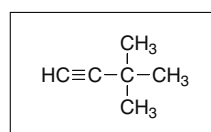
All H's are identical,
 so there is only one
 singlet in the NMR.

14.73

a.

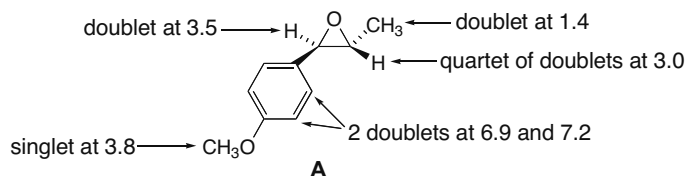
 $C_6H_{12}O_2$:**1 degree of unsaturation**IR peak at 1740 cm^{-1} : $C=O$ ^1H NMR 2 signals: 2 types of H's ^{13}C NMR: 4 signals: 4 kinds of C's, including one at $\sim 170\text{ ppm}$ due a $C=O$ 

b.

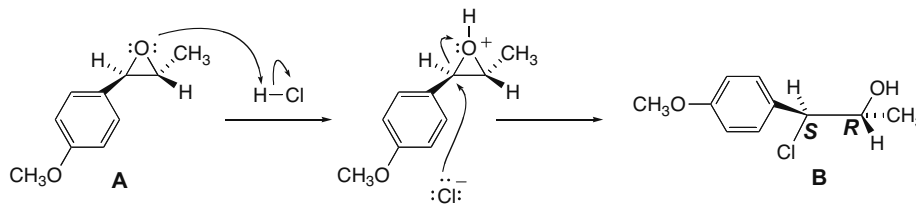
 C_6H_{10} :**2 degrees of unsaturation**IR peak at 3000 cm^{-1} : $C_{sp^3}-H$ bondspeak at 3300 cm^{-1} : $C_{sp}-H$ bondpeak at $\sim 2150\text{ cm}^{-1}$: $C\equiv C$ bond ^{13}C NMR: 4 signals: 4 kinds of C's

Chapter 14–24

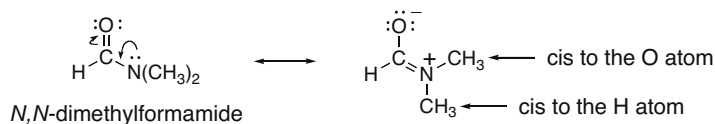
- 14.74** a. Since **A** has no absorptions at 1700 cm^{-1} or $3600\text{--}3200\text{ cm}^{-1}$, it has no $\text{C}=\text{O}$ or OH . An oxygen-containing compound without these functional groups is an ether (or an epoxide). Since **B** is formed from a reaction with HCl , **A** must contain an epoxide, because ethers are unreactive with HCl .



- b. Epoxide **A** is equally substituted by R groups on both C's. With HCl , the epoxide is protonated first and then backside attack by Cl^- forms the chlorohydrin. Attack at the C adjacent to the benzene ring is preferred because the δ^+ in the transition state at this carbon can be delocalized on the benzene ring.



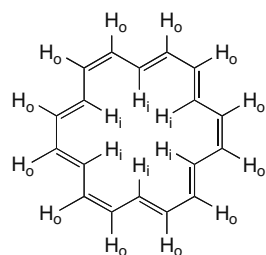
The benzene ring and CH_3 group must be trans in the epoxide to give the correct configuration at the two stereogenic centers in the product.

14.75

A second resonance structure for *N,N*-dimethylformamide places the two CH_3 groups in different environments. One CH_3 group is cis to the O atom, and one is cis to the H atom. This gives rise to two different absorptions for the CH_3 groups.

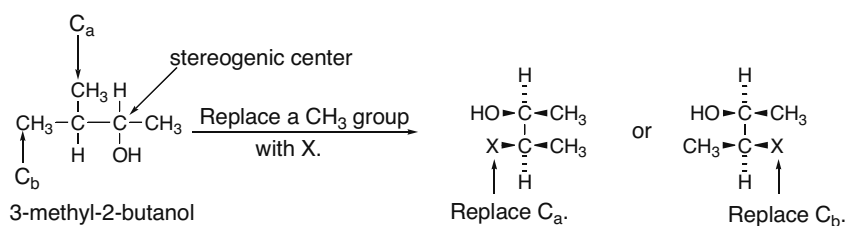
Nuclear Magnetic Resonance Spectroscopy 14–25

14.76



18-Annulene has 18 π electrons that create an **induced magnetic field** similar to the 6 π electrons of benzene. 18-Annulene has 12 protons that are oriented on the outside of the ring (labeled H_o), and 6 protons that are oriented inside the ring (labeled H_i). The induced magnetic field reinforces the external field in the vicinity of the protons on the outside of the ring. These H_o protons are deshielded and so they absorb downfield (8.9 ppm). In contrast, the induced magnetic field is opposite in direction to the applied magnetic field in the vicinity of the protons on the inside of the ring. This shields the H_i protons and the absorption is therefore very far upfield, even higher than TMS (−1.8 ppm).

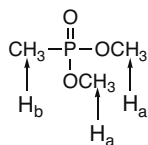
14.77



The CH_3 groups are not equivalent to each other, since replacement of each by X forms two diastereomers.

Thus, every C in this compound is different and there are five ^{13}C signals.

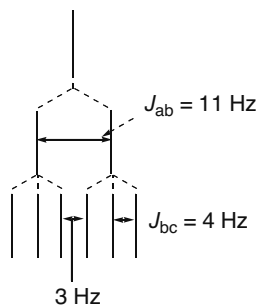
14.78



All 6 H_a protons are equivalent.

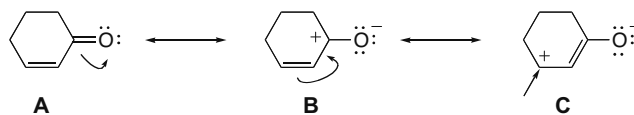
One P atom splits each nearby CH_3 into a doublet by the $n + 1$ rule, making two doublets.

14.79 a. Splitting pattern:



Chapter 14–26

- b. Three resonance structures can be drawn for 2-cyclohexenone.



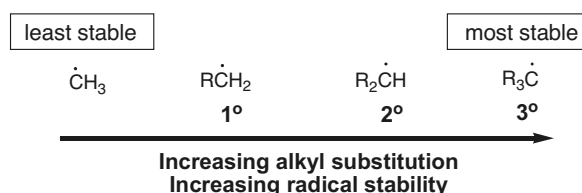
Resonance structure **C** places a (+) charge on one C of the C=C, deshielding the H attached to it and shifting the absorption downfield.

Chapter 15 Radical Reactions

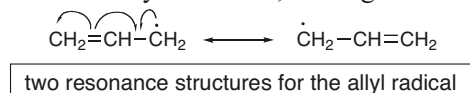
Chapter Review

General features of radicals

- A radical is a reactive intermediate with an unpaired electron (15.1).
- A carbon radical is sp^2 hybridized and trigonal planar (15.1).
- The stability of a radical increases as the number of C's bonded to the radical carbon increases (15.1).

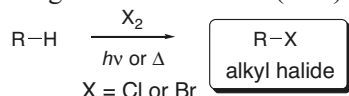


- Allylic radicals are stabilized by resonance, making them more stable than 3° radicals (15.10).



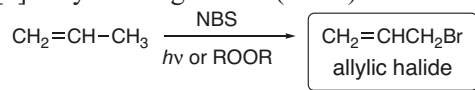
Radical reactions

[1] Halogenation of alkanes (15.4)



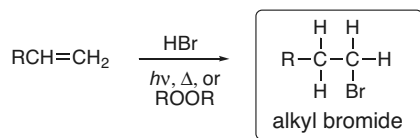
- The reaction follows a radical chain mechanism.
- The weaker the C-H bond, the more readily the H is replaced by X.
- Chlorination is faster and less selective than bromination (15.6).
- Radical substitution results in racemization at a stereogenic center (15.8).

[2] Allylic halogenation (15.10)



- The reaction follows a radical chain mechanism.

[3] Radical addition of HBr to an alkene (15.13)



- A radical addition mechanism is followed.
- Br bonds to the less substituted carbon atom to form the more substituted, more stable radical.

[4] Radical polymerization of alkenes (15.14)

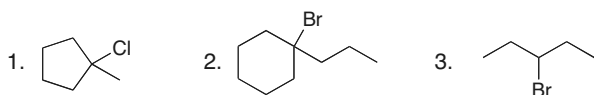


- A radical addition mechanism is followed.

Chapter 15-2

Practice Test on Chapter Review

1. a. Which alkyl halide(s) can be made in good yield by radical halogenation of an alkane?

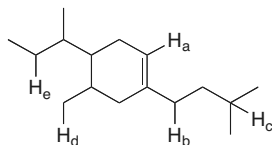


4. Both (1) and (2) can be made in good yield.
5. Compounds (1), (2), and (3) can all be made in good yield.

b. In which of the following reactions will rearrangement **not** occur?

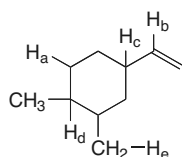
1. halogenation of an alkane with Cl_2 and heat
2. addition of Cl_2 to an alkene
3. addition of HCl to an alkene
4. Rearrangements do not occur in reactions (1) and (2).
5. Rearrangements do not occur in reactions (1), (2), and (3).

c. Which labeled H is most easily abstracted in a radical halogenation reaction?



1. H_a
2. H_b
3. H_c
4. H_d
5. H_e

d. Which of the labeled C-H bonds in the following compound has the smallest bond dissociation energy?



1. C- H_a
2. C- H_b
3. C- H_c
4. C- H_d
5. C- H_e

2. (a) Which radical is the most stable? (b) Which radical is the least stable?



A



B

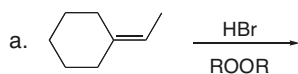


C

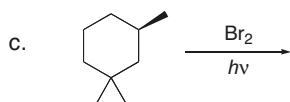
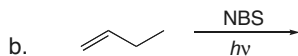


D

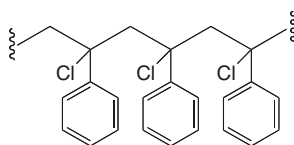
3. Draw all of the organic products formed in each reaction. Indicate stereochemistry in part (c).



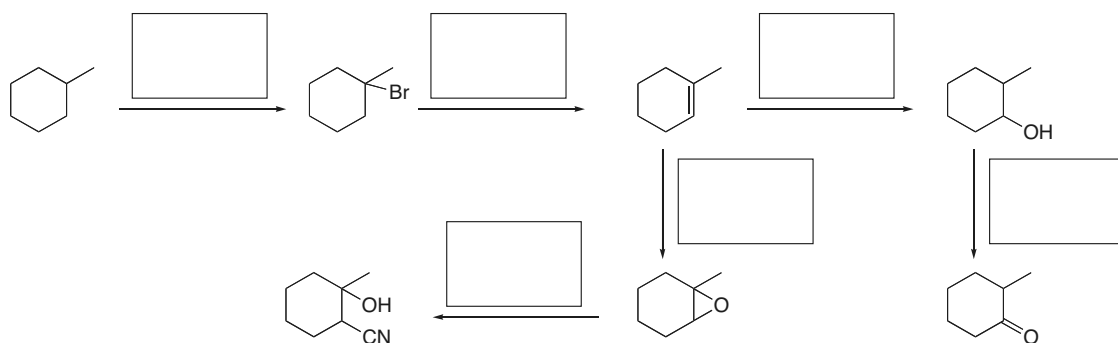
Radical Reactions 15-3



4. What monomer is needed to make the following polymer?



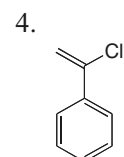
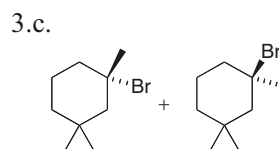
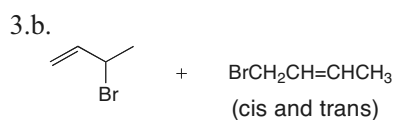
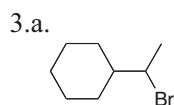
5. In each box, fill in the appropriate reagents needed to carry out the given reaction. This question involves reactions from Chapter 15, as well as previous chapters.



Answers to Practice Test

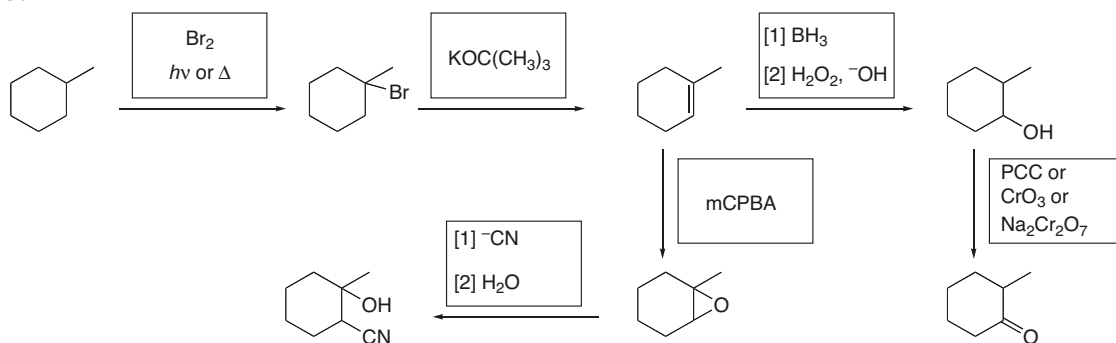
1. a. 2
b. 4
c. 2
d. 3

2. a. **A**
b. **B**



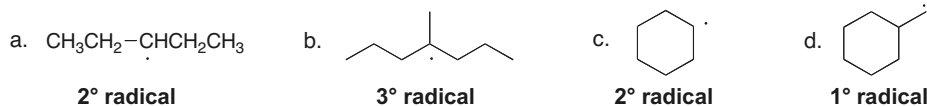
Chapter 15-4

5.

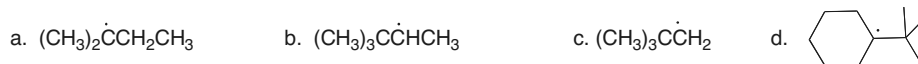


Answers to Problems

15.1 1° Radicals are on C's bonded to one other C; 2° radicals are on C's bonded to two other C's; 3° radicals are on C's bonded to three other C's.

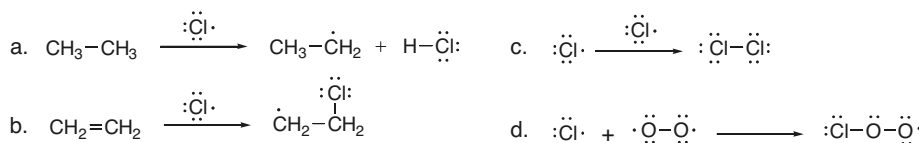


15.2 The stability of a radical increases as the number of alkyl groups bonded to the radical carbon increases. Draw the most stable radical.

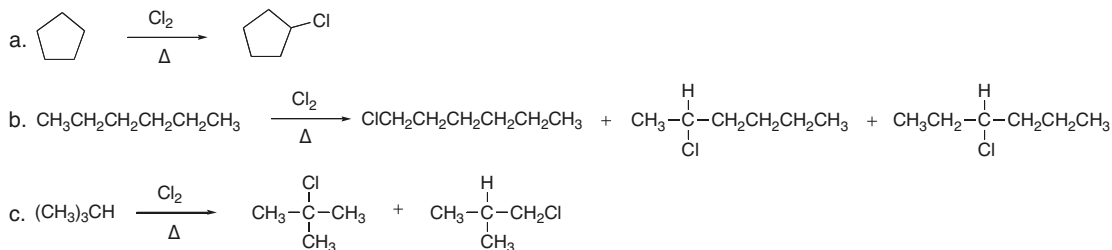


15.3 Reaction of a radical with:

- an alkane abstracts a hydrogen atom and creates a new carbon radical.
- an alkene generates a new bond to one carbon and a new carbon radical.
- another radical forms a bond.

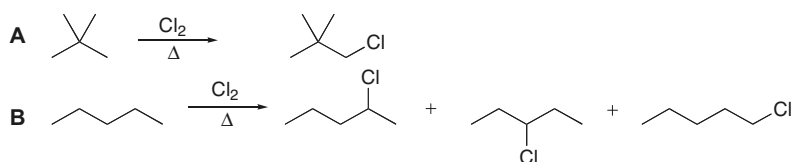


15.4 **Monochlorination** is a radical substitution reaction in which a Cl replaces a H, thus generating an alkyl halide.

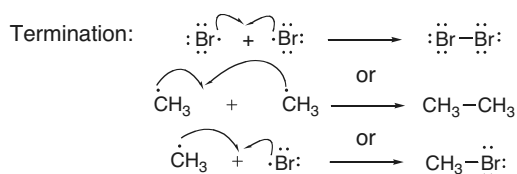
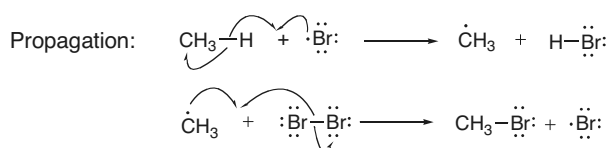
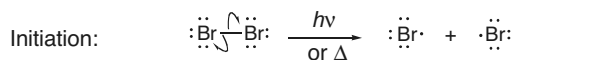


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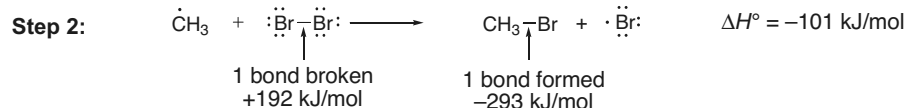
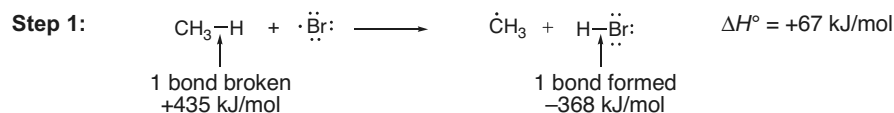
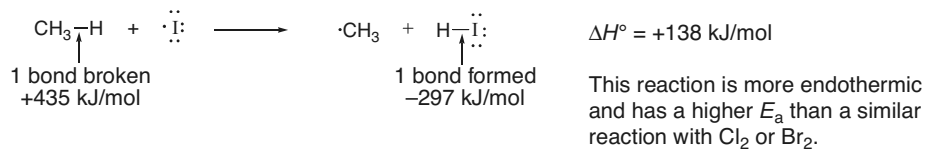
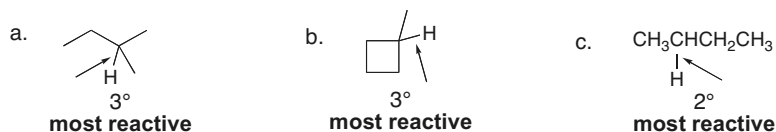
15.5



15.6



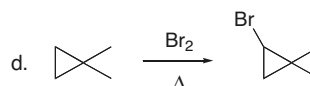
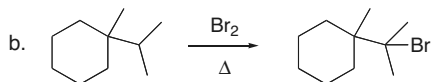
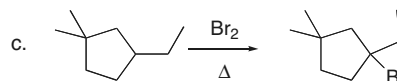
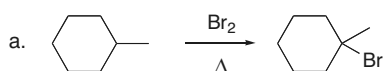
15.7

15.8 The rate-determining step for halogenation reactions is formation of $\text{CH}_3\cdot + \text{HX}$.15.9 The **weakest C-H bond** in each alkane is the **most readily cleaved** during radical halogenation.

Chapter 15-6

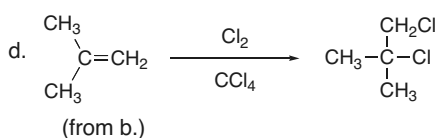
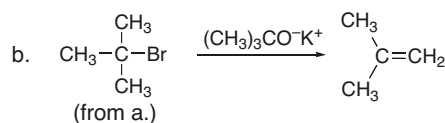
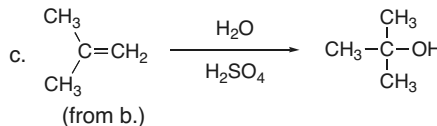
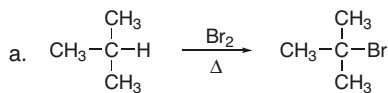
15.10 To draw the product of bromination:

- Draw out the starting material and find the most reactive C–H bond (on the most substituted C).
- The major product is formed by **cleavage of the weakest C–H bond**.

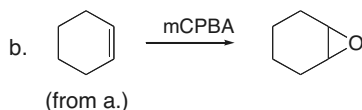
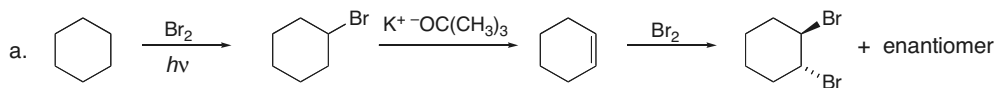


15.11 If 1° C–H and 3° C–H bonds were equally reactive there would be nine times as much (CH₃)₂CHCH₂Cl as (CH₃)₃CCl since the ratio of 1° to 3° H's is 9:1. The fact that the ratio is only 63:37 shows that the 1° C–H bond is less reactive than the 3° C–H bond. (CH₃)₂CHCH₂Cl is still the major product, though, because there are nine 1° C–H bonds and only one 3° C–H bond.

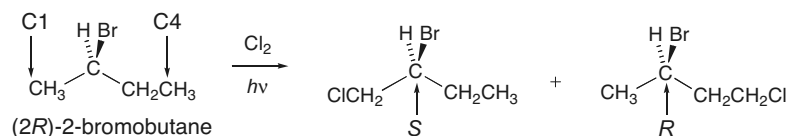
15.12



15.13

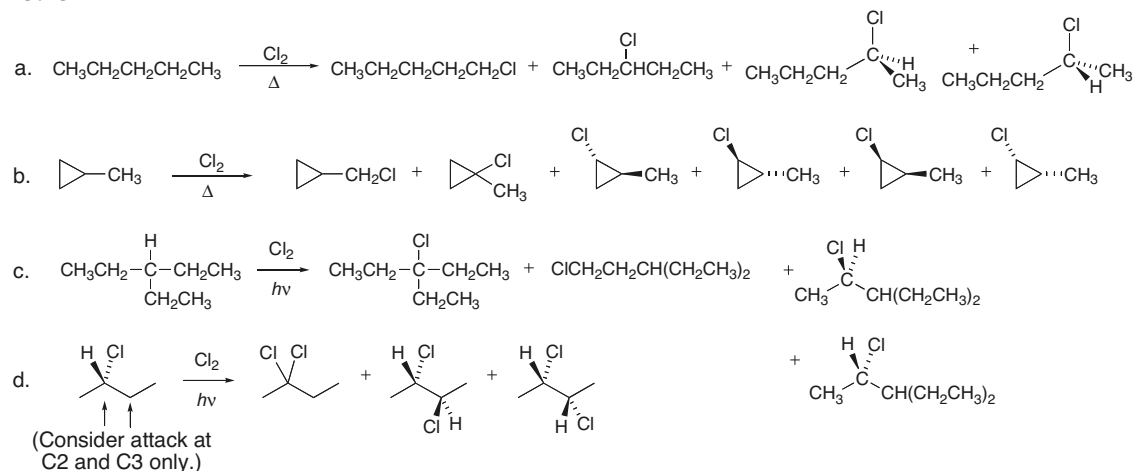


15.14 Since the reaction does not occur at the stereogenic center, leave it as is.

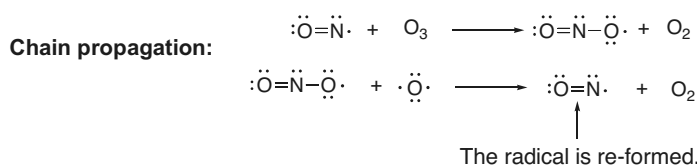


Radical Reactions 15-7

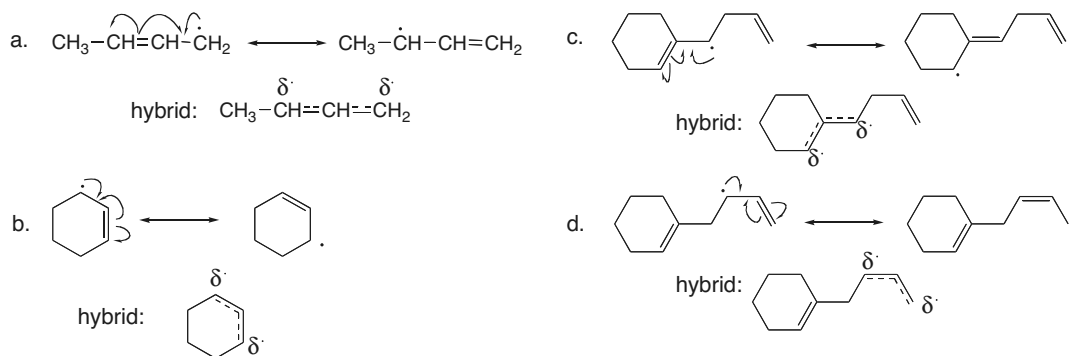
15.15



15.16

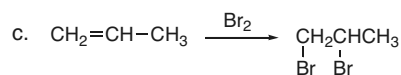
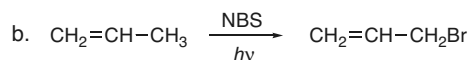
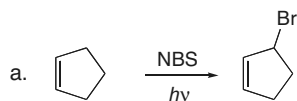
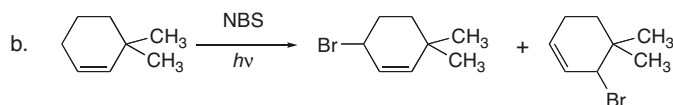
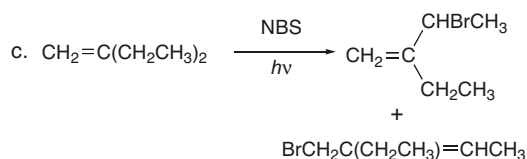
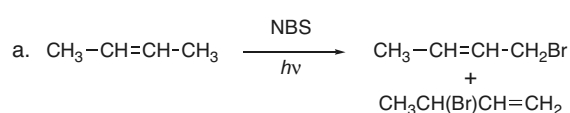
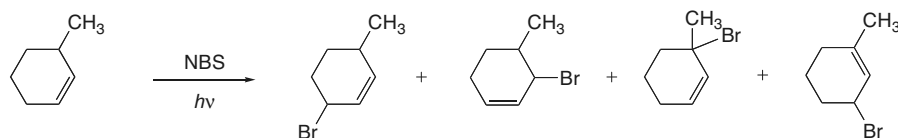


15.17 Draw the resonance structure by moving the π bond and the unpaired electron. The hybrid is drawn with dashed lines for bonds that are in one resonance structure but not another. The symbol $\delta^\cdot$ is used on any atom that has an unpaired electron in any resonance structure.

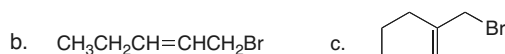
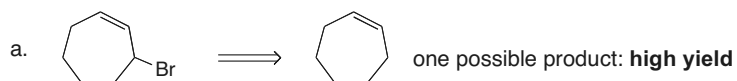


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15.18 Reaction of an alkene with NBS or $\text{Br}_2 + h\nu$ yields allylic substitution products.

**15.19****15.20**

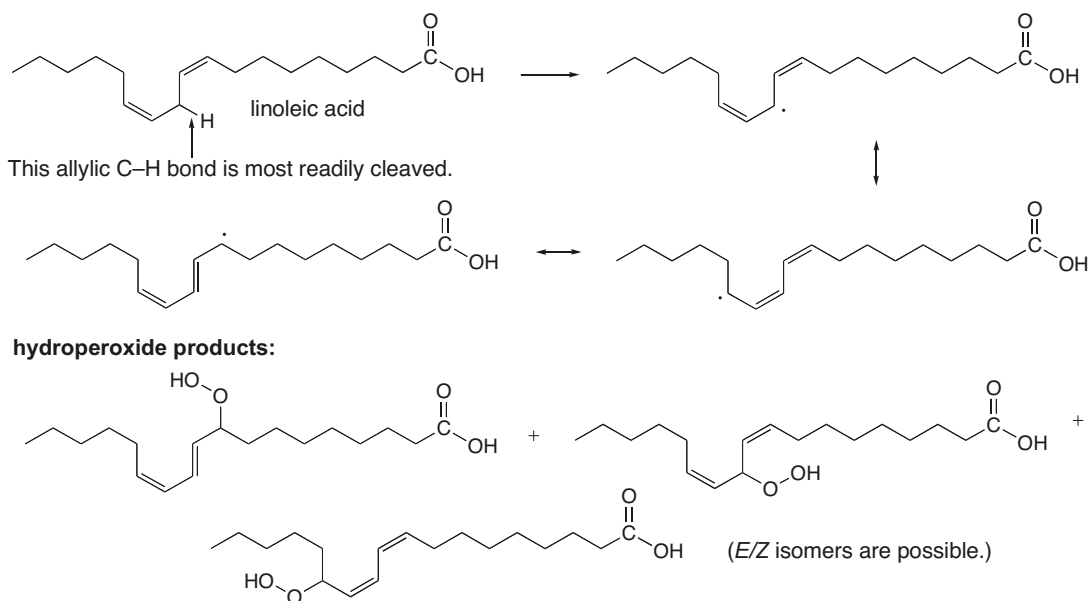
15.21 Reaction of an alkene with NBS + $h\nu$ yields allylic substitution products.



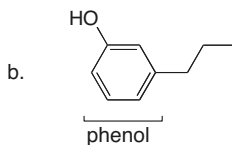
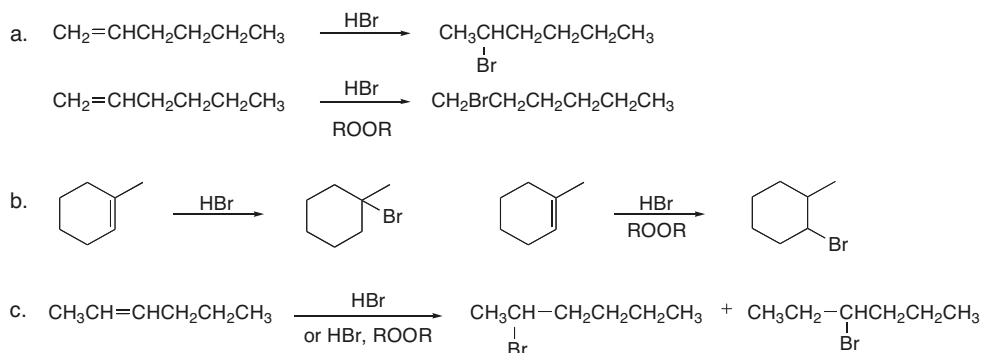
Cannot be made in high yield by allylic halogenation.
Any alkene starting material would yield a mixture of allylic halides.

Radical Reactions 15-9

- 15.22** The weakest C-H bond is most readily cleaved. To draw the hydroperoxide products, add OOH to each carbon that bears a radical in one of the resonance structures.



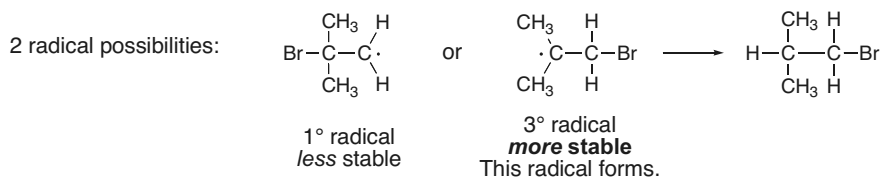
- 15.23** Only (b) has an OH on a benzene ring, so it may be an antioxidant.

**15.24**

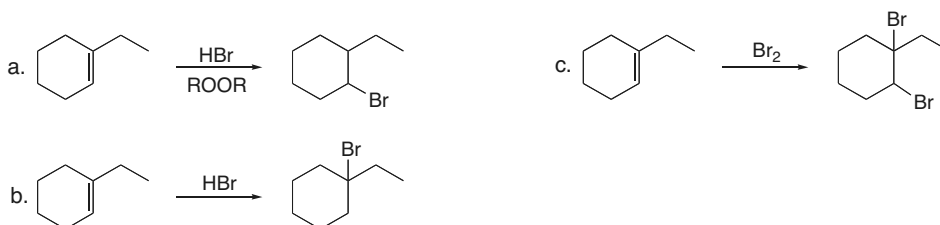
- 15.25** In addition of HBr under radical conditions:

- Br• adds first to form the more stable radical.
- Then H• is added to the carbon radical.

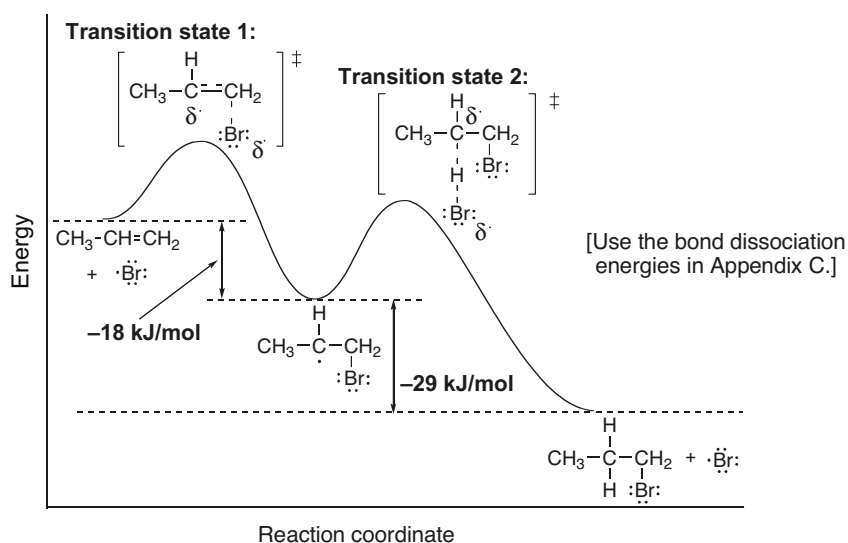
Chapter 15–10



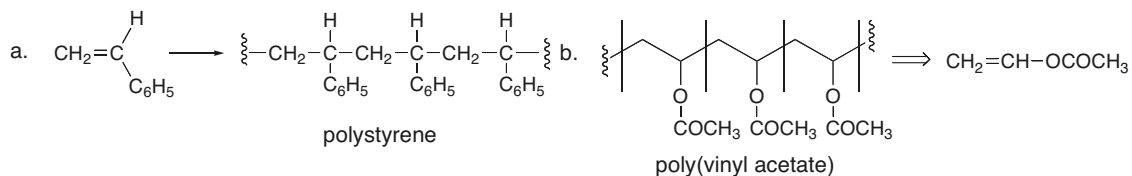
15.26



15.27

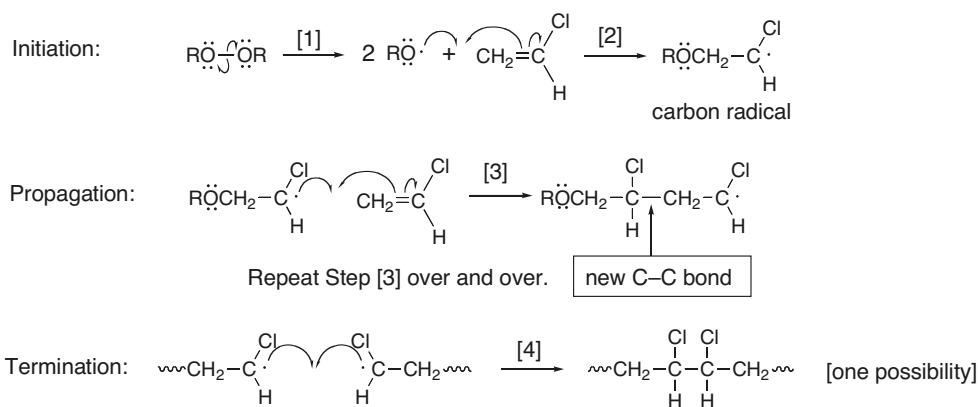


15.28

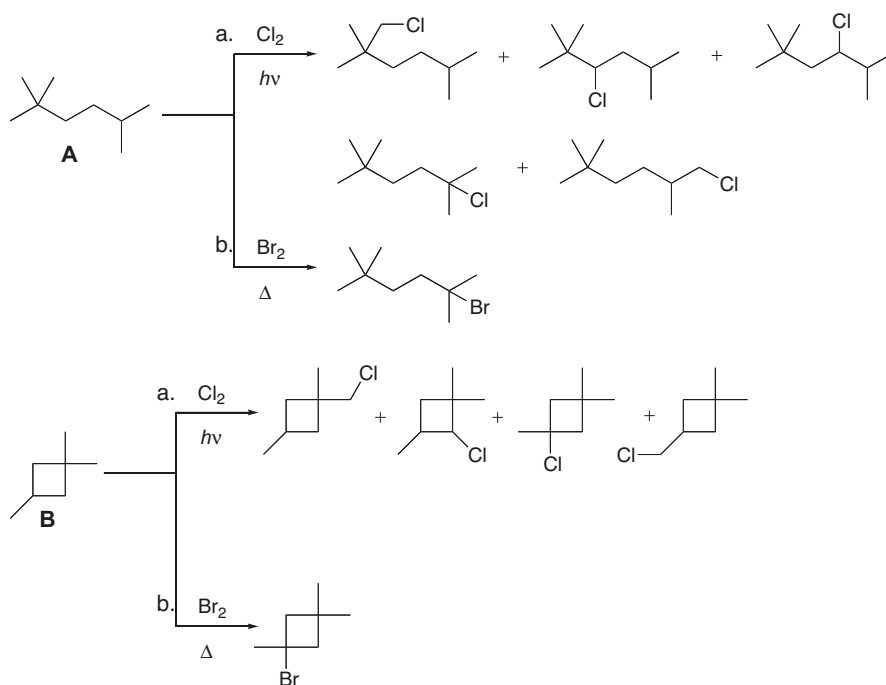


Radical Reactions 15–11

15.29

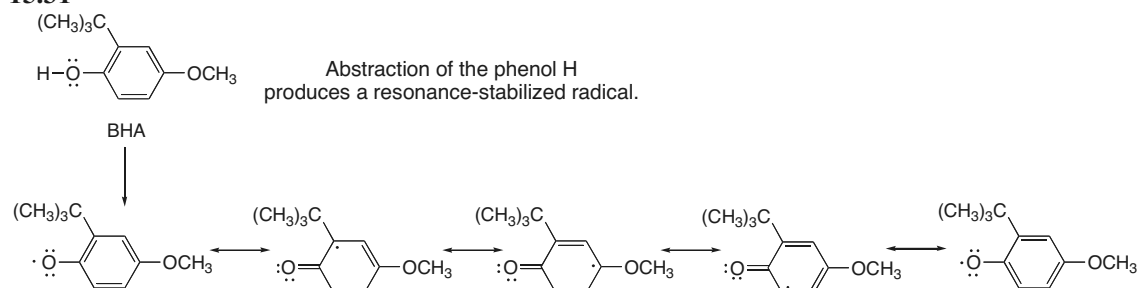


15.30 With Cl_2 , each H of the starting material can be replaced by Cl. With Br_2 , cleavage of the weakest C–H bond is preferred.



Chapter 15–12

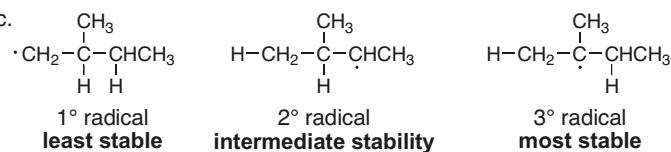
15.31



15.32

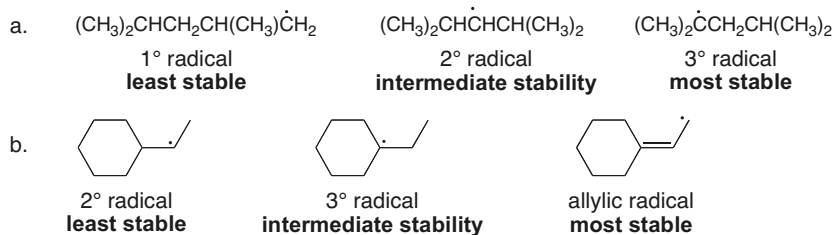
a. increasing bond strength: $2 < 3 < 1$

b. and c.

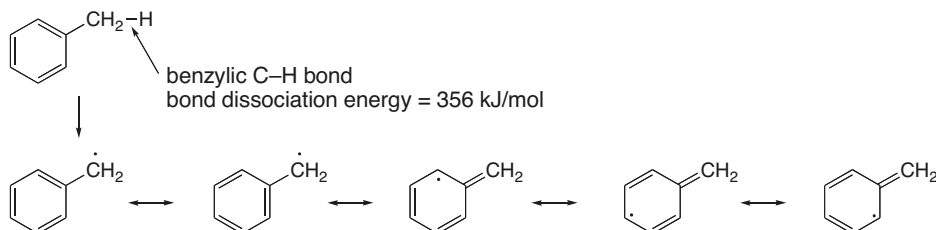


d. increasing ease of H abstraction: $1 < 3 < 2$

15.33 Use the directions from Answer 15.2 to rank the radicals.

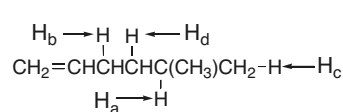


15.34 Draw the radical formed by cleavage of the benzylic C–H bond. Then draw all of the resonance structures. Having more resonance structures (five in this case) makes the radical more stable, and the benzylic C–H bond weaker.



Radical Reactions 15–13

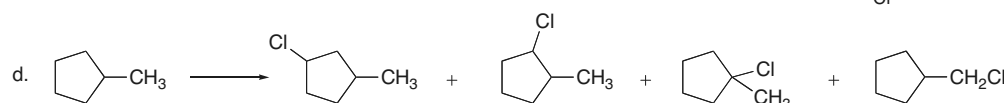
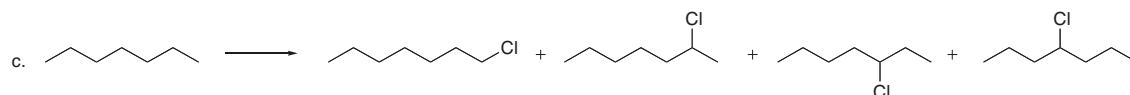
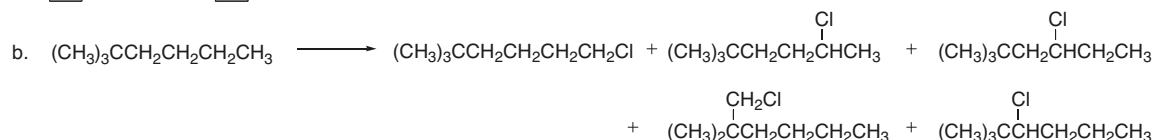
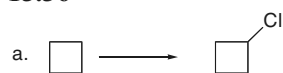
15.35



H_a = bonded to an sp^3 3° carbon
 H_b = bonded to an allylic carbon
 H_c = bonded to an sp^3 1° carbon
 H_d = bonded to an sp^3 2° carbon

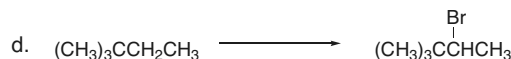
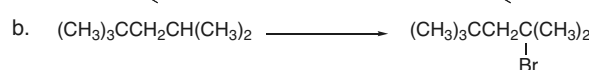
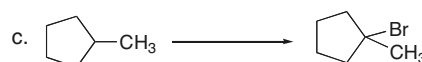
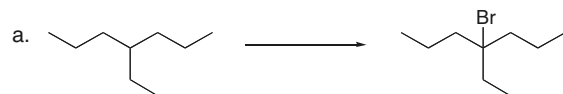
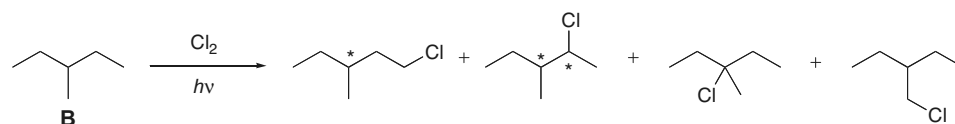
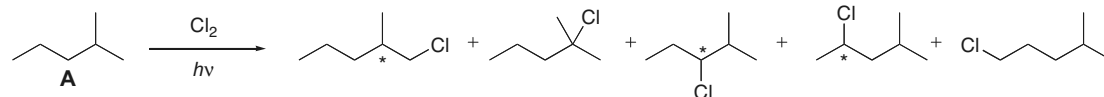
Increasing ease of abstraction:
 $\text{H}_c < \text{H}_d < \text{H}_a < \text{H}_b$

15.36

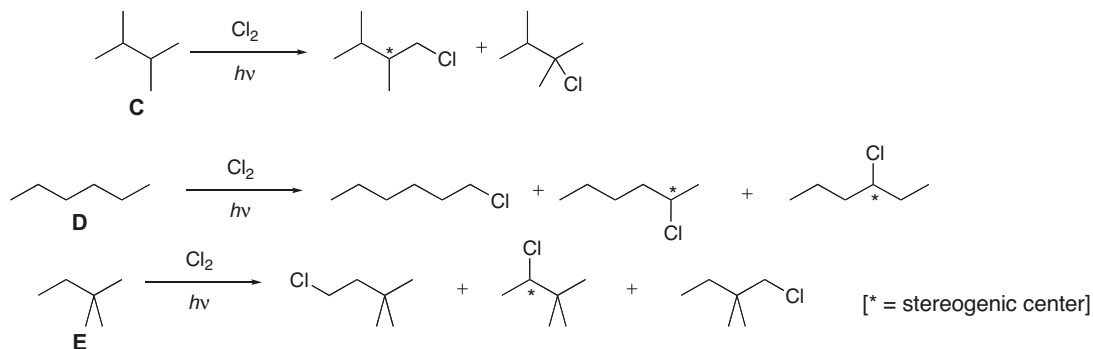


15.37 To draw the product of bromination:

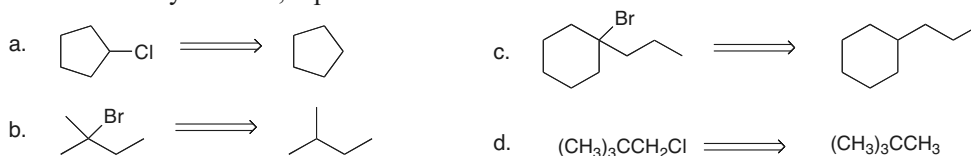
- Draw out the starting material and find the most reactive C–H bond (on the most substituted C).
- The major product is formed by **cleavage of the weakest C–H bond**.

15.38 Draw all of the alkane isomers of C_6H_{14} and their products on chlorination. Then determine which letter corresponds to which alkane.

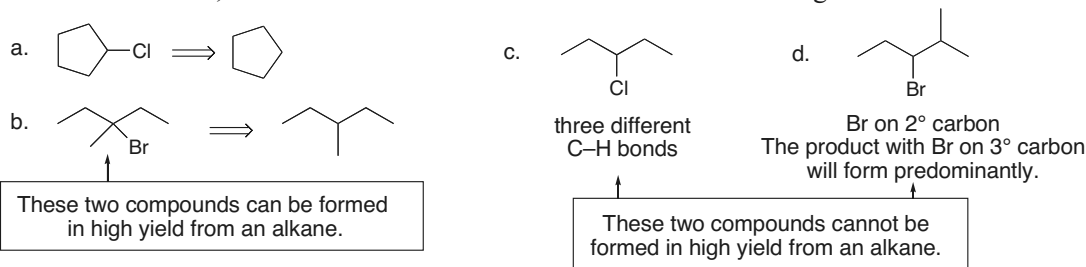
Chapter 15-14



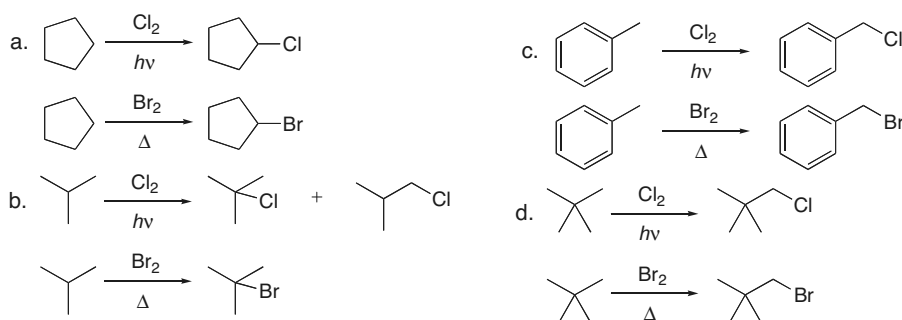
15.39 Halogenation replaces a C–H bond with a C–X bond. To find the alkane needed to make each of the alkyl halides, replace the X with an H.



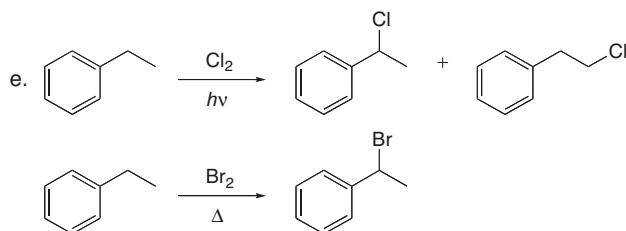
15.40 For an alkane to yield one major product on monohalogenation with Cl_2 , all of the hydrogens must be identical in the starting material. For an alkane to yield one major product on bromination, it must have a more substituted carbon in the starting material.



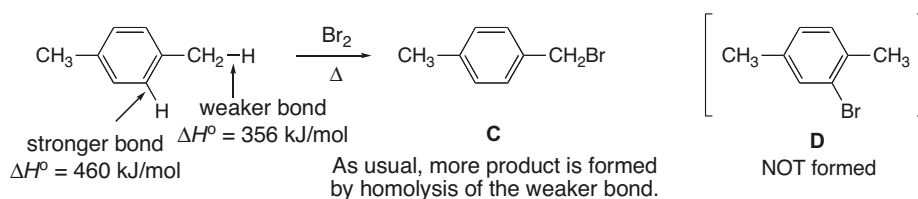
15.41 A single constitutional isomer is formed in both halogenations in (a), (c), and (d). Bromination often forms a single product by cleavage of the weakest C–H bond. For chlorination to form a single product, the starting material must have only one kind of H that reacts. In (c), a single chlorination product is formed because there is only one type of sp^3 hybridized C–H bond.



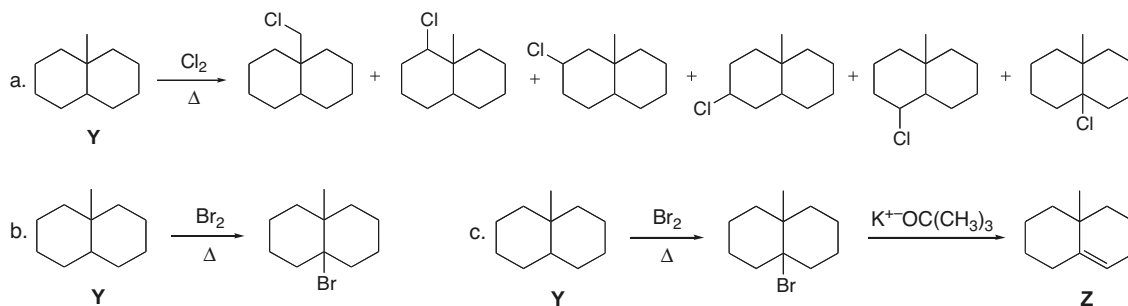
Radical Reactions 15–15



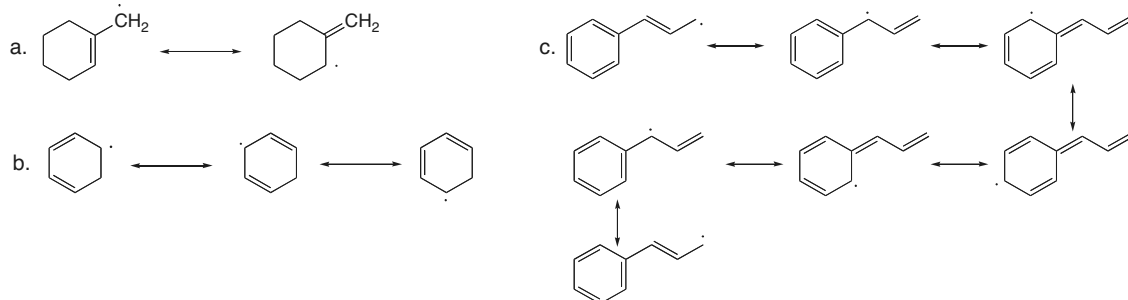
- 15.42** In bromination, the predominant (or exclusive) product is formed by cleavage of the weaker C–H bond to form the more stable radical intermediate.



- 15.43** Chlorination is not selective so a mixture of products results. Bromination is selective, and the major product is formed by cleavage of the weakest C–H bond.

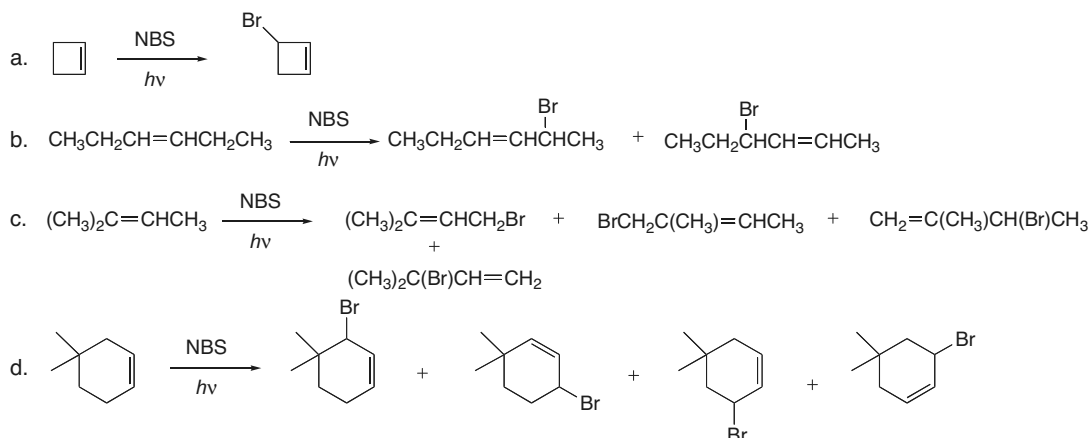


- 15.44** Draw the resonance structures by moving the π bonds and the radical.

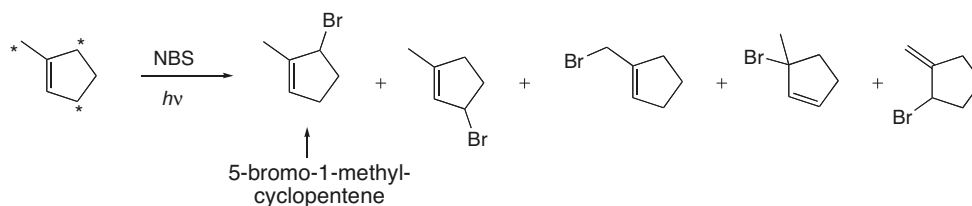


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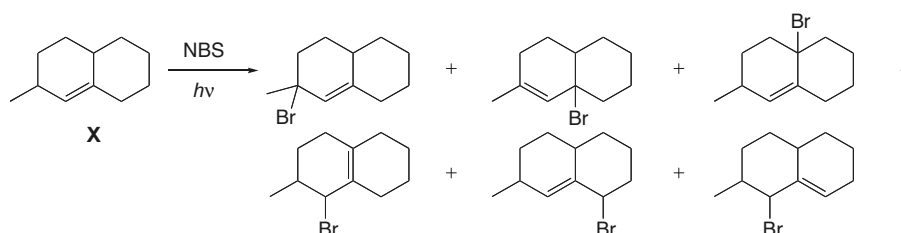
15.45 Reaction of an alkene with NBS + $h\nu$ yields allylic substitution products.



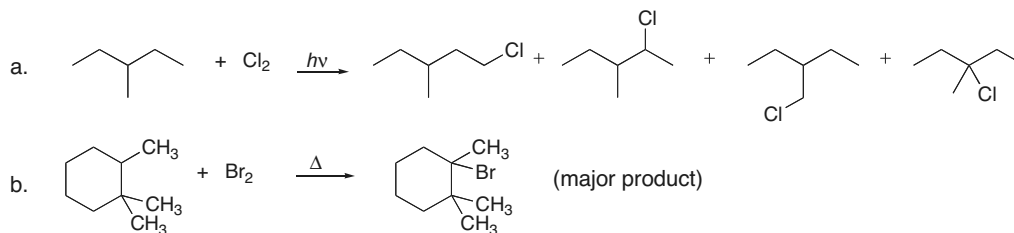
15.46 It is not possible to form 5-bromo-1-methylcyclopentene in good yield by allylic bromination because several other products are formed. 1-Methylcyclopentene has three different types of allylic hydrogens (labeled with *), all of which can be removed during radical bromination.



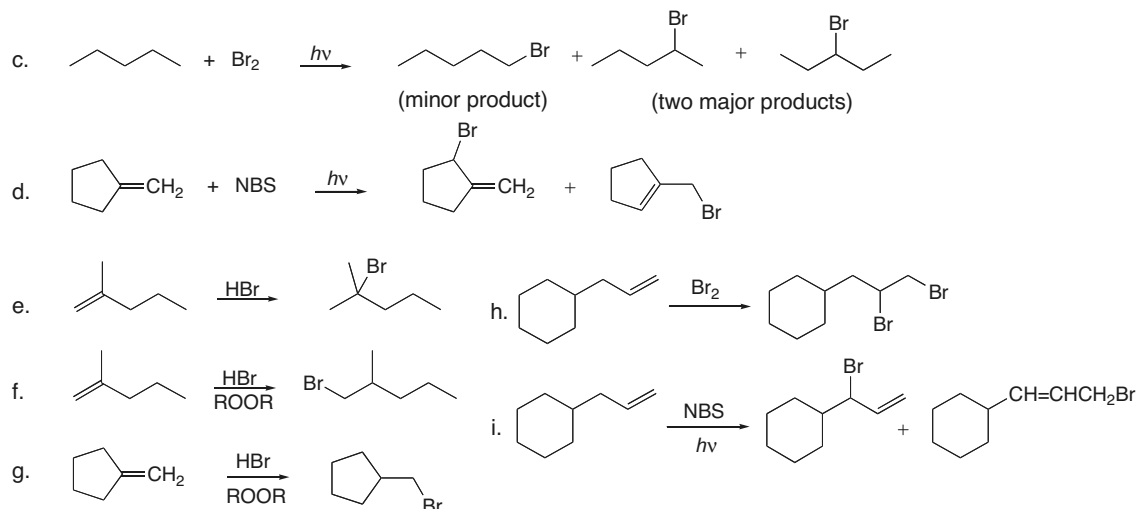
15.47



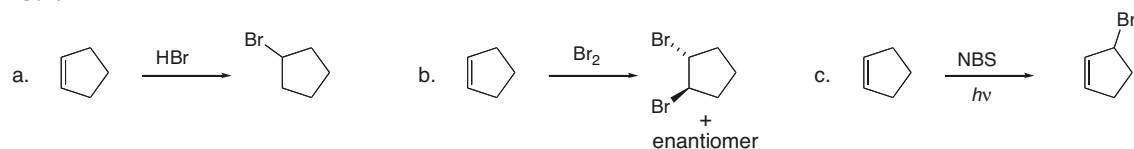
15.48



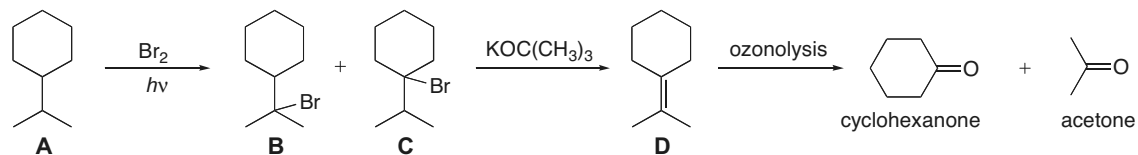
Radical Reactions 15–17



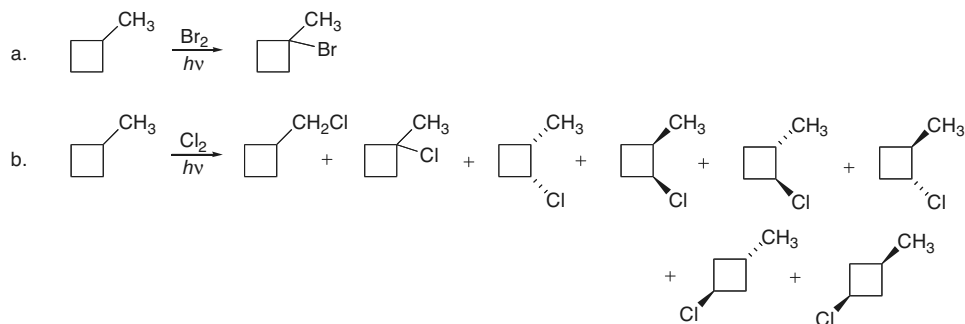
15.49



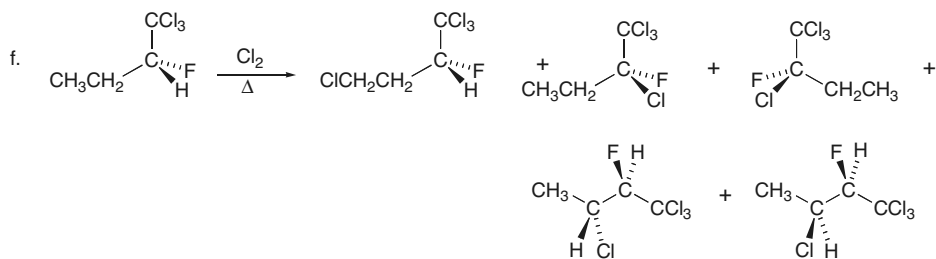
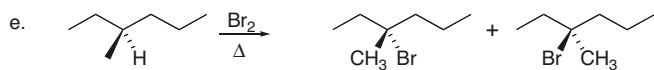
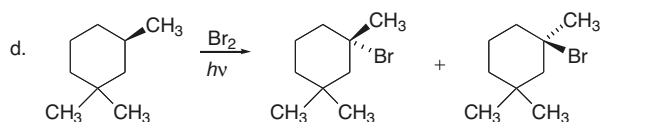
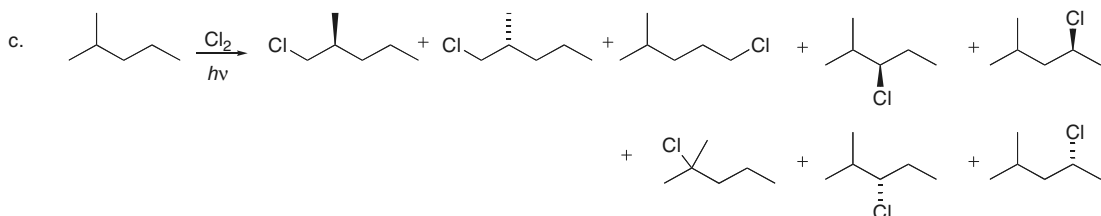
15.50



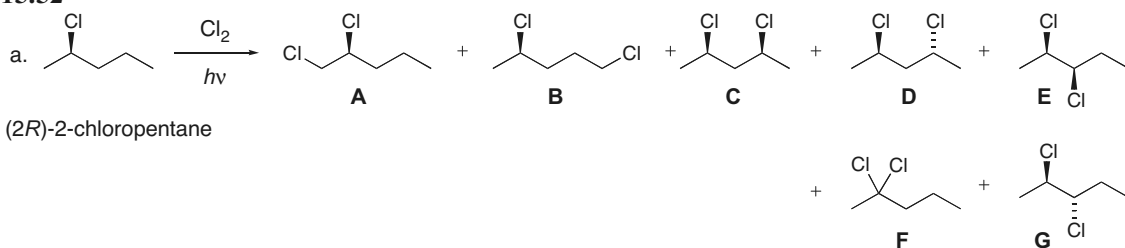
15.51



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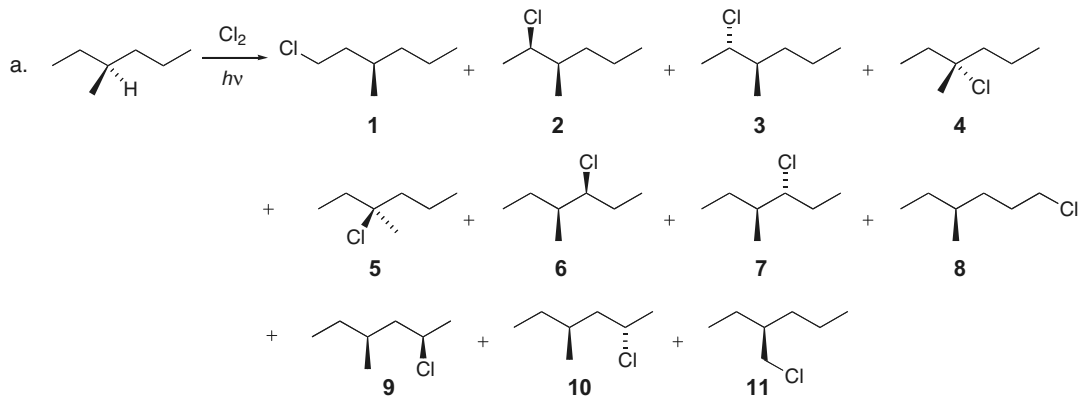
15.52



b. There would be seven fractions, since each molecule drawn has different physical properties.

c. Fractions **A, B, D, E,** and **G** would show optical activity.

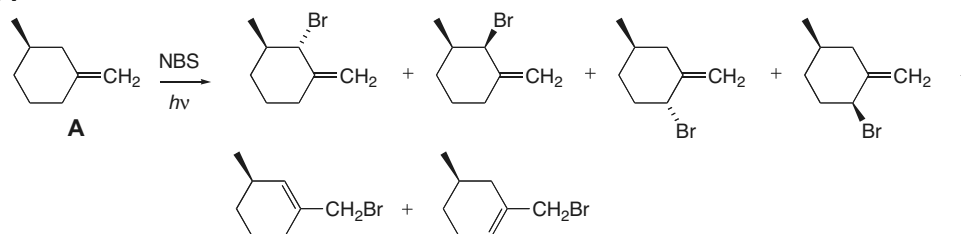
15.53



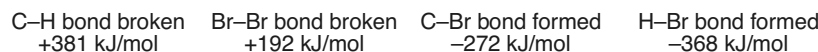
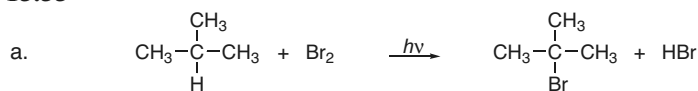
Radical Reactions 15–19

- a. There would be 10 fractions, since **4** and **5** (two enantiomers) would be in the same fraction.
 b. All fractions except the one that contains **4** and **5** would be optically active.

15.54

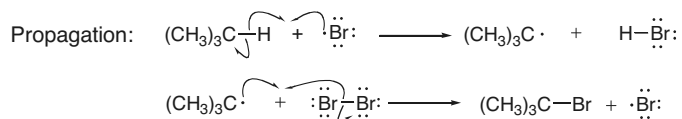
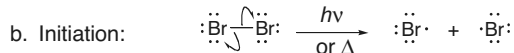


15.55



total bonds broken = +573 kJ/mol

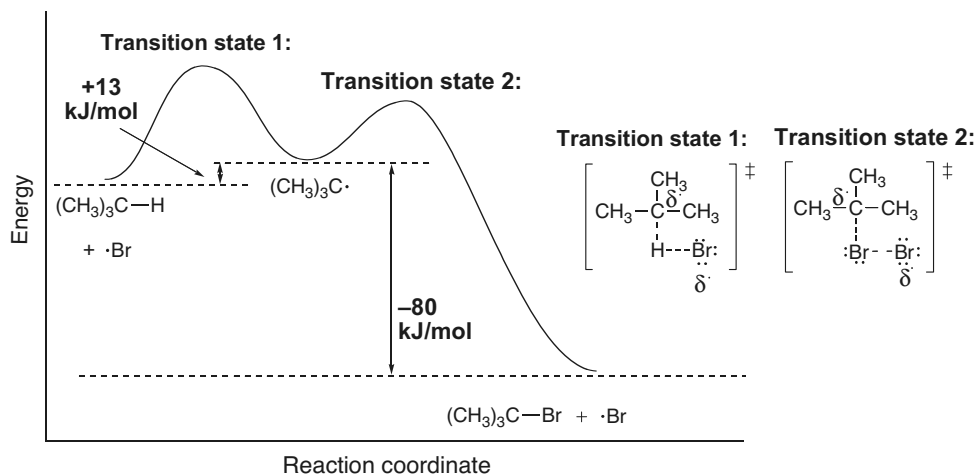
total bonds formed = –640 kJ/mol

 $\Delta H^\circ = -67 \text{ kJ/mol}$ 

c. $\Delta H^\circ = (\text{bonds broken}) - (\text{bonds formed})$
 $= (+381 \text{ kJ/mol}) + (-368 \text{ kJ/mol})$
 $= +13 \text{ kJ/mol}$
 $\Delta H^\circ = (\text{bonds broken}) - (\text{bonds formed})$
 $= (+192 \text{ kJ/mol}) + (-272 \text{ kJ/mol})$
 $= -80 \text{ kJ/mol}$

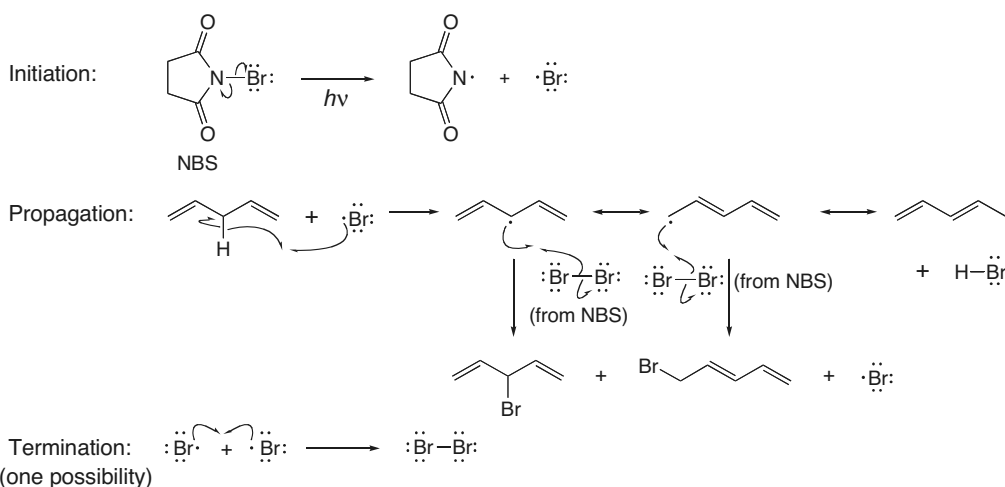
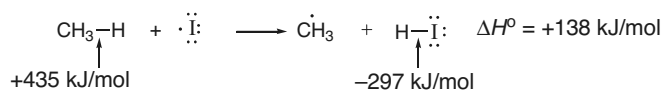


d, e.

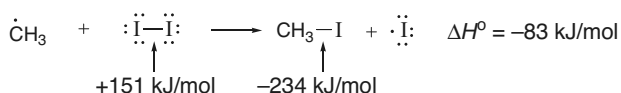
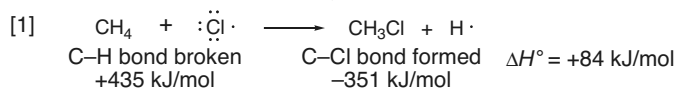


Chapter 15–20

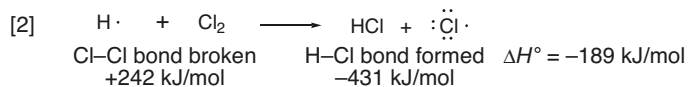
15.56

15.57 Calculate the ΔH° for the propagation steps of the reaction of CH_4 with I_2 to show why it does not occur at an appreciable rate.

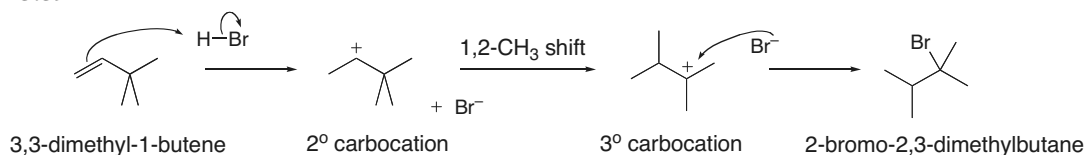
This step is highly endothermic, making it difficult for chain propagation to occur over and over again.

15.58 Calculate ΔH° for each of these steps, and use these values to explain why this alternate mechanism is unlikely.

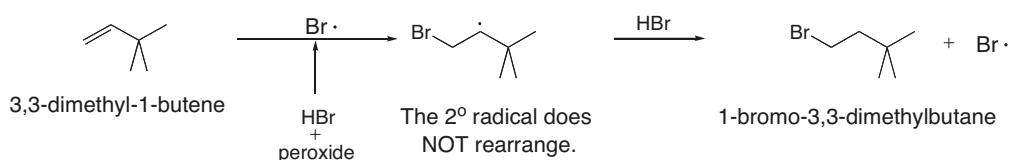
The ΔH° for Step [1] is very endothermic, making this mechanism unlikely.



15.59

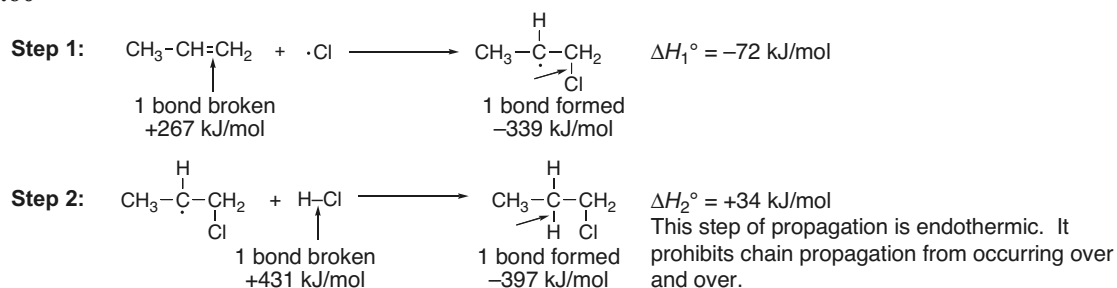


Radical Reactions 15–21

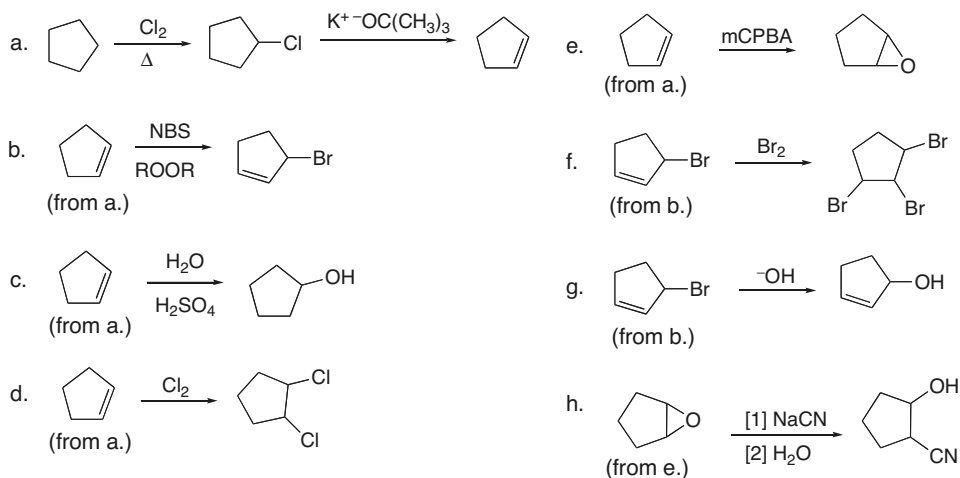


Addition of HBr without added peroxide occurs by an ionic mechanism and forms a 2° carbocation, which rearranges to a more stable 3° carbocation. The addition of H^+ occurs first, followed by Br^- . Addition of HBr with added peroxide occurs by a radical mechanism and forms a 2° radical that does not rearrange. In the radical mechanism $\text{Br}\cdot$ adds first, followed by $\text{H}\cdot$.

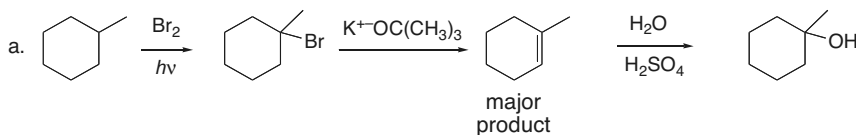
15.60



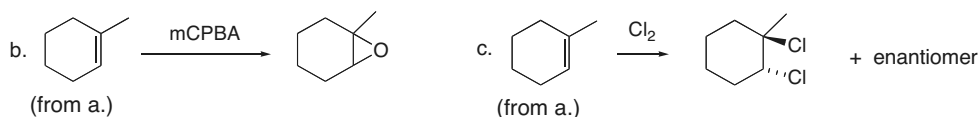
15.61



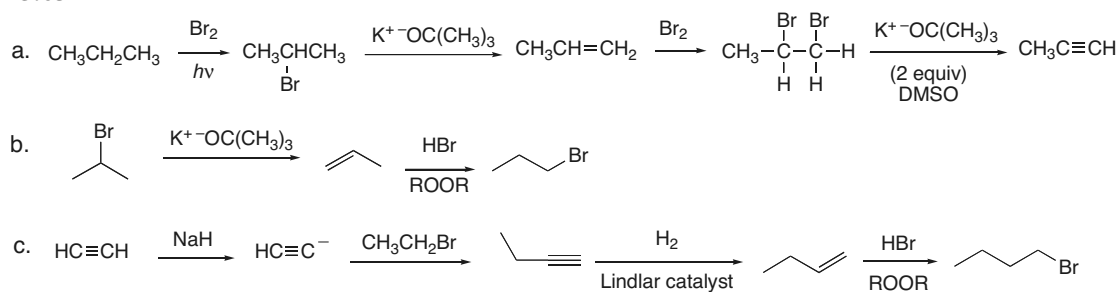
15.62



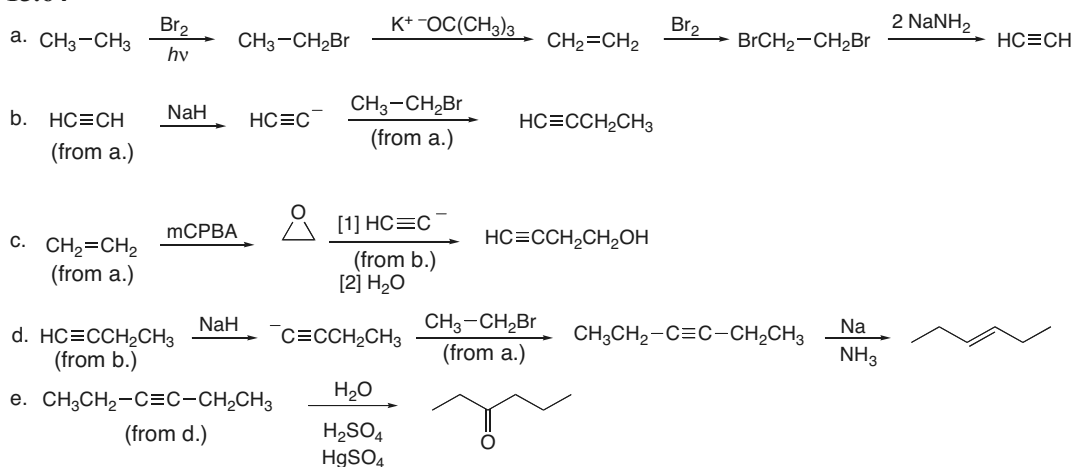
Chapter 15-22



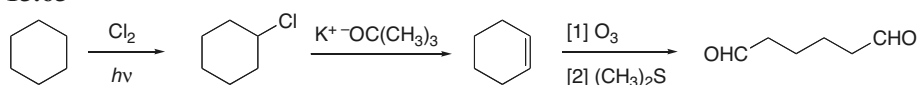
15.63



15.64

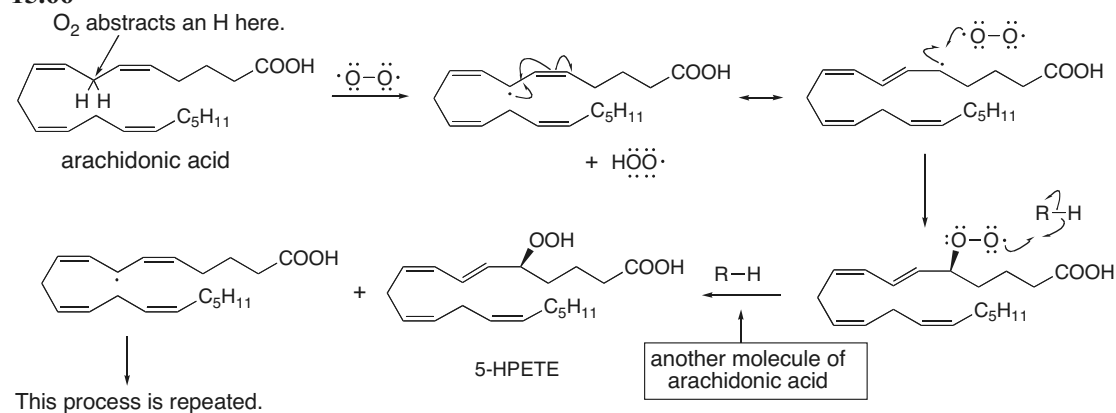


15.65

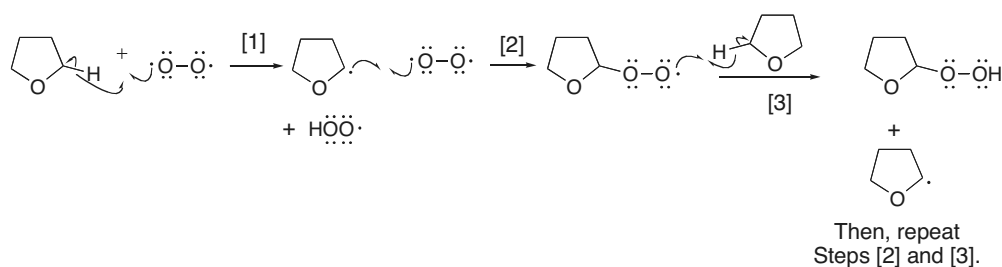


Radical Reactions 15–23

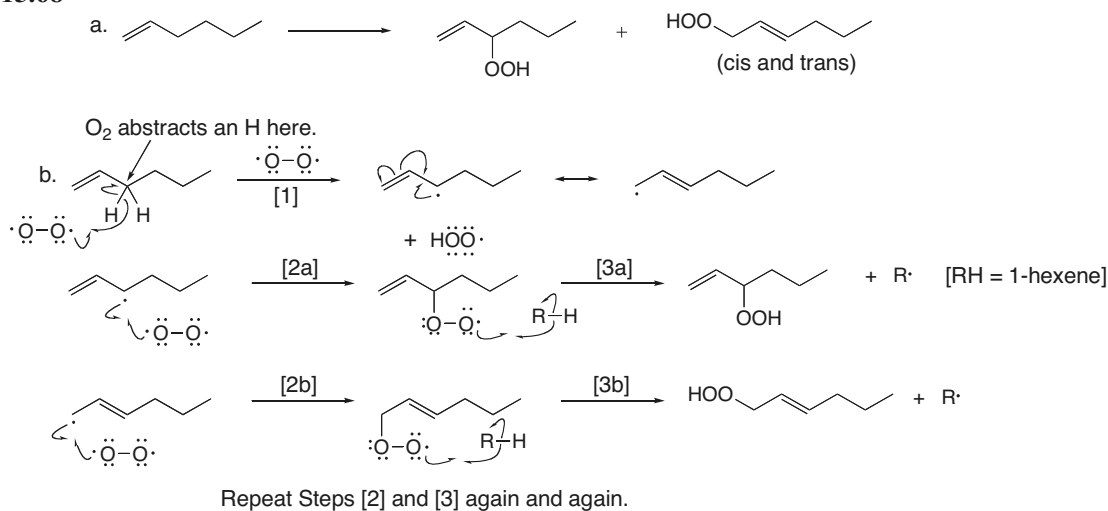
15.66



15.67

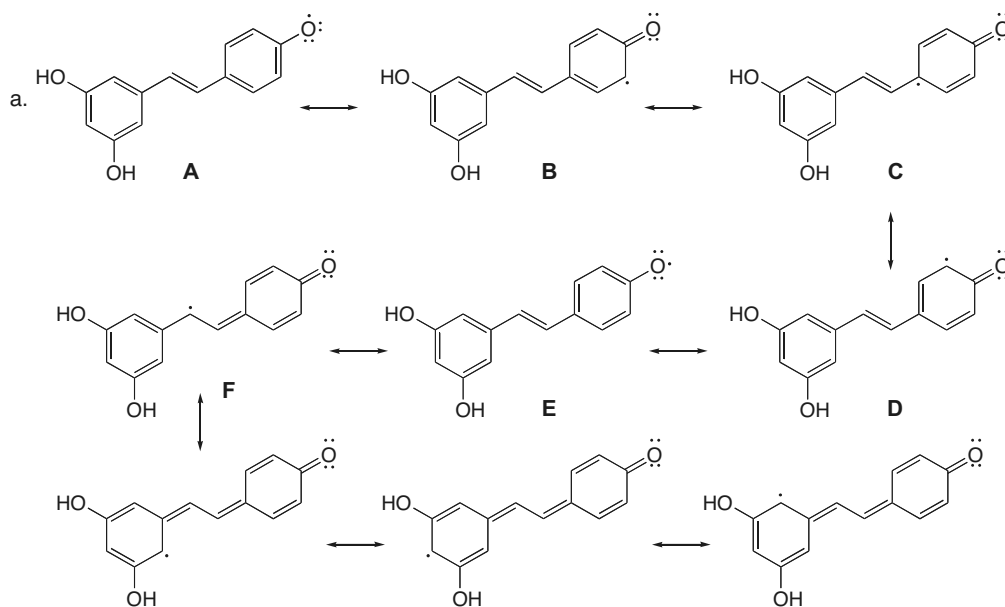


15.68



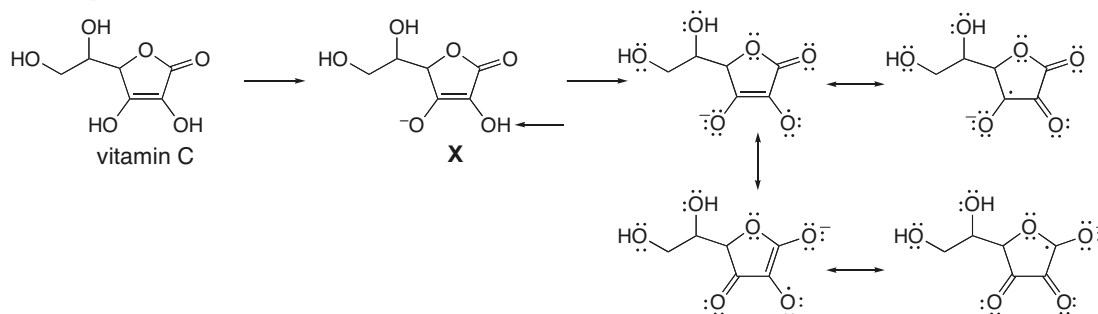
15.69 For resonance structures A–F, an additional resonance form can be drawn that moves the position of the three π bonds in the ring bonded to two OH groups.

Chapter 15–24

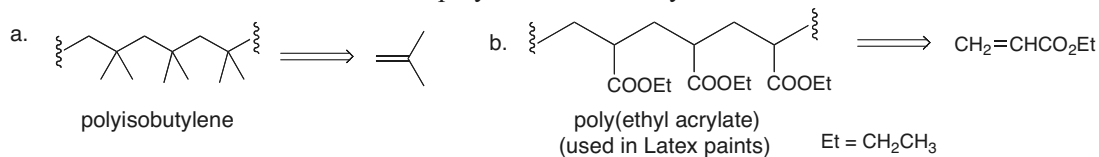


- b. Homolysis of the indicated OH bond is preferred because it allows the resulting radical to delocalize over both benzene rings. Cleavage of one of the other OH bonds gives a radical that delocalizes over only one of the benzene rings.

15.70 Abstraction of the labeled H forms a highly resonance-stabilized radical. Four of the possible resonance structures are drawn.

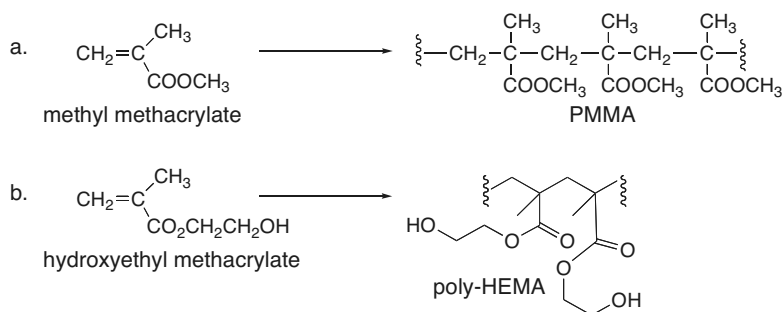


15.71 The monomers used in radical polymerization always contain double bonds.

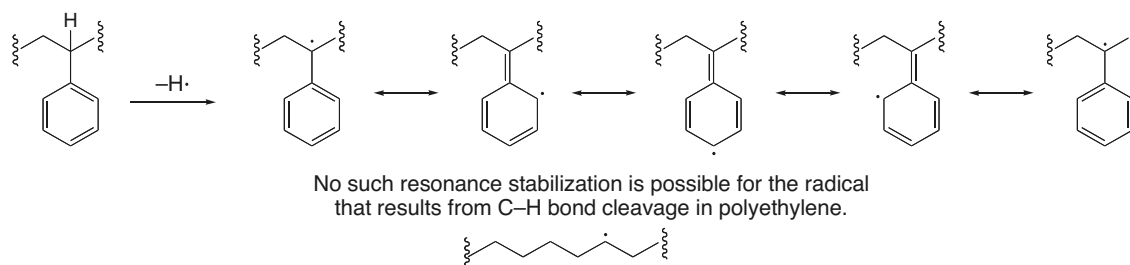


Radical Reactions 15–25

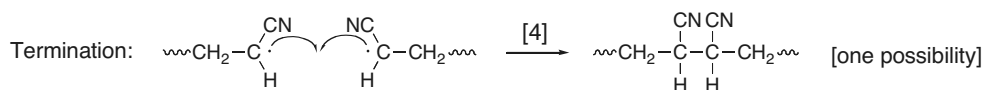
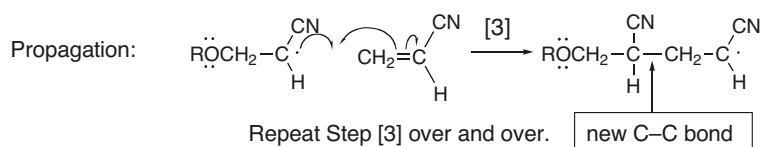
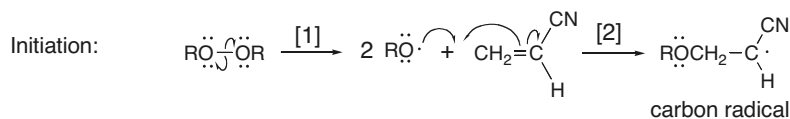
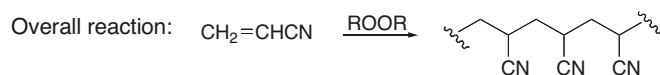
15.72



15.73 Polystyrene has H atoms bonded to benzylic carbons, carbons bonded directly to a benzene ring. These C–H bonds are unusually weak because the radical that results from homolysis is resonance stabilized.

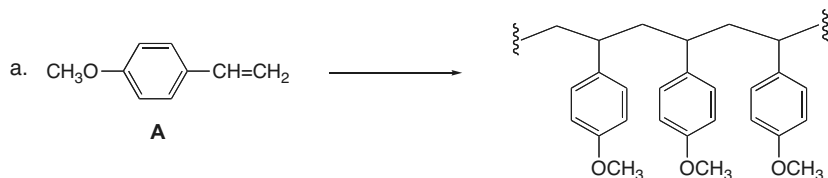


15.74

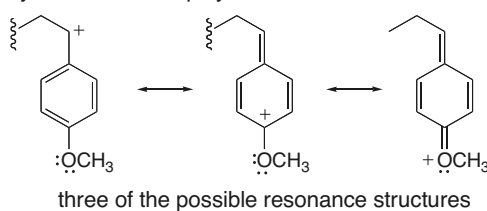


Chapter 15–26

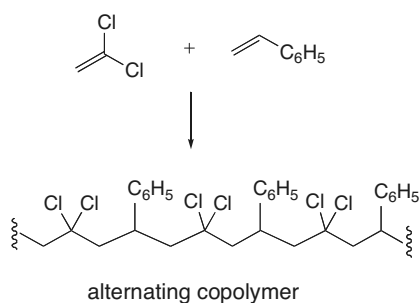
15.75



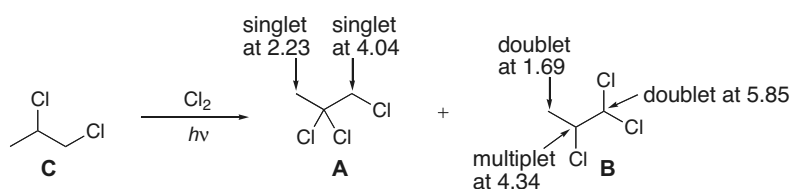
- b. The OCH_3 group stabilizes an intermediate carbocation by resonance. This makes **A** react faster than styrene in cationic polymerization.



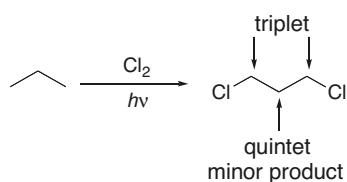
15.76



15.77



15.78



molecular formula $\text{C}_3\text{H}_6\text{Cl}_2$

Integration:

$(57 \text{ units} + 29 \text{ units})/6 \text{ H's} = 14 \text{ units per H}$

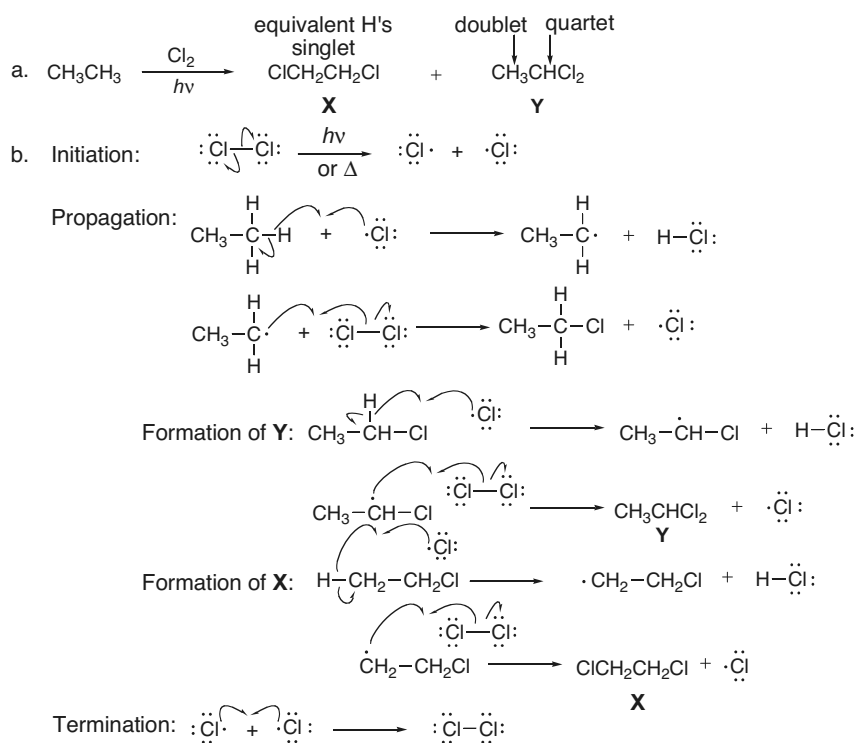
one signal is $57 \text{ units}/14 \text{ units per H} = 4 \text{ H's}$

second signal is $29 \text{ units}/14 \text{ units per H} = 2 \text{ H's}$

^1H NMR data:

quintet at 2.2 (2 H's) split by 4 H's

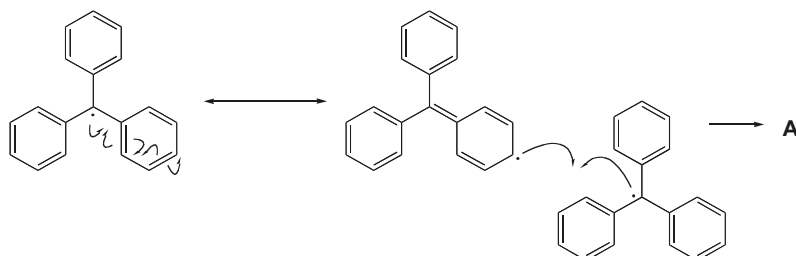
triplet at 3.7 (4 H's) split by 2 H's

[illegible]

In addition, the radical is very sterically hindered, making it difficult to undergo reactions.

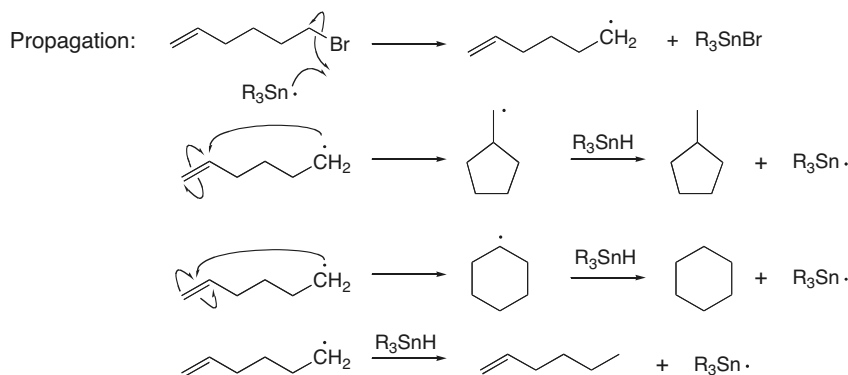
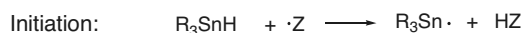
Chapter 15–28

- b. First, draw the resonance form of the radical that places the unpaired electron on the C that forms the new C–C bond.

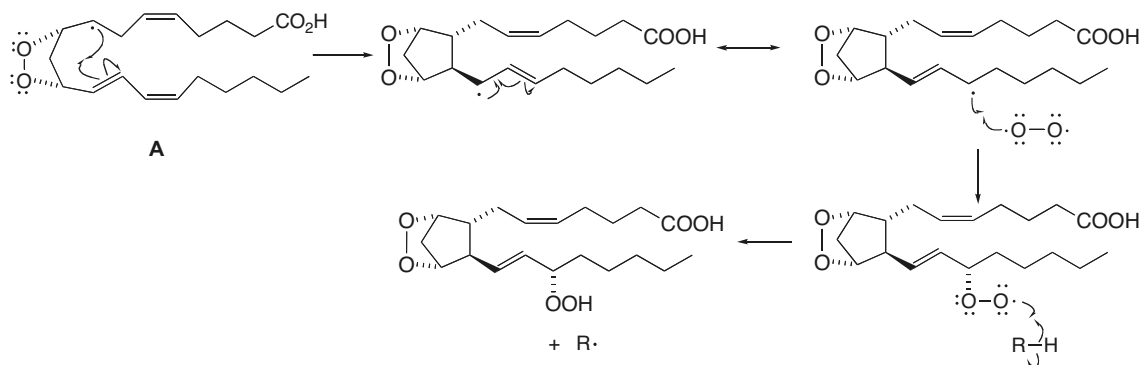


- c. Hexaphenylethane formation would require two very crowded 3° radicals to combine. The formation of **A** results from a radical on one of the six-membered rings, which is much more accessible for reaction.
- d. The ^1H NMR spectrum of hexaphenylethane should show signals only in the aromatic region (7–8 ppm), whereas the ^1H NMR spectrum of **A** will also have signals for the sp^2 hybridized C–H bonds (4.5–6.0 ppm) of the alkenes, as well as the single H on the sp^3 hybridized carbon. The ^{13}C NMR spectrum of hexaphenylethane should consist of lines due to the 4° C's and the aromatic C's. For **A**, the ^{13}C NMR spectrum will also have lines for the sp^3 and sp^2 hybridized C's that are not contained in the aromatic rings.

15.82



15.83



Chapter 16 Conjugation, Resonance, and Dienes

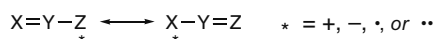
Chapter Review

Conjugation and delocalization of electron density

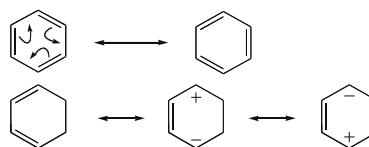
- The overlap of p orbitals on three or more adjacent atoms allows electron density to delocalize, thus adding stability (16.1).
- An allyl carbocation ($\text{CH}_2=\text{CHCH}_2^+$) is more stable than a 1° carbocation because of p orbital overlap (16.2).
- In a system $\text{X}=\text{Y}-\text{Z}:$, Z is generally sp^2 hybridized to allow the lone pair to occupy a p orbital, making the system conjugated (16.5).

Four common examples of resonance (16.3)

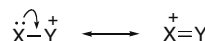
[1] The three atom "allyl" system:



[2] Conjugated double bonds:



[3] Cations having a positive charge adjacent to a lone pair:

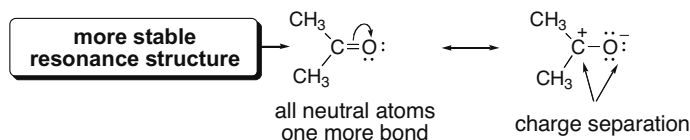


[4] Double bonds having one atom more electronegative than the other:

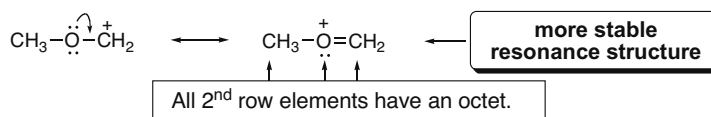


Rules on evaluating the relative "stability" of resonance structures (16.4)

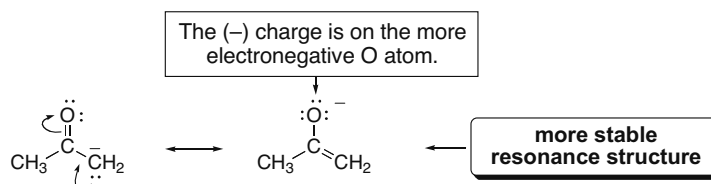
[1] Structures with more bonds and fewer charges are more stable.



[2] Structures in which every atom has an octet are more stable.



[3] Structures that place a negative charge on a more electronegative element are more stable.



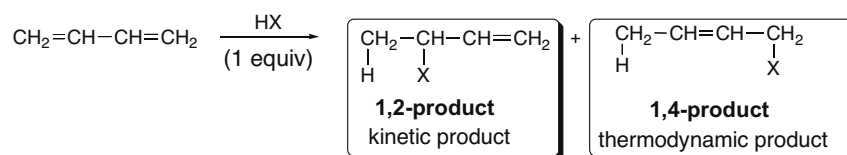
Chapter 16-2

The unusual properties of conjugated dienes

- [1] The C–C σ bond joining the two double bonds is unusually short (16.8).
- [2] Conjugated dienes are more stable than similar isolated dienes. ΔH° of hydrogenation is smaller for a conjugated diene than for an isolated diene converted to the same product (16.9).
- [3] The reactions are unusual:
- Electrophilic addition affords products of 1,2-addition and 1,4-addition (16.10, 16.11).
 - Conjugated dienes undergo the Diels–Alder reaction, a reaction that does not occur with isolated dienes (16.12–16.14).
- [4] Conjugated dienes absorb UV light in the 200–400 nm region. As the number of conjugated π bonds increases, the absorption shifts to longer wavelength (16.15).

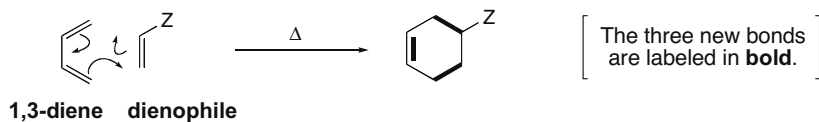
Reactions of conjugated dienes

- [1] Electrophilic addition of HX (X = halogen) (16.10, 16.11)



- The mechanism has two steps.
- Markovnikov's rule is followed. Addition of H^+ forms the more stable allylic carbocation.
- The 1,2-product is the kinetic product. When H^+ adds to the double bond, X^- adds to the end of the allylic carbocation to which it is closer (C2 not C4). The kinetic product is formed faster at low temperature.
- The thermodynamic product has the more substituted, more stable double bond. The thermodynamic product predominates at equilibrium. With 1,3-butadiene, the thermodynamic product is the 1,4-product.

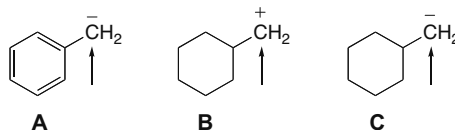
- [2] Diels–Alder reaction (16.12–16.14)



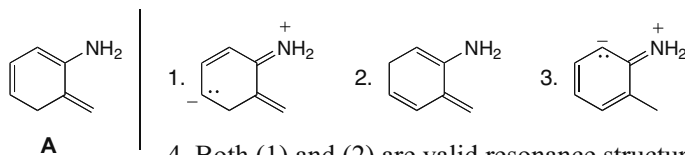
- The reaction forms two σ and one π bond in a six-membered ring.
- The reaction is initiated by heat.
- The mechanism is concerted: all bonds are broken and formed in a single step.
- The diene must react in the *s-cis* conformation (16.13A).
- Electron-withdrawing groups in the dienophile increase the reaction rate (16.13B).
- The stereochemistry of the dienophile is retained in the product (16.13C).
- Endo products are preferred (16.13D).

Practice Test on Chapter Review

1. a. Which of the following statements is true about the Diels–Alder reaction?
1. The reaction is faster with electron-donating groups in the dienophile.
 2. The reaction is endothermic.
 3. The diene must adopt the *s*-cis conformation.
 4. Statements (1) and (2) are true.
 5. Statements (1), (2), and (3) are all true.
- b. Which of the following statements is true about the absorption of ultraviolet light by unsaturated systems?
1. 1,4-Pentadiene requires light having a wavelength < 200 nm for electron promotion.
 2. 1,3-Cyclohexadiene absorbs ultraviolet light with a wavelength > 200 nm.
 3. As the number of conjugated π bonds increases, the energy difference between the excited state and ground state decreases.
 4. Statements (1) and (2) are true.
 5. Statements (1), (2), and (3) are all true.
- c. Which of the following compounds contains a labeled carbon atom that is sp^2 hybridized?

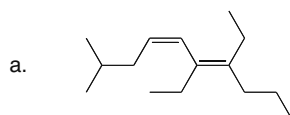


1. **A** only
 2. **B** only
 3. **C** only
 4. **A** and **B**
 5. **A**, **B**, and **C**
- d. Which of the following represent valid resonance structures for **A**?

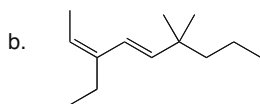


4. Both (1) and (2) are valid resonance structures.
5. Structures (1), (2), and (3) are all valid.

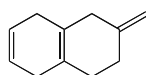
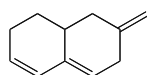
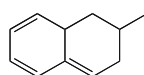
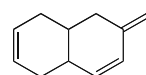
2. Name the following compounds and indicate the conformation around the σ bond that joins the two double bonds.



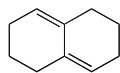
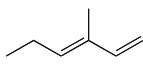
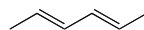
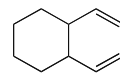
Chapter 16-4



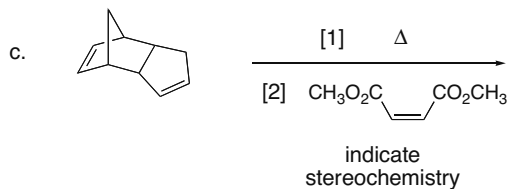
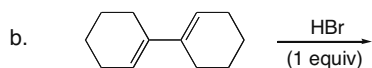
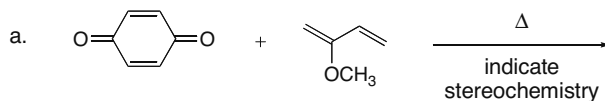
3. a. Consider the four hydrocarbons (**A–D**) drawn below. [1] Which compound absorbs the *shortest* wavelength of ultraviolet light? [2] Which compound absorbs the *longest* wavelength of ultraviolet light?

**A****B****C****D**

- b. Consider the four dienes (**A–D**) drawn below. [1] Which diene is *most* reactive in the Diels–Alder reaction? [2] Which diene is the *least* reactive in the Diels–Alder reaction?

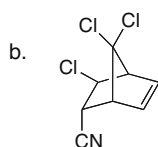
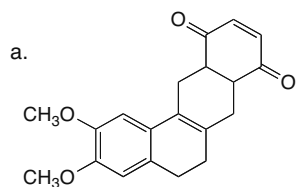
**A****B****C****D**

4. Draw the organic products formed in each reaction. In part (b), label the kinetic and thermodynamic products.



Conjugation, Resonance, and Dienes 16–5

5. What diene and dienophile are needed to synthesize the following Diels–Alder adducts?



Answers to Practice Test

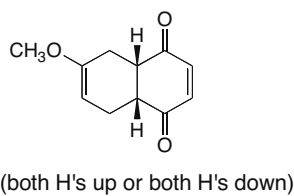
- 1.a. 3
b. 5
c. 4
d. 1

2.a. (4*Z*,6*E*)-6,7-diethyl-2-methyl-4,6-decadiene, *s*-trans

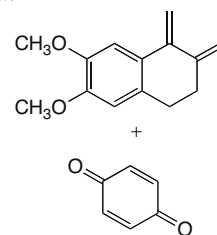
b. (2*Z*,4*E*)-3-ethyl-6,6-dimethyl-2,4-nonadiene, *s*-trans

- 3.a. [1] **A**; [2] **C**
b. [1] **D**; [2] **A**

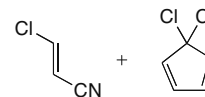
4.a.



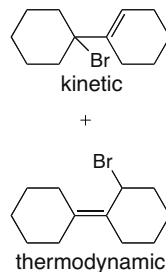
5.a.



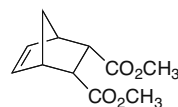
b.



b.



c.

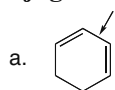


Chapter 16–6

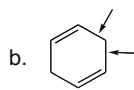
Answers to Problems

16.1 Isolated dienes have two double bonds separated by two or more σ bonds.

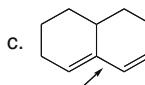
Conjugated dienes have two double bonds separated by only one σ bond.



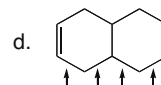
One σ bond separates two double bonds = **conjugated diene**



Two σ bonds separate two double bonds = **isolated diene**



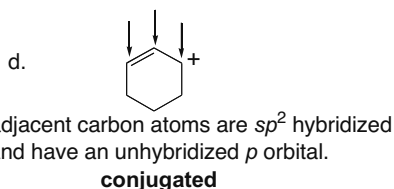
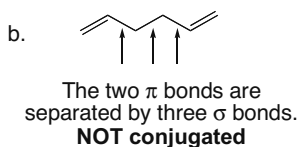
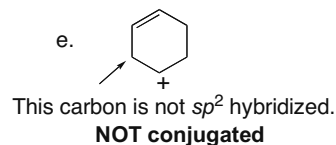
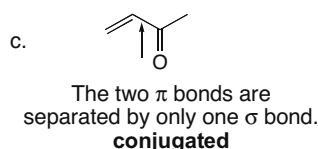
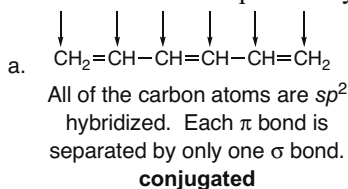
One σ bond separates two double bonds = **conjugated diene**



Four σ bonds separate two double bonds = **isolated diene**

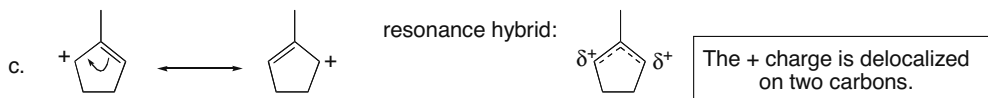
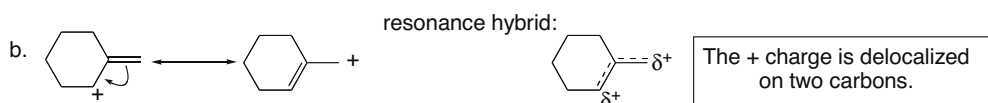
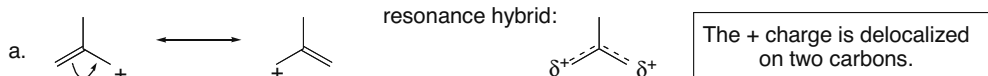
16.2 Conjugation occurs when there are overlapping p orbitals on three or more adjacent atoms.

Double bonds separated by two σ bonds are not conjugated.



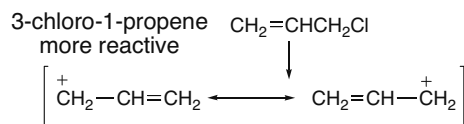
16.3 Two resonance structures differ only in the placement of electrons. All σ bonds stay in the same place. Nonbonded electrons and π bonds can be moved. To draw the hybrid:

- Use a dashed line between atoms that have a π bond in one resonance structure and not the other.
- Use a δ symbol for atoms with a charge or radical in one structure but not the other.



16.4 S_N1 reactions proceed via a carbocation intermediate. Draw the carbocation formed on loss of Cl and compare. The more stable the carbocation, the faster the S_N1 reaction.

Conjugation, Resonance, and Dienes 16-7

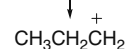
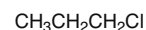


resonance-stabilized carbocation

Two resonance structures delocalize the positive charge on 2 C's making 3-chloro-1-propene more reactive.

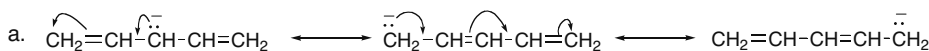
$\text{CH}_3\text{CH}_2\text{CH}_2\text{Cl}$ is a 1° halide, which does not react by an $\text{S}_{\text{N}}1$ reaction because cleavage of the C-Cl bond forms a highly unstable 1° carbocation.

1-chloropropane less reactive

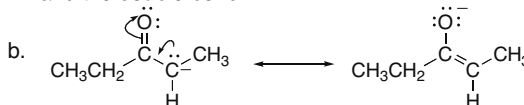


only one Lewis structure
very unstable

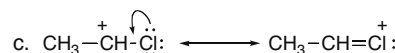
16.5



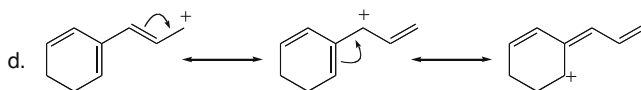
Move the charge and the double bond.



Move the charge and the double bond.



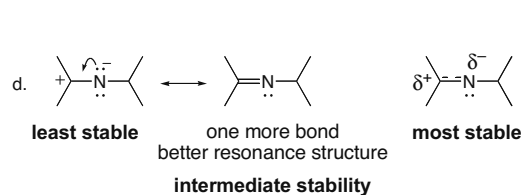
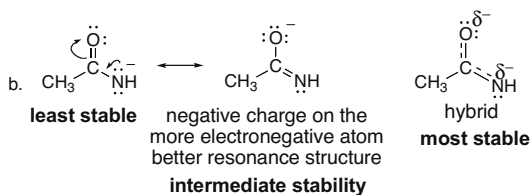
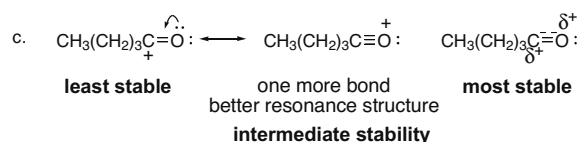
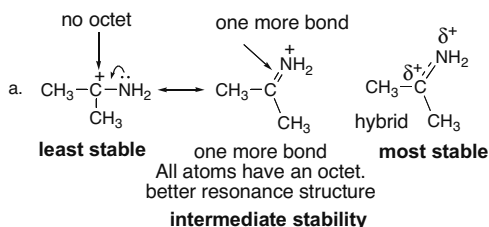
Move the lone pair.



Move the charge and the double bond.

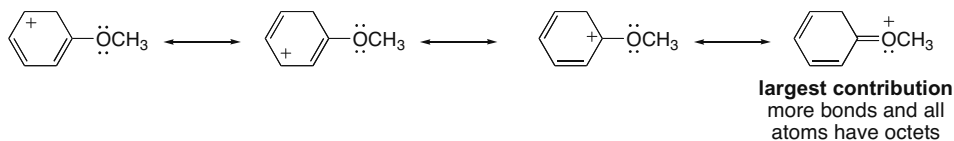
16.6 To compare the resonance structures remember:

- Resonance structures with **more bonds** are better.
- Resonance structures in which **every atom has an octet** are better.
- Resonance structures with **neutral atoms** are better than those with charge separation.
- Resonance structures that place a **negative charge on a more electronegative atom** are better.

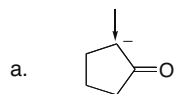


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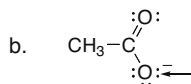
16.7



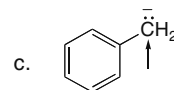
16.8 Remember that in any allyl system, there must be *p* orbitals to delocalize the lone pair.



sp^2 hybridized
trigonal planar geometry



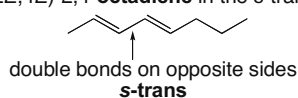
sp^2 hybridized
trigonal planar geometry



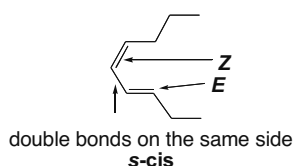
sp^2 hybridized
trigonal planar geometry

16.9 The **s-cis** conformation has two double bonds on the **same side** of the single bond.
The **s-trans** conformation has two double bonds on **opposite sides** of the single bond.

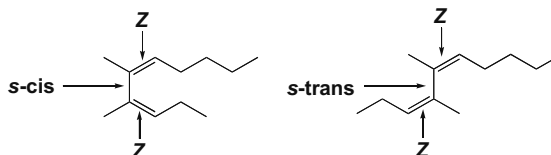
a. (2*E*,4*E*)-2,4-octadiene in the s-trans conformation



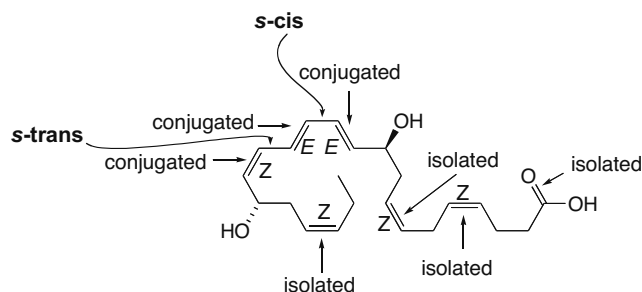
b. (3*E*,5*Z*)-3,5-nonadiene in the s-cis conformation



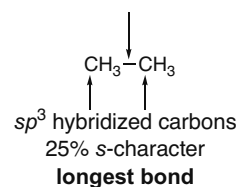
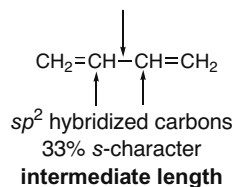
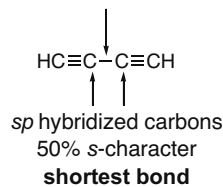
c. (3*Z*,5*Z*)-4,5-dimethyl-3,5-decadiene in both the s-cis and s-trans conformations



16.10

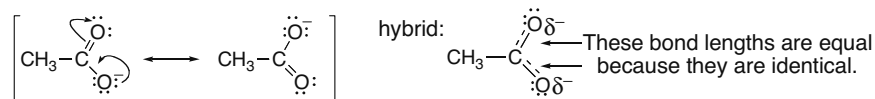


16.11 Bond length depends on hybridization and percent *s*-character. Bonds with a higher percent *s*-character have smaller orbitals and are shorter.

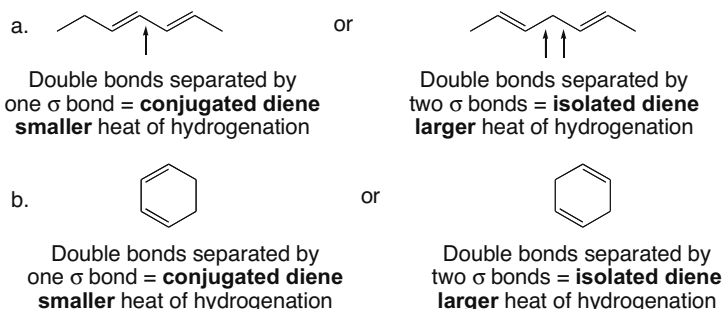


Conjugation, Resonance, and Dienes 16-9

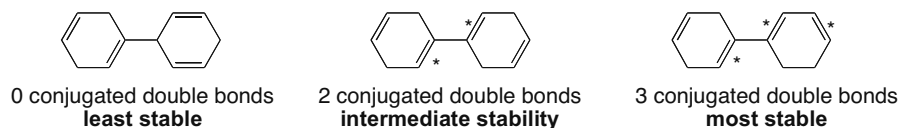
16.12 Two equivalent resonance structures delocalize the π bond and the negative charge.



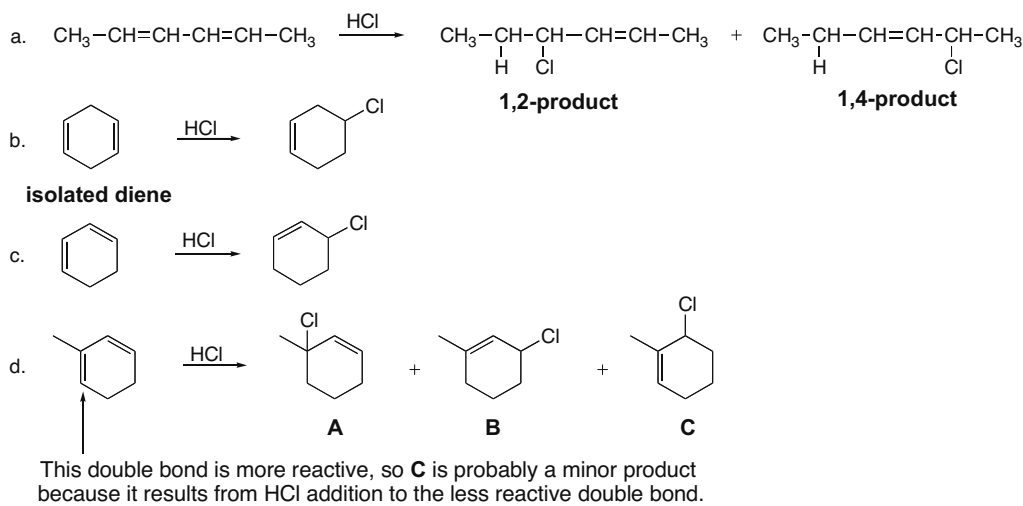
16.13 The **less stable** (higher energy) **diene** has the **larger heat of hydrogenation**. Isolated dienes are higher in energy than conjugated dienes, so they will have a larger heat of hydrogenation.



16.14 Isolated dienes are higher in energy than conjugated dienes. Compare the location of the double bonds in the compounds below.



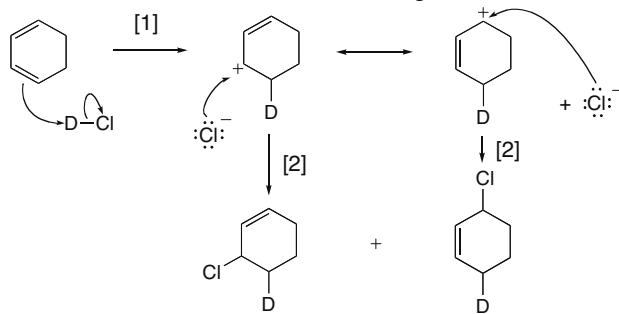
16.15 Conjugated dienes react with HX to form 1,2- and 1,4-products.



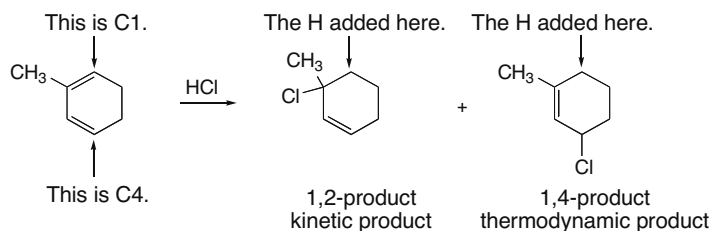
Chapter 16–10

16.16 The mechanism for addition of DCl has two steps:

- [1] **Addition of D^+** forms a resonance-stabilized carbocation.
- [2] **Nucleophilic attack of Cl^-** forms 1,2- and 1,4-products.

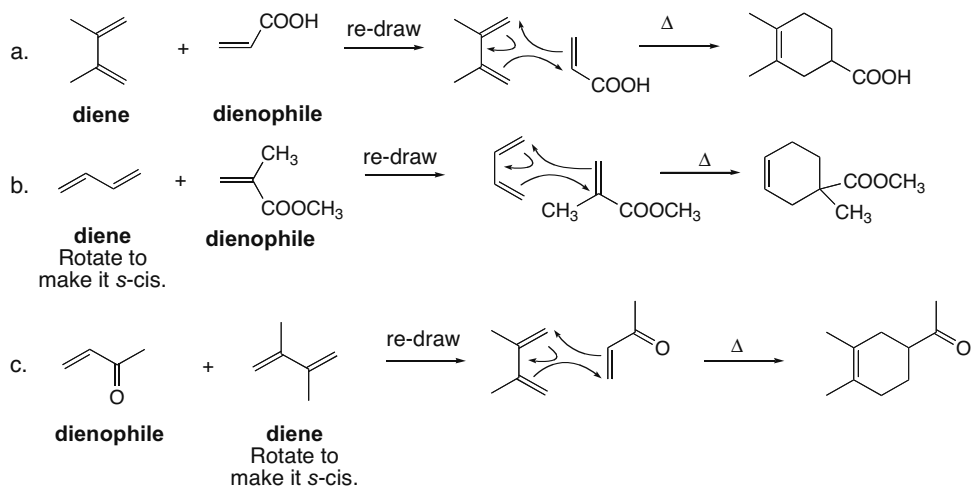


16.17 Label the products as 1,2- or 1,4-products. The 1,2-product is the kinetic product, and the 1,4-product, which has the more substituted double bond, is the thermodynamic product.



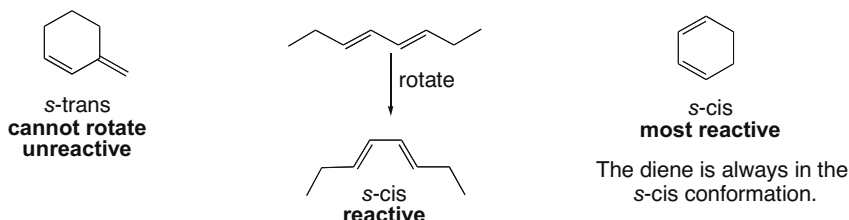
16.18 To draw the products of a Diels–Alder reaction:

- [1] Find the 1,3-diene and the dienophile.
- [2] Arrange them so the diene is on the left and the dienophile is on the right.
- [3] Cleave three bonds and use arrows to show where the new bonds will be formed.



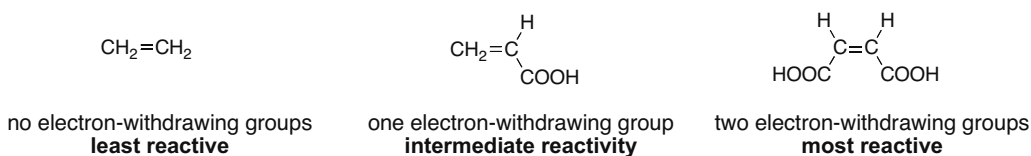
Conjugation, Resonance, and Dienes 16–11

16.19 For a diene to be reactive in a Diels–Alder reaction, a diene must be able to adopt an *s*-cis conformation.

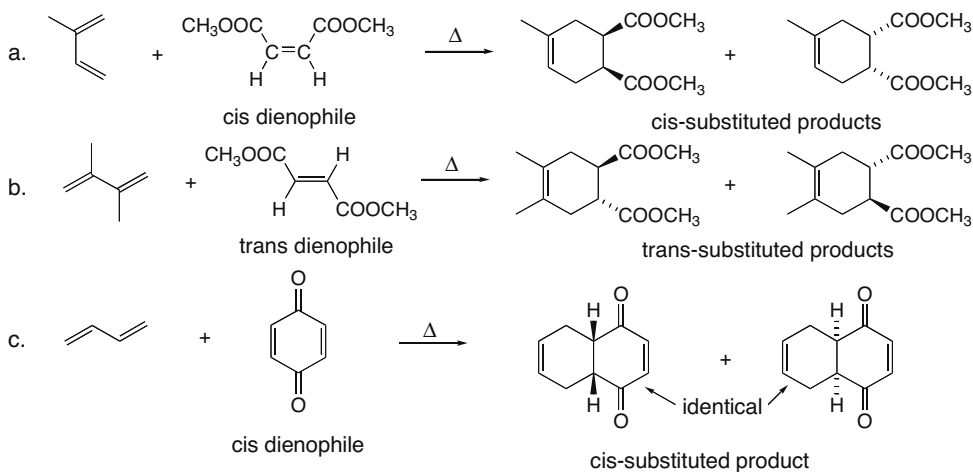


16.20 Zingiberene reacts much faster than β -sesquiphellandrene as a Diels–Alder diene because its diene is constrained in the *s*-cis conformation. The diene in β -sesquiphellandrene is constrained in the *s*-trans conformation, so it is unreactive in the Diels–Alder.

16.21 Electron-withdrawing substituents in the dienophile increase the reaction rate.

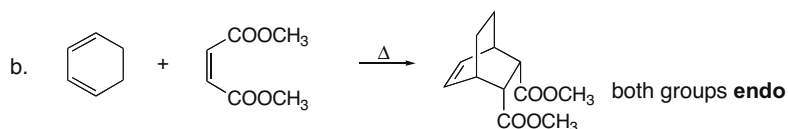
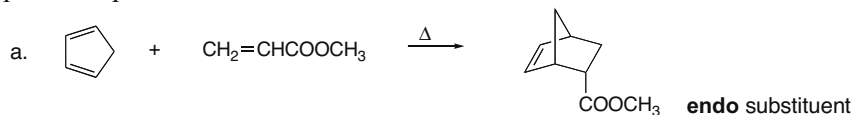


16.22 A cis dienophile forms a cis-substituted cyclohexene.
A trans dienophile forms a trans-substituted cyclohexene.



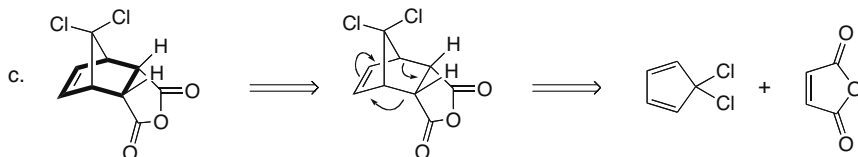
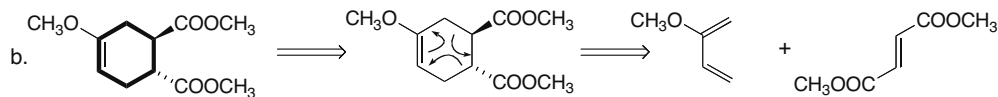
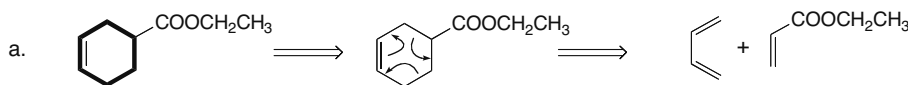
Chapter 16–12

16.23 The **endo product** (with the substituents under the plane of the new six-membered ring) is the preferred product.

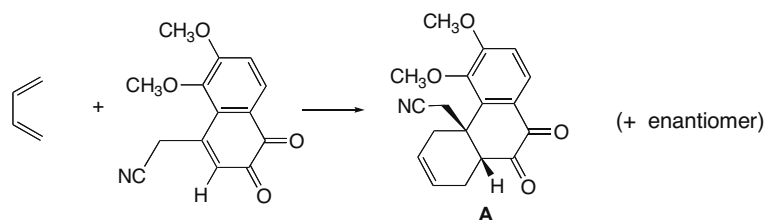


16.24 To find the diene and dienophile needed to make each of the products:

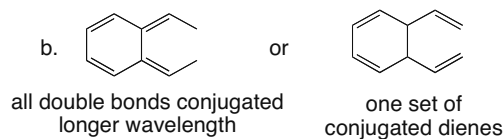
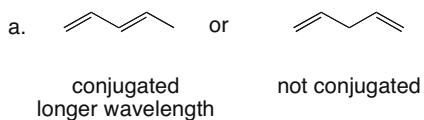
- [1] Find the six-membered ring with a C–C double bond.
- [2] Draw three arrows to work backwards.
- [3] Follow the arrows to show the diene and dienophile.



16.25

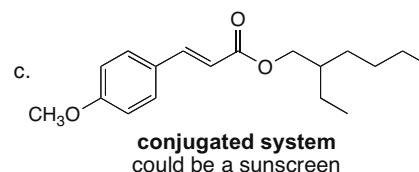
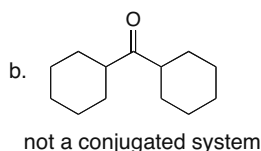
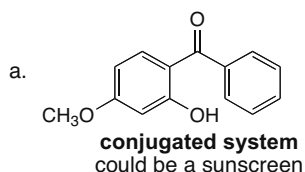


16.26 Conjugated molecules absorb light at a longer wavelength than molecules that are not conjugated.

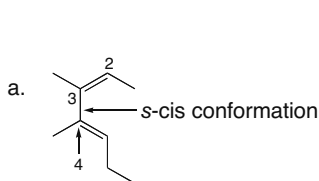


Conjugation, Resonance, and Dienes 16-13

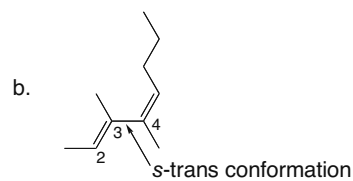
16.27 Sunscreens contain conjugated systems to absorb UV radiation from sunlight. Look for conjugated systems in the compounds below.



16.28

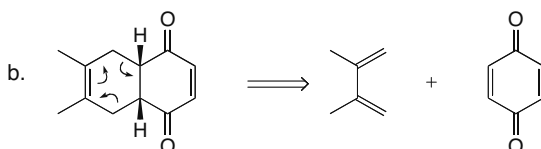
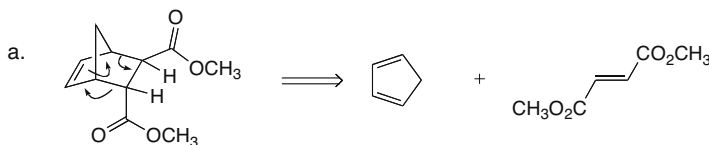


(2Z,4E)-3,4-dimethyl-2,4-heptadiene

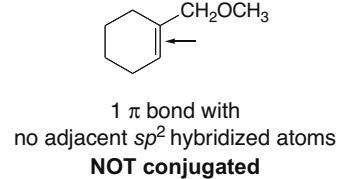
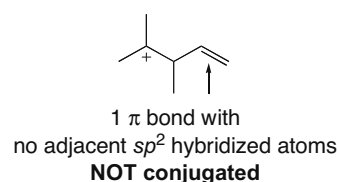
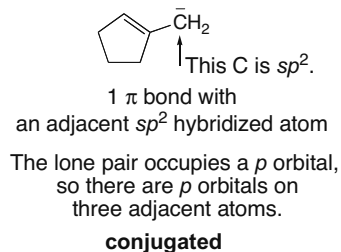
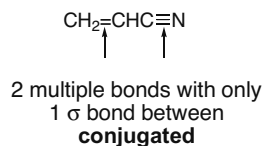
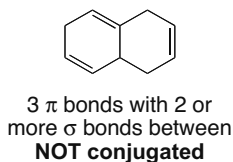
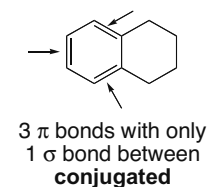


(2E,4Z)-3,4-dimethyl-2,4-octadiene

16.29

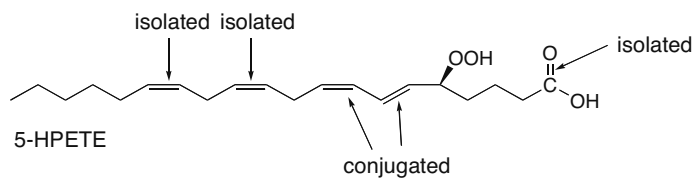


16.30 Use the definition from Answer 16.1.

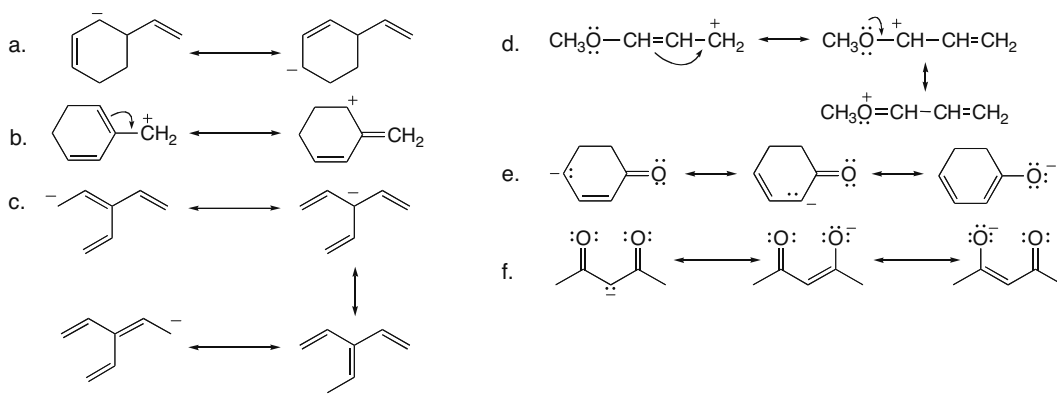


Chapter 16–14

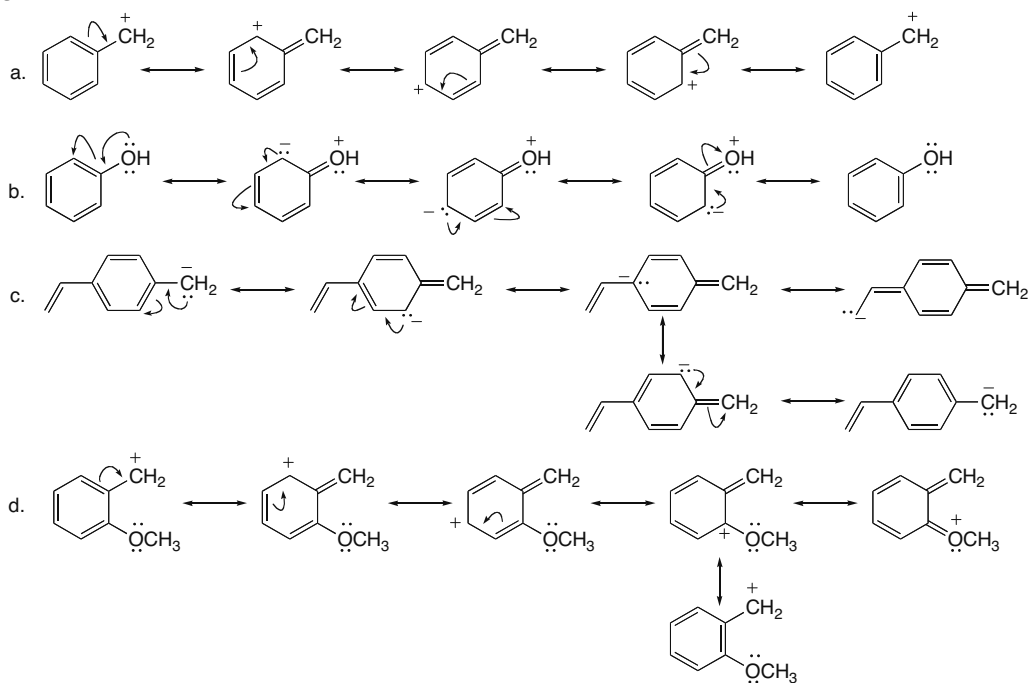
16.31



16.32

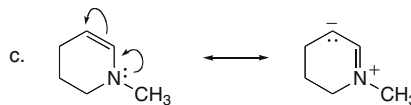
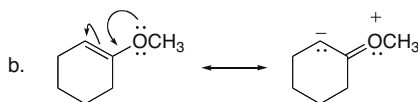


16.33

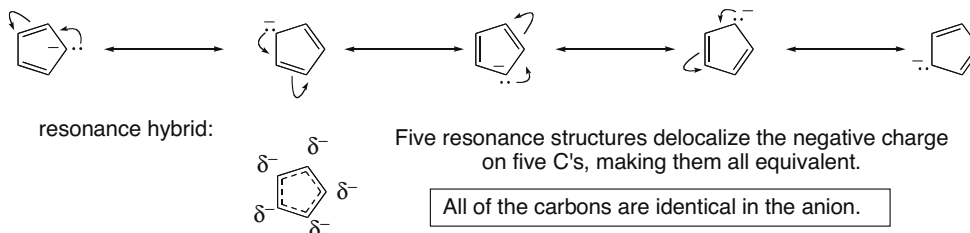


Conjugation, Resonance, and Dienes 16-15

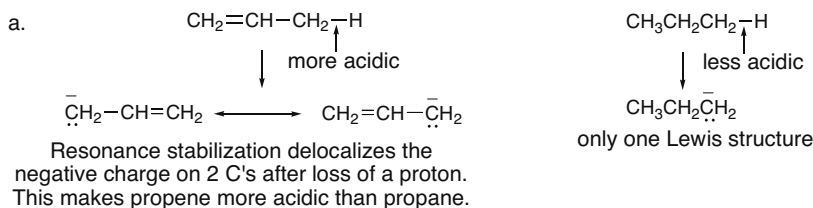
16.34 No additional resonance structures can be drawn for compounds (a) and (d).



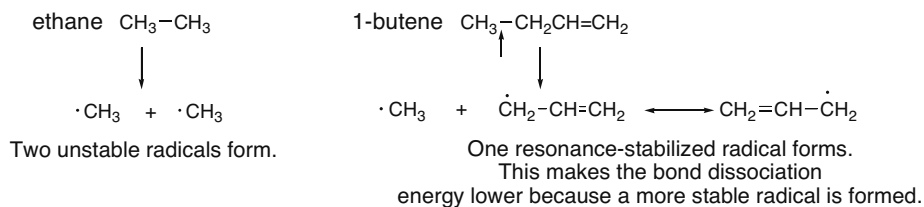
16.35



16.36

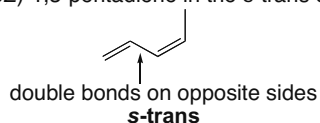


b. Draw the products of cleavage of the bond.

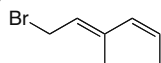


16.37 Use the directions from Answer 16.9.

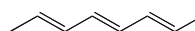
a. (3Z)-1,3-pentadiene in the s-trans conformation



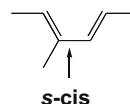
b. (2E,4Z)-1-bromo-3-methyl-2,4-hexadiene



c. (2E,4E,6E)-2,4,6-octatriene

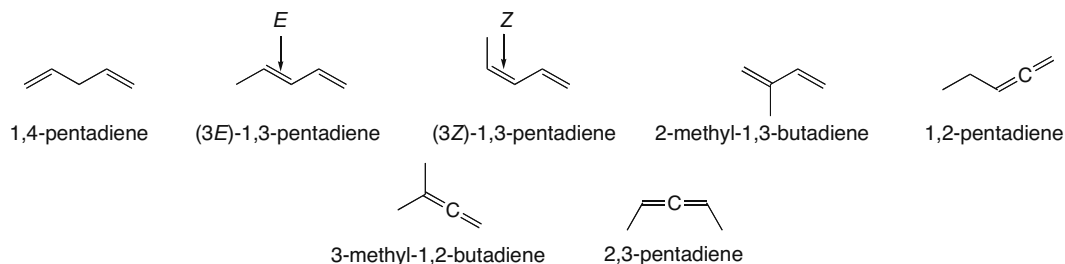


d. (2E,4E)-3-methyl-2,4-hexadiene in the s-cis conformation

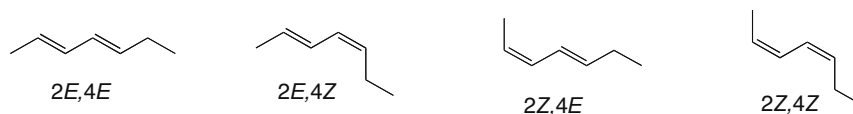


Chapter 16–16

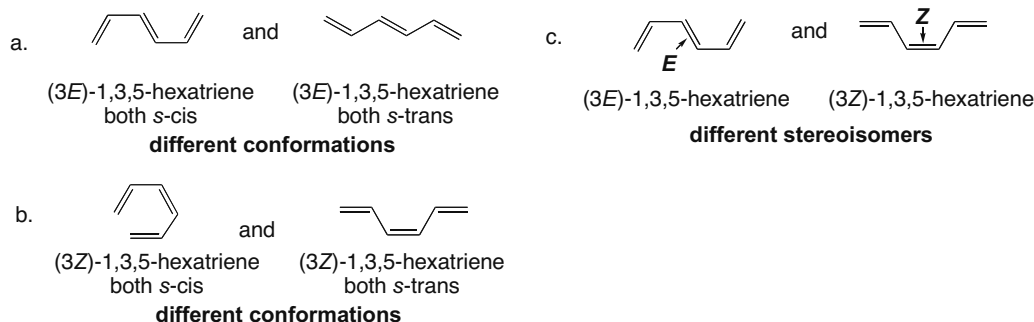
16.38



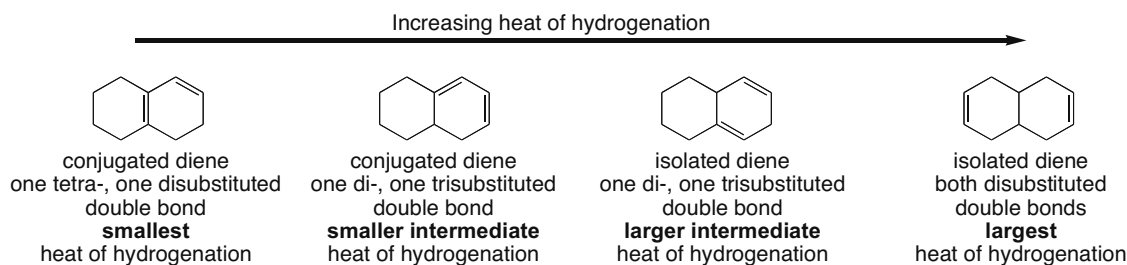
16.39



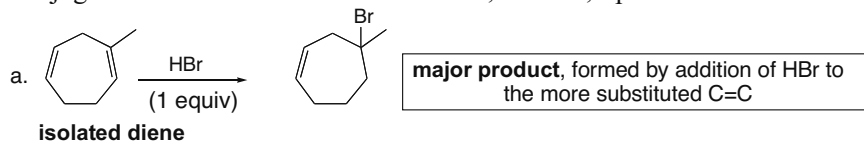
16.40



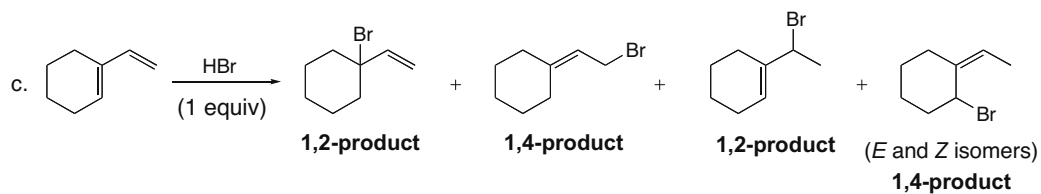
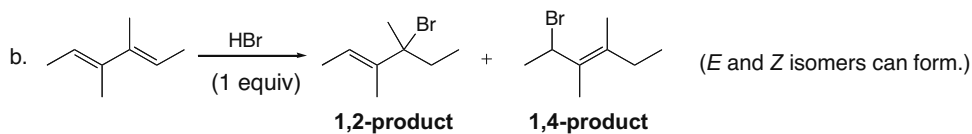
16.41 Use the directions from Answer 16.13 and recall that more substituted double bonds are more stable.



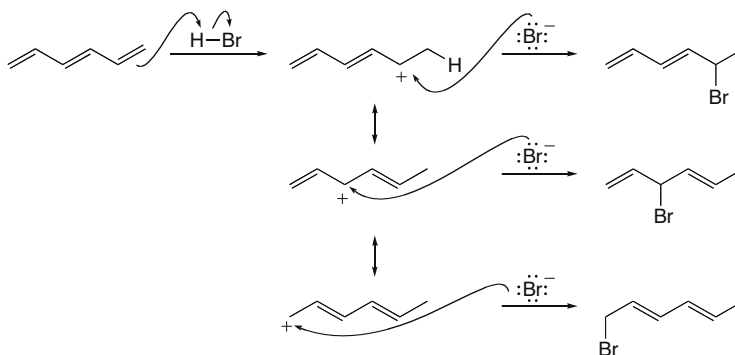
16.42 Conjugated dienes react with HX to form 1,2- and 1,4-products.



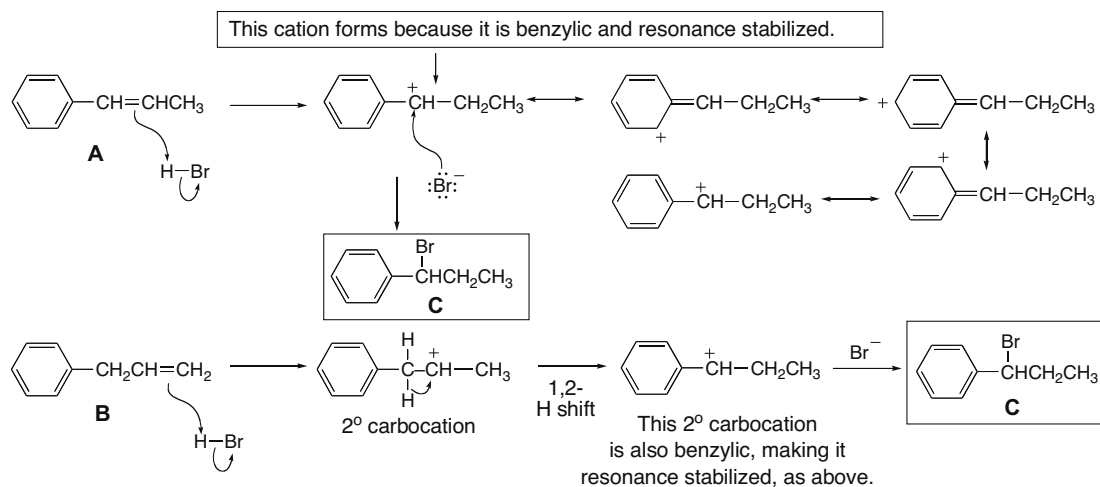
Conjugation, Resonance, and Dienes 16–17



16.43

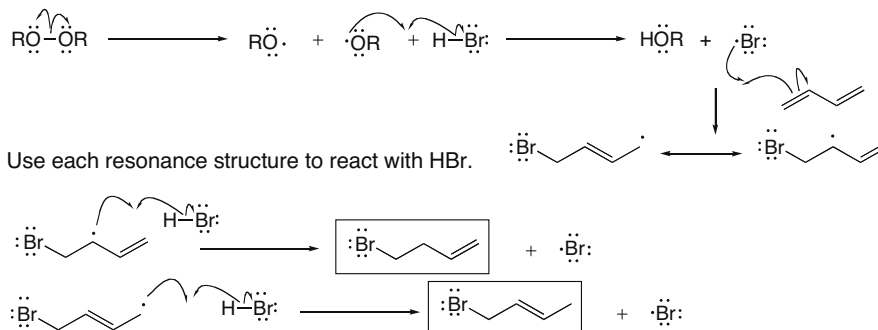


16.44

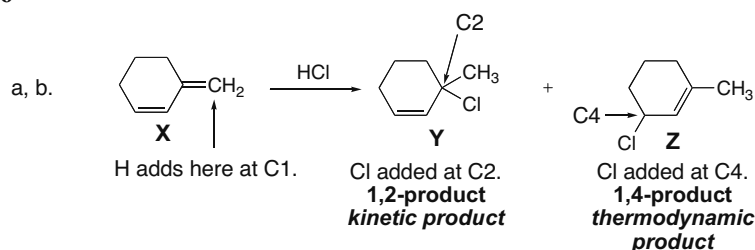


16.45 To draw the mechanism for reaction of a diene with HBr and ROOR, recall from Chapter 15 that when an alkene is treated with HBr under these radical conditions, the Br ends up on the carbon with more H's to begin with.

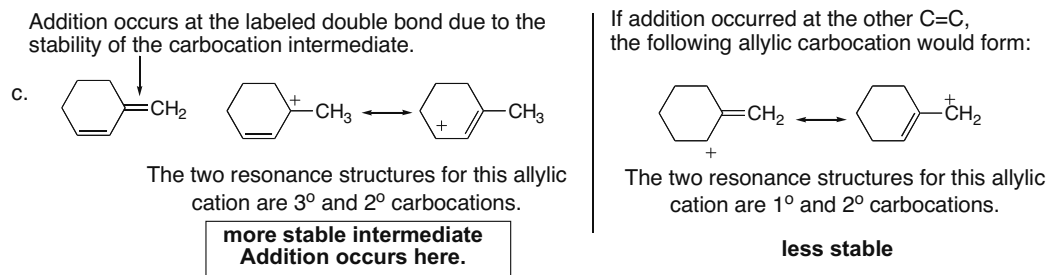
Chapter 16–18



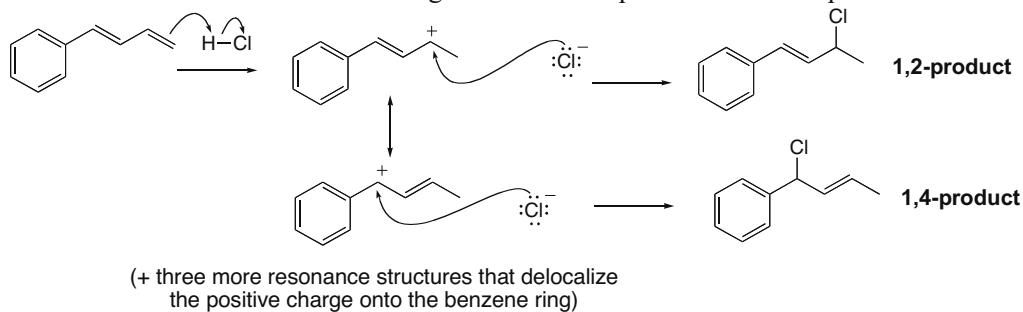
16.46



Y is the kinetic product because of the proximity effect. H and Cl add across two adjacent atoms.
Z is the thermodynamic product because it has a more stable trisubstituted double bond.

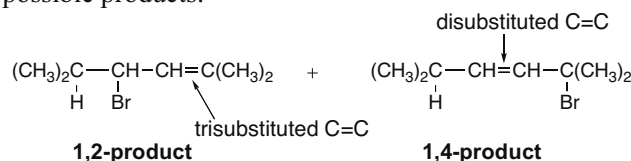


16.47 Addition of HCl at the terminal double bond forms a carbocation that is highly resonance stabilized since it is both allylic and benzylic. Such stabilization does not occur when HCl is added to the other double bond. This gives rise to two products of electrophilic addition.



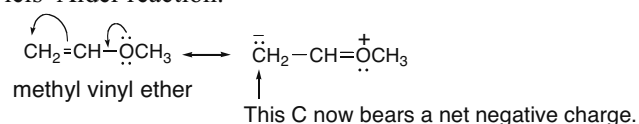
Conjugation, Resonance, and Dienes 16–19

16.48 There are two possible products:

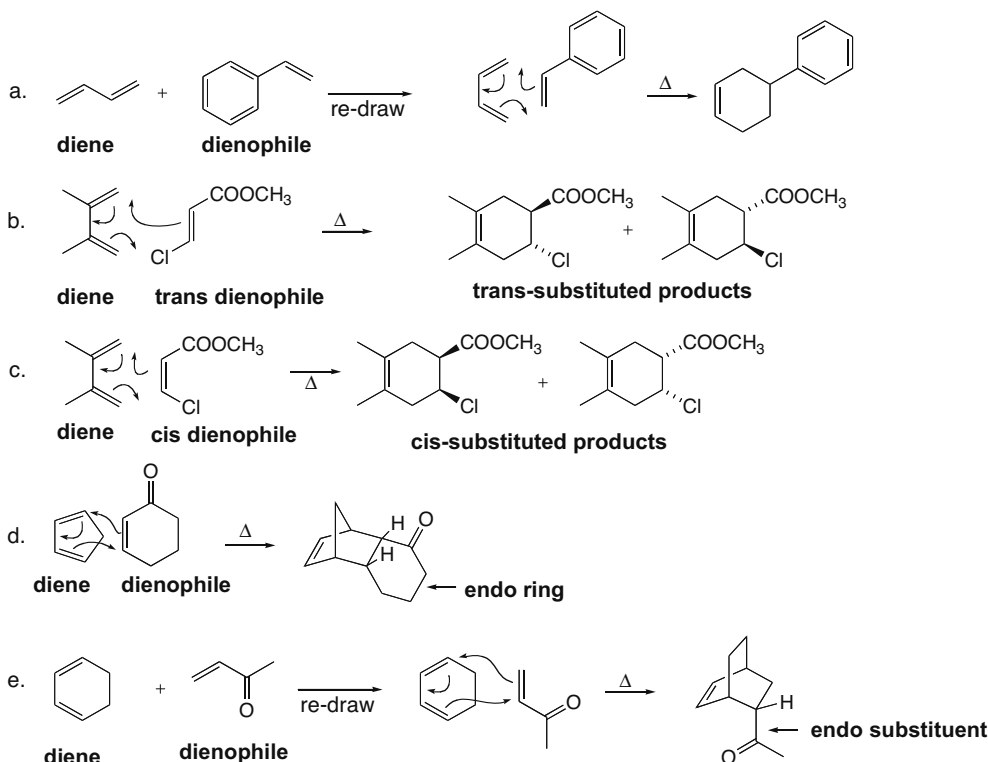


The 1,2-product is always the kinetic product because of the proximity effect. In this case, it is also the thermodynamic (more stable) product because it contains a more highly substituted C=C (trisubstituted) than the 1,4-product (disubstituted). Thus, the 1,2-product is the major product at high and low temperature.

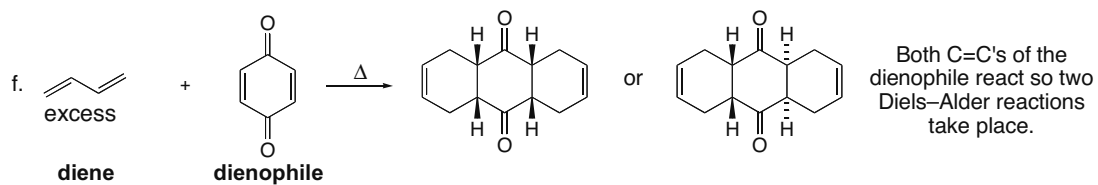
16.49 The electron pairs on O can be donated to the double bond through resonance. This increases the electron density of the double bond, making it less electrophilic and therefore less reactive in a Diels–Alder reaction.



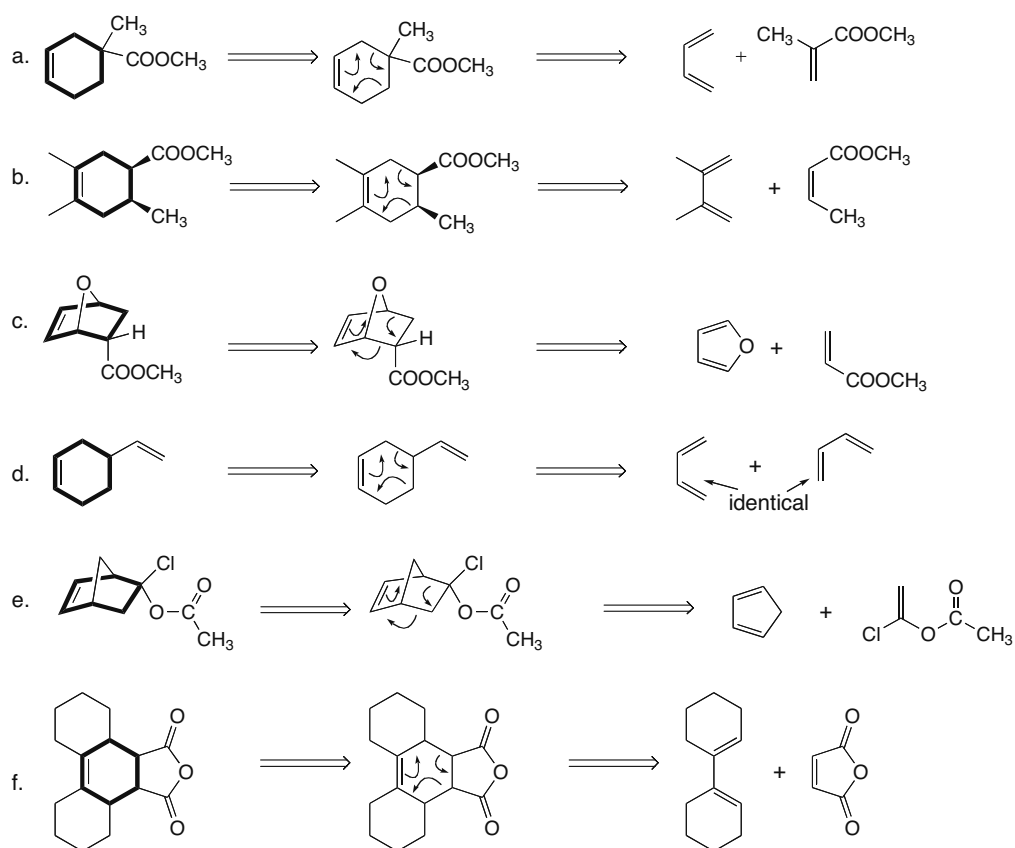
16.50 Use the directions from Answer 16.18.



Chapter 16–20

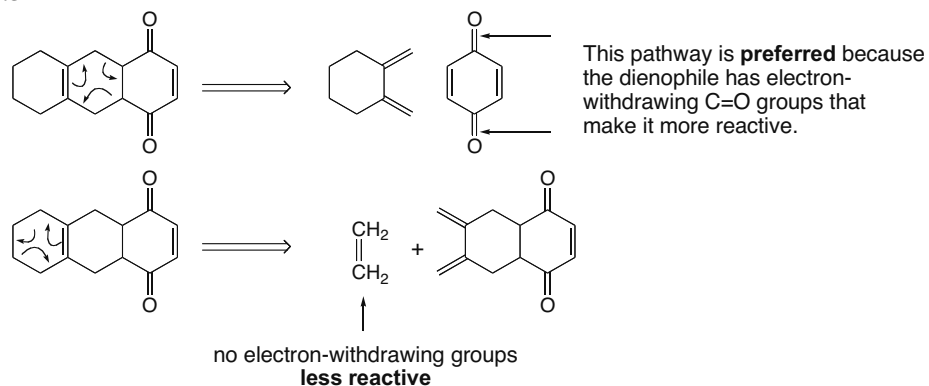


16.51 Use the directions from Answer 16.24.

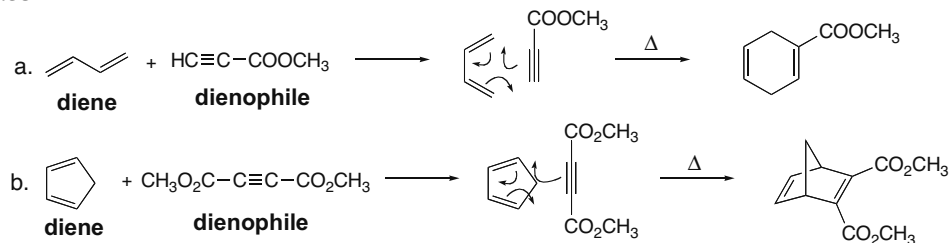


Conjugation, Resonance, and Dienes 16–21

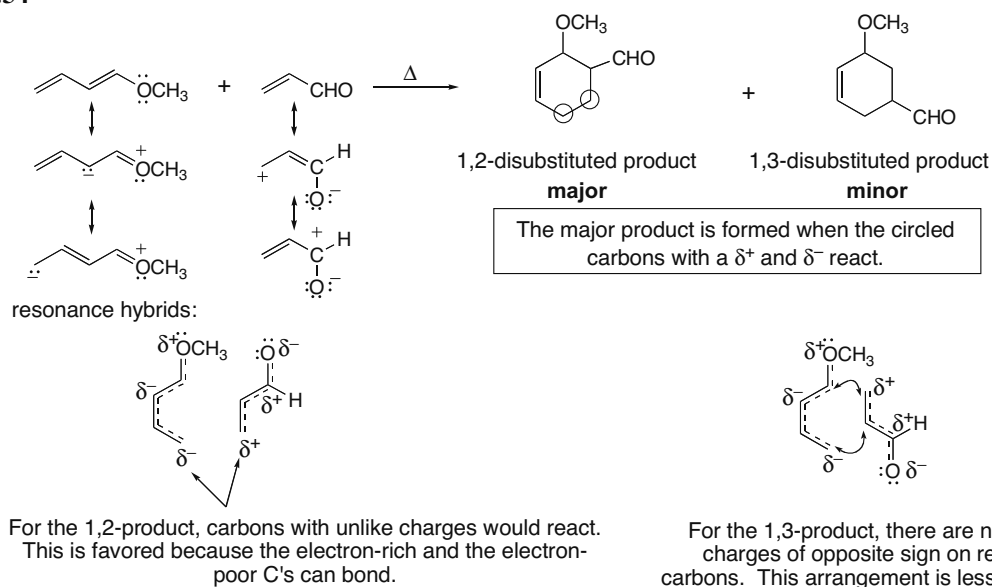
16.52



16.53

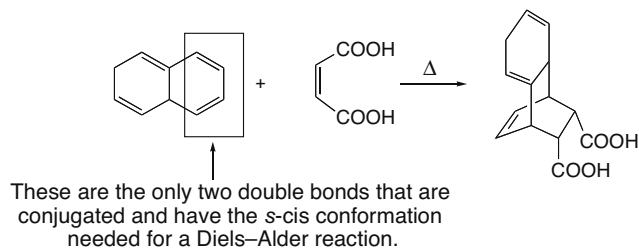


16.54

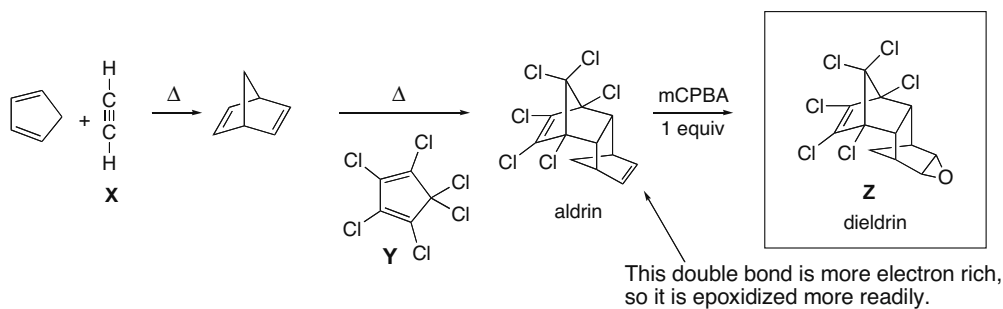


Chapter 16–22

16.55

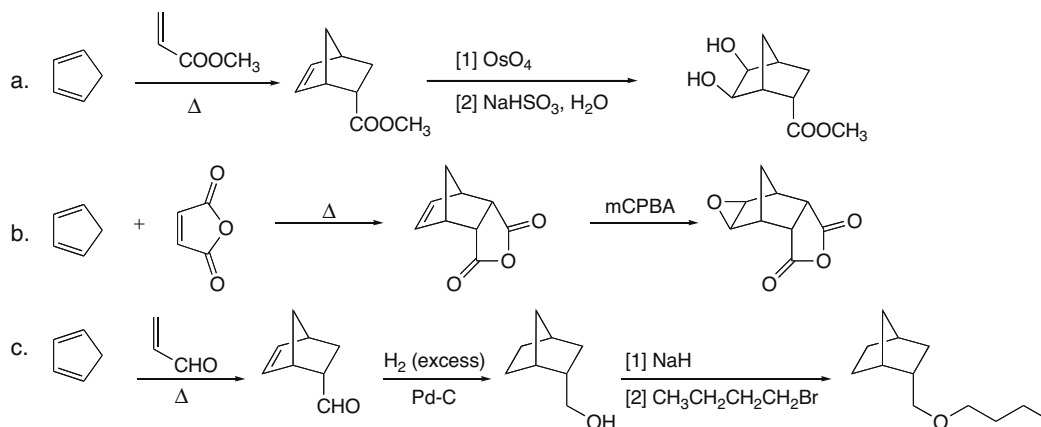
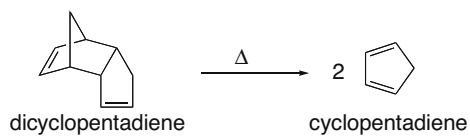


16.56



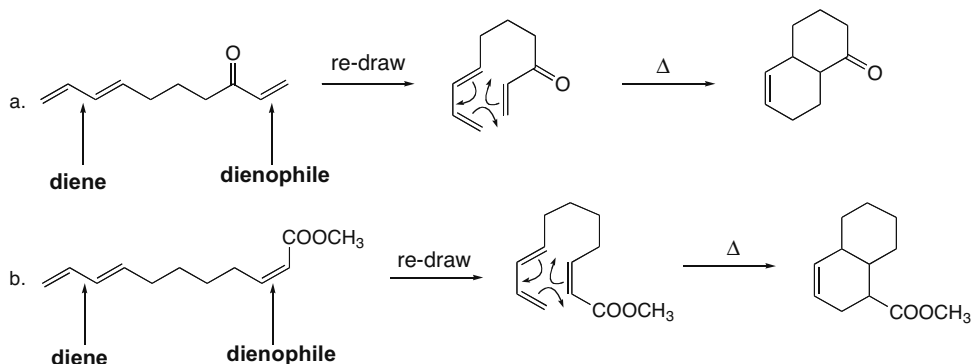
16.57

In each problem, the synthesis must begin with the preparation of cyclopentadiene from dicyclopentadiene.

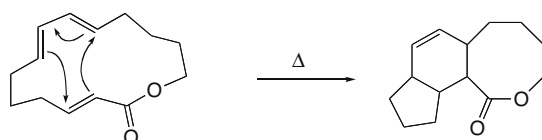


Conjugation, Resonance, and Dienes 16–23

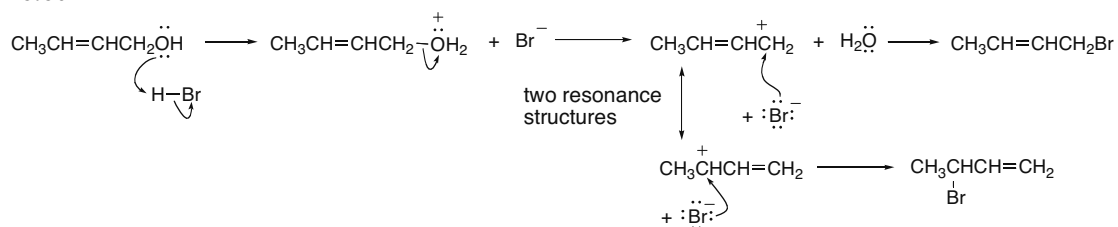
16.58



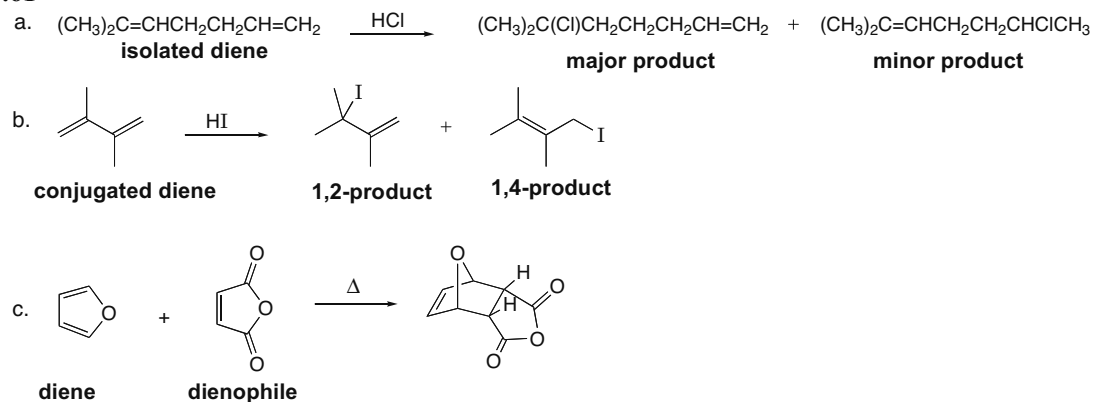
16.59 A transannular Diels–Alder reaction forms a tricyclic product from a monocyclic starting material.



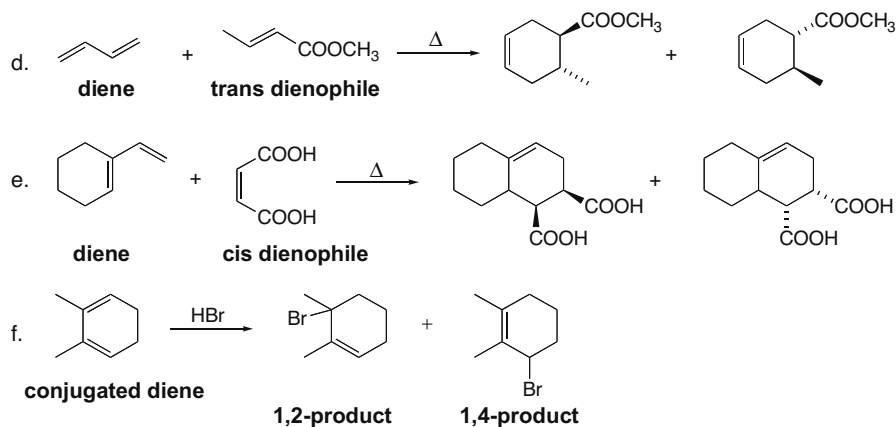
16.60



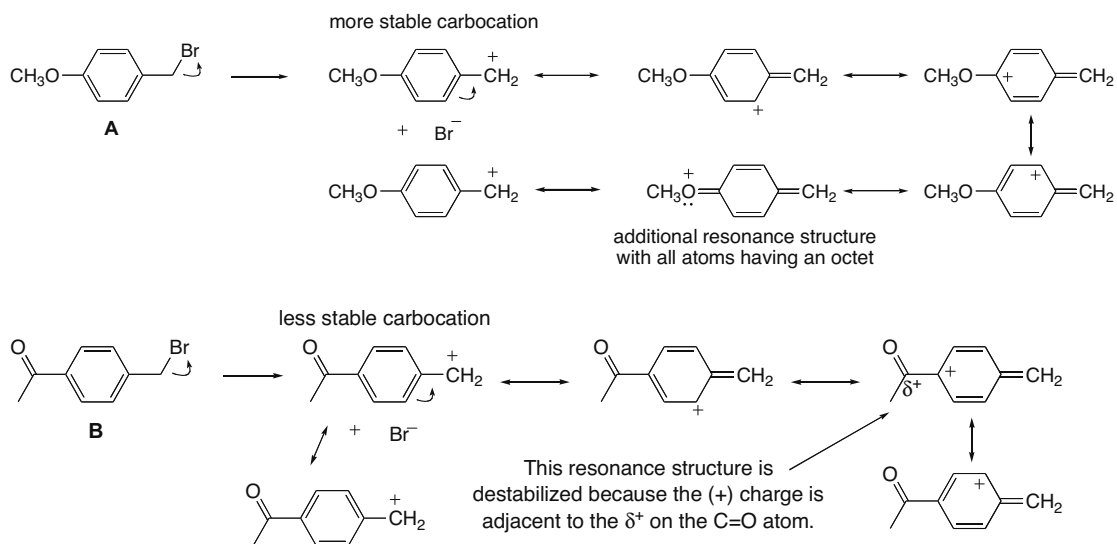
16.61



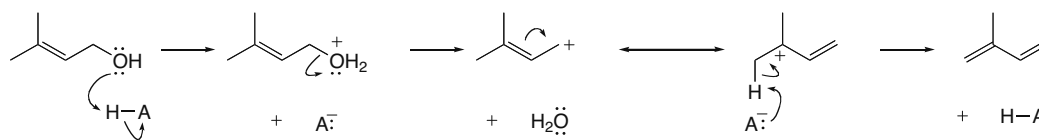
Chapter 16–24



16.62 The more stable the carbocation, the faster the S_N1 reaction. The carbocation from **A** is more stable because the lone pairs on the O atom of the OCH_3 afford additional resonance stabilization.

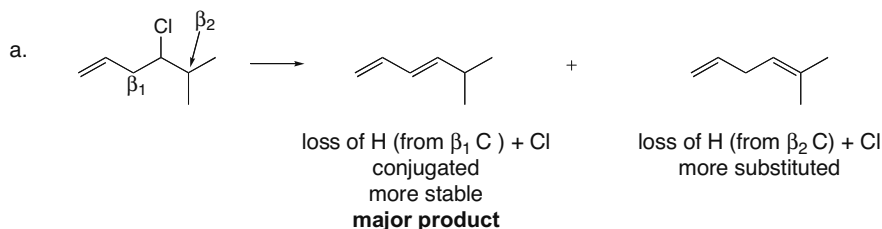


16.63 The mechanism is $E1$, with formation of a resonance-stabilized carbocation.



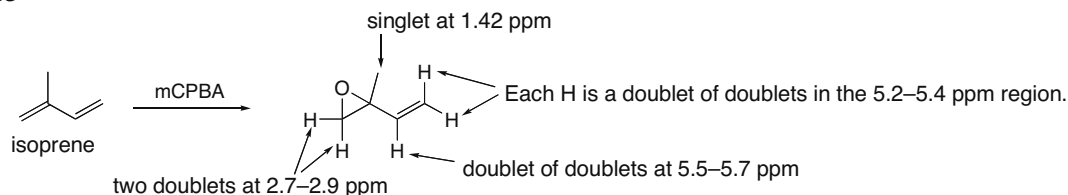
Conjugation, Resonance, and Dienes 16–25

16.64

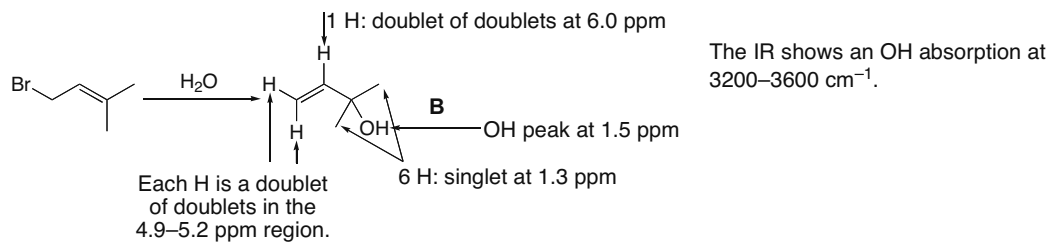


b. Dehydrohalogenation generally forms the more stable product. In this reaction, loss of H from the β_1 carbon forms a more stable conjugated diene, so this product is preferred even though it does not contain the more substituted C=C.

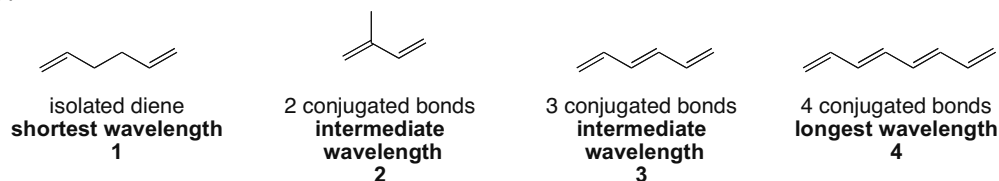
16.65



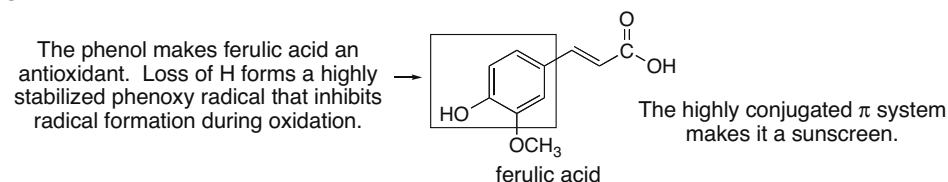
16.66



16.67

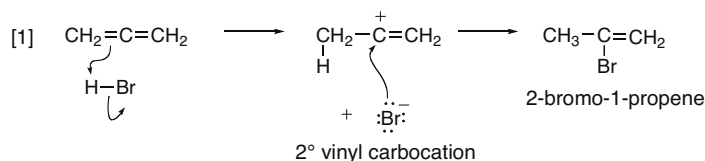


16.68

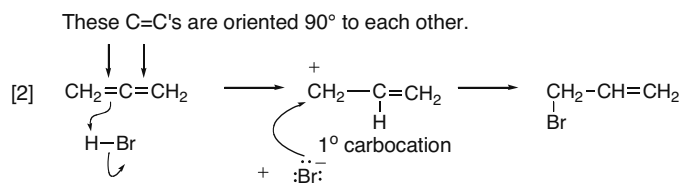


Chapter 16–26

16.69 There are two possible modes of addition of HBr to allene. When H^+ adds to the terminal carbon, a 2° vinyl carbocation is formed, which affords 2-bromo-1-propene after nucleophilic attack.



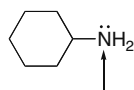
When H^+ adds to the middle carbon, an intermediate carbocation with a (+) charge adjacent to the $\text{C}=\text{C}$ is formed. This carbocation is not resonance stabilized (at least initially), because the two $\text{C}=\text{C}$'s of allene are oriented 90° to each other, a geometry that does not allow for overlap of the $\text{C}=\text{C}$ with the empty p orbital of the carbocation.



As a result, path [1] forms a more stable carbocation and is preferred.

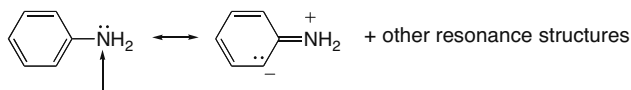
16.70

cyclohexanamine



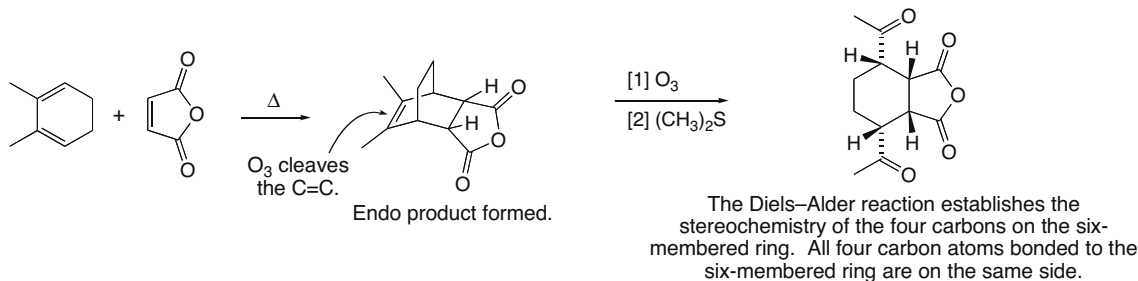
N is surrounded by 3 atoms and 1 lone pair so it is sp^3 hybridized.

aniline



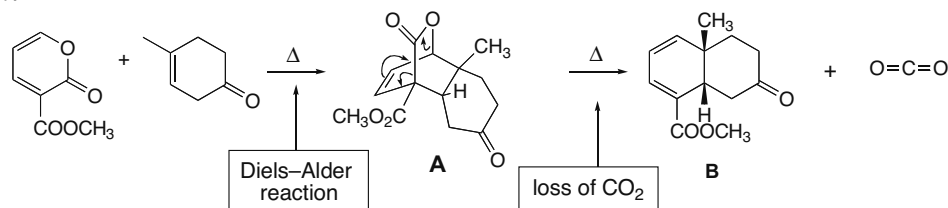
N has a lone pair on an atom adjacent to a $\text{C}=\text{C}$. N must be sp^2 hybridized to delocalize the lone pair by resonance.

Basicity is a measure of how willing an atom is to donate an electron pair. Since the lone pair on the N in aniline is delocalized on the benzene ring, it is less available for donation to a proton. This makes aniline much less basic.

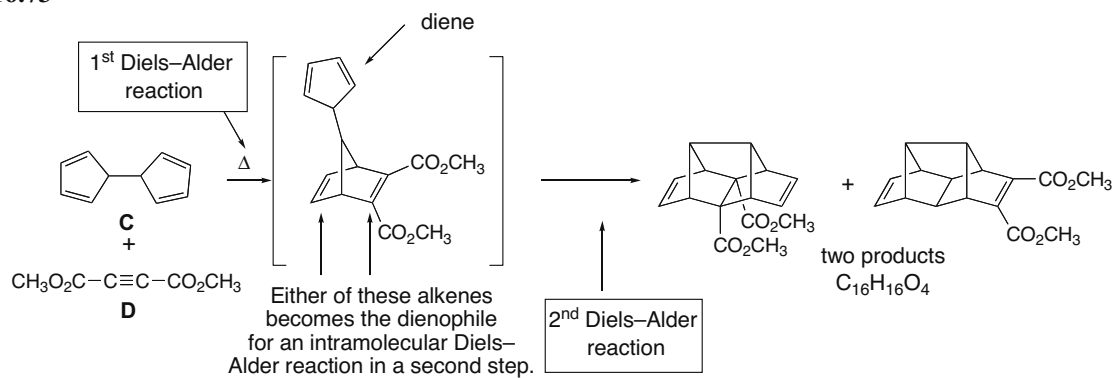
16.71

Conjugation, Resonance, and Dienes 16-27

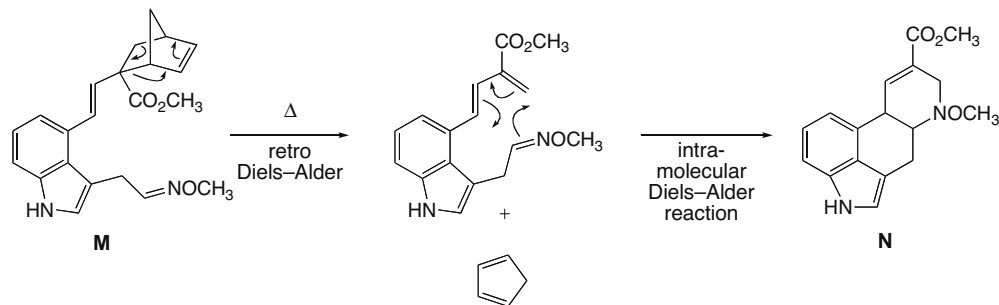
16.72



16.73



16.74 Retro Diels-Alder reaction forms a conjugated diene. Intramolecular Diels-Alder reaction then forms N.



Chapter 17 Benzene and Aromatic Compounds

Chapter Review

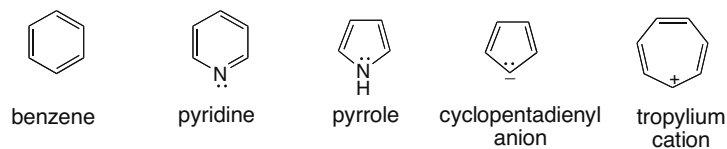
Comparing aromatic, antiaromatic, and nonaromatic compounds (17.7)

- Aromatic compound**
 - A cyclic, planar, completely conjugated compound that contains $4n + 2 \pi$ electrons ($n = 0, 1, 2, 3$, and so forth).
 - An aromatic compound is more stable than a similar acyclic compound having the same number of π electrons.
- Antiaromatic compound**
 - A cyclic, planar, completely conjugated compound that contains $4n \pi$ electrons ($n = 0, 1, 2, 3$, and so forth).
 - An antiaromatic compound is less stable than a similar acyclic compound having the same number of π electrons.
- A compound that is not aromatic**
 - A compound that lacks one (or more) of the requirements to be aromatic or antiaromatic.

Properties of aromatic compounds

- Every carbon has a p orbital to delocalize electron density (17.2).
- They are unusually stable. ΔH° for hydrogenation is much less than expected, given the number of degrees of unsaturation (17.6).
- They do not undergo the usual addition reactions of alkenes (17.6).
- ^1H NMR spectra show highly deshielded protons because of ring currents (17.4).

Examples of aromatic compounds with 6 π electrons (17.8)



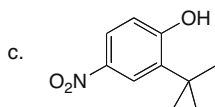
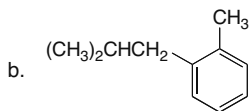
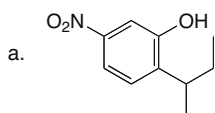
Examples of compounds that are not aromatic (17.8)



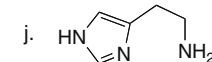
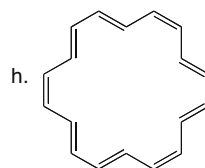
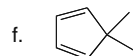
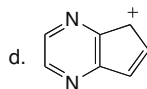
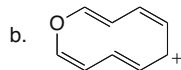
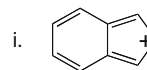
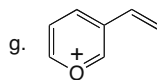
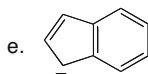
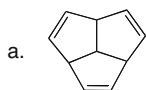
Chapter 17-2

Practice Test on Chapter Review

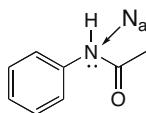
1. Give the IUPAC name for each of the following compounds.



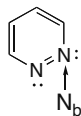
2. Label each compound as aromatic, nonaromatic, or antiaromatic. Choose only **one** possibility. Assume all completely conjugated rings are planar.



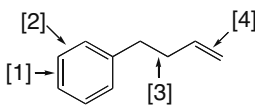
3. Answer the following questions about compounds A–E drawn below.



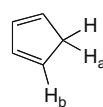
A



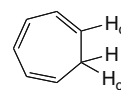
B



C



D



E

Benzene and Aromatic Compounds 17-3

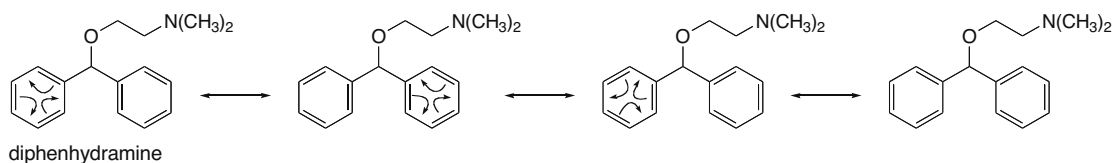
- How is nitrogen N_a in compound **A** hybridized?
- In what type of orbital does the lone pair on N_a reside?
- How is nitrogen N_b in compound **B** hybridized?
- In what type of orbital does the lone pair on N_b reside?
- Which of the labeled bonds in compound **C** is the shortest?
- Which of the labeled bonds in compound **C** is the longest?
- When considering both compounds **D** and **E**, which of the labeled hydrogen atoms (H_a , H_b , H_c , or H_d) is the most acidic? Give only **one** answer.
- When considering both compounds **D** and **E**, which of the labeled hydrogen atoms (H_a , H_b , H_c , or H_d) is the least acidic? Give only **one** answer.

Answers to Practice Test

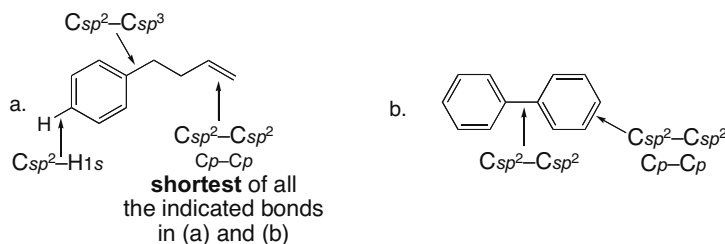
1.a. 2-sec-butyl-5-nitrophenol	2.a. nonaromatic	3.a. sp^2
b. o-isobutyltoluene	b. aromatic	b. p
c. 2-tert-butyl-4-nitrophenol	c. nonaromatic	c. sp^2
	d. antiaromatic	d. sp^2
	e. aromatic	e. 4
	f. nonaromatic	f. 3
	g. aromatic	g. H_a
	h. aromatic	h. H_c
	i. antiaromatic	
	j. aromatic	

Answers to Problems

- 17.1 Move the electrons in the π bonds to draw all major resonance structures.



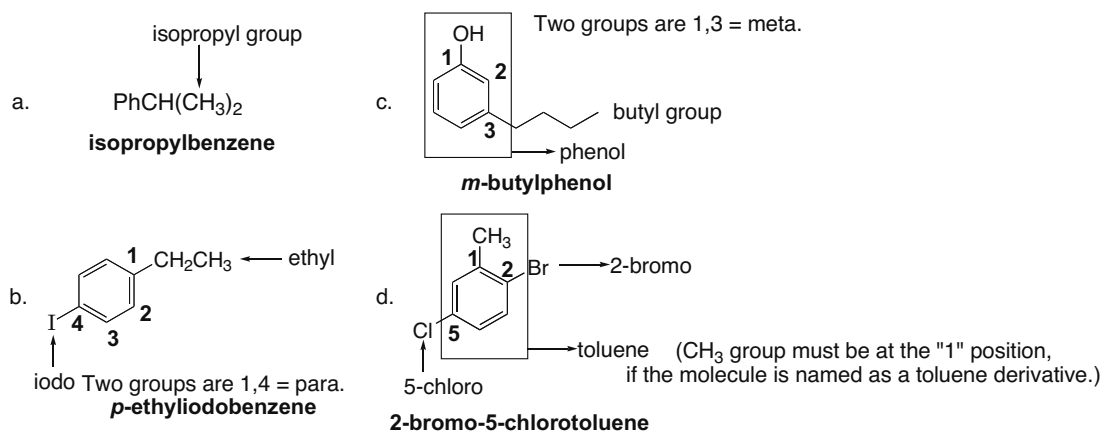
- 17.2 Look at the hybridization of the atoms involved in each bond. Carbons in a benzene ring are surrounded by three groups and are sp^2 hybridized.



Chapter 17-4

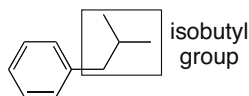
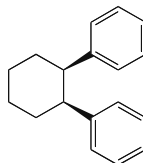
17.3

- To name a benzene ring with **one substituent**, name the substituent and add the word *benzene*.
- To name a **disubstituted ring**, select the correct prefix (ortho = 1,2; meta = 1,3; para = 1,4) and alphabetize the substituents. Use a common name if it is a derivative of that monosubstituted benzene.
- To name a **polysubstituted ring**, number the ring to give the lowest possible numbers and then follow other rules of nomenclature.

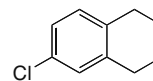


17.4 Work backwards to draw the structures from the names.

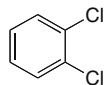
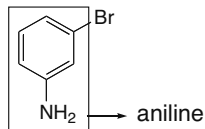
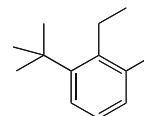
a. isobutylbenzene

c. *cis*-1,2-diphenylcyclohexane

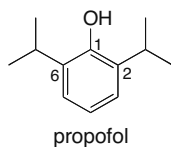
e. 4-chloro-1,2-diethylbenzene



b. o-dichlorobenzene

d. *m*-bromoanilinef. 3-*tert*-butyl-2-ethyltoluene

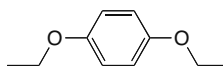
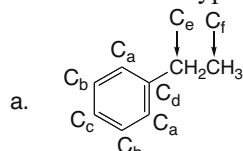
17.5



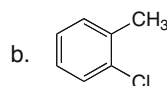
Benzene and Aromatic Compounds 17–5

17.6

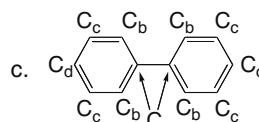
Molecular formula $C_{10}H_{14}O_2$: 4 degrees of unsaturation
 IR absorption at $3150\text{--}2850\text{ cm}^{-1}$: sp^2 and sp^3 hybridized C–H bonds
 NMR absorptions (ppm):
 1.4 (triplet, 6 H)
 4.0 (quartet, 4 H)
 6.8 (singlet, 4 H)

17.7 Count the different types of carbons to determine the number of ^{13}C NMR signals.

4 types of C's in the benzene ring
 6 signals

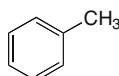


All C's are different.
 7 signals



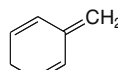
4 signals

17.8 The less stable compound has a larger heat of hydrogenation.



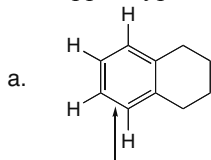
A

benzene ring, more stable
 smaller ΔH°

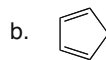


B

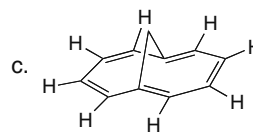
no benzene ring, less stable
 larger ΔH°

17.9 The protons on sp^2 hybridized carbons in aromatic hydrocarbons are highly deshielded and absorb at 6.5–8 ppm whereas hydrocarbons that are not aromatic show an absorption at 4.5–6 ppm, typical of protons bonded to the C=C of an alkene.

aromatic ring
 H's ~6.5–8 ppm



not aromatic
 alkene H's ~4.5–6 ppm



aromatic ring
 H's ~6.5–8 ppm

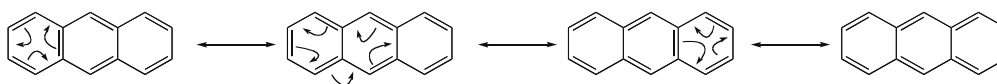
17.10 To be aromatic, a ring must have $4n + 2 \pi$ electrons.

$16 \pi e^-$
 $4n$
 $4(4) = 16$
antiaromatic

$20 \pi e^-$
 $4n$
 $4(5) = 20$
antiaromatic

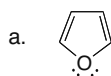
$22 \pi e^-$
 $4n + 2$
 $4(5) + 2 = 22$
aromatic

17.11

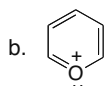


Chapter 17–6

17.12 In determining if a heterocycle is aromatic, count a nonbonded electron pair if it makes the ring aromatic in calculating $4n + 2$. Lone pairs on atoms already part of a multiple bond cannot be delocalized in a ring, and so they are never counted in determining aromaticity.



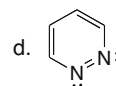
Count one lone pair from O.
 $4n + 2 = 4(1) + 2 = 6$
aromatic



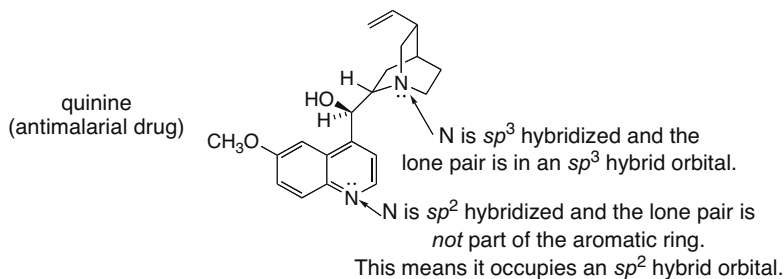
no lone pair from O
 $4n + 2 = 4(1) + 2 = 6$
aromatic



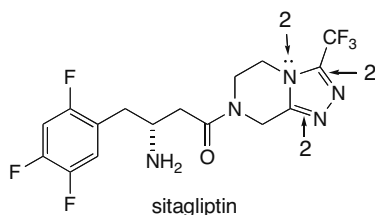
With one lone pair from each O there would be 8 electrons. If O's are sp^3 hybridized, the ring is not completely conjugated.
not aromatic



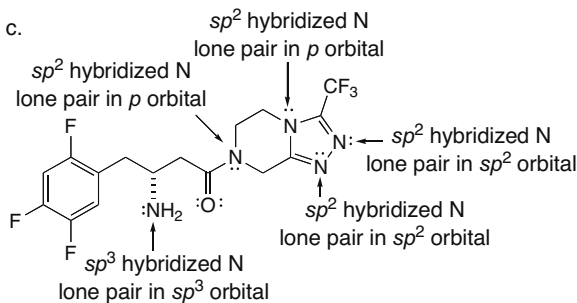
Both N atoms are part of a double bond, so the lone pairs cannot be counted: there are 6 electrons.
 $4n + 2 = 4(1) + 2 = 6$
aromatic

17.13**17.14**

a. The five-membered ring is aromatic because it has 6 π electrons, two from each π bond and two from the N atom that is not part of a double bond.



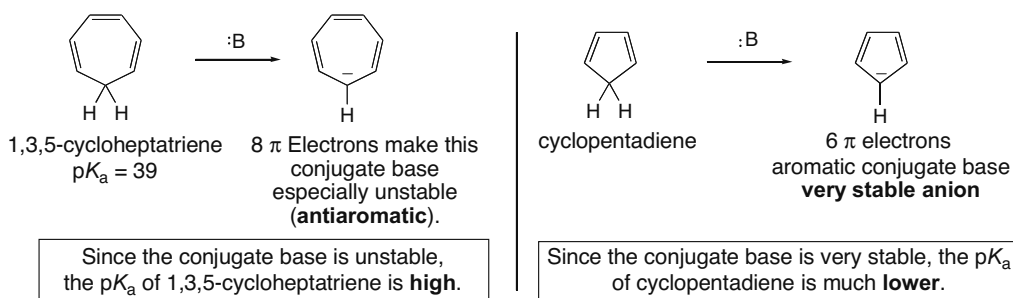
b, c.



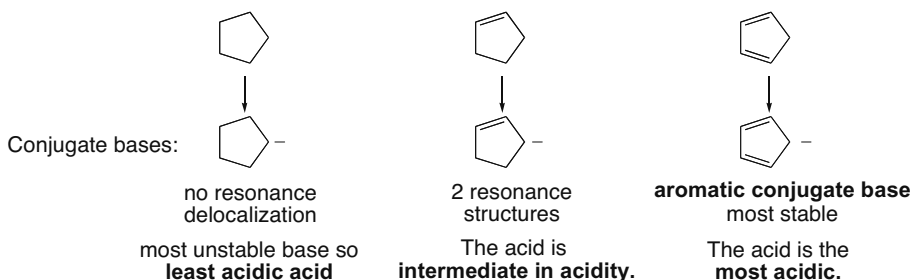
17.15 Since a neutral oxygen atom forms only two bonds, it must always donate its electron pair to a delocalized π electron system (like the N atom of pyrrole). It can never be part of a double bond, because it would carry a net (+) charge. With nitrogen, however, a N atom can either donate an electron pair or be part of a double bond, since N forms three bonds. In a neutral five-membered aromatic ring, there are two π bonds (where the O atom cannot be located), and only one atom that can donate its electron pair (where the O atom may reside).

17.16 Compare the conjugate base of 1,3,5-cycloheptatriene with the conjugate base of cyclopentadiene. Remember that the compound with the more stable conjugate base will have a lower pK_a .

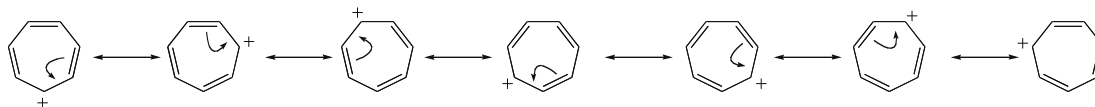
Benzene and Aromatic Compounds 17-7



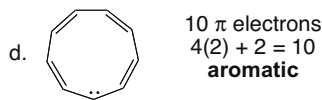
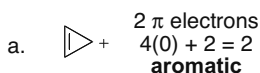
17.17 The compound with the most stable conjugate base is the most acidic.



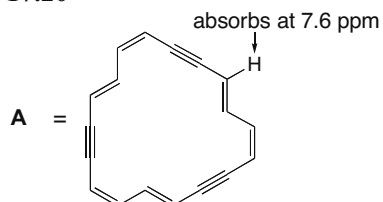
17.18



17.19 To be aromatic, the ions must have $4n + 2 \pi$ electrons. Ions in (b) and (c) do not have the right number of π electrons to be aromatic.



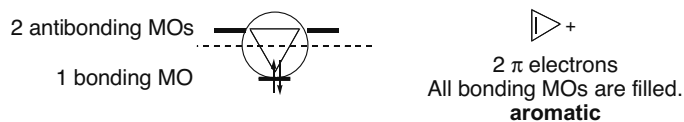
17.20



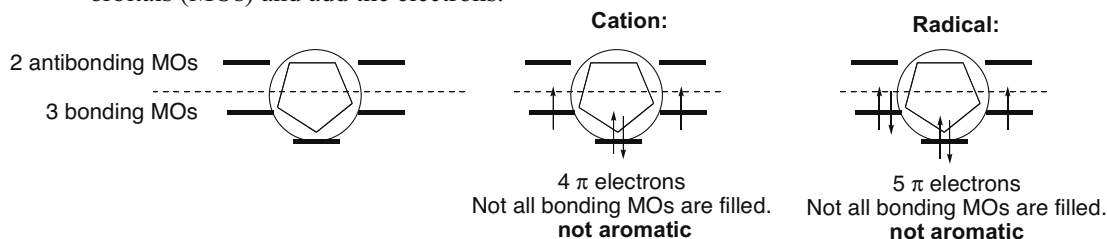
The NMR indicates that **A** is aromatic. The C's of the triple bond are sp hybridized. Each triple bond has one set of electrons in p orbitals that overlap with other p orbitals on adjacent atoms in the ring. This overlap allows electrons to delocalize. Each C of the triple bonds also has a p orbital in the plane of the ring. The electrons in these p orbitals are localized between the C's of the triple bond, not delocalized in the ring. Although **A** has $24 \pi e^-$ total, only $18 e^-$ are delocalized around the ring.

Chapter 17–8

17.21 In using the inscribed polygon method, always draw the vertex pointing down.

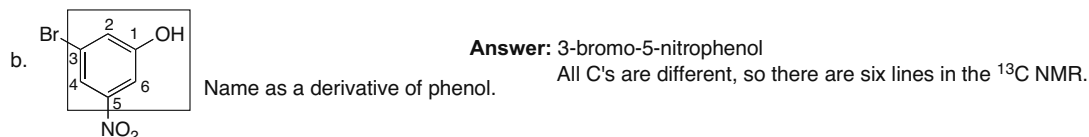
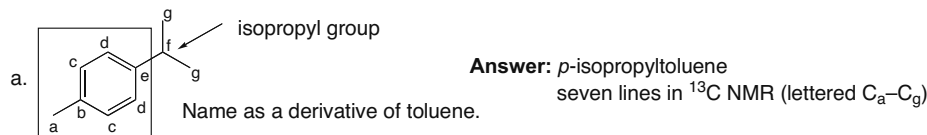


17.22 Draw the inscribed pentagons with the vertex pointing down. Then draw the molecular orbitals (MOs) and add the electrons.

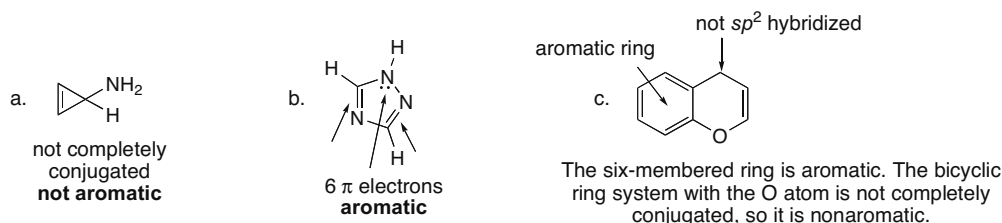


17.23 C_{60} would exhibit only one ^{13}C NMR signal because all the carbons are identical.

17.24



17.25

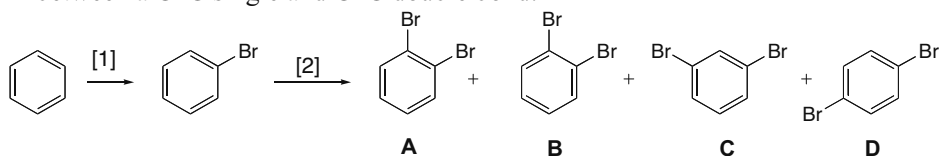


17.26

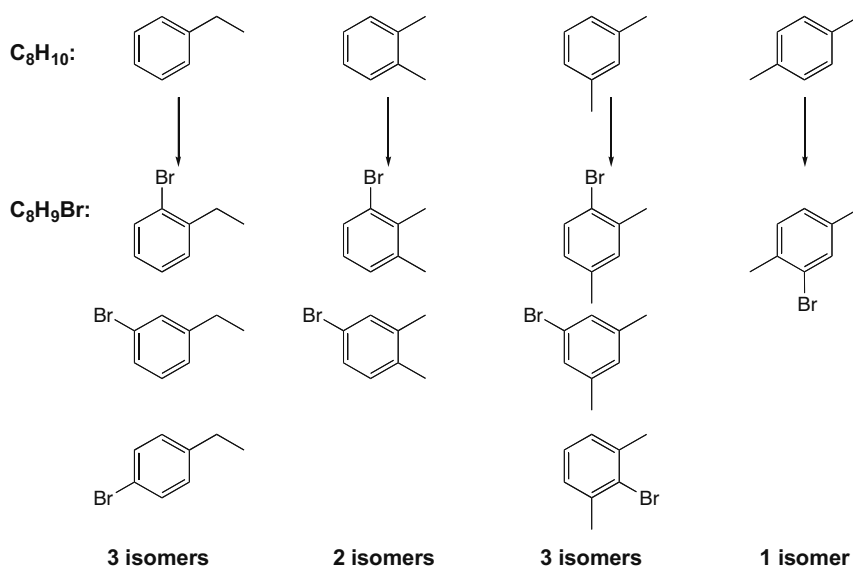
- If the Kekulé description of benzene was accurate, only one product would form in Reaction [1], but there would be four (not three) dibromobenzenes (**A–D**), because adjacent C–C bonds are different—one is single and one is double. Thus, compounds **A** and **B** would *not* be identical. **A** has two Br's bonded to the same double bond, but **B** has two Br's on different double bonds.
- In the resonance description, only one product would form in Reaction [1], since all C's are identical, but only three dibromobenzenes (ortho, meta, and para isomers) are possible.

Benzene and Aromatic Compounds 17-9

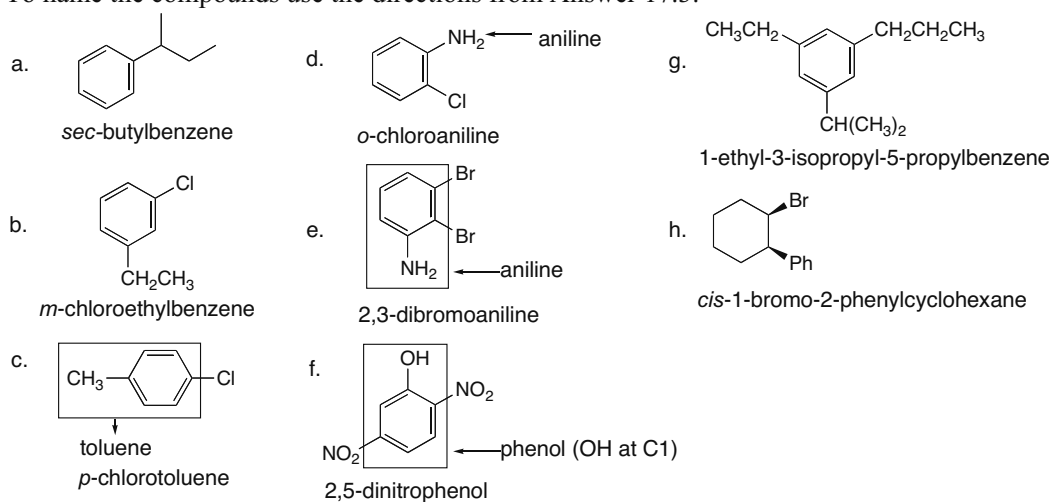
A and **B** are identical because each C–C bond is identical and intermediate in bond length between a C–C single and C–C double bond.



17.27

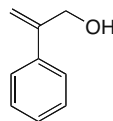
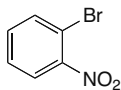
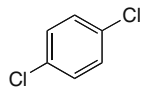


17.28 To name the compounds use the directions from Answer 17.3.

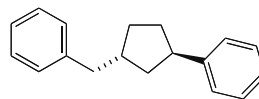
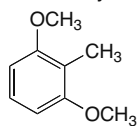
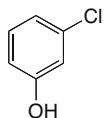


17.29

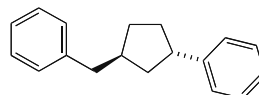
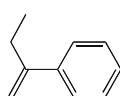
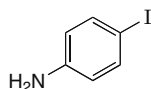
- g. 2-phenyl-2-propen-1-ol



- h. *trans*-1-benzyl-3-phenylcyclopentane

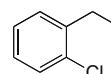
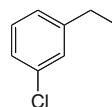
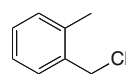
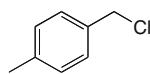
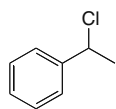
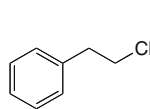


- f. 2-phenyl-1-butene

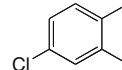
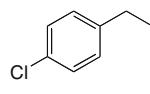
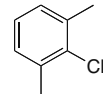
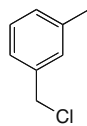


a, b. constitutional isomers of molecular formula **C₈H₉Cl** and names of the trisubstituted benzenes

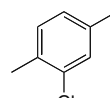
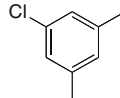
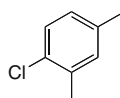
- a, b. constitutional isomers of molecular formula **C₈H₉Cl** and names of the trisubstituted benzenes



stereoisomers
for this isomer

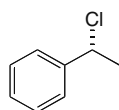


- 4-chloro-1,2-dimethylbenzene



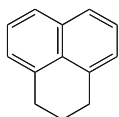
- 2-chloro-1,4-dimethylbenzene

-



17.31 Count the electrons in the π bonds. Each π bond holds two electrons.

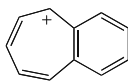
- a.



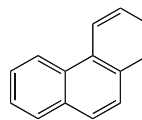
- b.



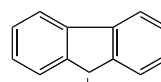
- C.



- d.



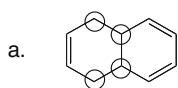
- e.



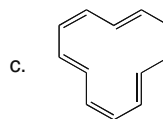
- 12 π electrons

Benzene and Aromatic Compounds 17-11

17.32 To be aromatic, the compounds must be cyclic, planar, completely conjugated, and have $4n + 2$ π electrons.



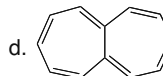
Circled C's are not sp^2 .
not completely conjugated
not aromatic



12 π electrons
does **not** have $4n + 2$
 π electrons
not aromatic

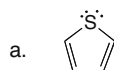


Circled C is not sp^2 .
not completely conjugated
not aromatic

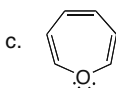


12 π electrons
does **not** have $4n + 2$
 π electrons
not aromatic

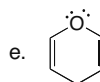
17.33 In determining if a heterocycle is aromatic, count a nonbonded electron pair if it makes the ring aromatic in calculating $4n + 2$. Lone pairs on atoms already part of a multiple bond cannot be delocalized in a ring, and so they are never counted in determining aromaticity.



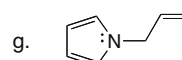
6 π electrons
counting a lone pair from S
 $4(1) + 2 = 6$
aromatic



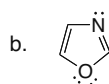
not aromatic



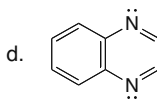
not aromatic



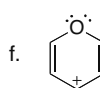
6 π electrons
counting the lone pair from N
 $4(1) + 2 = 6$
aromatic



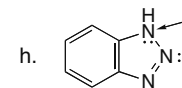
6 π electrons
counting a lone pair from O
 $4(1) + 2 = 6$
aromatic



10 π electrons
 $4(2) + 2 = 10$
aromatic



6 π electrons,
counting a lone pair from O
 $4(1) + 2 = 6$
aromatic

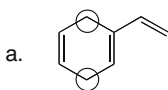


10 π electrons
 $4(2) + 2 = 10$
aromatic

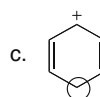
Count these $2e^-$.

These lone pairs are on doubly bonded N atoms, so they can't be counted.

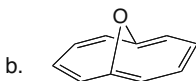
17.34



Circled C's are not sp^2 .
not aromatic



Circled C is not sp^2 .
not aromatic

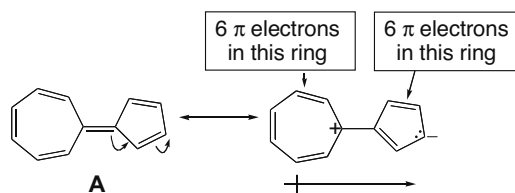


10 π electrons
in 10-membered ring
 $4(2) + 2 = 10$
aromatic



4 π electrons
 $4(1) = 4$
antiaromatic

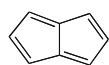
17.35



Chapter 17-12

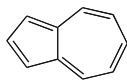
A resonance structure can be drawn for **A** that places a negative charge in the five-membered ring and a positive charge in the seven-membered ring. This resonance structure shows that each ring has six π electrons, making it aromatic. The molecule possesses a dipole such that the seven-membered ring is electron deficient and the five-membered ring is electron rich.

- 17.36** Each compound is completely conjugated. A compound with $4n + 2$ π electrons is especially stable, while a compound with $4n$ π electrons is especially unstable.



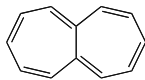
pentalene

8 π electrons
 $4(2) = 8$
 antiaromatic
unstable



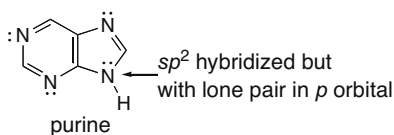
azulene

10 π electrons
 $4(2) + 2 = 10$
 aromatic
very stable

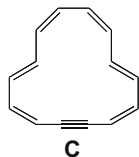


heptalene

12 π electrons
 $6(2) = 12$
 antiaromatic
unstable

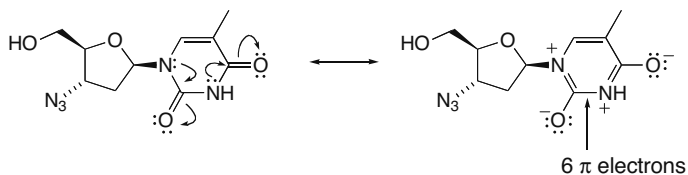
17.37

- Each N atom is sp^2 hybridized.
- The three unlabeled N atoms are sp^2 hybridized with lone pairs in one of the sp^2 hybrid orbitals. The labeled N has its lone pair in a p orbital.
- 10 π electrons
- Purine is cyclic, planar, completely conjugated, and has 10 π electrons [$4(2) + 2$] so it is aromatic.

17.38

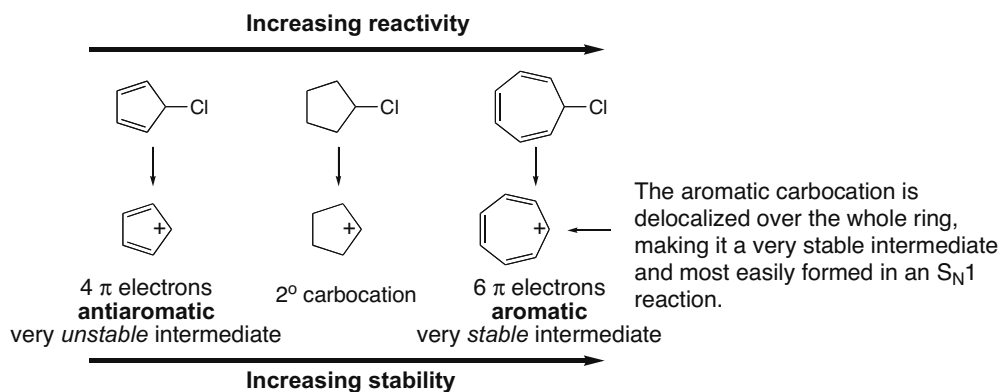
- 16 total π electrons
- 14 π electrons delocalized in the ring. [Note: Two of the electrons in the triple bond are localized between two C's, perpendicular to the π electrons delocalized in the ring.]
- By having two of the p orbitals of the C-C triple bond co-planar with the p orbitals of all the C=C's, the total number of π electrons delocalized in the ring is 14. $4(3) + 2 = 14$, so the ring is **aromatic**.

- 17.39** A second resonance structure can be drawn for the six-membered ring that gives it three π bonds, thus making it aromatic with six π electrons.

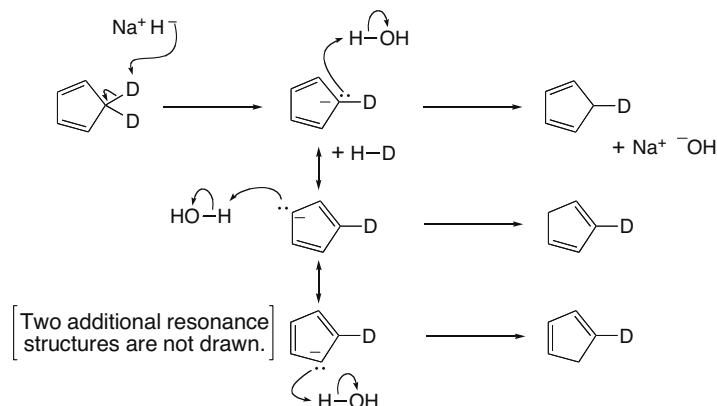


Benzene and Aromatic Compounds 17-13

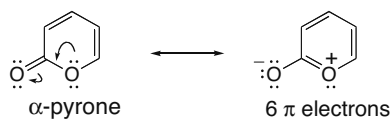
17.40 The rate of an S_N1 reaction increases with increasing stability of the intermediate carbocation.



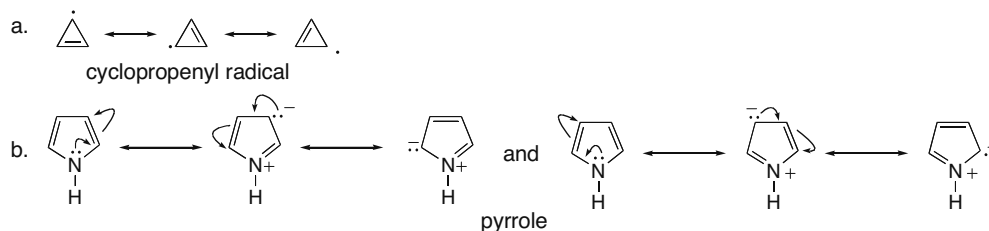
17.41



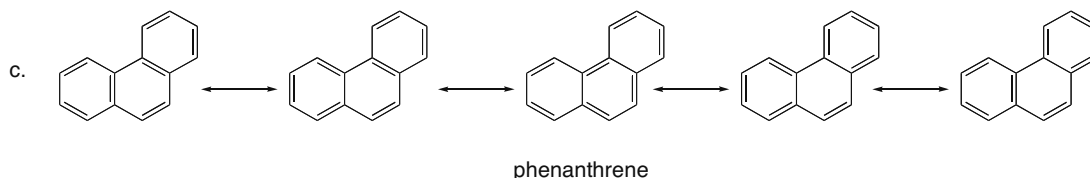
17.42 α -Pyrone reacts like benzene because it is aromatic. A second resonance structure can be drawn showing how the ring has six π electrons. Thus, α -pyrone undergoes reactions characteristic of aromatic compounds—that is, substitution rather than addition.



17.43

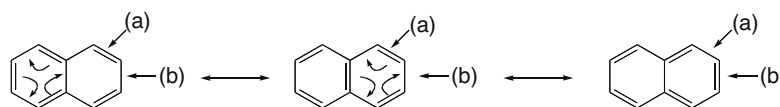


Chapter 17-14



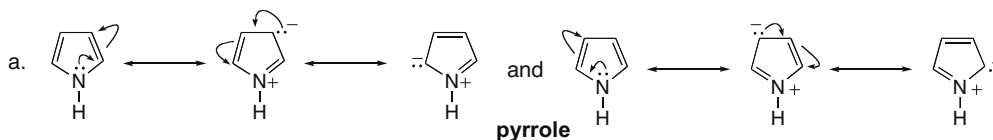
17.44

Naphthalene can be drawn as three resonance structures:

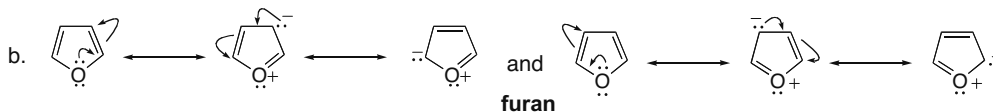


In two of the resonance structures bond (a) is a double bond, and bond (b) is a single bond. Therefore, bond (b) has more single bond character, making it longer.

17.45

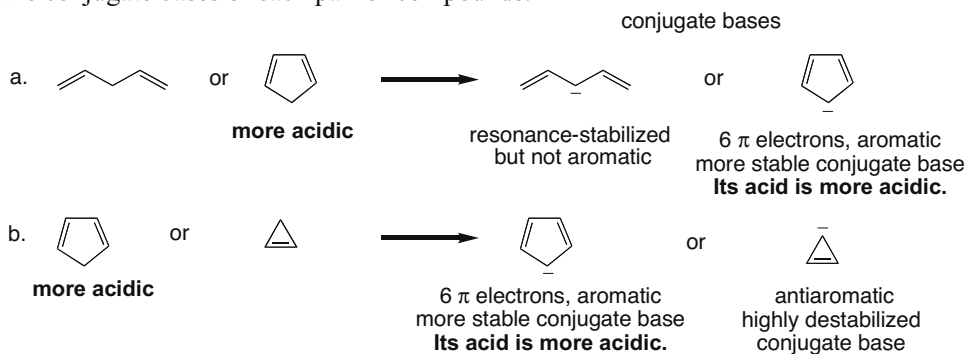


Pyrrole is less resonance stabilized than benzene because four of the resonance structures have charges, making them less good.



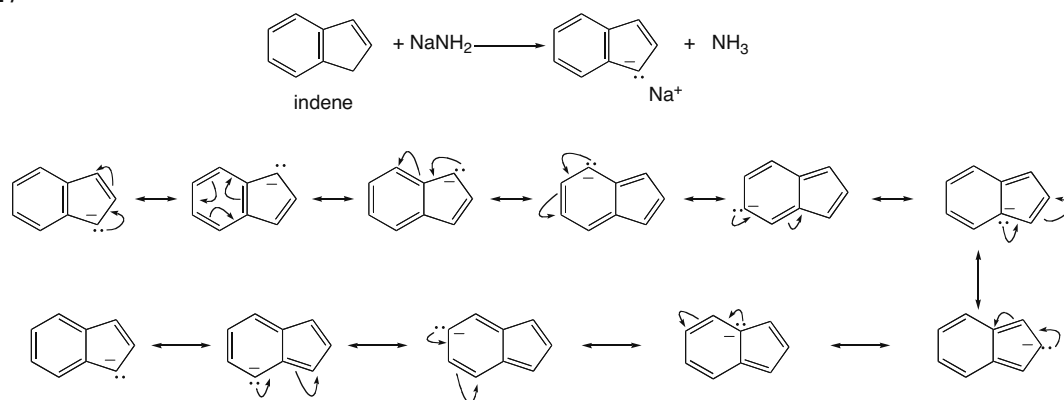
Furan is less resonance stabilized than pyrrole because its O atom is less basic, so it donates electron density less "willingly." Thus, charge-separated resonance forms are more minor contributors to the hybrid than the charge-separated resonance forms of pyrrole.

17.46 The compound with the more stable conjugate base is the stronger acid. Draw and compare the conjugate bases of each pair of compounds.



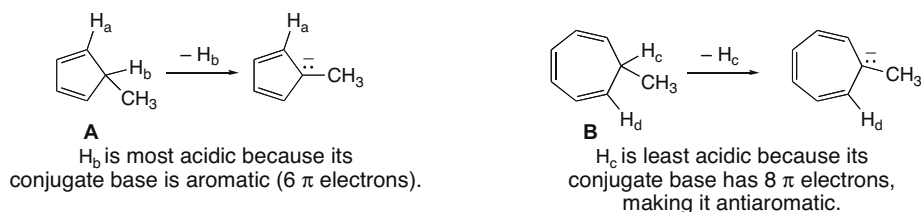
Benzene and Aromatic Compounds 17-15

17.47

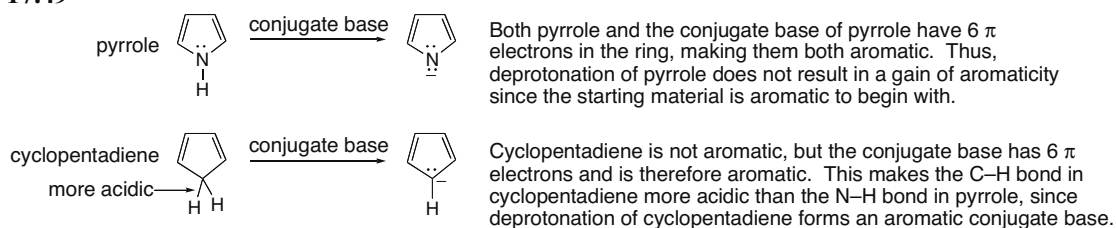


The conjugate base of indene has 10 π electrons, making it aromatic and very stable. Therefore, indene is more acidic than many hydrocarbons.

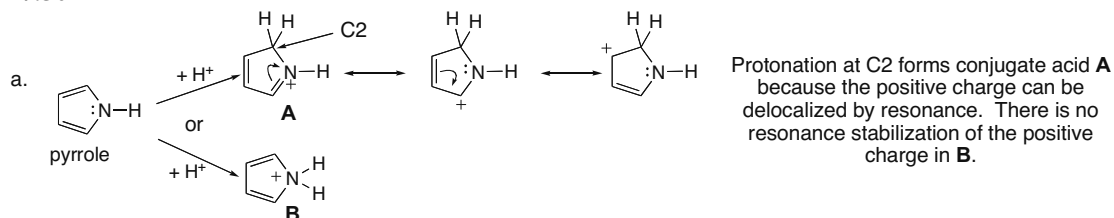
17.48



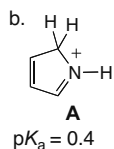
17.49



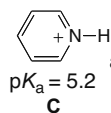
17.50



Chapter 17–16



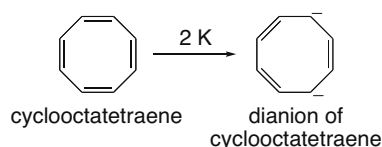
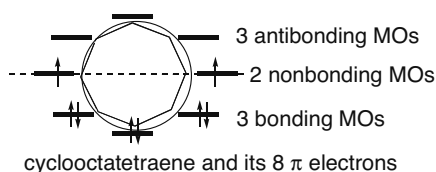
Loss of a proton from **A** (which is not aromatic) gives two electrons to N, and forms pyrrole, which has six π electrons that can then delocalize in the five-membered ring, making it aromatic. This makes deprotonation a highly favorable process, and **A** more acidic.



Both **C** and its conjugate base pyridine are aromatic. Since **C** has six π electrons, it is already aromatic to begin with, so there is less to be gained by deprotonation, and **C** is thus less acidic than **A**.

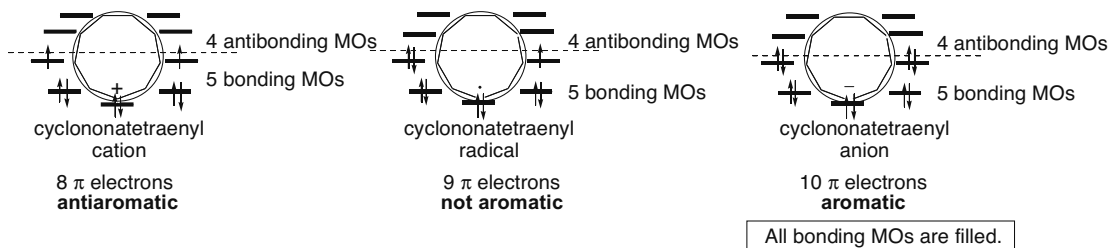
17.51

a.

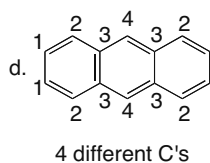
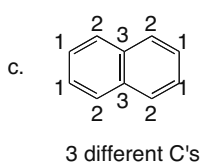
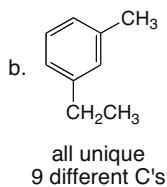
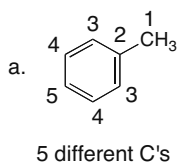


- Even if cyclooctatetraene were flat, it has two unpaired electrons in its HOMOs (nonbonding MOs) so it cannot be aromatic.
- The dianion has 10 π electrons.
- The two additional electrons fill the nonbonding MOs; that is, all the bonding and nonbonding MOs are filled with electrons in the dianion.
- The dianion is aromatic since its HOMOs are completely filled, and it has no electrons in antibonding MOs.

17.52

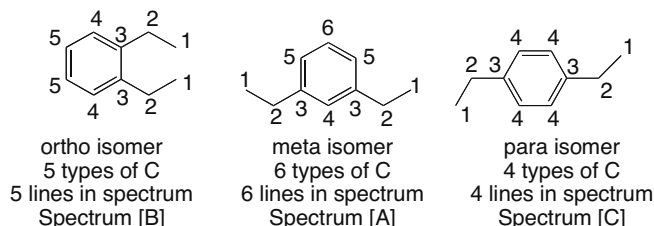


17.53 The number of different types of C's = the number of signals.



Benzene and Aromatic Compounds 17–17

- 17.54 Draw the three isomers and count the different types of carbons in each. Then match the structures with the data.

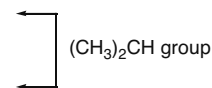


17.55

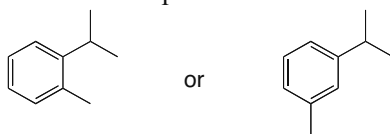
- a. $C_{10}H_{14}$: IR absorptions at 3150–2850 (sp^2 and sp^3 hybridized C–H), 1600, and 1500 (due to a benzene ring) cm^{-1}

^1H NMR data:

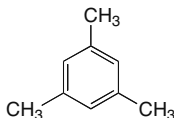
Absorption	ppm	# of H's	Explanation
doublet	1.2	6	6 H's adjacent to 1 H
singlet	2.3	3	CH_3
septet	3.1	1	1 H adjacent to 6 H's
multiplet	7–7.4	4	a disubstituted benzene ring



You can't tell from these data where the two groups are on the benzene ring. They are not para, since the para arrangement usually gives two sets of distinct peaks (resembling two doublets) so there are two possible structures—ortho and meta isomers.



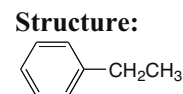
- b. C_9H_{12} : ^{13}C NMR signals at 21, 127, and 138 ppm $\rightarrow$ means three different types of C's. ^1H NMR shows two types of H's: 9 H's probably means 3 CH_3 groups; the other 3 H's are very deshielded so they are bonded to a benzene ring. Only one possible structure fits:



- c. C_8H_{10} : IR absorptions at 3108–2875 (sp^2 and sp^3 hybridized C–H), 1606, and 1496 (due to a benzene ring) cm^{-1}

^1H NMR data:

Absorption	ppm	# of H's	Explanation
triplet	1.3	3	3 H's adjacent to 2 H's
quartet	2.7	2	2 H's adjacent to 3 H's
multiplet	7.3	5	a monosubstituted benzene ring



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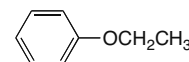
17.56

- a. Compound
- A**
- : Molecular formula
- $C_8H_{10}O$

IR absorption at 3150–2850 (sp^2 and sp^3 hybridized C–H) cm^{-1} ^1H NMR data:

Absorption	ppm	# of H's	Explanation
triplet	1.4	3	3 H's adjacent to 2 H's
quartet	3.95	2	2 H's adjacent to 3 H's
multiplet	6.8–7.3	5	a monosubstituted benzene ring

Structure:

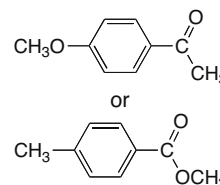


- b. Compound
- B**
- : Molecular formula
- $C_9H_{10}O_2$

IR absorption at 1669 (C=O) cm^{-1} ^1H NMR data:

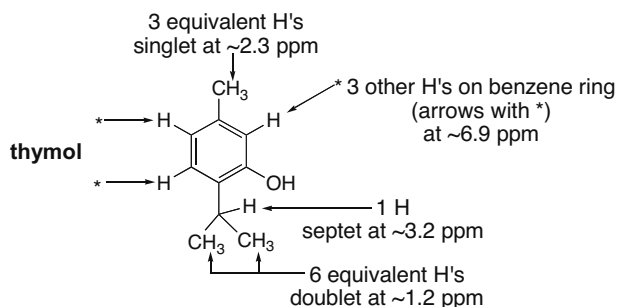
Absorption	ppm	# of H's	Explanation
singlet	2.5	3	CH_3 group
singlet	3.8	3	CH_3 group
doublet	6.9	2	2 H's on a benzene ring
doublet	7.9	2	2 H's on a benzene ring

Structure:

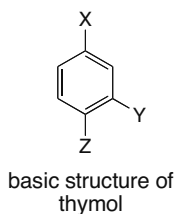


It would be hard to distinguish these two compounds with the given data.

17.57



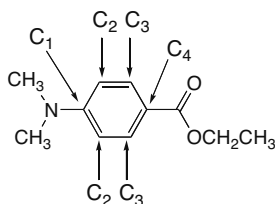
IR absorptions:
 3500–3200 cm^{-1} (O–H)
 3150–2850 cm^{-1} (C–H bonds)
 1621 and 1585 cm^{-1} (benzene ring)



Thymol must have this basic structure, given the NMR and IR data since it is a trisubstituted benzene ring with one singlet and two doublets in the NMR at ~6.9 ppm. However, which group [OH, CH_3 , or $CH(CH_3)_2$] corresponds to X, Y, and Z is not readily distinguished with the given data. The correct structure for thymol is given.

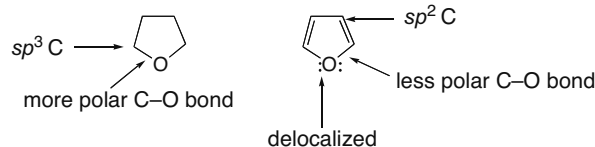
Benzene and Aromatic Compounds 17–19

17.58



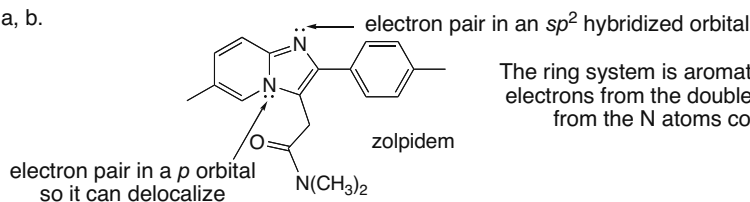
^{13}C NMR has four lines that are located in the aromatic region ($\sim 110\text{--}155$ ppm), corresponding to the four different types of carbons in the aromatic ring of the para isomer. The ortho and meta isomers have six different C's, and so six lines would be expected for each of them.

- 17.59** Because tetrahydrofuran has a higher boiling point and is more water soluble, it must be more polar and have stronger intermolecular forces than furan. There are two contributing factors. One lone pair on furan's O atom is delocalized on the five-membered ring to make it aromatic. This makes it less available for H-bonding with water and other intermolecular interactions. Also, the C–O bonds in furan are less polar than the C–O bonds in tetrahydrofuran because of hybridization. The sp^2 hybridized C's of furan pull a little more electron density towards them than do the sp^3 hybridized C's of tetrahydrofuran. This counteracts the higher electronegativity of O compared to C to a small extent.



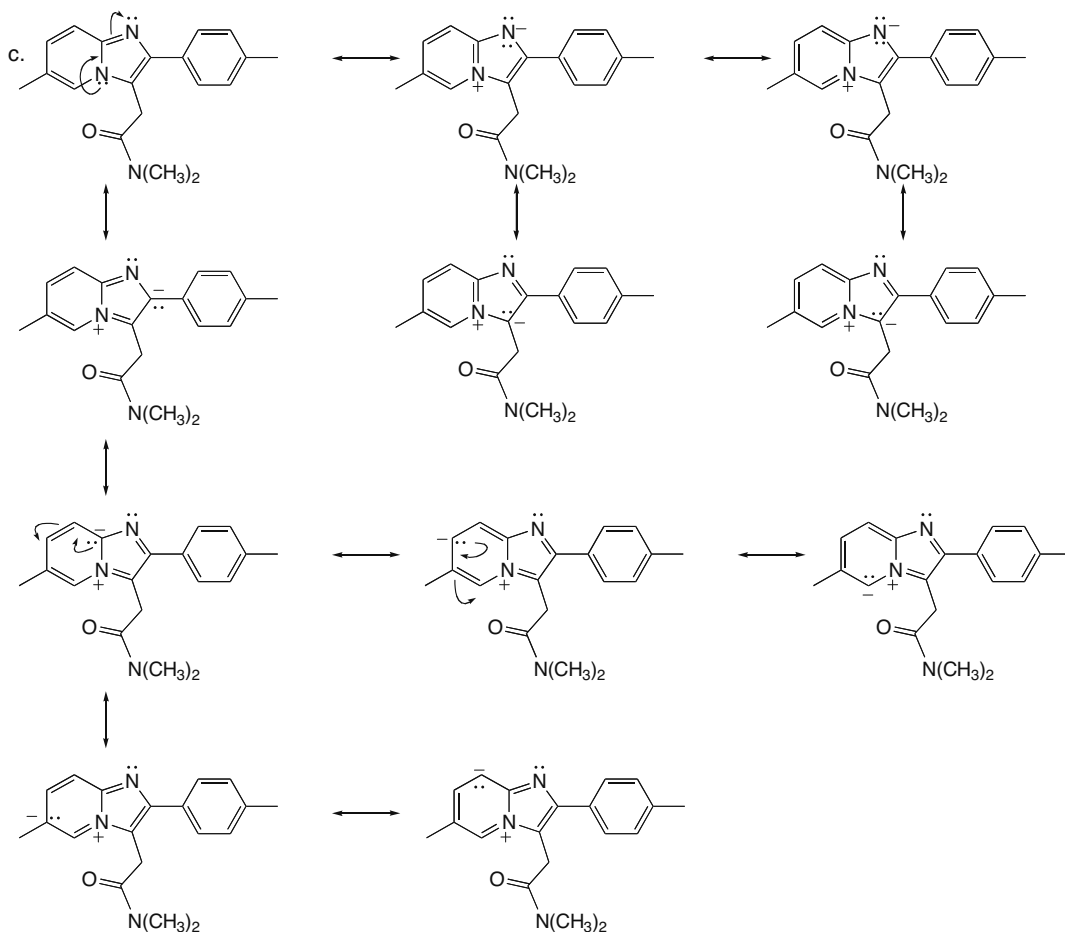
17.60

a, b.

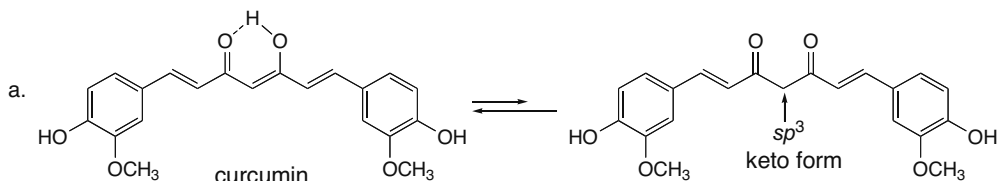


The ring system is aromatic with 10π electrons, 8π electrons from the double bonds and 2π electrons from the N atoms common to both rings.

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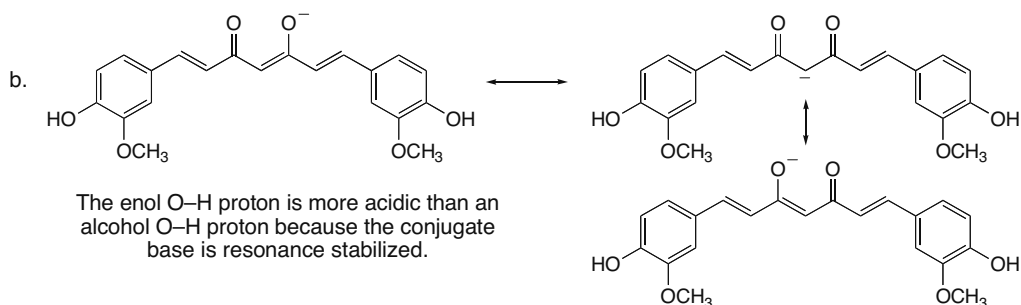


17.61



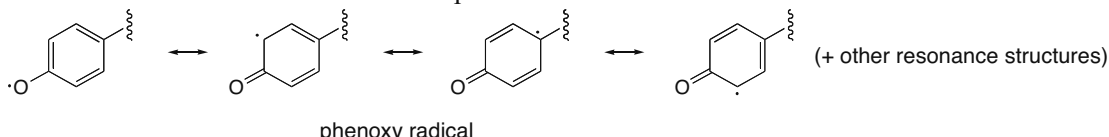
The enol form is more stable because the enol double bond makes a highly conjugated system. The enol OH can also intramolecularly hydrogen bond to the nearby carbonyl O atom.

Benzene and Aromatic Compounds 17–21



c. Curcumin is colored because it has many conjugated π electrons, which shift absorption of light from the UV to the visible region.

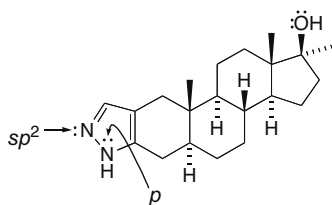
d. Curcumin is an antioxidant because it contains a phenol. Homolytic cleavage affords a resonance-stabilized phenoxyl radical, which can inhibit oxidation from occurring, much like vitamin E and BHT in Chapter 15.



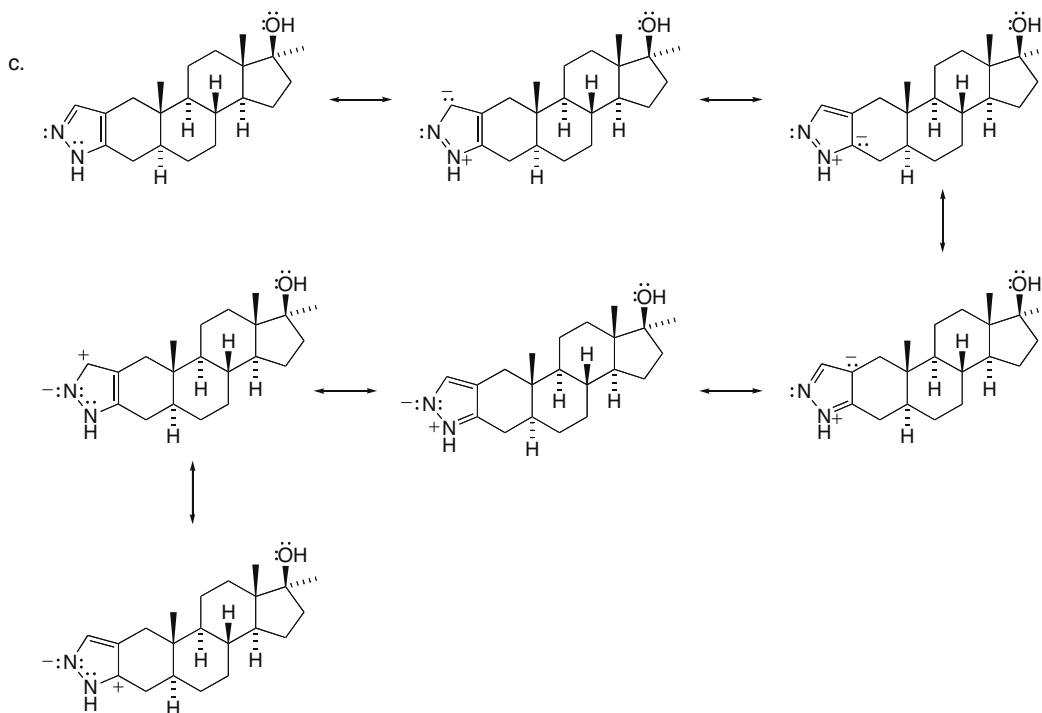
Resonance delocalizes the radical on the ring and C chain of curcumin.

17.62 a. Pyrazole rings are aromatic because they have six π electrons—two from the lone pair on the N atom that is not part of the double bond and four from the double bonds.

b.

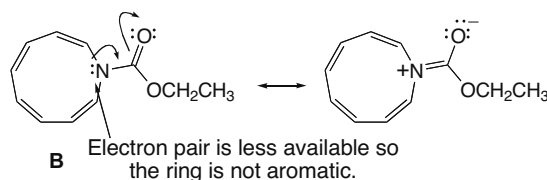
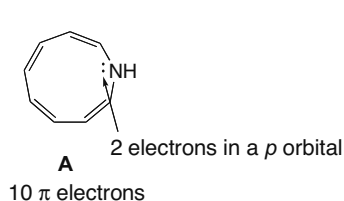


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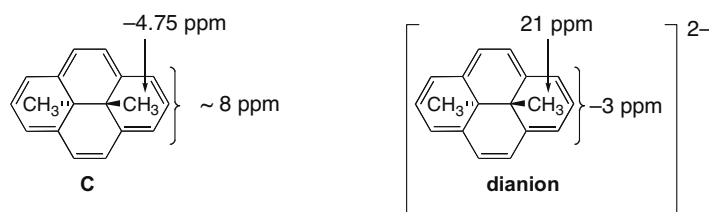
- d. The N atom in the NH bond in the pyrazole ring is sp^2 hybridized with 33% s -character, increasing the acidity of the N–H bond. The N–H bond of CH_3NH_2 contains an sp^3 hybridized N atom.

17.63 Both **A** and **B** are cyclic, and if the lone pair of electrons on N is in a p orbital, they are completely conjugated with 10 π electrons, a number that satisfies Hückel's rule. To be aromatic, **A** and **B** must be planar, and the internal bond angles of **A** and **B** would be much larger than 120° , the theoretical bond angle of sp^2 hybridized C's. The fact that **A** is aromatic means that the lone pair on N occupies a p orbital, so it can delocalize on the nine-membered ring. The stabilization gained by being aromatic is greater than any angle strain. With **B**, the lone pair on N is also delocalized on the $\text{C}=\text{O}$, making it less available for donation to the ring, so the ring is not aromatic.

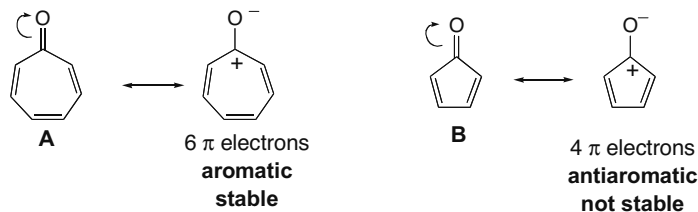


Benzene and Aromatic Compounds 17-23

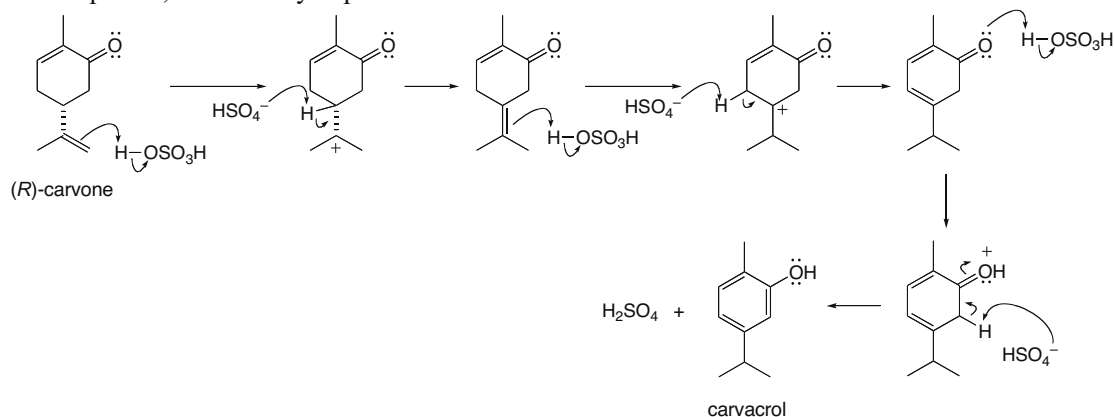
- 17.64** With 14 π electrons in the double bonds, the system is aromatic [$4(3) + 2 = 14 \pi$ electrons]. The ring current generated by the circulating π electrons deshields the protons on the $C=C$'s, so they absorb downfield (8.14–8.67 ppm). The CH_3 groups, however, are very shielded since they lie above and below the plane, so they absorb far upfield (–4.25 ppm). The dianion of **C** now has 16 π electrons, making it antiaromatic, so the position of the absorptions reverses. The $C=C$ protons are now shielded (–3 ppm), and the CH_3 protons are now deshielded (21 ppm).



- 17.65** A second resonance structure for **A** shows that the ring is completely conjugated and has six π electrons, making it aromatic and especially stable. A similar charge-separated resonance structure for **B** makes the ring completely conjugated, but gives the ring four π electrons, making it antiaromatic and especially unstable.

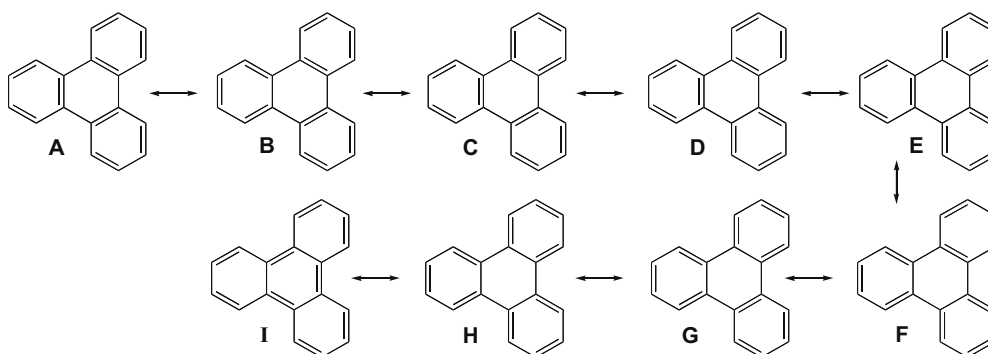


- 17.66** The conversion of carvone to carvacrol involves acid-catalyzed isomerization of two double bonds and tautomerization of a ketone to an enol tautomer. In this case the enol form is part of an aromatic phenol. Each isomerization of a $C=C$ involves Markovnikov addition of a proton, followed by deprotonation.



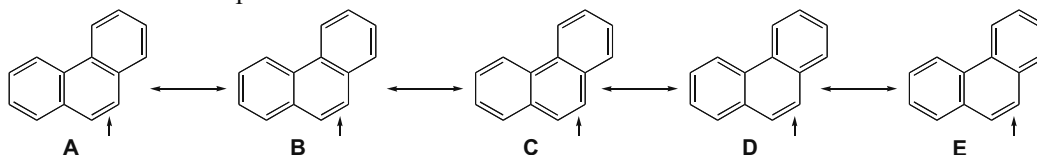
Chapter 17-24

17.67 Resonance structures for triphenylene:



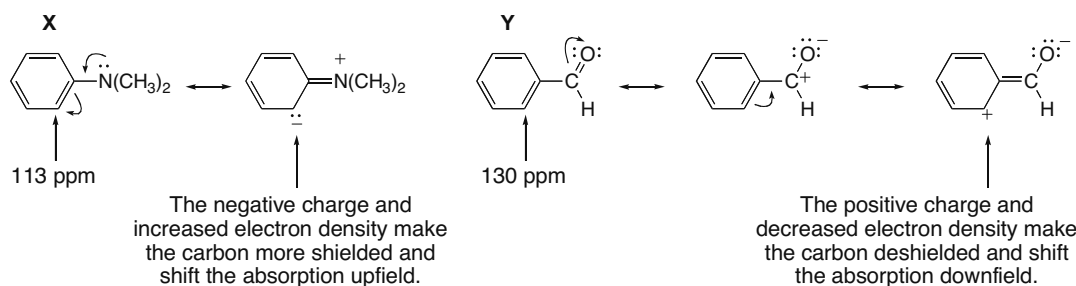
Resonance structures **A–H** all keep three double and three single bonds in the three six-membered rings on the periphery of the molecule. This means that each ring behaves like an isolated benzene ring undergoing substitution rather than addition because the π electron density is delocalized within each six-membered ring. Only resonance structure **I** does not have this form. Each C–C bond of triphenylene has four (or five) resonance structures in which it is a single bond and four (or five) resonance structures in which it is a double bond.

Resonance structures for phenanthrene:



With phenanthrene, however, four of the five resonance structures keep a double bond at the labeled C's. (Only **C** does not.) This means that these two C's have more double bond character than other C–C bonds in phenanthrene, making them more susceptible to addition rather than substitution.

17.68

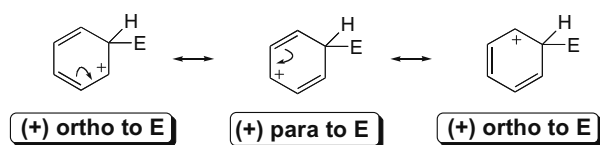


Chapter 18 Reactions of Aromatic Compounds

Chapter Review

Mechanism of electrophilic aromatic substitution (18.2)

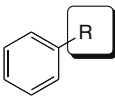
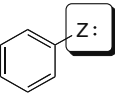
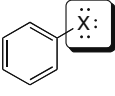
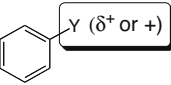
- Electrophilic aromatic substitution follows a two-step mechanism. Reaction of the aromatic ring with an electrophile forms a carbocation, and loss of a proton regenerates the aromatic ring.
- The first step is rate-determining.
- The intermediate carbocation is stabilized by resonance; a minimum of three resonance structures can be drawn. The positive charge is always located ortho or para to the new C–E bond.



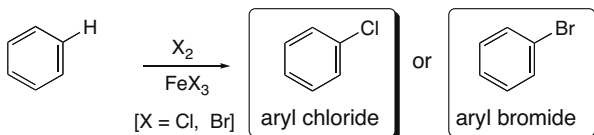
Three rules describing the reactivity and directing effects of common substituents (18.7–18.9)

- All ortho, para directors except the halogens activate the benzene ring.
- All meta directors deactivate the benzene ring.
- The halogens deactivate the benzene ring.

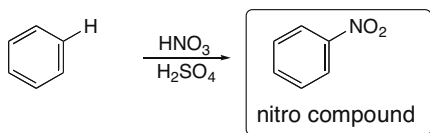
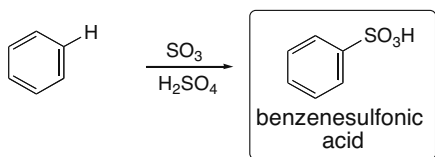
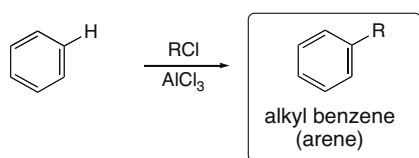
Summary of substituent effects in electrophilic aromatic substitution (18.6–18.9)

	Substituent	Inductive effect	Resonance effect	Reactivity	Directing effect
[1]	 R = alkyl	donating	none	activating	ortho, para
[2]	 Z = N or O	withdrawing	donating	activating	ortho, para
[3]	 X = halogen	withdrawing	donating	deactivating	ortho, para
[4]	 Y (δ^+ or +)	withdrawing	withdrawing	deactivating	meta

Chapter 18-2

Five examples of electrophilic aromatic substitution**[1] Halogenation—Replacement of H by Cl or Br (18.3)**

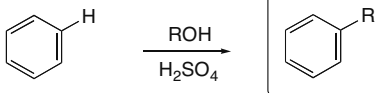
- Polyhalogenation occurs on benzene rings substituted by OH and NH₂ (and related substituents) (18.10A).

[2] Nitration—Replacement of H by NO₂ (18.4)**[3] Sulfonation—Replacement of H by SO₃H (18.4)****[4] Friedel-Crafts alkylation—Replacement of H by R (18.5)**

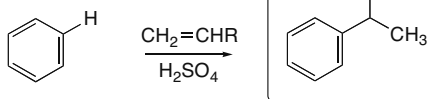
- Rearrangements can occur.
- Vinyl halides and aryl halides are unreactive.
- The reaction does not occur on benzene rings substituted by meta deactivating groups or NH₂ groups (18.10B).
- Polyalkylation can occur.

Variations:

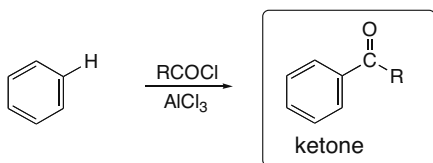
[1] with alcohols



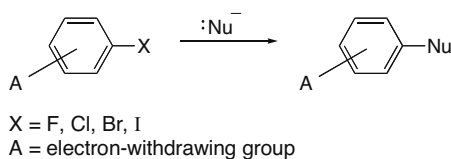
[2] with alkenes



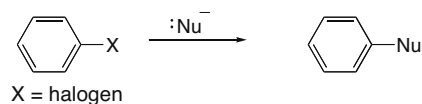
Reactions of Aromatic Compounds 18-3

[5] Friedel-Crafts acylation—Replacement of H by RCO (18.5)

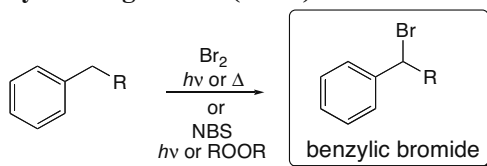
- The reaction does not occur on benzene rings substituted by meta deactivating groups or NH_2 groups (18.10B).

Nucleophilic aromatic substitution (18.13)**[1] Nucleophilic substitution by an addition-elimination mechanism**

- The mechanism has two steps.
- Strong electron-withdrawing groups at the ortho or para position are required.
- Increasing the number of electron-withdrawing groups increases the rate.
- Increasing the electronegativity of the halogen increases the rate.

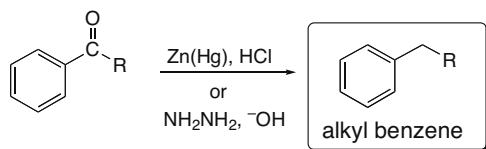
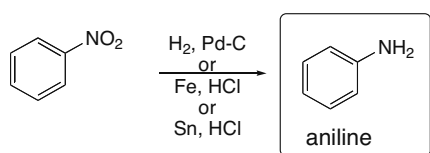
[2] Nucleophilic substitution by an elimination-addition mechanism

- Reaction conditions are harsh.
- Benzyne is formed as an intermediate.
- Product mixtures may result.

Other reactions of benzene derivatives**[1] Benzylic halogenation (18.14)****[2] Oxidation of alkyl benzenes (18.15A)**

- A benzylic C-H bond is needed for reaction.

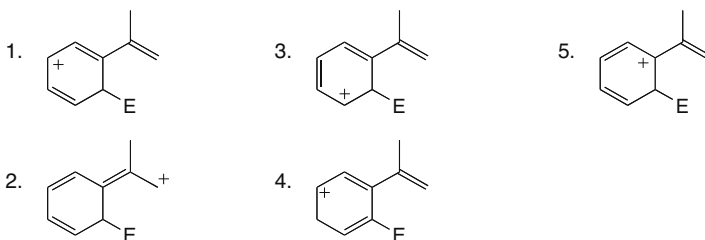
Chapter 18-4

[3] Reduction of ketones to alkyl benzenes (18.15B)**[4] Reduction of nitro groups to amino groups (18.15C)****Practice Test on Chapter Review**

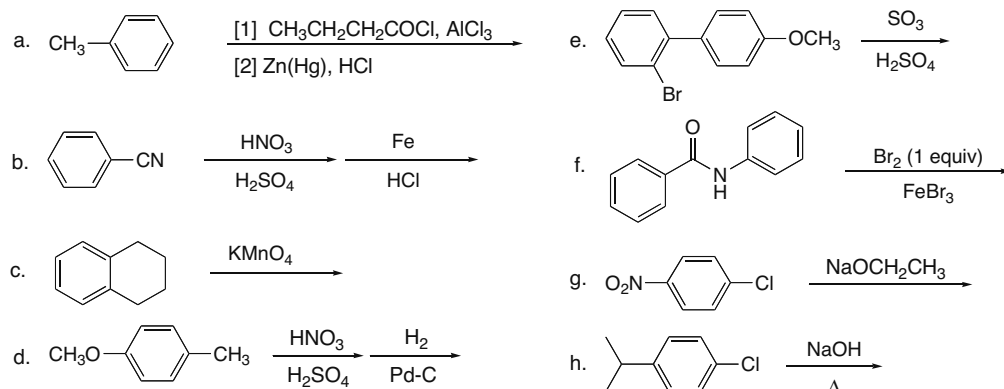
1. a. Which of the following statements is true about an ethoxy substituent ($-\text{OCH}_2\text{CH}_3$) on a benzene ring?
 1. OCH_2CH_3 increases the rates of both electrophilic substitution and nucleophilic substitution.
 2. OCH_2CH_3 decreases the rates of both electrophilic substitution and nucleophilic substitution.
 3. OCH_2CH_3 increases the rate of electrophilic substitution and decreases the rate of nucleophilic substitution.
 4. OCH_2CH_3 decreases the rate of electrophilic substitution and increases the rate of nucleophilic substitution.
 5. None of these statements is true.
- b. Which of the following statements is true about a $-\text{CO}_2\text{CH}_3$ group on a benzene ring?
 1. CO_2CH_3 increases the rates of both electrophilic substitution and nucleophilic substitution.
 2. CO_2CH_3 decreases the rates of both electrophilic substitution and nucleophilic substitution.
 3. CO_2CH_3 increases the rate of electrophilic substitution and decreases the rate of nucleophilic substitution.
 4. CO_2CH_3 decreases the rate of electrophilic substitution and increases the rate of nucleophilic substitution.
 5. None of these statements is true.

Reactions of Aromatic Compounds 18-5

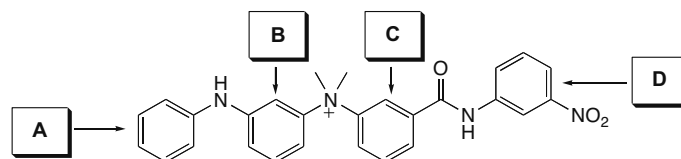
- c. Which of the following is *not* a valid resonance structure for the carbocation that results from ortho attack of an electrophile on $\text{C}_6\text{H}_5\text{C}(\text{CH}_3)=\text{CH}_2$?



2. Draw the organic products formed in the following reactions.



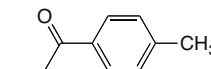
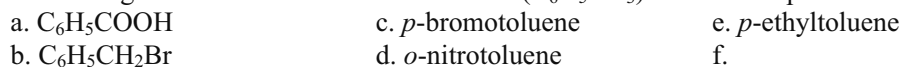
3. (a) Considering the compound drawn below, which ring is most reactive in electrophilic aromatic substitution? Which ring is the least reactive in electrophilic aromatic substitution?



4. Classify each substituent as [1] ortho, para activating, [2] ortho, para deactivating, or [3] meta deactivating.



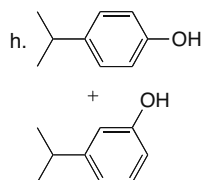
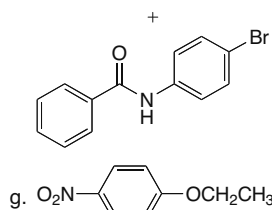
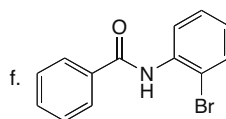
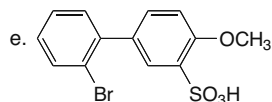
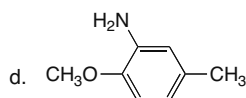
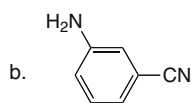
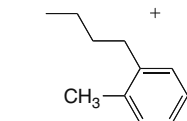
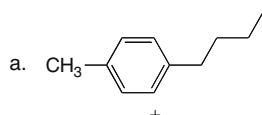
5. What reagents are needed to convert toluene ($\text{C}_6\text{H}_5\text{CH}_3$) to each compound?



Chapter 18–6

Answers to Practice Test

1. a. 3
b. 4
c. 4



3. a. A
b. C

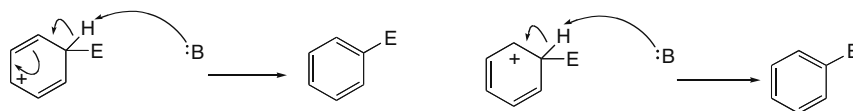
4. a. 2
b. 1
c. 3
d. 1
e. 1
f. 3

5. a. KMnO_4
b. $\text{Br}_2, h\nu$
c. $\text{Br}_2, \text{FeBr}_3$
d. $\text{HNO}_3, \text{H}_2\text{SO}_4$
e. $\text{CH}_3\text{CH}_2\text{Cl}, \text{AlCl}_3$
f. $\text{CH}_3\text{CH}_2\text{COCl}, \text{AlCl}_3$

Answers to Problems

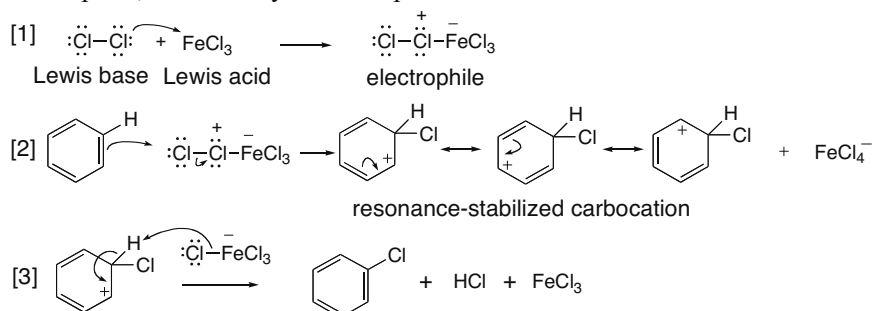
- 18.1 The π electrons of benzene are delocalized over the six atoms of the ring, increasing benzene's stability and making them less available for electron donation. With an alkene, the two π electrons are localized between the two C's, making them more nucleophilic and thus more reactive with an electrophile than the delocalized electrons in benzene.

18.2

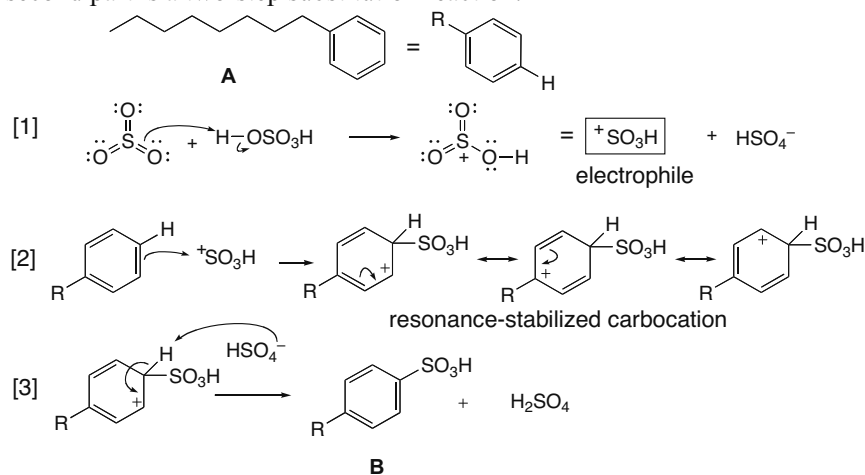


Reactions of Aromatic Compounds 18–7

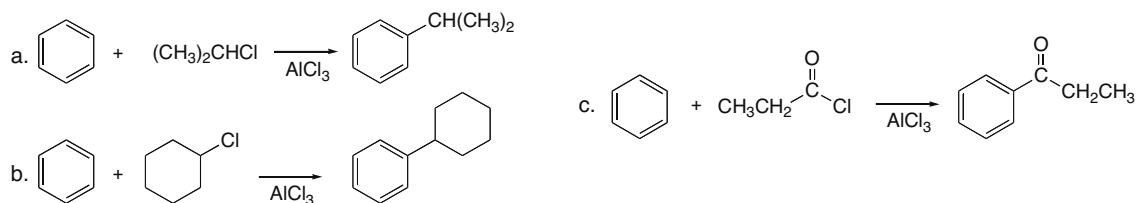
18.3 Reaction with Cl_2 and FeCl_3 as the catalyst occurs in two parts. First is the formation of an electrophile, followed by a two-step substitution reaction.



18.4 There are two parts in the mechanism. The first part is formation of an electrophile. The second part is a two-step substitution reaction.

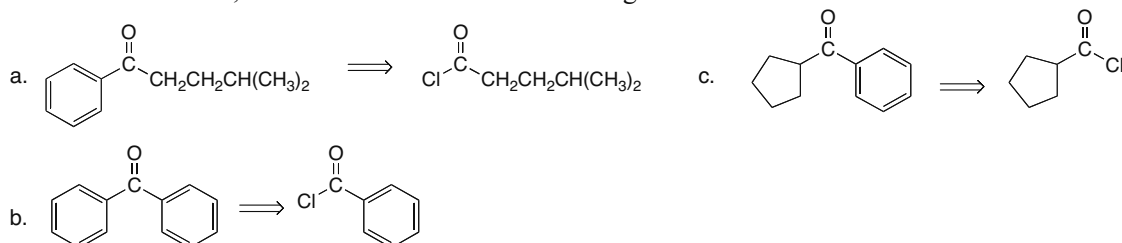


18.5 Friedel–Crafts alkylation results in the transfer of an alkyl group from a halogen to a benzene ring. In Friedel–Crafts acylation an acyl group is transferred from a halogen to a benzene ring.

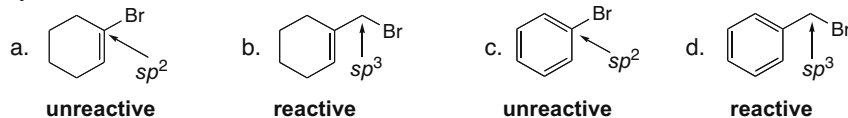


Chapter 18–8

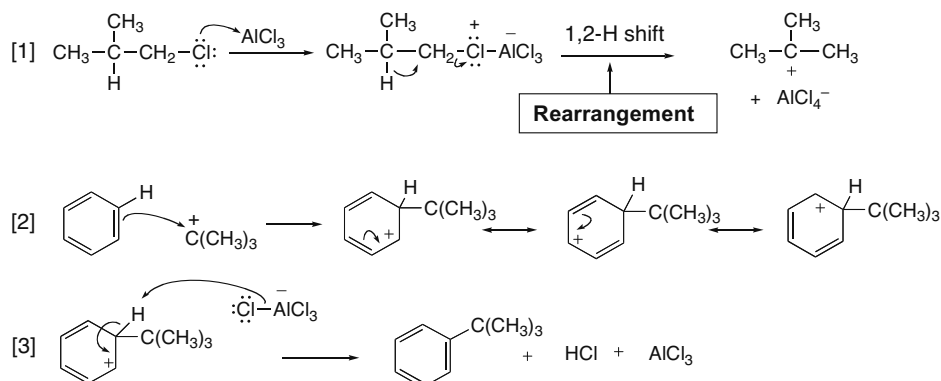
18.6 Remember that an acyl group is transferred from a Cl atom to a benzene ring. To draw the acid chloride, substitute a Cl for the benzene ring.



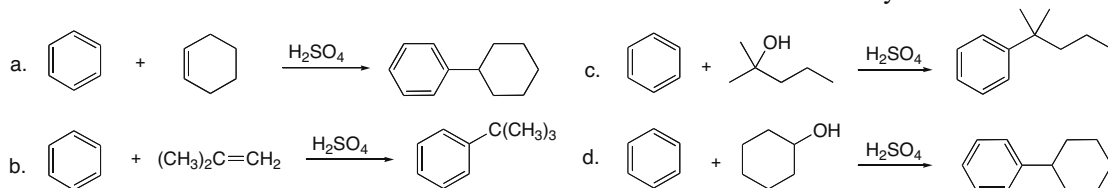
18.7 To be reactive in a Friedel–Crafts alkylation reaction, the X must be bonded to an sp^3 hybridized carbon atom.



18.8 The product has an “unexpected” carbon skeleton, so rearrangement must have occurred.

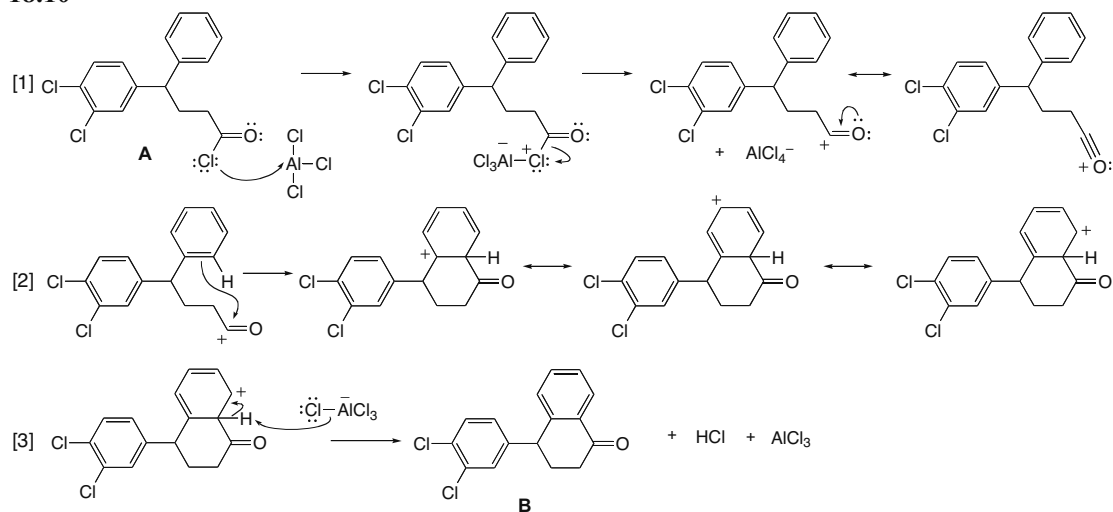


18.9 Both alkenes and alcohols can form carbocations for Friedel–Crafts alkylation reactions.

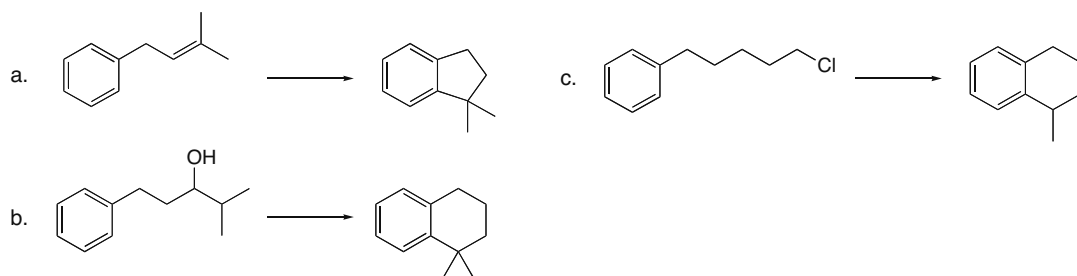


Reactions of Aromatic Compounds 18–9

18.10



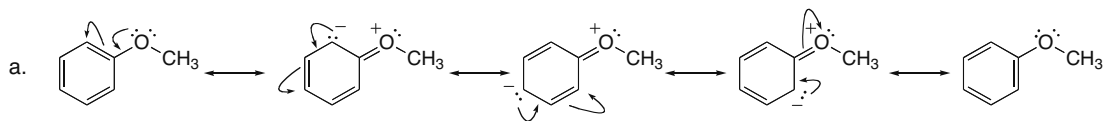
18.11 In parts (b) and (c), a 1,2-shift occurs to afford a rearrangement product.



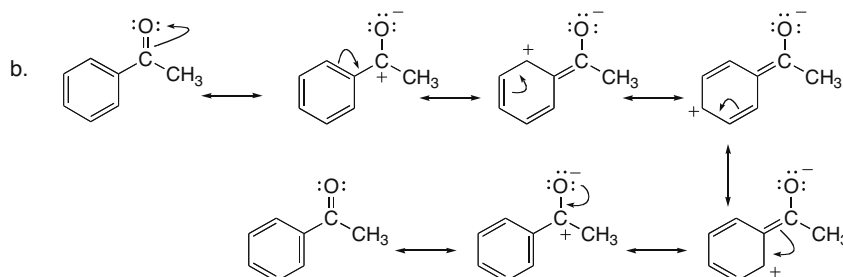
18.12

- a. $-\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}_3$
alkyl group
electron donating
- b. $-\text{Br}$
halide
electron withdrawing
- c. $-\text{OCH}_2\text{CH}_3$
electronegative O
electron withdrawing

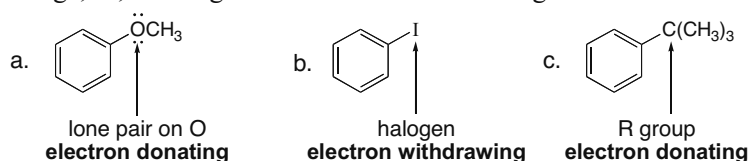
18.13 Electron-donating groups place a negative charge in the benzene ring. Draw the resonance structures to show how $-\text{OCH}_3$ puts a negative charge in the ring. Electron-withdrawing groups place a positive charge in the benzene ring. Draw the resonance structures to show how $-\text{COCH}_3$ puts a positive charge in the ring.



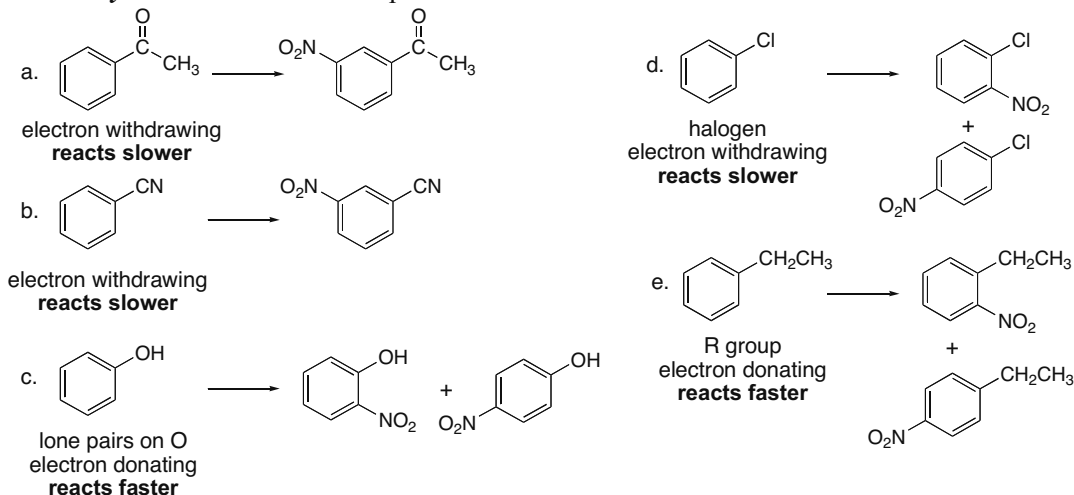
Chapter 18–10



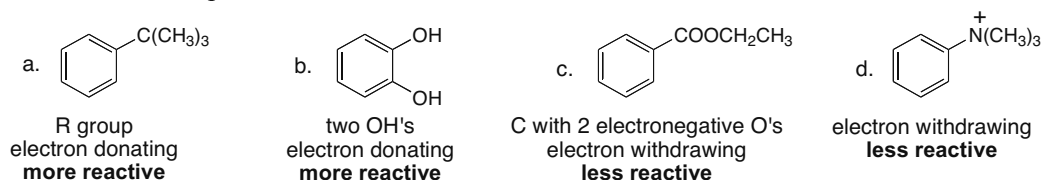
18.14 To classify each substituent, look at the atom bonded directly to the benzene ring. All R groups and Z groups (except halogens) are electron donating. All groups with a positive charge, δ^+ , or halogens are electron withdrawing.



18.15 **Electron-donating groups** make the compound *react faster* than benzene in electrophilic aromatic substitution. **Electron-withdrawing groups** make the compound *react more slowly* than benzene in electrophilic aromatic substitution.

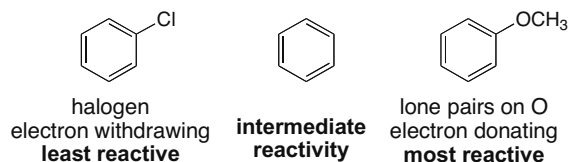


18.16 **Electron-donating groups** make the compound *more reactive* than benzene in electrophilic aromatic substitution. **Electron-withdrawing groups** make the compound *less reactive* than benzene in electrophilic aromatic substitution.

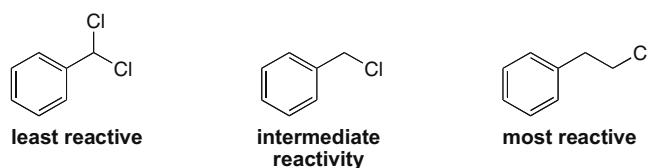


Reactions of Aromatic Compounds 18-11

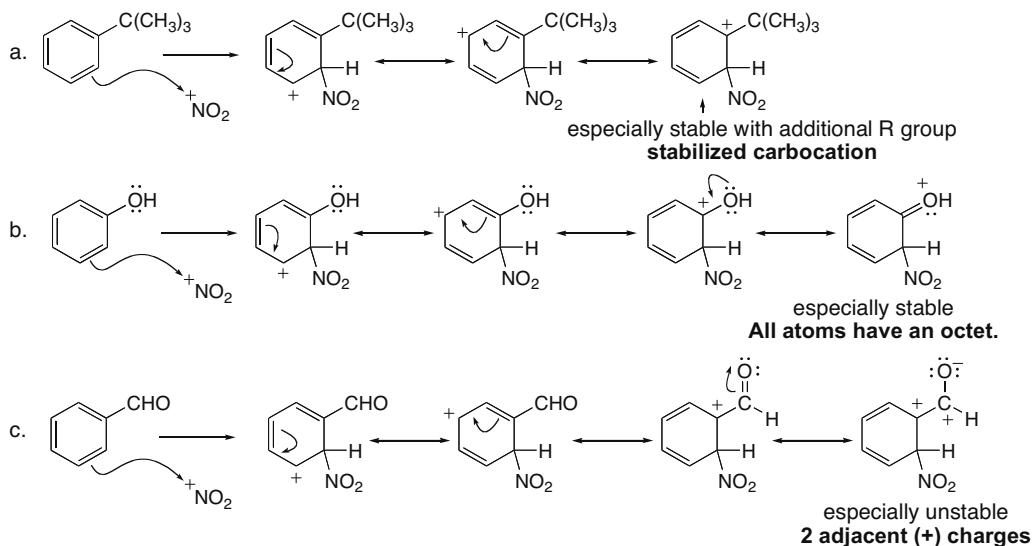
18.17



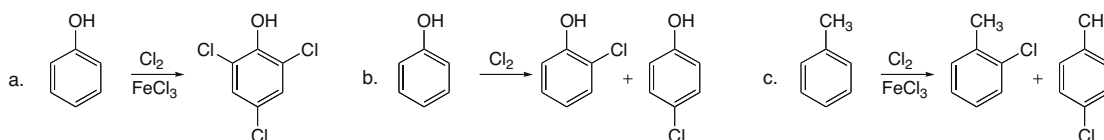
18.18 Chlorine inductively withdraws electron density and decreases the rate of electrophilic aromatic substitution. The closer the Cl is to the ring, the larger the effect it has. The larger the number of Cl's, the larger the effect.



18.19 Especially stable resonance structures have all atoms with an octet. Carbocations with additional electron donor R groups are also more stable structures. Especially unstable resonance structures have adjacent like charges.

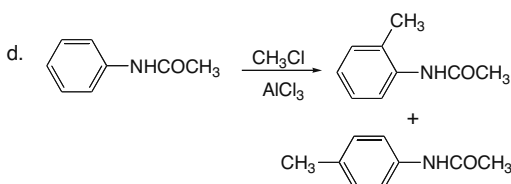
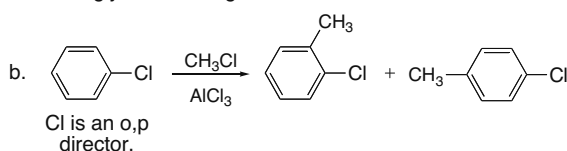
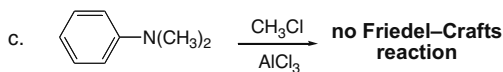
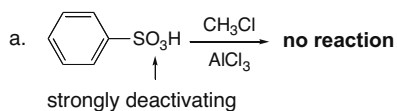


18.20 Polyhalogenation occurs with highly activated benzene rings containing OH, NH₂, and related groups with a catalyst.



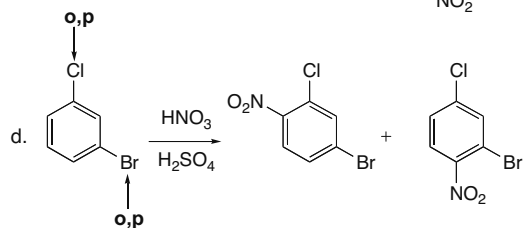
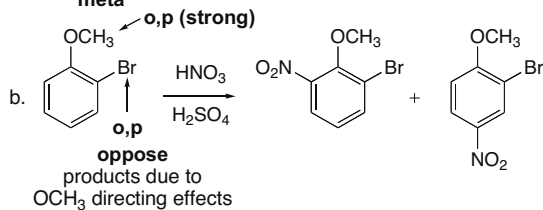
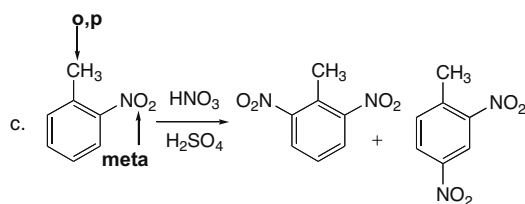
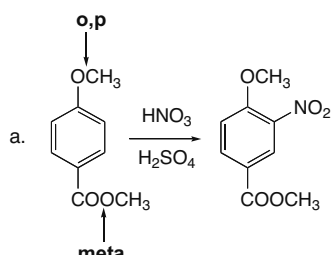
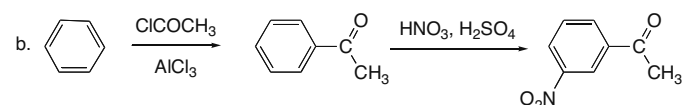
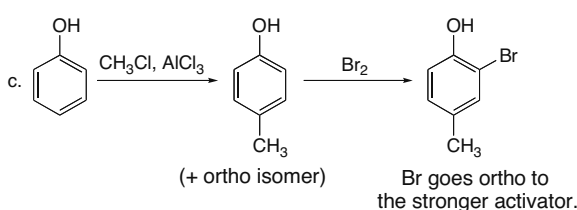
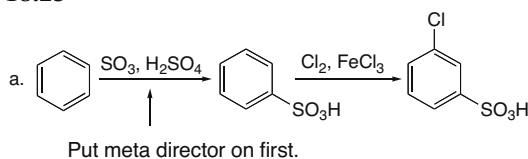
Chapter 18–12

18.21 Friedel–Crafts reactions do not occur with strongly deactivating substituents including NO_2 , or with NH_2 , NR_2 , or NHR groups.



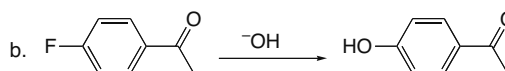
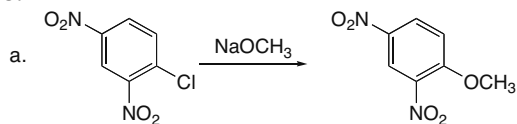
18.22 To draw the product of reaction with these disubstituted benzene derivatives and HNO_3 , H_2SO_4 remember:

- If the two directing effects reinforce each other, the new substituent will be on the position reinforced by both.
- If the directing effects oppose each other, the stronger activator wins.
- No substitution occurs between two meta substituents.

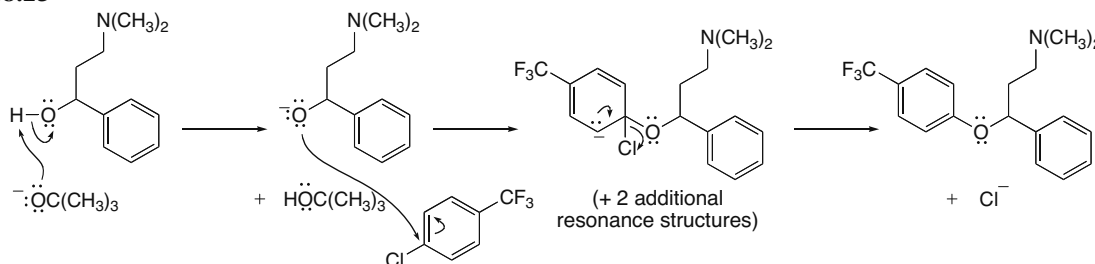
**18.23**

Reactions of Aromatic Compounds 18-13

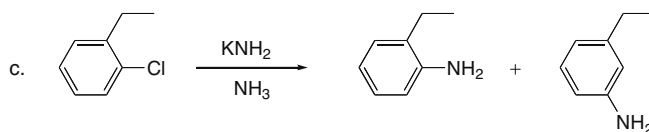
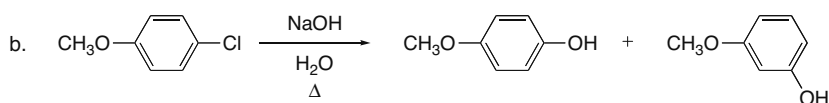
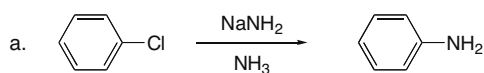
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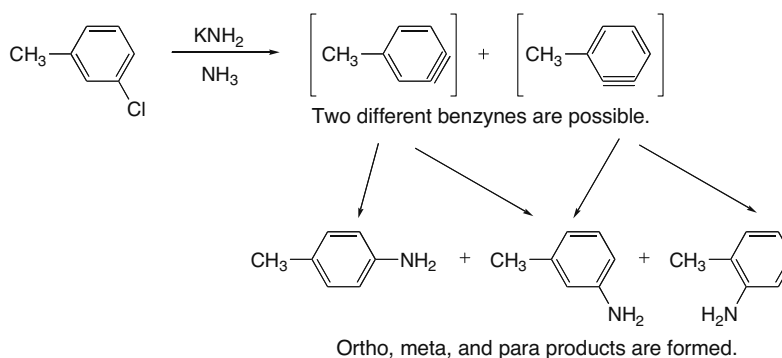
18.25



18.26

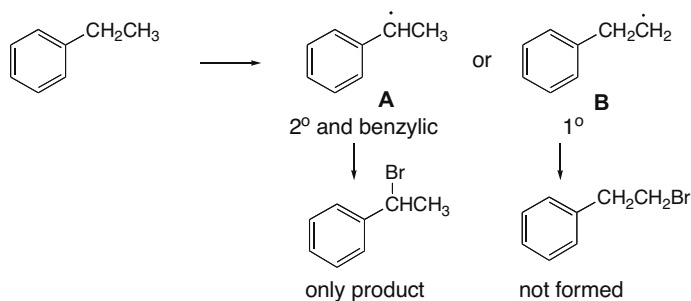


18.27

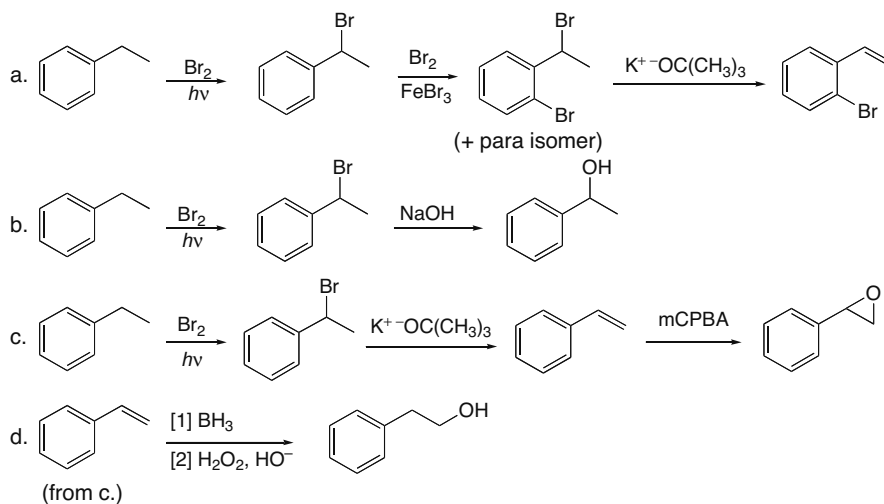


18.28 This reaction proceeds via a radical bromination mechanism and two radicals are possible: **A** (2° and benzylic) and **B** (1°). Since **B** (which leads to $\text{C}_6\text{H}_5\text{CH}_2\text{CH}_2\text{Br}$) is much less stable, this radical is not formed so only $\text{C}_6\text{H}_5\text{CH}(\text{Br})\text{CH}_3$ is formed as product.

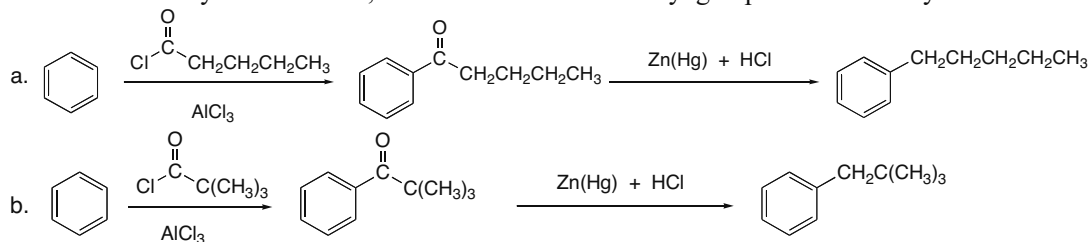
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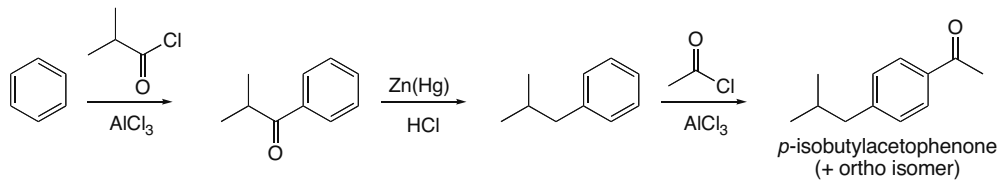
18.29



18.30 First use an acylation reaction, and then reduce the carbonyl group to form the alkyl benzenes.

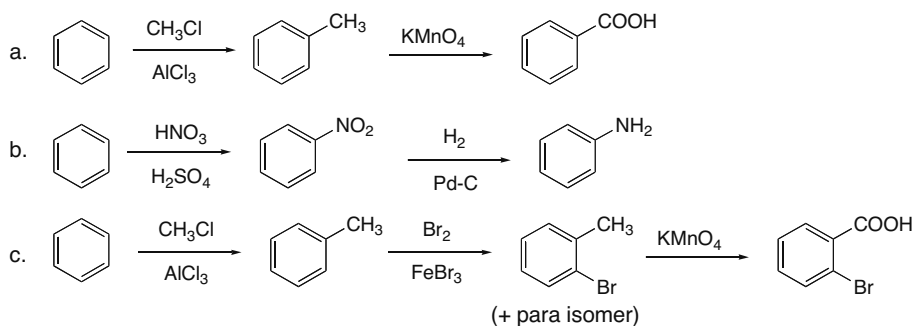


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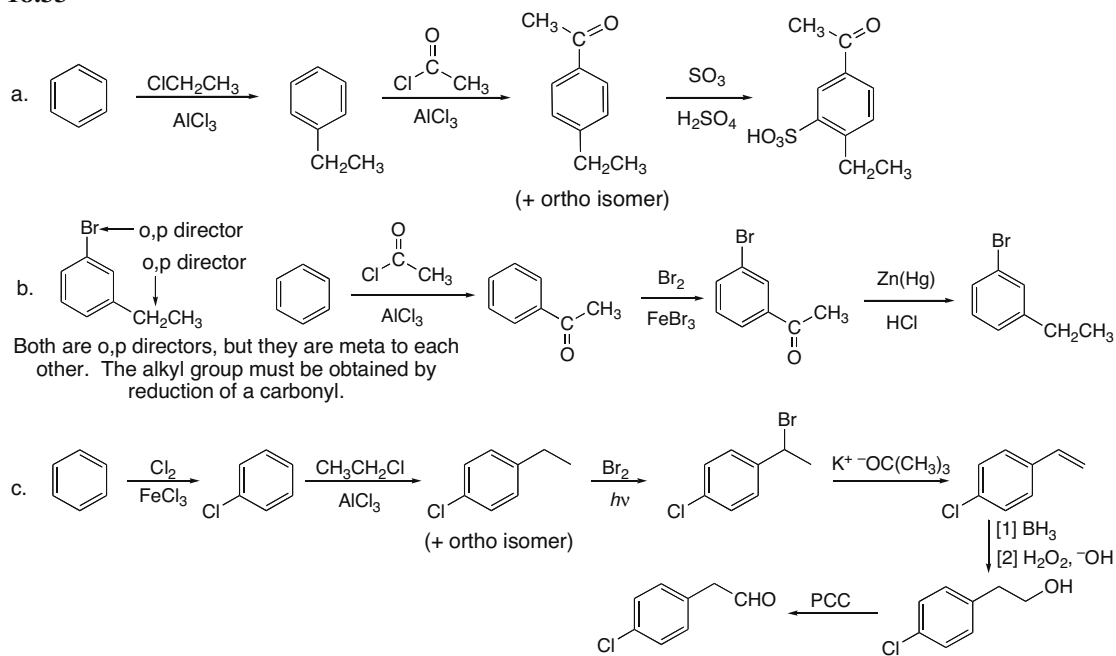


Reactions of Aromatic Compounds 18-15

18.32

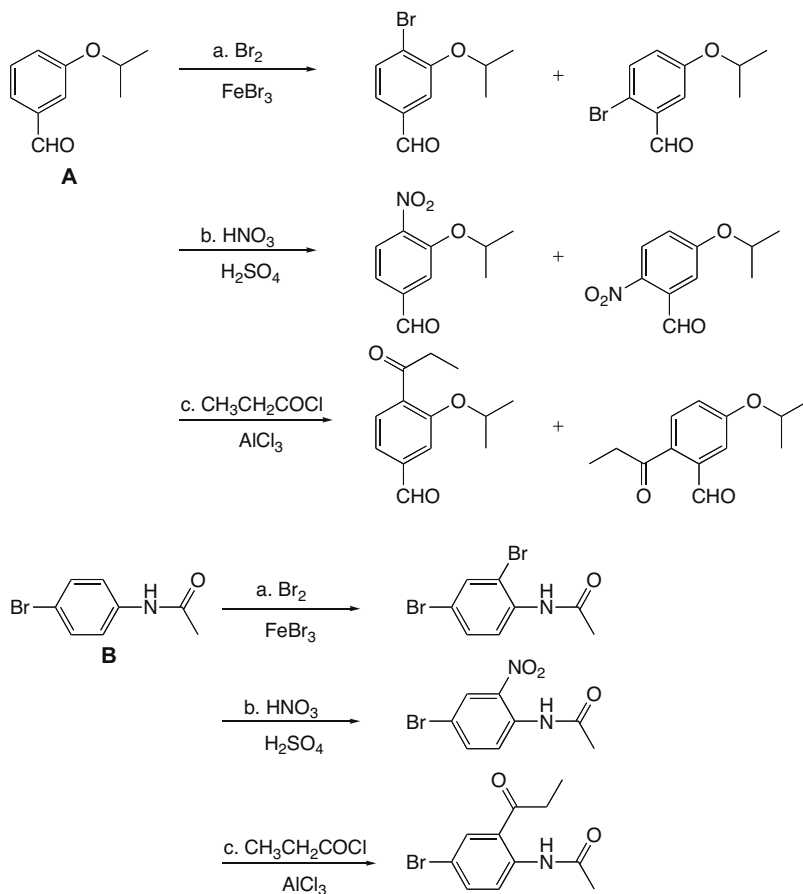


18.33

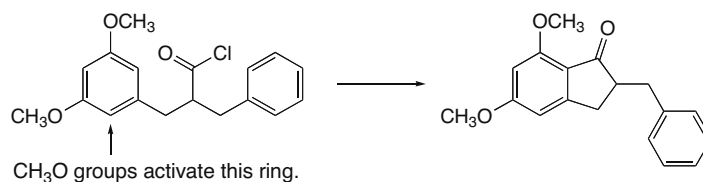


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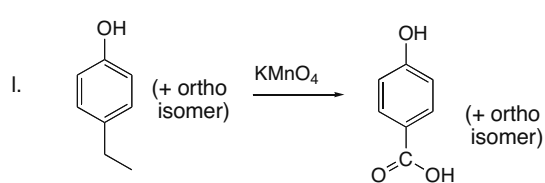
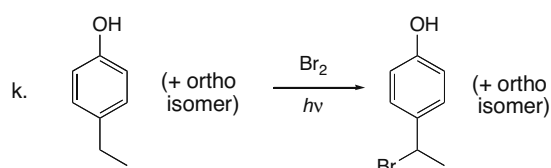
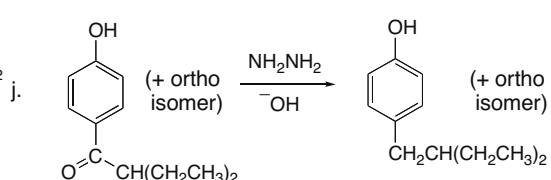
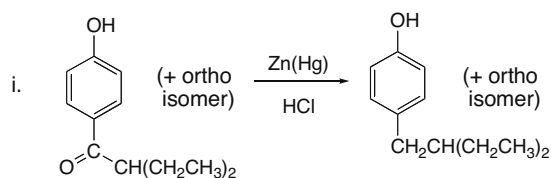
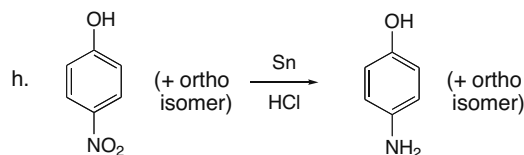
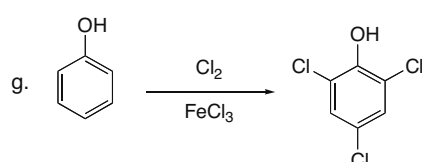
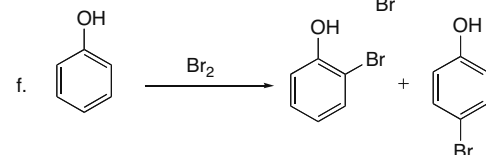
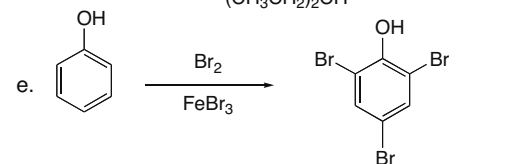
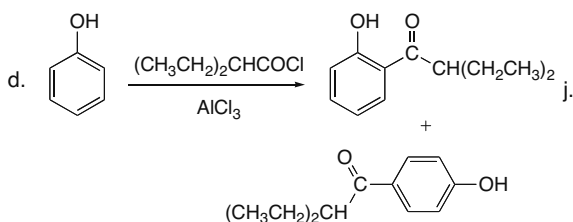
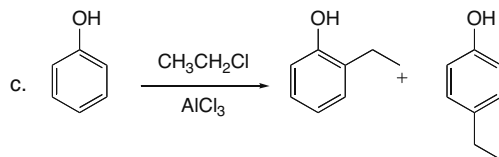
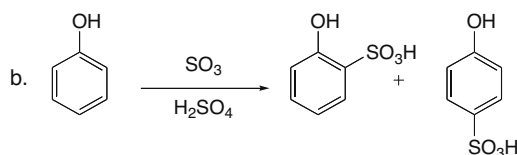
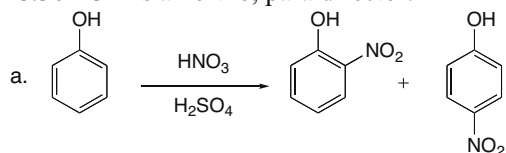
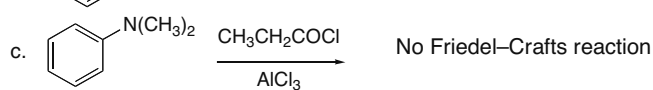
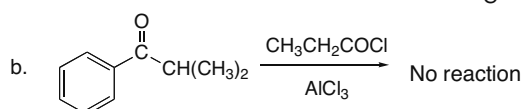
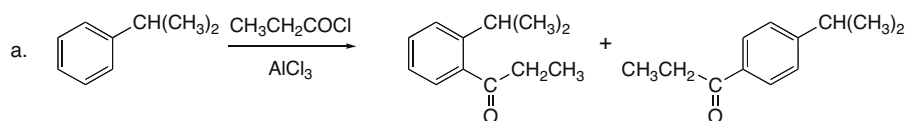
18.34



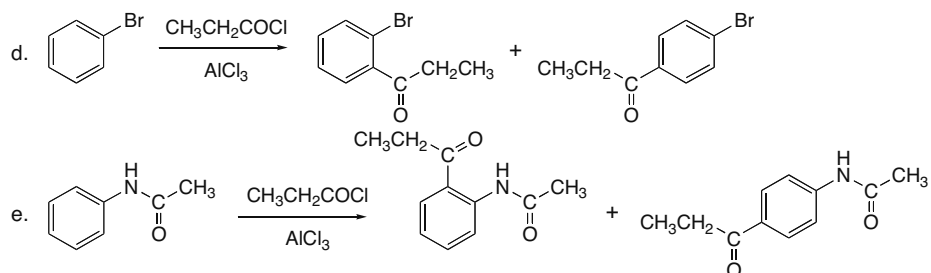
18.35 Intramolecular Friedel–Crafts acylation occurs on the more activated aromatic ring.



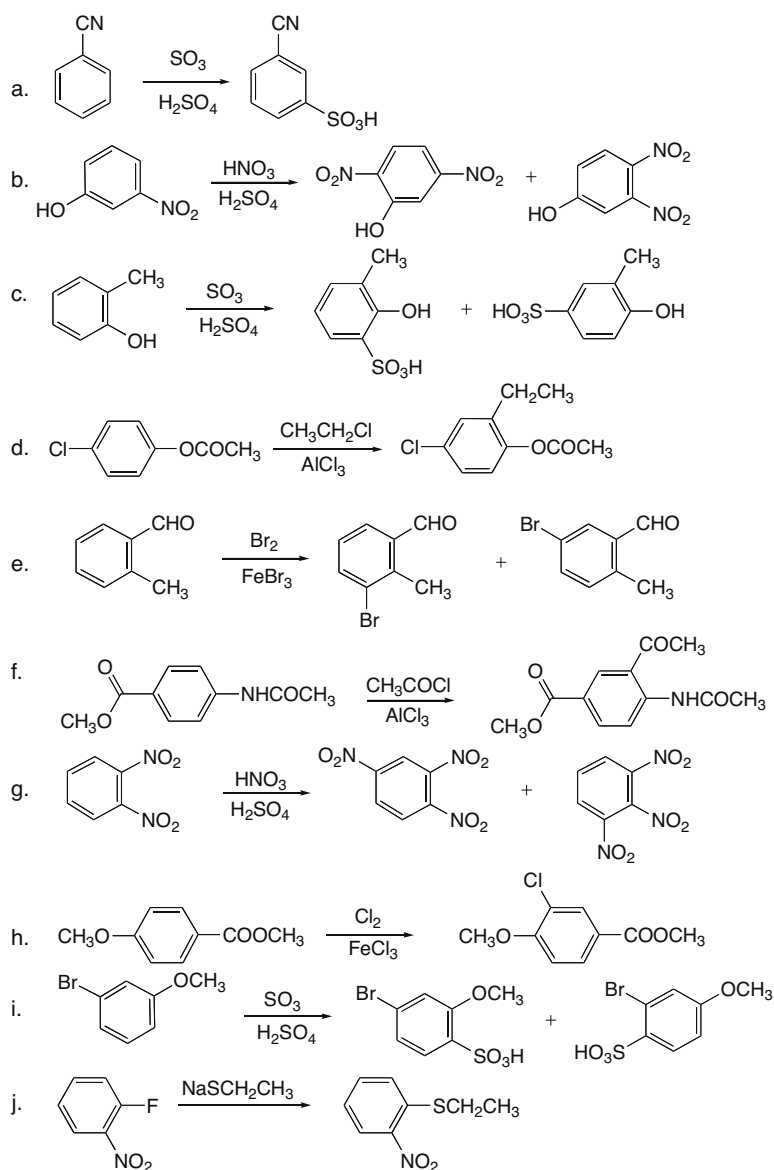
Reactions of Aromatic Compounds 18-17

18.36 OH is an ortho, para director.**18.37**

Chapter 18–18

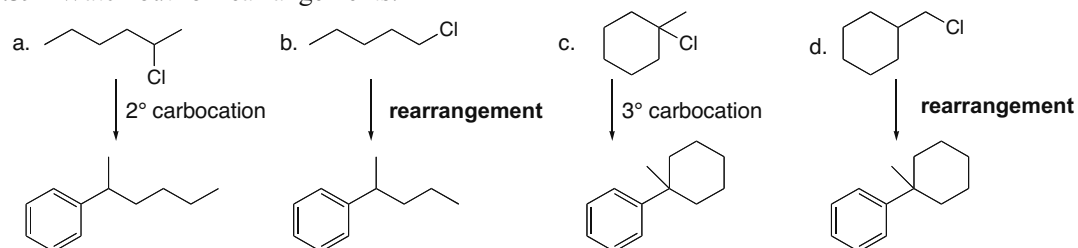


18.38

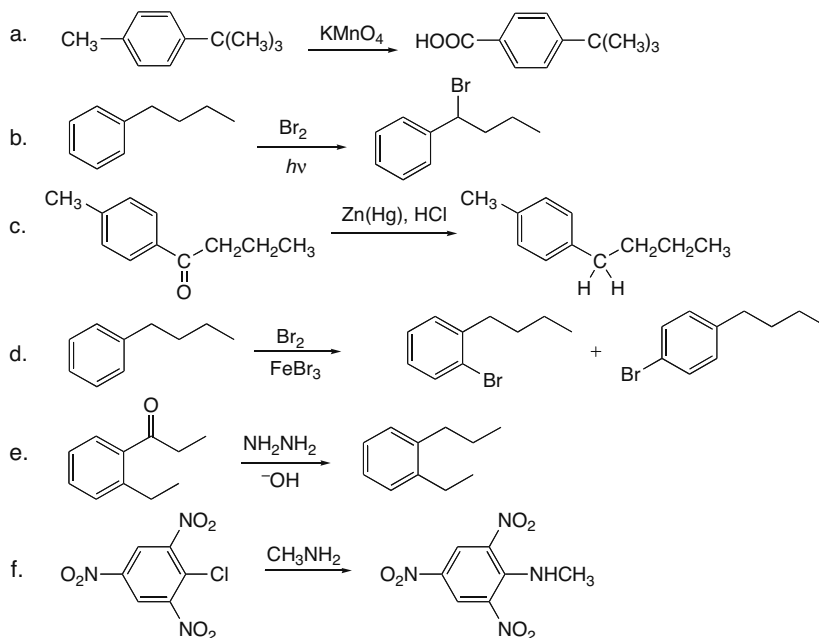


Reactions of Aromatic Compounds 18–19

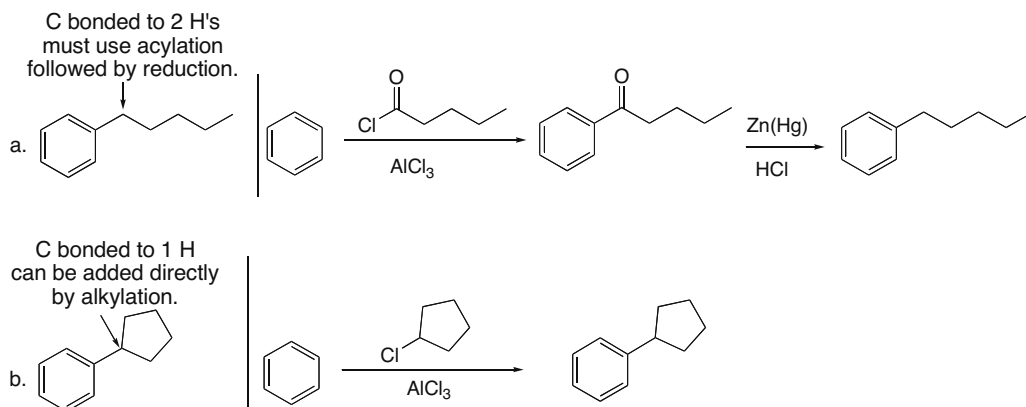
18.39 Watch out for rearrangements.



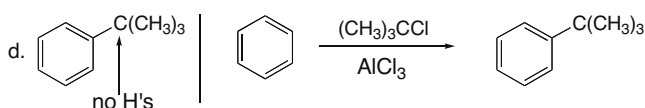
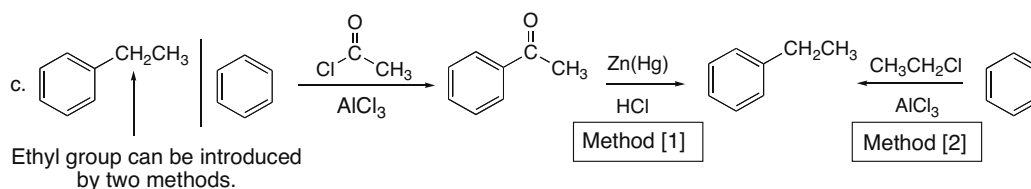
18.40



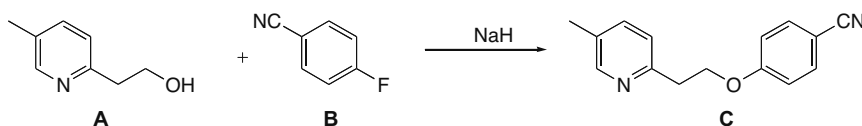
18.41



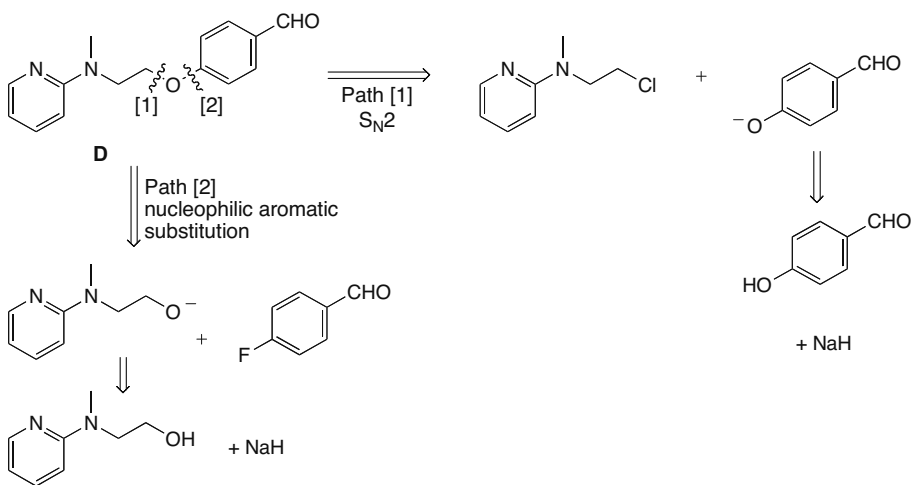
Chapter 18–20



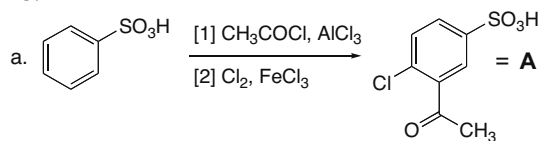
18.42



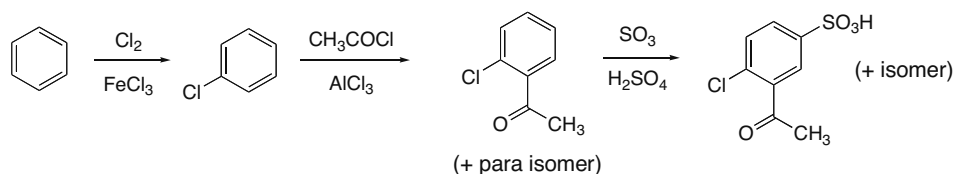
18.43



18.44

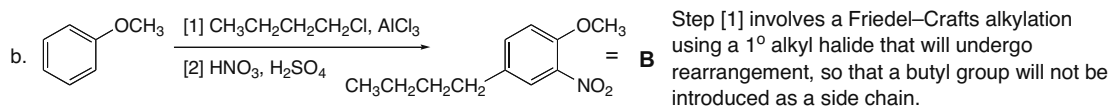


Alternate synthesis:

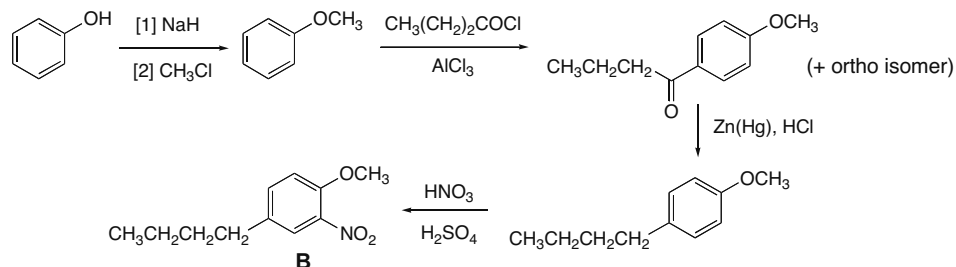


Step [1] won't work because a Friedel–Crafts reaction can't be done on a deactivated benzene ring, as is the case with the SO_3H substituent. Even if Step [1] did work, the second step would introduce Cl meta to SO_3H , not para as drawn.

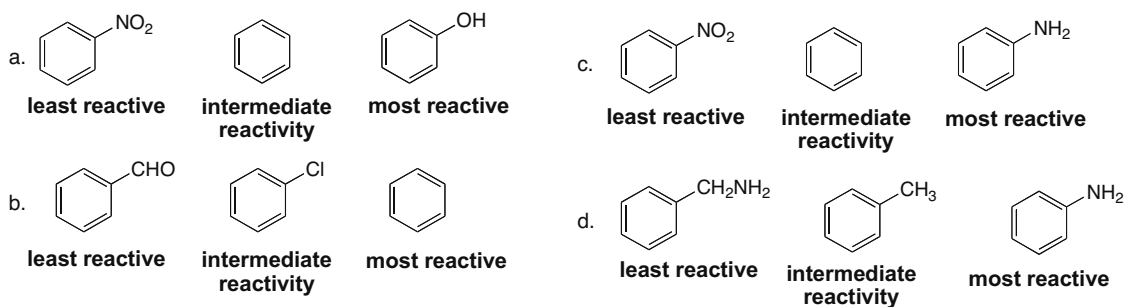
Reactions of Aromatic Compounds 18–21



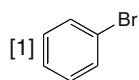
Alternate synthesis:



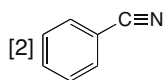
18.45 Use the directions from Answer 18.16 to rank the compounds.



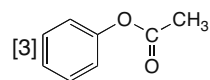
18.46



- withdraw
- donate
- less
- deactivate

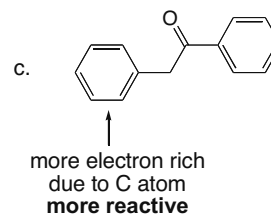
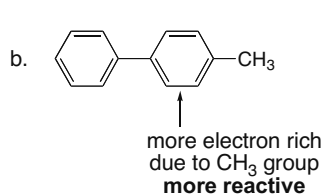
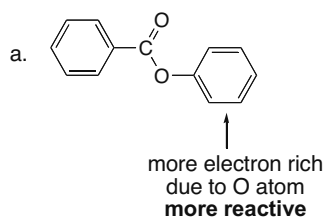


- withdraw
- withdraw
- less
- deactivate



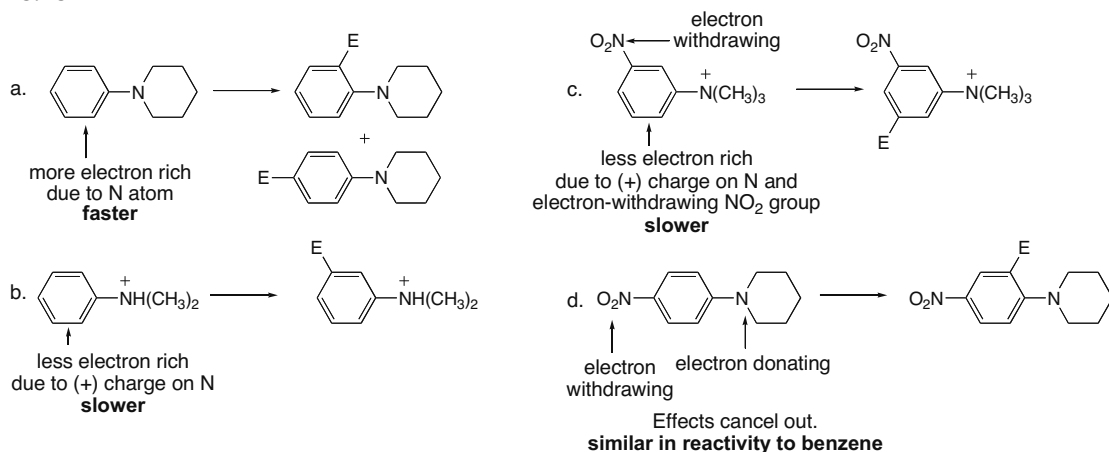
- withdraw
- donate
- more
- activate

18.47

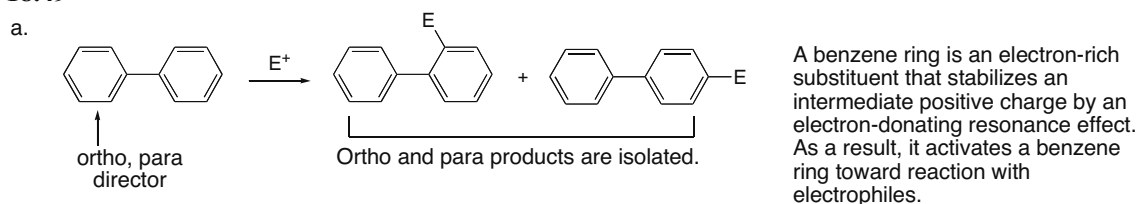


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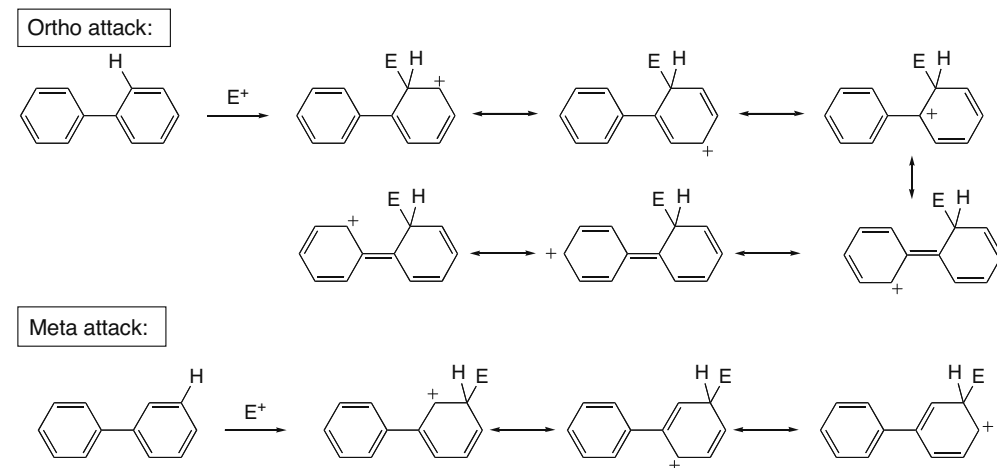
18.48



18.49

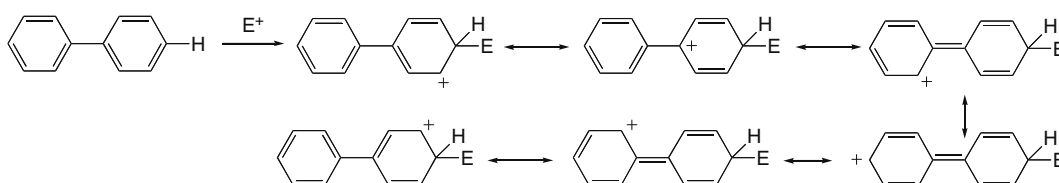


With ortho and para attack there is additional resonance stabilization that delocalizes the positive charge onto the second benzene ring. Such additional stabilization is not possible with meta attack.

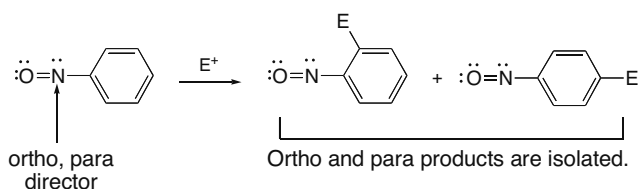


Reactions of Aromatic Compounds 18–23

Para attack:

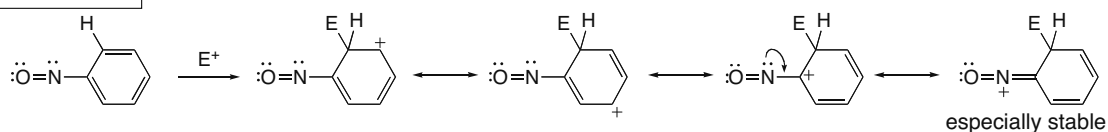


b.

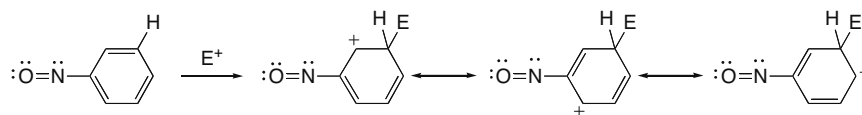


With ortho and para attack there is additional resonance stabilization that delocalizes the positive charge onto the nitroso group. Such additional stabilization is not possible with meta attack. This makes $-\text{NO}$ an ortho, para director. Since the N atom bears a partial (+) charge (because it is bonded to a more electronegative O atom), the $-\text{NO}$ group inductively withdraws electron density, thus deactivating the benzene ring towards electrophilic attack. In this way, the $-\text{NO}$ group resembles the halogens. Thus, the electron-donating resonance effect makes $-\text{NO}$ an o,p director, but the electron-withdrawing inductive effect makes it a deactivator.

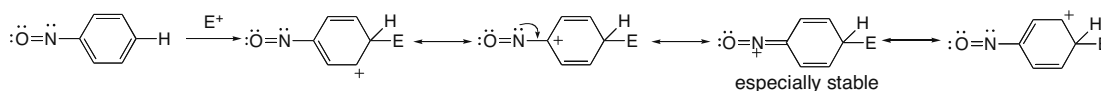
Ortho attack:



Meta attack:

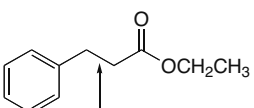


Para attack:



Chapter 18-24

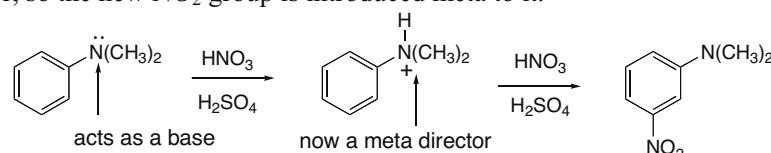
18.50


 alkyl group on the benzene ring
 R stabilizes (+) charges on the o,p positions by an electron-donating inductive effect. This group behaves like any other R group so that ortho and para products are formed in electrophilic aromatic substitution.

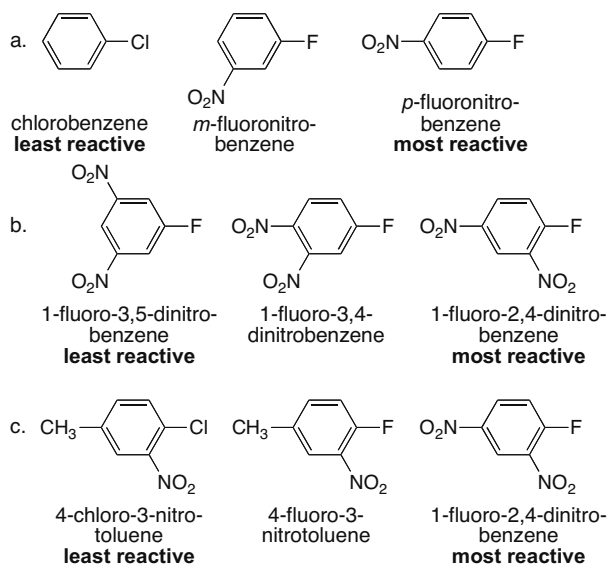


(+) charge on atom bonded to the benzene ring
 Drawing resonance structures in electrophilic aromatic substitution results in especially unstable structures for attack at the o,p positions—two (+) charges on adjacent atoms. This doesn't happen with meta attack, so meta attack is preferred. This is identical to the situation observed with all meta directors.

- 18.51 Under the acidic conditions of nitration, the N atom of the starting material gets protonated, so the atom directly bonded to the benzene ring bears a (+) charge. This makes it a meta director, so the new NO₂ group is introduced meta to it.



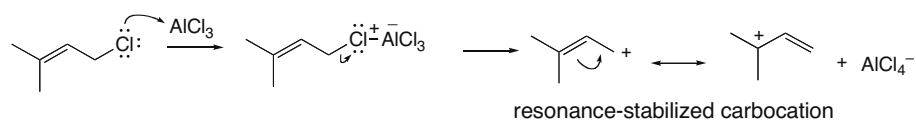
- 18.52 Increasing the number of electron-withdrawing groups (especially at the ortho and para positions to the leaving group) increases the rate of nucleophilic aromatic substitution. Increasing the electronegativity of the halogen increases the rate.



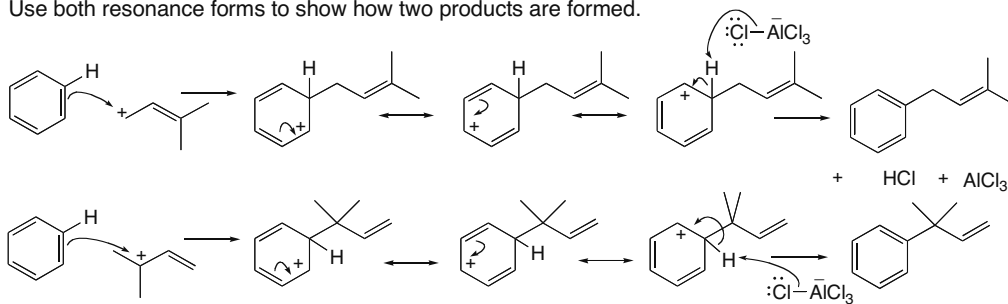
Reactions of Aromatic Compounds 18–25

18.53 A CH_3O group has an electron-donating resonance effect. This stabilizes a (+) charge, so it increases stability of the carbocation intermediate in electrophilic aromatic substitution. This destabilizes a (–) charge, so it decreases the stability of the carbanion intermediate in nucleophilic aromatic substitution.

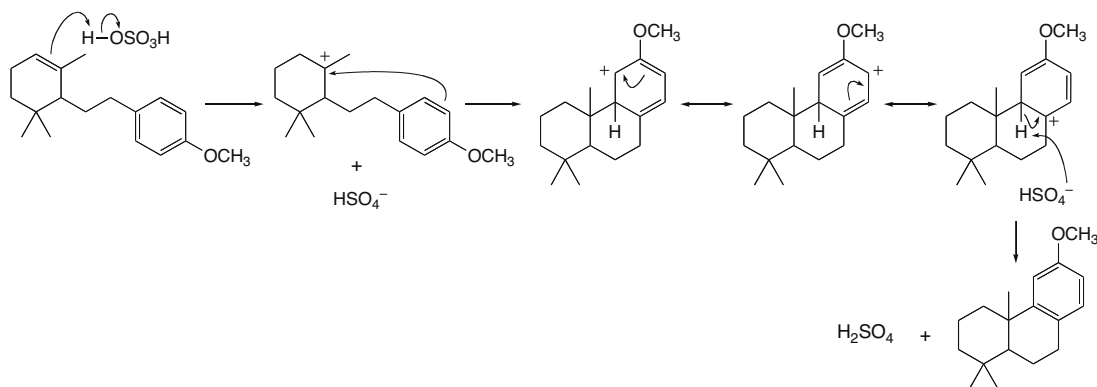
18.54



Use both resonance forms to show how two products are formed.

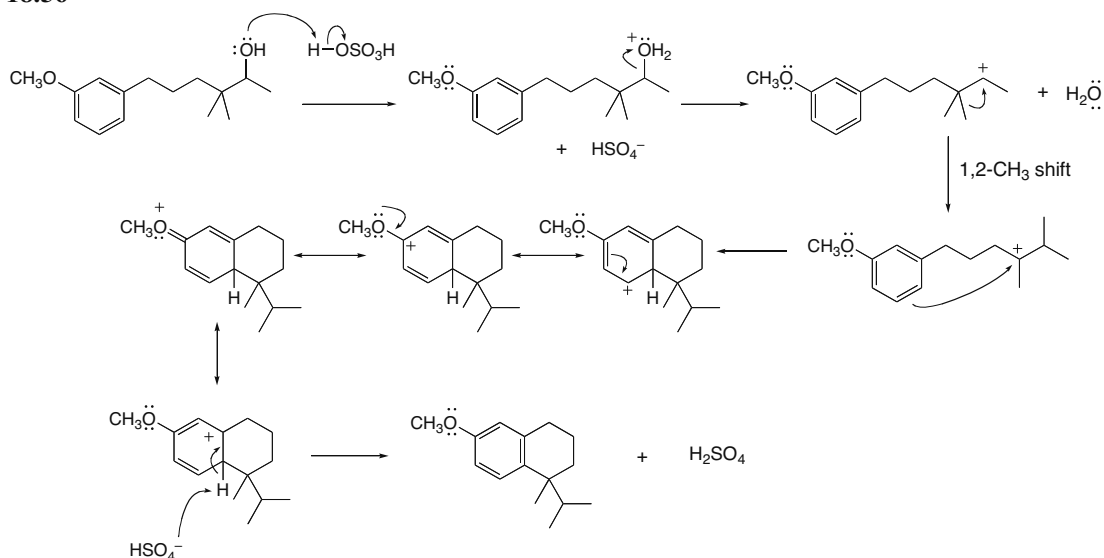


18.55



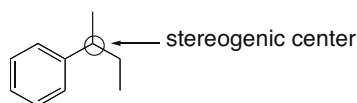
Chapter 18–26

18.56

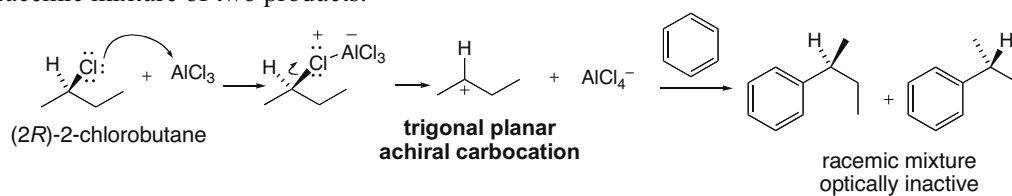


18.57

- a. The product has one stereogenic center.

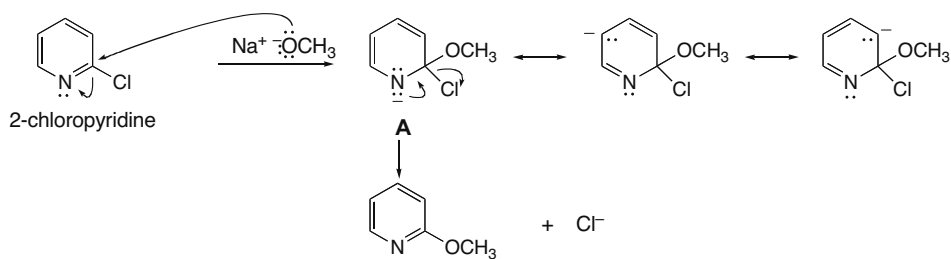


- b. The mechanism for Friedel–Crafts alkylation with this 2° halide involves formation of a trigonal planar carbocation. Since the carbocation is achiral, it reacts with benzene with equal probability from two possible directions (above and below) to afford an optically inactive, racemic mixture of two products.



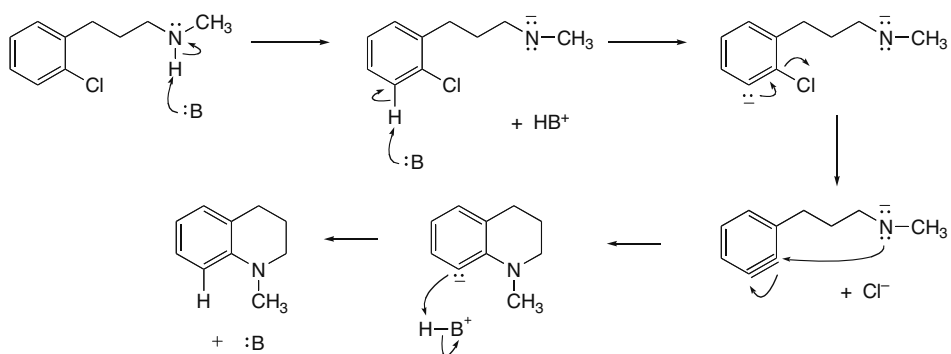
Reactions of Aromatic Compounds 18–27

- 18.58** The reaction follows the two-step addition–elimination mechanism for nucleophilic aromatic substitution.



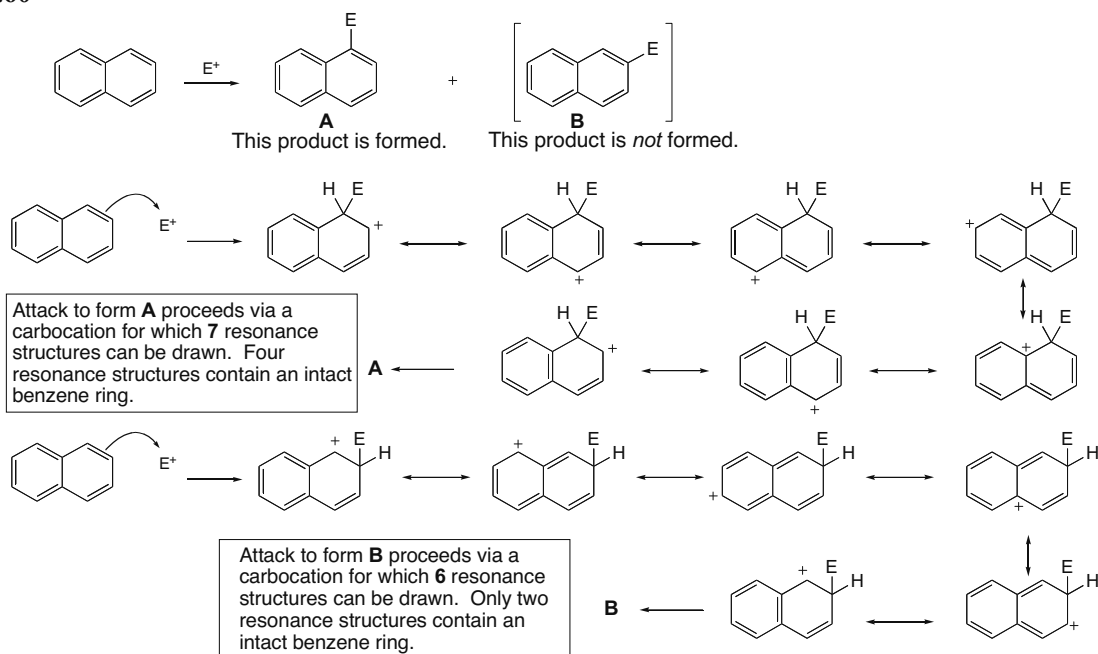
Resonance structure **A** is stabilized because the negative charge is located on an electronegative N. This makes nucleophilic aromatic substitution on 2-chloropyridine faster than a similar reaction with chlorobenzene, which has no N atom to stabilize the intermediate negative charge.

- 18.59** Since there is no electron-withdrawing group on the benzene ring, the mechanism likely proceeds via elimination–addition.



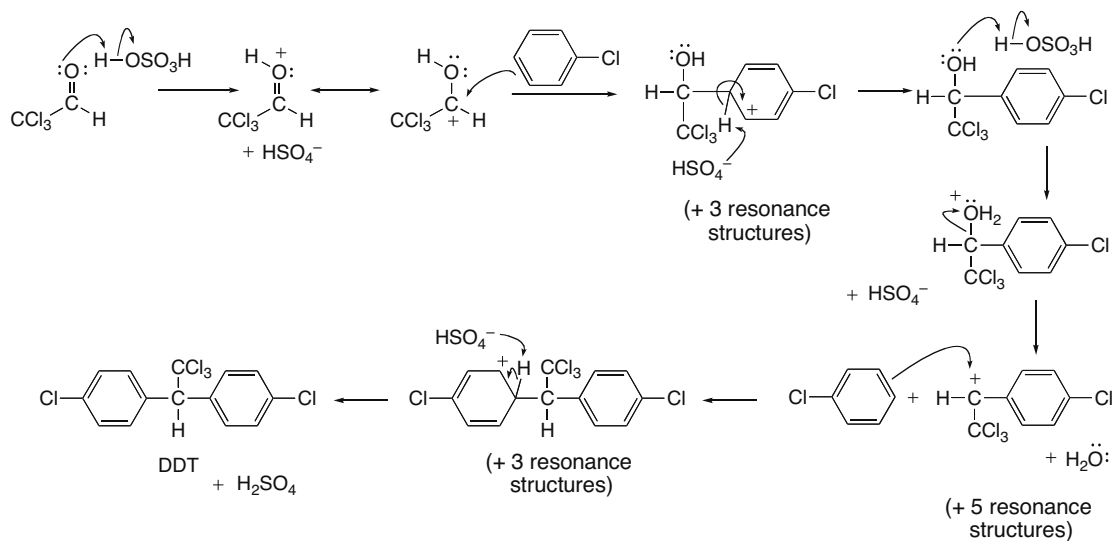
Chapter 18–28

18.60



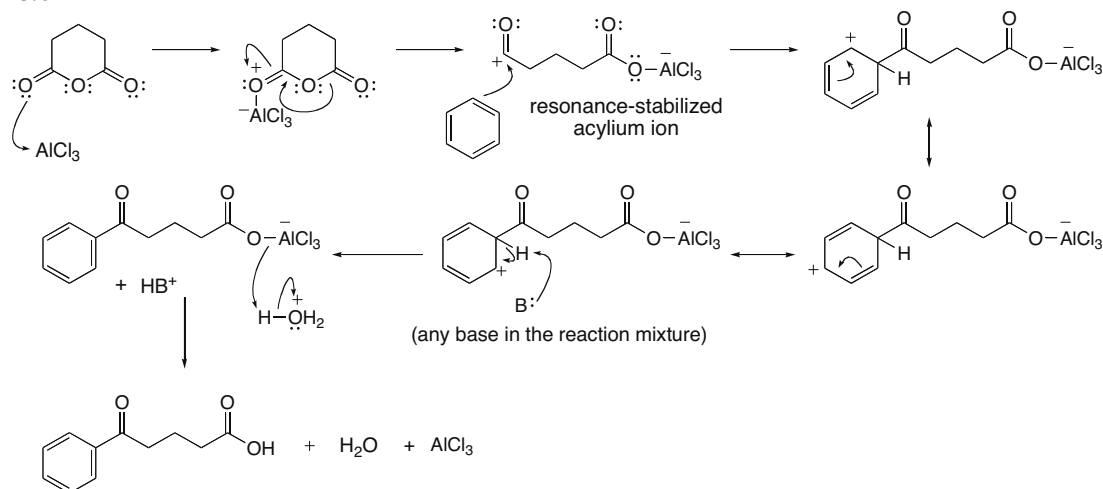
A reaction that occurs by way of the more stable carbocation is preferred, so product **A** is formed.

18.61

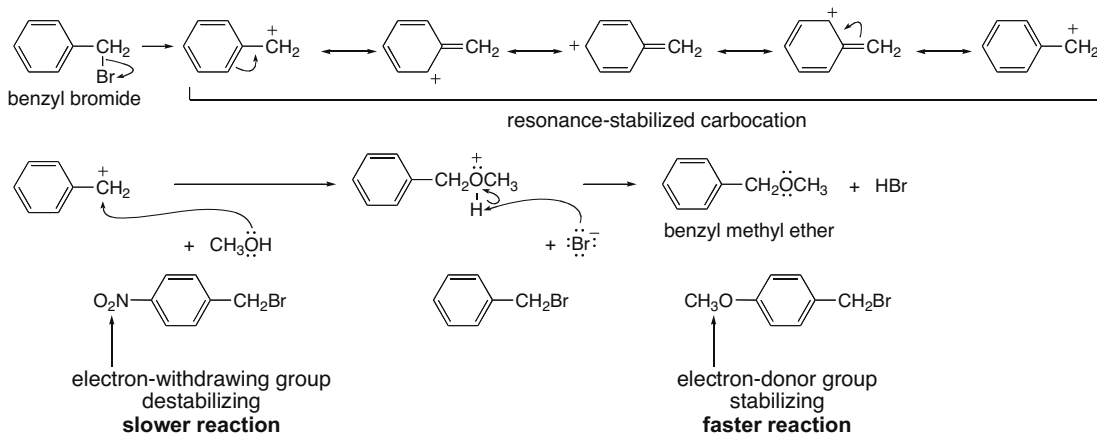


Reactions of Aromatic Compounds 18-29

18.62

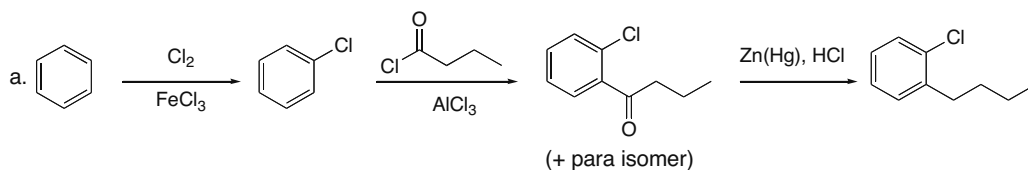
18.63 Benzyl bromide forms a resonance-stabilized intermediate that allows it to react rapidly under S_N1 conditions.

Formation of a resonance-stabilized carbocation:

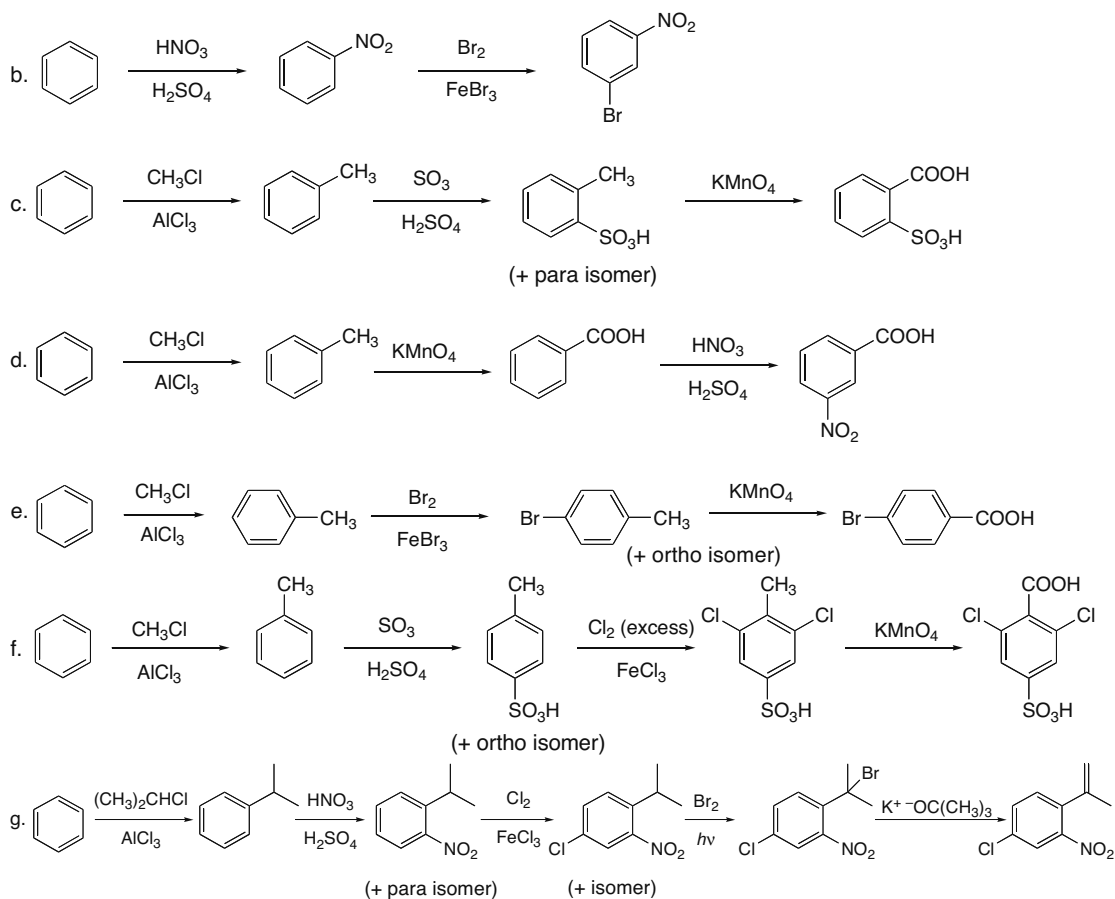


The electron-withdrawing NO_2 group will destabilize the carbocation so the benzylic halide will be less reactive, while the electron-donating OCH_3 group will stabilize the carbocation, so the benzylic halide will be more reactive.

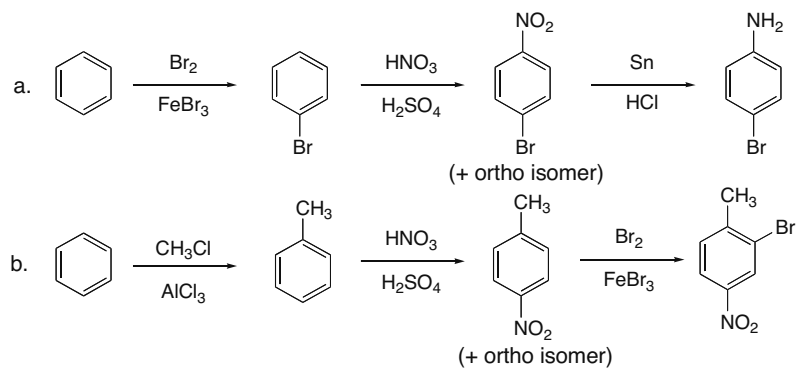
18.64



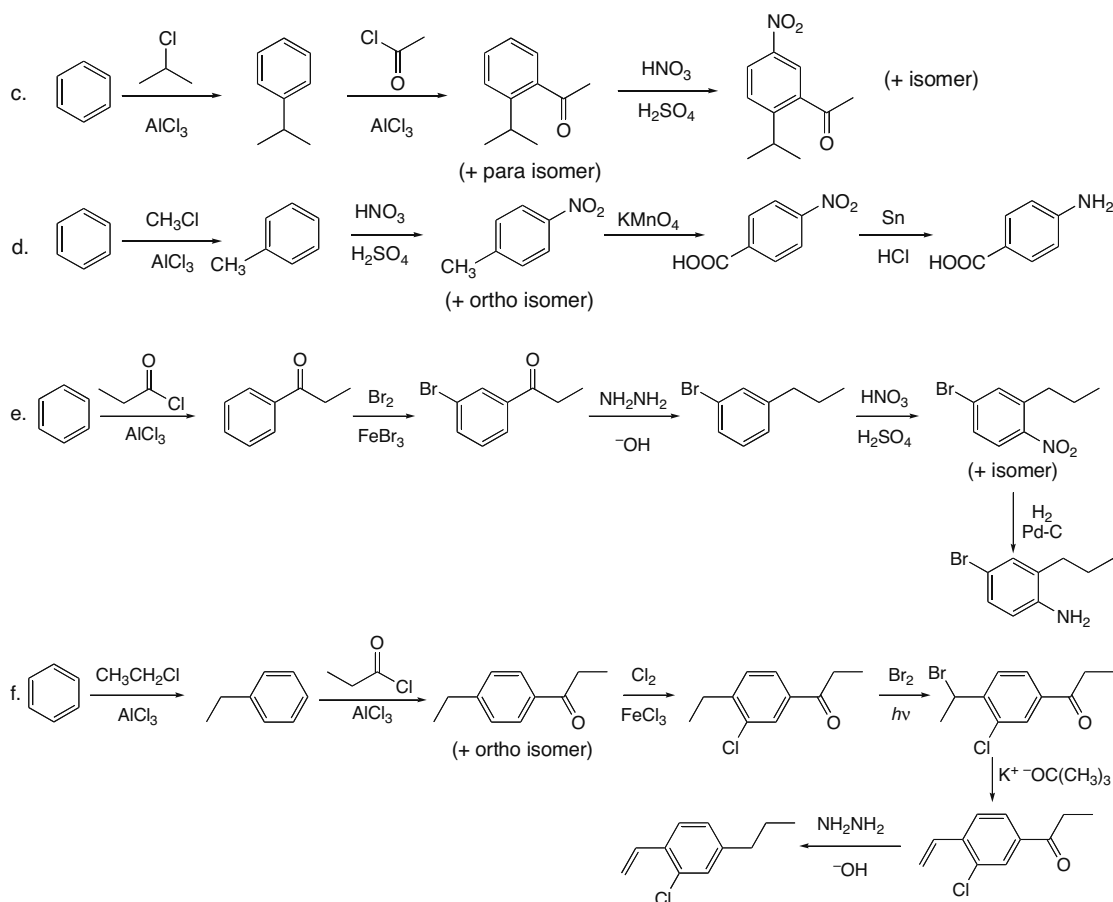
Chapter 18–30



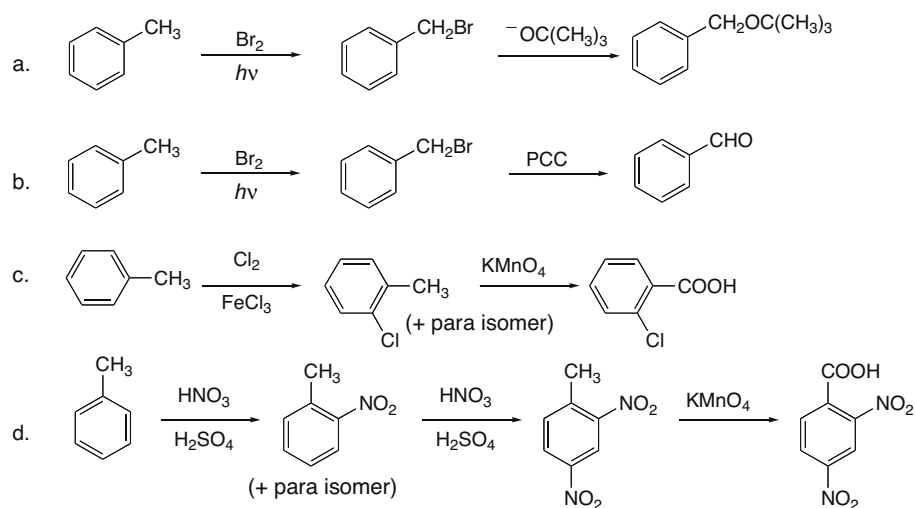
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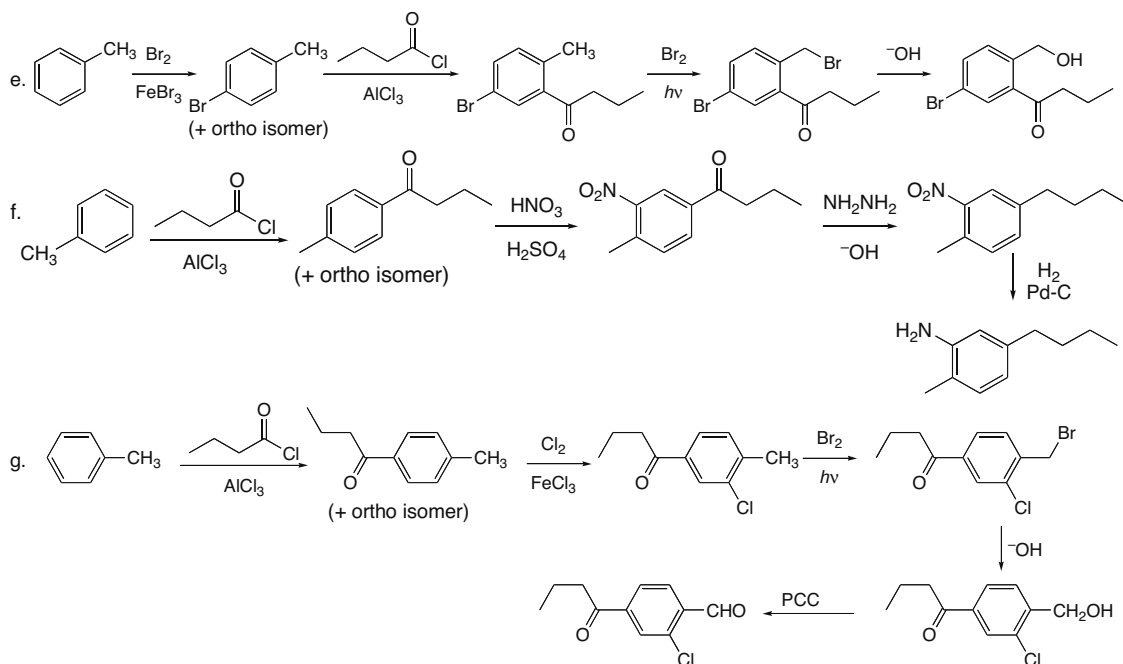
Reactions of Aromatic Compounds 18-31



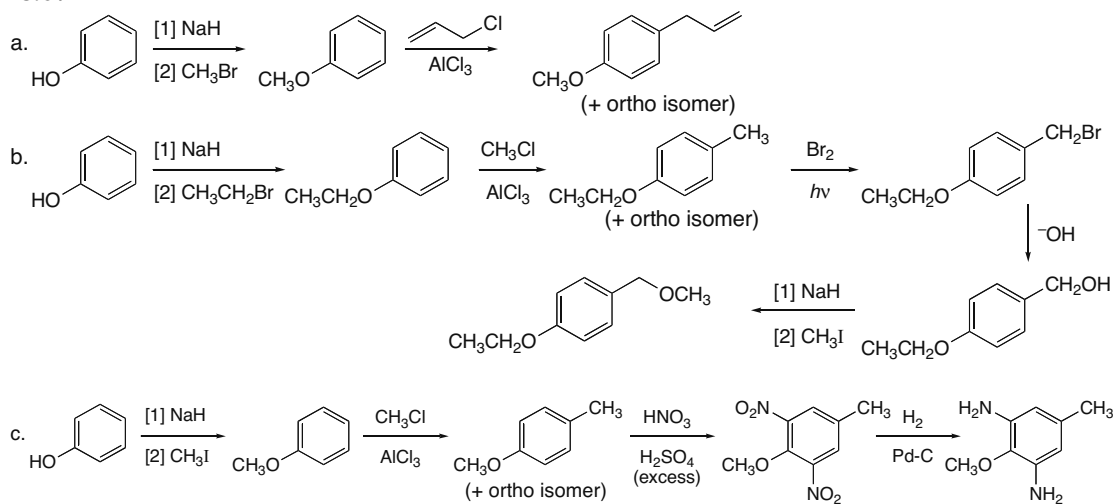
18.66



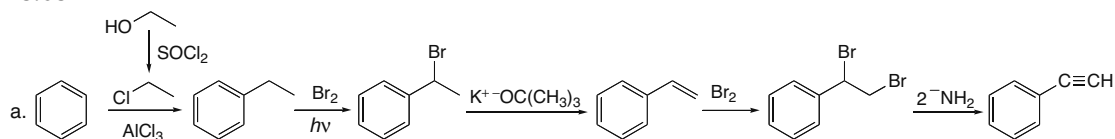
Chapter 18–32



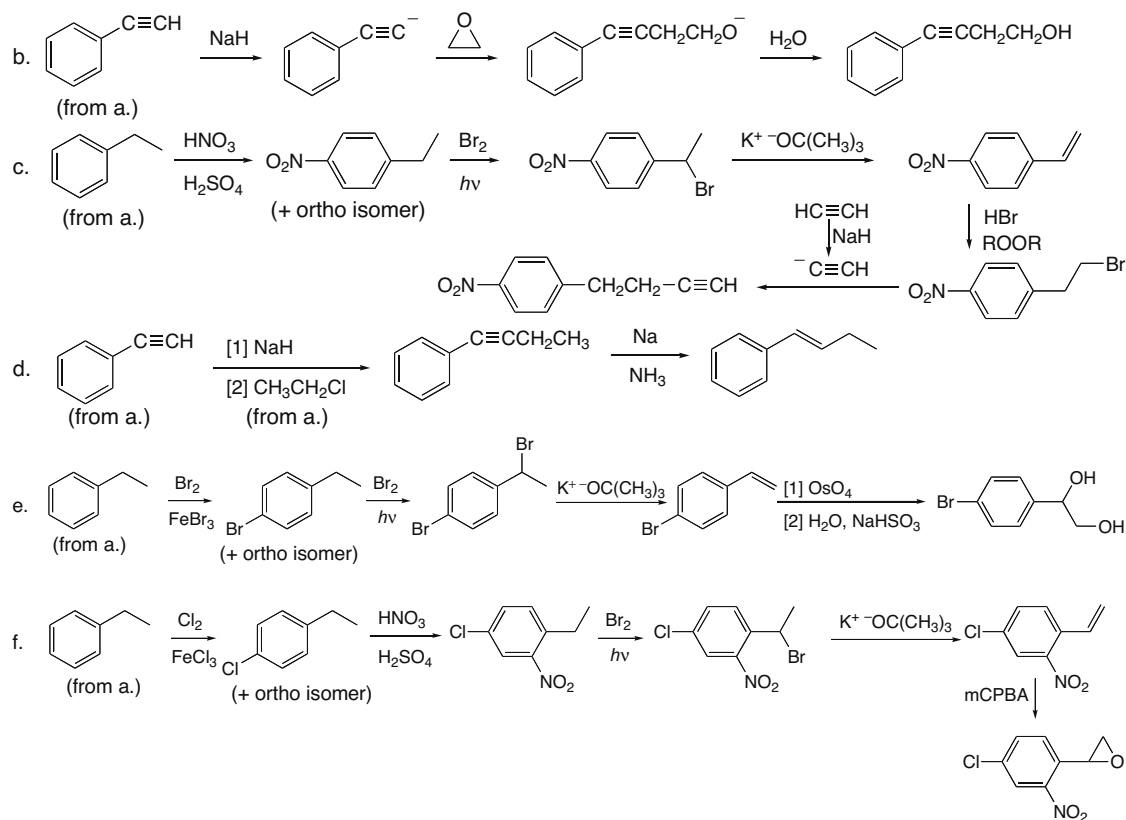
18.67



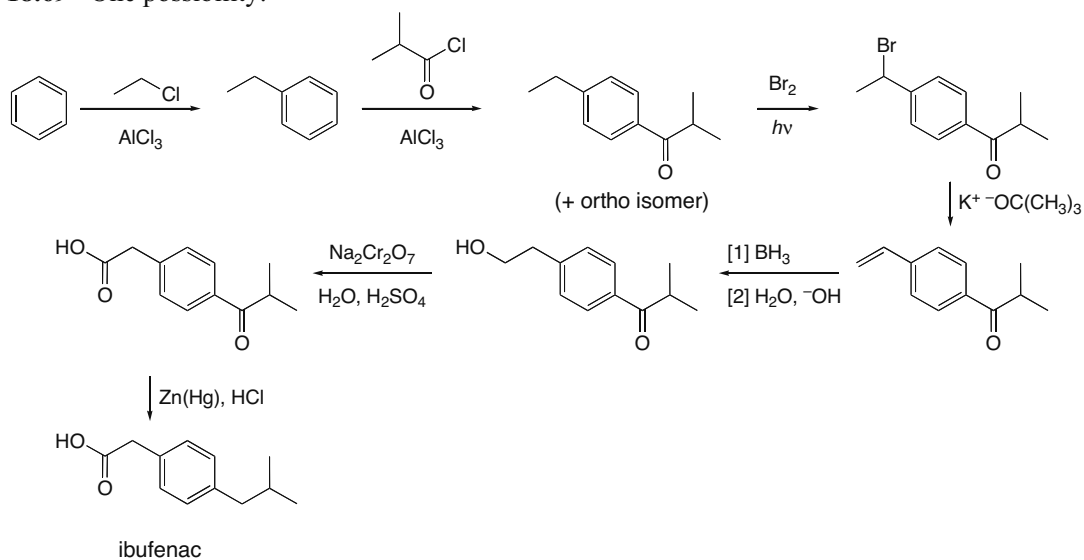
18.68



Reactions of Aromatic Compounds 18-33

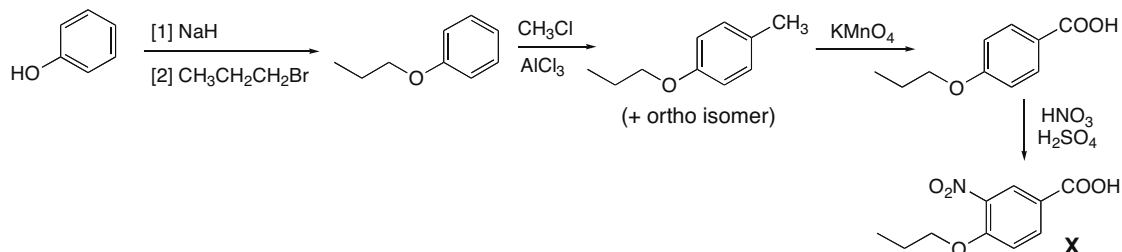


18.69 One possibility:



Chapter 18–34

18.70

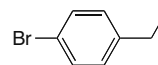


18.71 Use integration data and the molecular formula to determine the number of H's that give rise to each signal (Section 14.5, *How To*).

¹H NMR data of compound **A** (C₈H₉Br):

Absorption	ppm	# of H's	Explanation
triplet	1.2	3	3 H's adjacent to 2 H's
quartet	2.6	2	2 H's adjacent to 3 H's
two signals	7.1 and 7.4	2 + 2	para disubstituted benzene

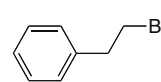
Structure:



¹H NMR data of compound **B** (C₈H₉Br):

Absorption	ppm	# of H's	Explanation
triplet	3.1	2	2 H's adjacent to 2 H's
triplet	3.5	2	2 H's adjacent to 2 H's
multiplet	7.1–7.4	5	monosubstituted benzene

Structure:

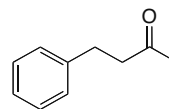


18.72 IR absorption at 1717 cm⁻¹ means compound **C** has a C=O.

¹H NMR data of compound **C** (C₁₀H₁₂O):

Absorption	ppm	# of H's	Explanation
singlet	2.1	3	3 H's
triplet	2.8	2	2 H's adjacent to 2 H's
triplet	2.9	2	2 H's adjacent to 2 H's
multiplet	7.1–7.4	5	monosubstituted benzene

Structure:

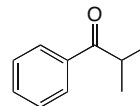


18.73

¹H NMR data of compound **X** (C₁₀H₁₂O):

Absorption	ppm	# of H's	Explanation
doublet	1.3	6	6 H's adjacent to 1 H
septet	3.5	1	1 H adjacent to 6 H's
multiplet	7.4–8.1	5	monosubstituted benzene

Structure:

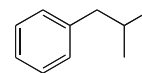


Reactions of Aromatic Compounds 18–35

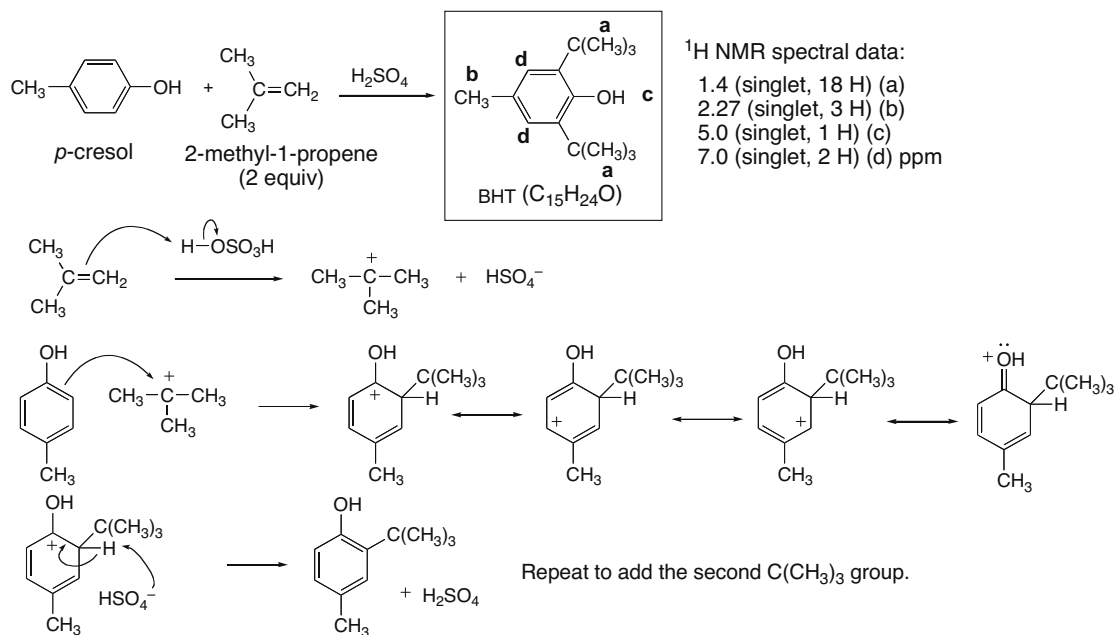
¹H NMR data of compound Y (C₁₀H₁₄):

Absorption	ppm	# of H's	Explanation
doublet	0.9	6	6 H's adjacent to 1 H
multiplet	1.8	1	1 H adjacent to many H's
doublet	2.5	2	2 H's adjacent to 1 H
multiplet	7.1–7.3	5	monosubstituted benzene

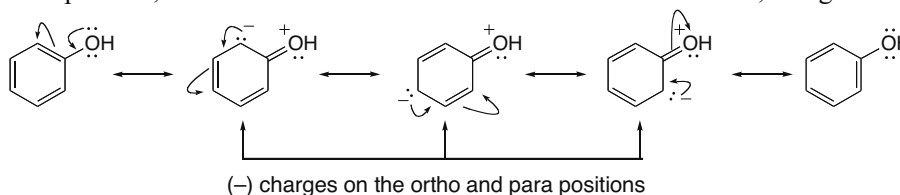
Structure:



18.74



- 18.75** Five resonance structures can be drawn for phenol, three of which place a negative charge on the ortho and para carbons. These illustrate that the electron density at these positions is increased, thus shielding the protons at these positions and shifting the absorptions to lower chemical shift. Similar resonance structures cannot be drawn with a negative charge at the meta position, so it is more deshielded and absorbs farther downfield, at higher chemical shift.

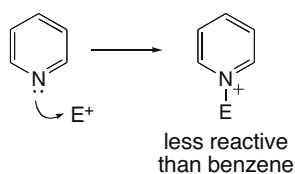


Chapter 18–36

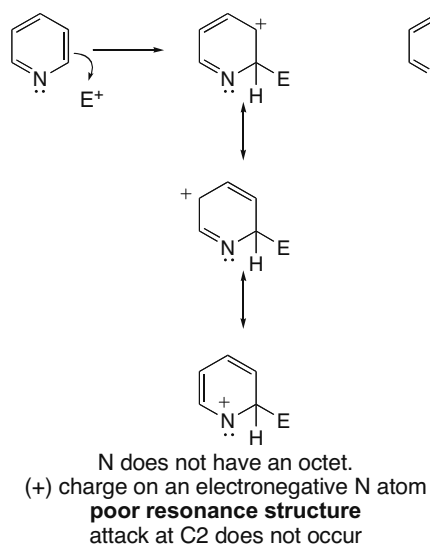
- 18.76** a. Pyridine: The electron-withdrawing inductive effect of N makes the ring electron poor. Also, electrophiles E^+ can react with N, putting a positive charge on the ring. This makes the ring less reactive with another positively charged species.

To understand why substitution occurs at C3, compare the stability of the carbocation formed by attack at C2 and C3.

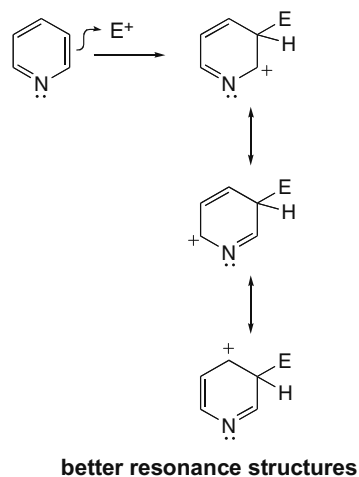
Electrophilic attack on N:



Electrophilic attack at C2:



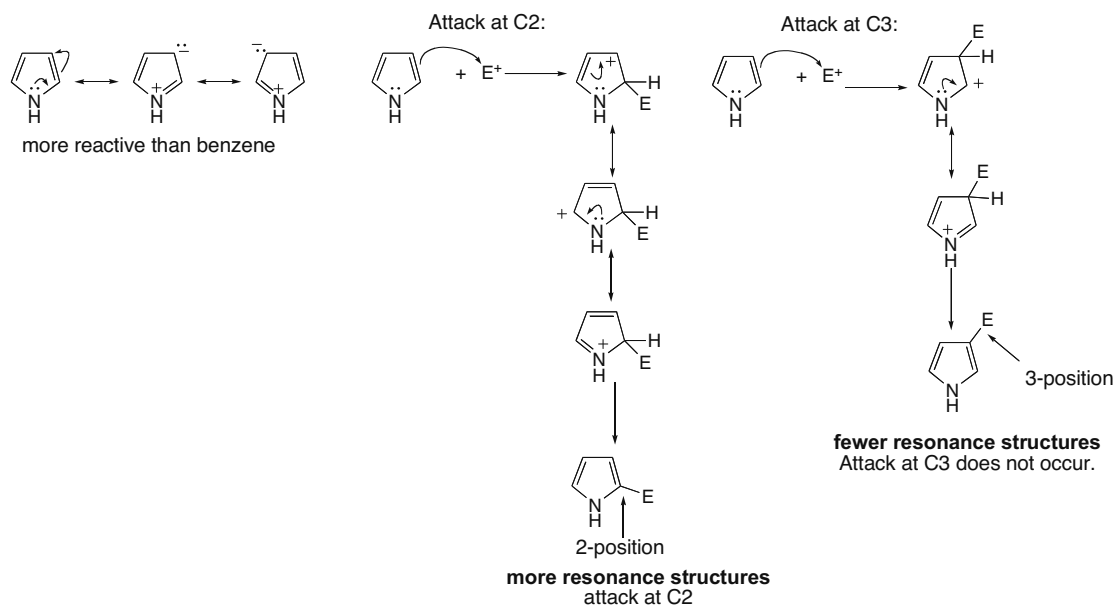
Electrophilic attack at C3:



Since attack at C3 forms a more stable carbocation, attack at C3 occurs. Attack at C4 generates a carbocation of similar stability to attack at C2, so attack at C4 does not occur.

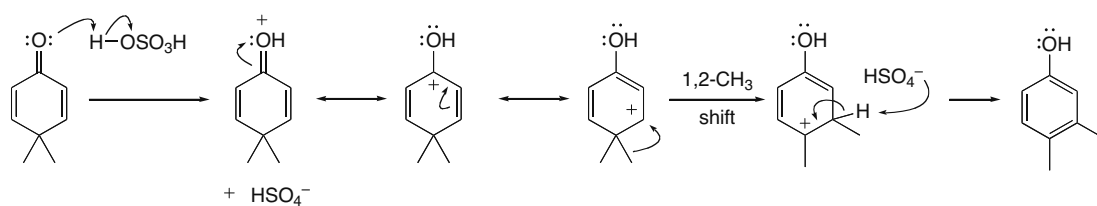
Reactions of Aromatic Compounds 18–37

- b. Pyrrole is more reactive than benzene because the C's are more electron rich. The lone pair on N has an electron-donating resonance effect.



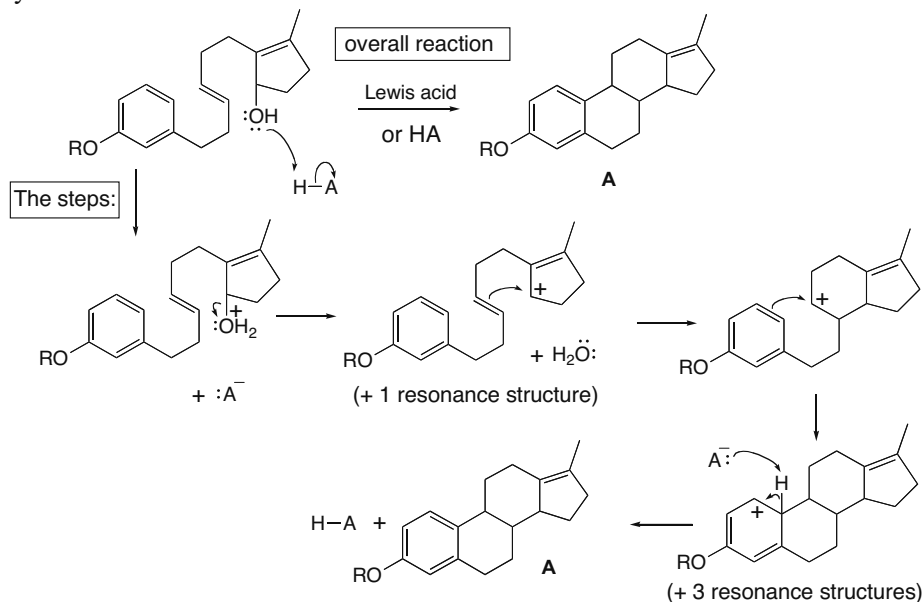
Since attack at C2 forms a more stable carbocation, electrophilic substitution occurs at C2.

18.77



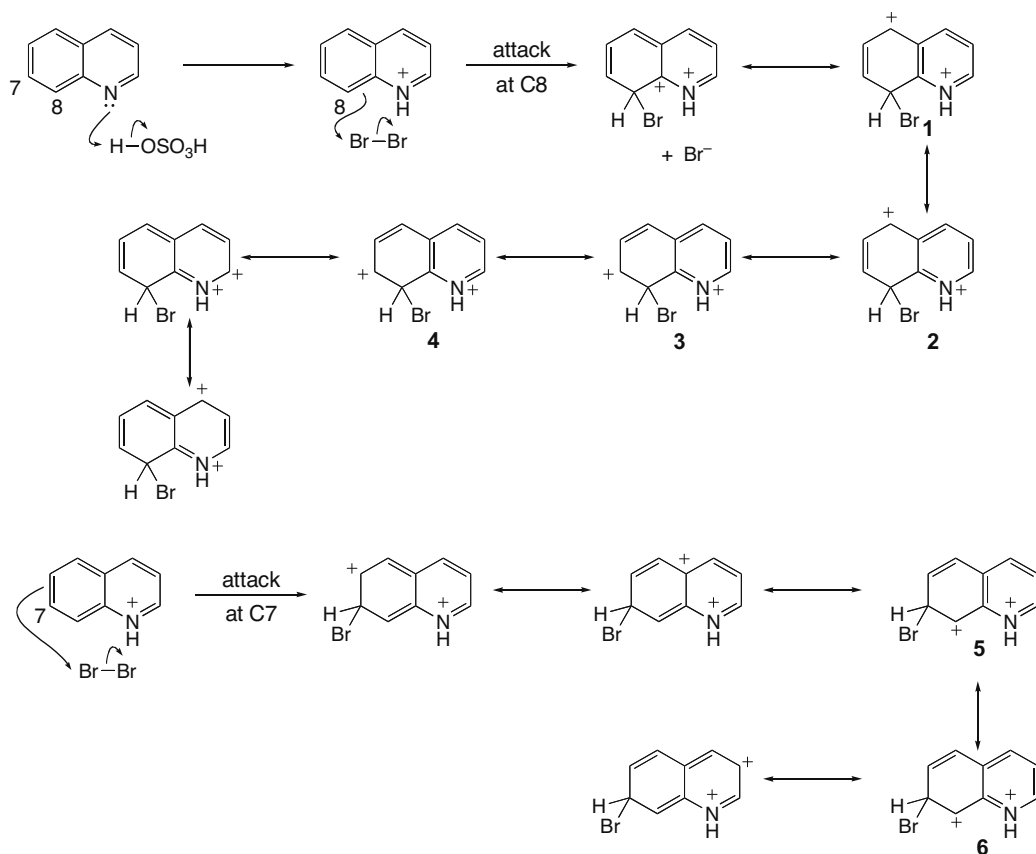
Chapter 18–38

18.78 Draw a stepwise mechanism for the following intramolecular reaction, which was used in the synthesis of the female sex hormone estrone.

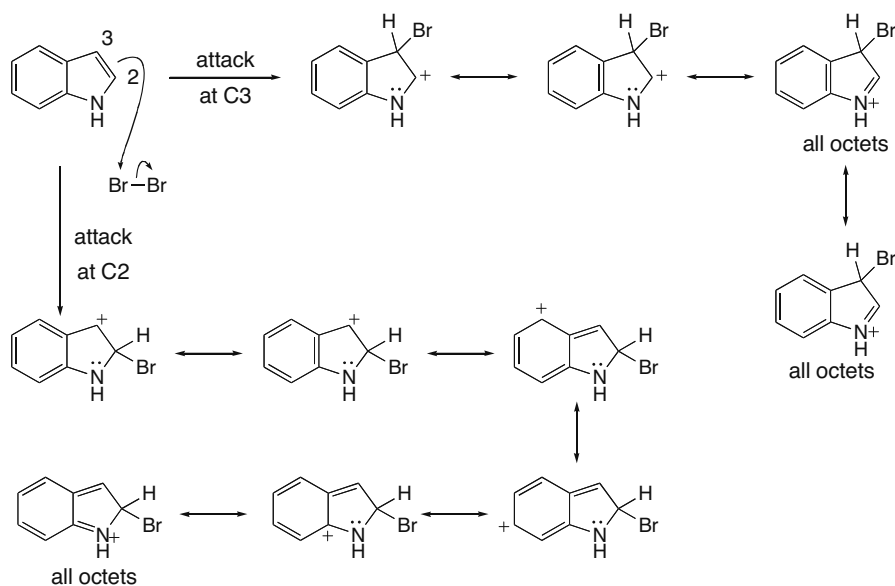


- 18.79** a. In quinoline the lone pair on N occupies an sp^2 hybrid orbital, so it can never be donated to the ring by resonance. The N atom decreases the electron density of the ring in which it is located by an electron-withdrawing inductive effect, so substitution occurs on the other ring. In indole, the N atom donates its electron pair (which is contained in a p orbital) to the five-membered ring, increasing its electron density, so substitution occurs on the five-membered ring with the N atom.
- b. In the presence of acid, the N atom is protonated prior to electrophilic attack. For substitution to occur at C8 rather than C7, the carbocation that results from electrophilic addition at C8 must be more stable. Attack at C8 generates a carbocation with more resonance structures and four structures keep one ring aromatic (**1–4**). Attack at C7 generates a carbocation with fewer resonance structures and only two have an intact aromatic ring (**5** and **6**).

Reactions of Aromatic Compounds 18–39



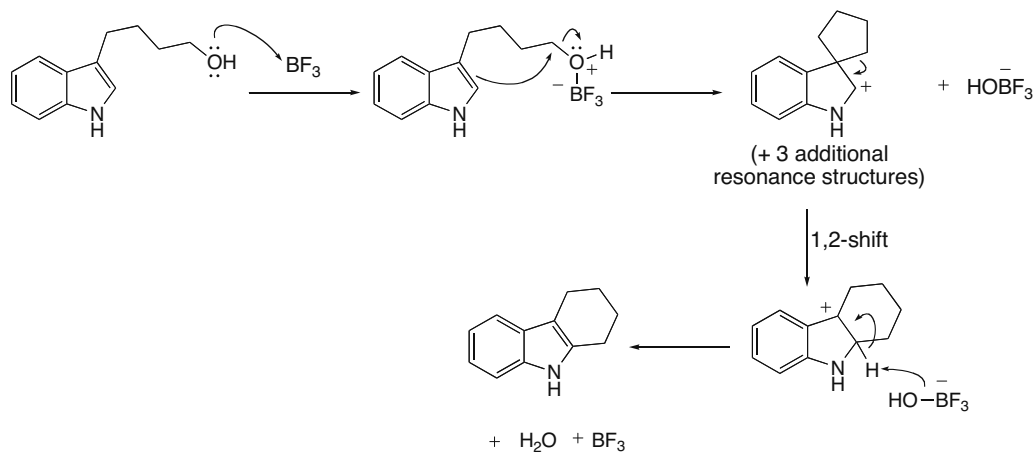
c. With indole, attack at C3 forms the more highly resonance-stabilized carbocation.



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Attack at C3 forms resonance structures, all of which have an intact aromatic ring, and two of which have all atoms with octets. Attack at C2 forms a cation with more resonance structures, but only two have an intact aromatic ring, and only one has complete octets.

18.80



Chapter 19 Carboxylic Acids and the Acidity of the O–H Bond

Chapter Review

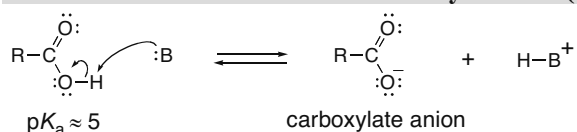
General facts

- Carboxylic acids contain a carboxy group (COOH). The central carbon is sp^2 hybridized and trigonal planar (19.1).
- Carboxylic acids are identified by the suffixes *-oic acid*, *carboxylic acid*, or *-ic acid* (19.2).
- Carboxylic acids are polar compounds that exhibit hydrogen bonding interactions (19.3).

Summary of spectroscopic absorptions (19.4)

IR absorptions	C=O	$\sim 1710\text{ cm}^{-1}$
	O–H	$3500\text{--}2500\text{ cm}^{-1}$ (very broad and strong)
^1H NMR absorptions	O–H	10–12 ppm (highly deshielded proton)
	C–H α to COOH	2–2.5 ppm (somewhat deshielded $C_{sp^3}\text{--H}$)
^{13}C NMR absorption	C=O	170–210 ppm (highly deshielded carbon)

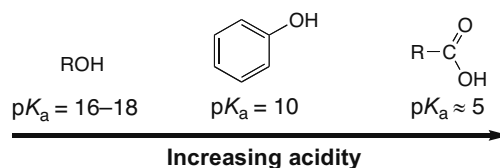
General acid–base reaction of carboxylic acids (19.9)



- Carboxylic acids are especially acidic because carboxylate anions are resonance stabilized.
- For equilibrium to favor the products, the base must have a conjugate acid with a $pK_a > 5$. Common bases are listed in Table 19.3.

Factors that affect acidity

Resonance effects. A carboxylic acid is more acidic than an alcohol or phenol because its conjugate base is more effectively stabilized by resonance (19.9).

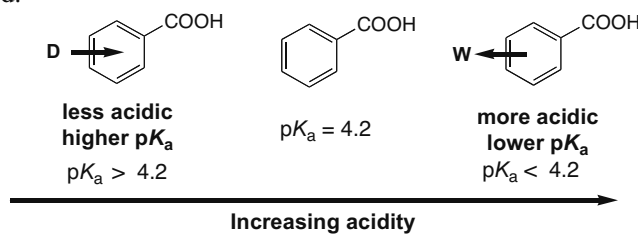


Inductive effects. Acidity increases with the presence of electron-withdrawing groups (like the electronegative halogens) and decreases with the presence of electron-donating groups (like polarizable alkyl groups) (19.10).

Chapter 19-2

Substituted benzoic acids.

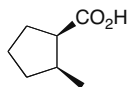
- Electron-donor groups (D) make a substituted benzoic acid less acidic than benzoic acid.
- Electron-withdrawing groups (W) make a substituted benzoic acid more acidic than benzoic acid.

**Other facts**

- Extraction is a useful technique for separating compounds having different solubility properties. Carboxylic acids can be separated from other organic compounds by extraction, because aqueous base converts a carboxylic acid into a water-soluble carboxylate anion (19.12).
- A sulfonic acid (RSO_3H) is a strong acid because it forms a weak, resonance-stabilized conjugate base on deprotonation (19.13).
- Amino acids have an amino group on the α carbon to the carboxy group [$\text{RCH}(\text{NH}_2)\text{COOH}$]. Amino acids exist as zwitterions at $\text{pH} \approx 6$. Adding acid forms a species with a net (+1) charge [$\text{RCH}(\text{NH}_3^+)\text{COOH}$]. Adding base forms a species with a net (-1) charge [$\text{RCH}(\text{NH}_2)\text{COO}^-$] (19.14).

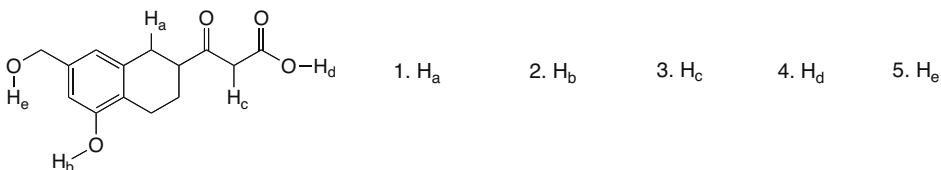
Practice Test on Chapter Review

1. a. Give the IUPAC name for the following compound.

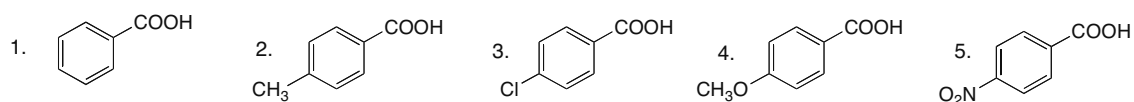


- b. Draw the structure corresponding to the following name: sodium *m*-bromobenzoate.

2. a. Which of the labeled atoms is least acidic?

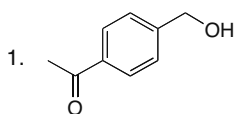
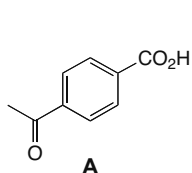


- b. Which of the following carboxylic acids has the lowest pK_a ?

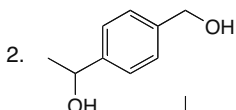


Carboxylic Acids and the Acidity of the O–H Bond 19–3

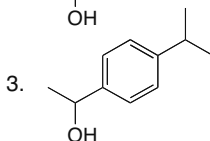
c. Which compound(s) can be converted to **A** by an oxidation reaction?



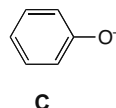
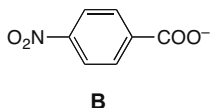
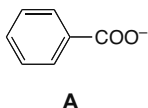
4. Both [1] and [2] can be converted to **A**.



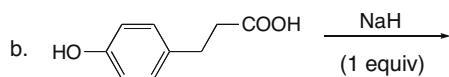
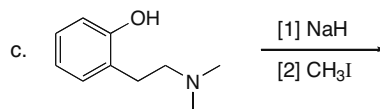
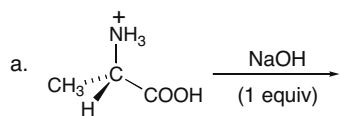
5. Compounds [1], [2], and [3] can all be converted to **A**.



3. Rank the following compounds in order of increasing basicity. Label the *least* basic compound as **1**, the *most* basic compound as **3**, and the compound of *intermediate* basicity as **2**.



4. Draw the organic products formed in each of the following reactions.



Answers to Practice Test

1.a. *cis*-2-methylcyclopentanecarboxylic acid

2.a. 1

b. 5

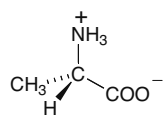
c. 5

3. **A**–2

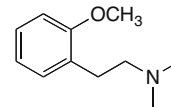
B–1

C–3

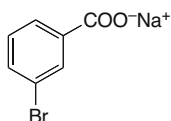
4.a.



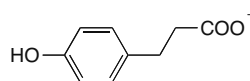
c.



b.



b.



Chapter 19-4

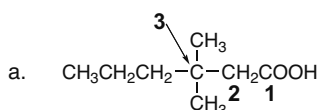
Answers to Problems

19.1 To name a carboxylic acid:

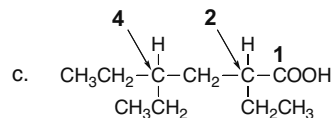
[1] Find the longest chain containing the COOH group and change the *-e* ending to *-oic acid*.

[2] Number the chain to put the COOH carbon at C1, but omit the number from the name.

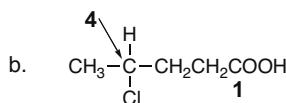
[3] Follow all other rules of nomenclature.



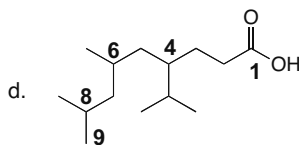
Number the chain to put COOH at C1.

6 carbon chain = **hexanoic acid****3,3-dimethylhexanoic acid**

Number the chain to put COOH at C1.

6 carbon chain = **hexanoic acid****2,4-diethylhexanoic acid**

Number the chain to put COOH at C1.

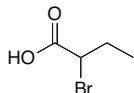
5 carbon chain = **pentanoic acid****4-chloropentanoic acid**

Number the chain to put COOH at C1.

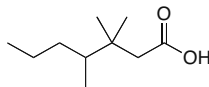
9 carbon chain = **nonanoic acid****4-isopropyl-6,8-dimethylnonanoic acid**

19.2

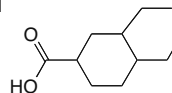
a. 2-bromobutanoic acid



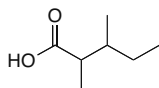
c. 3,3,4-trimethylheptanoic acid



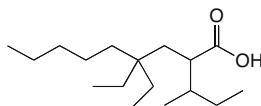
e. 3,4-diethylcyclohexanecarboxylic acid



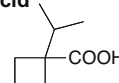
b. 2,3-dimethylpentanoic acid



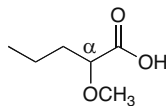
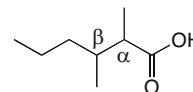
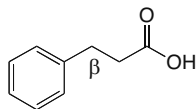
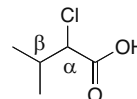
d. 2-sec-butyl-4,4-diethylnonanoic acid



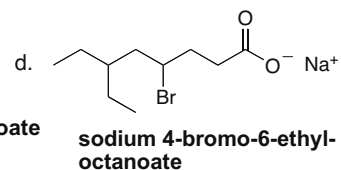
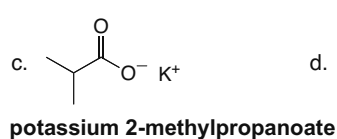
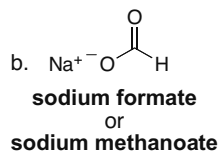
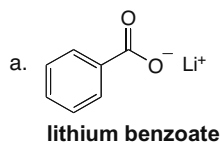
f. 1-isopropylcyclobutanecarboxylic acid



19.3

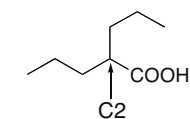
a. α -methoxyvaleric acidc. α,β -dimethylcaproic acidb. β -phenylpropionic acidd. α -chloro- β -methylbutyric acid

19.4

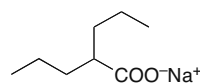


Carboxylic Acids and the Acidity of the O–H Bond 19–5

19.5

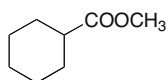
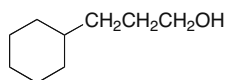
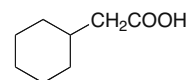
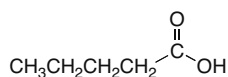
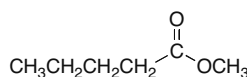
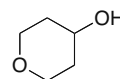


2-propylpentanoic acid

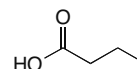


sodium 2-propylpentanoate

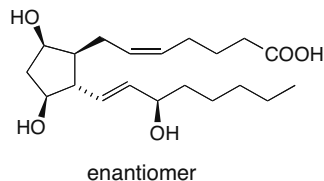
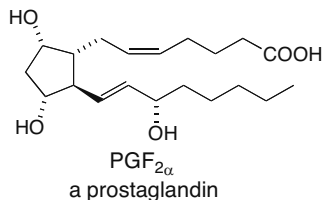
19.6 More polar molecules have a higher boiling point and are more water soluble.

least polar
lowest boiling point
least H₂O solubleintermediate polarity
intermediate boiling pointmost polar
highest boiling point
most H₂O soluble19.7 Look for functional group differences to distinguish the compounds by IR. Besides sp^3 hybridized C–H bonds at 3000–2850 cm^{-1} (which all three compounds have), the following functional group absorptions are seen:carboxylic acid
2 strong absorptions
~1710 (C=O)
~2500–3500 (OH) cm^{-1} ester
1 strong absorption
~1700 (C=O) cm^{-1} alcohol
1 strong absorption
~3600–3200 (OH) cm^{-1}

19.8

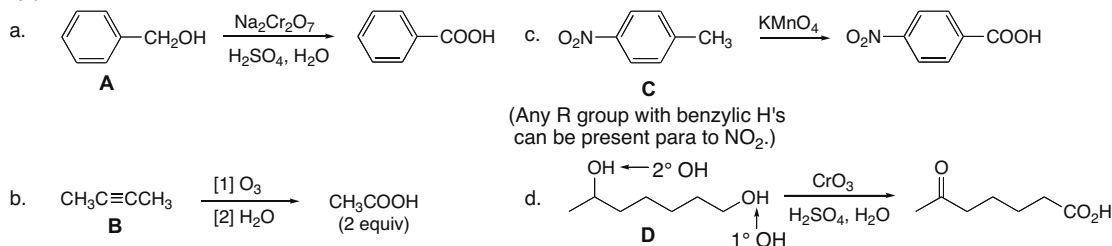
Molecular formula: $\text{C}_4\text{H}_8\text{O}_2$
one degree of unsaturation ^1H NMR data (ppm):
0.95 (triplet, 3 H)
1.65 (multiplet, 2 H)
2.30 (triplet, 2 H)
11.8 (singlet, 1 H)

19.9

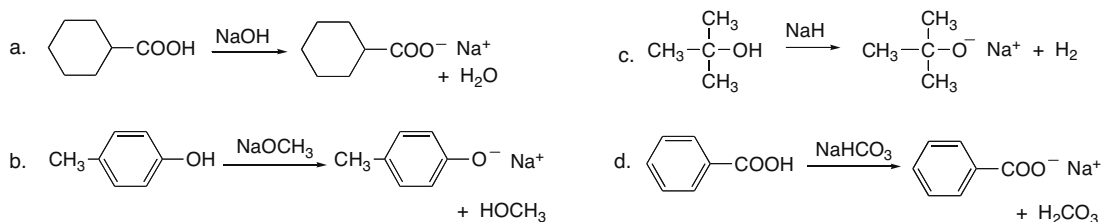
There are five tetrahedral stereogenic centers. Both double bonds can exhibit cis–trans isomerism. Therefore, there are $2^7 = 128$ stereoisomers.19.10 1° Alcohols are converted to carboxylic acids by oxidation reactions.

Chapter 19-6

19.11



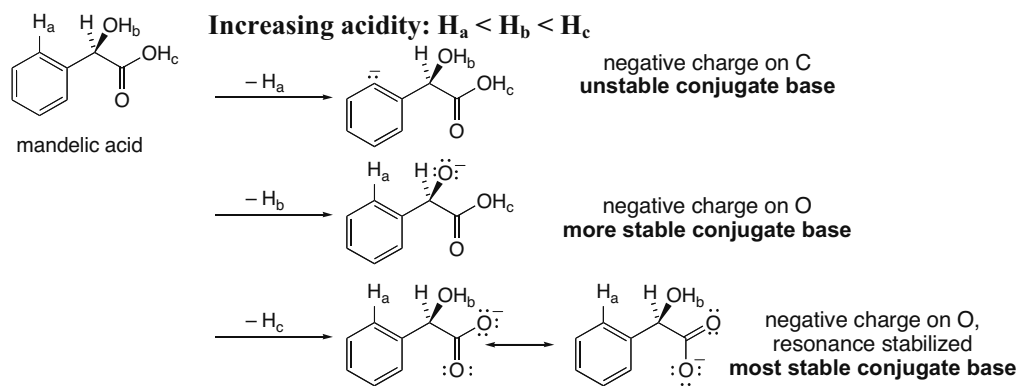
19.12



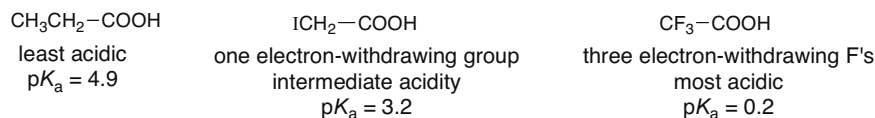
19.13 CH₃COOH has a pK_a of 4.8. Any base having a conjugate acid with a pK_a higher than 4.8 can deprotonate it.

- a. F⁻ pK_a (HF) = 3.2 **not strong enough** d. ⁻NH₂ pK_a (NH₃) = 38 **strong enough**
 b. (CH₃)₃CO⁻ pK_a [(CH₃)₃COH] = 18 **strong enough** e. Cl⁻ pK_a (HCl) = -7.0 **not strong enough**
 c. CH₃⁻ pK_a (CH₄) = 50 **strong enough**

19.14



19.15 Electron-withdrawing groups make an acid more acidic, lowering its pK_a.

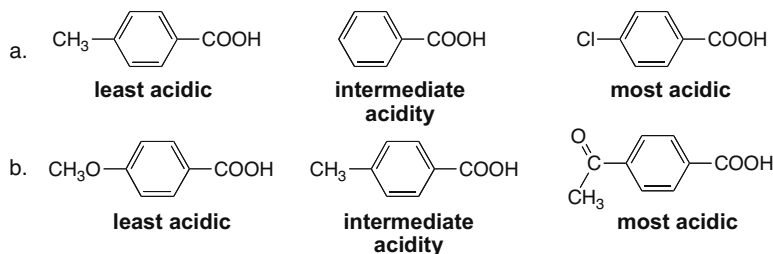


Carboxylic Acids and the Acidity of the O–H Bond 19–7

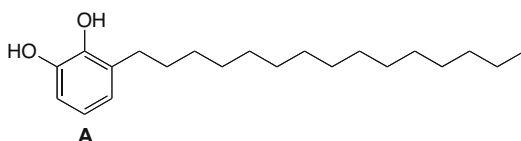
19.16

- a. CH_3COOH **least acidic** HSCH_2COOH **intermediate acidity** HOCH_2COOH **most acidic**
- b. $\text{ICH}_2\text{CH}_2\text{COOH}$ **least acidic** ICH_2COOH **intermediate acidity** I_2CHCOOH **most acidic**

19.17



19.18

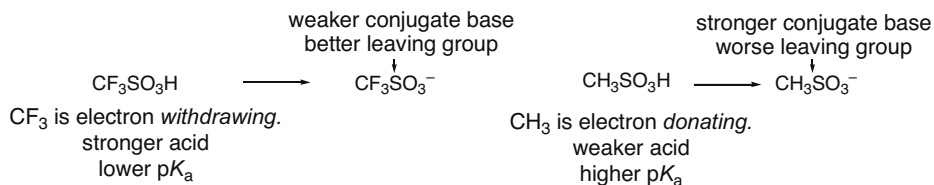


Phenol **A** has a higher $\text{p}K_a$ than phenol because of its substituents. Both the OH and CH_3 are electron-donating groups, which make the conjugate base less stable. Therefore, the acid is **less acidic**.

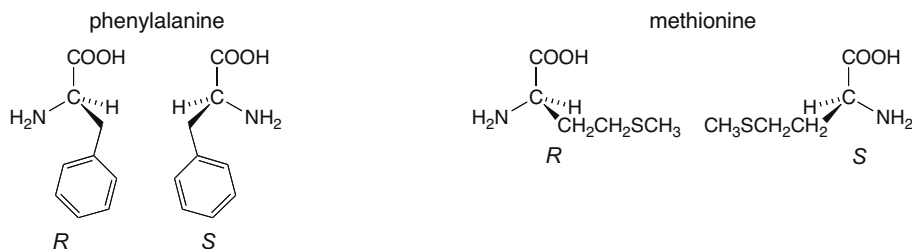
19.19 To separate compounds by an extraction procedure, they must have different solubility properties.

- a. $\text{CH}_3(\text{CH}_2)_6\text{COOH}$ and $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}=\text{CH}_2$: **YES**. The acid can be extracted into aqueous base, while the alkene will remain in an organic layer.
- b. $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{CH}=\text{CH}_2$ and $(\text{CH}_3\text{CH}_2\text{CH}_2)_2\text{O}$: **NO**. Both compounds are soluble in organic solvents and insoluble in water. Neither is acidic enough to be extracted into aqueous base.
- c. $\text{CH}_3(\text{CH}_2)_6\text{COOH}$ and NaCl : one carboxylic acid, one salt: **YES**. The carboxylic acid is soluble in an organic solvent while the salt is soluble in water.
- d. NaCl and KCl : two salts: **NO**.

19.20



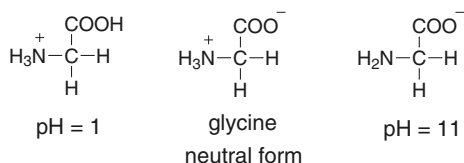
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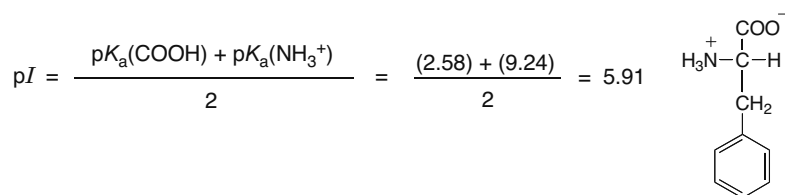
Chapter 19–8

19.22 Since amino acids exist as zwitterions (i.e., salts), they are too polar to be soluble in organic solvents like diethyl ether. Thus, they are soluble in water.

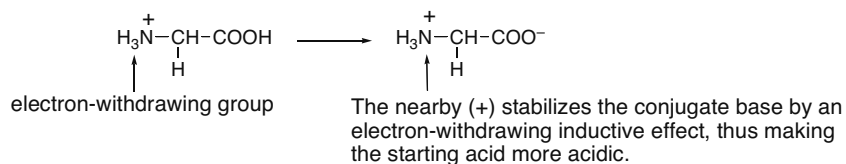
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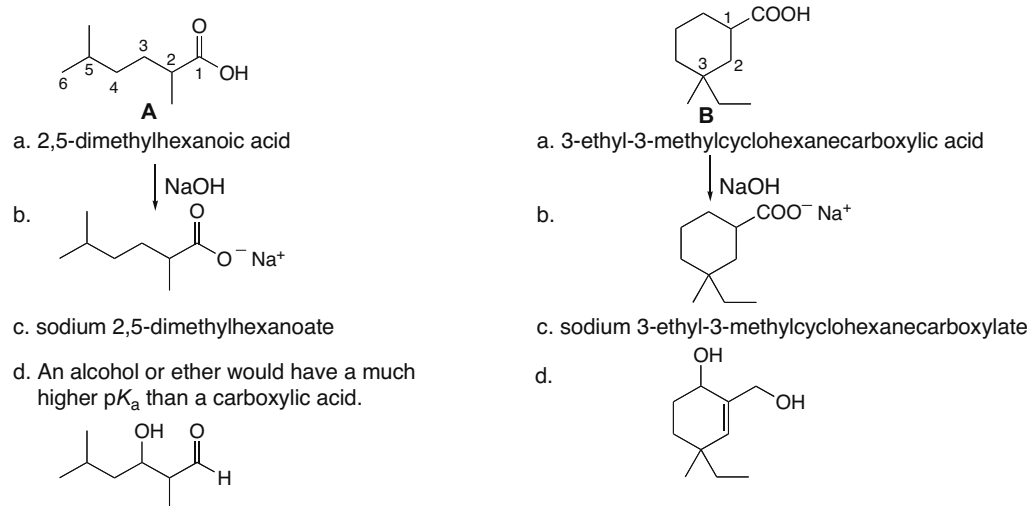
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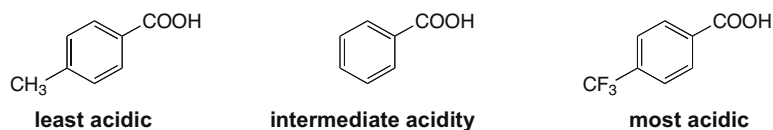
19.25



19.26



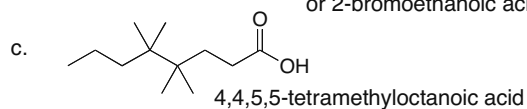
19.27



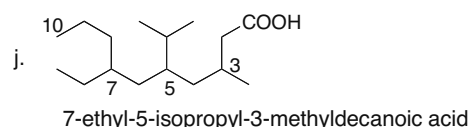
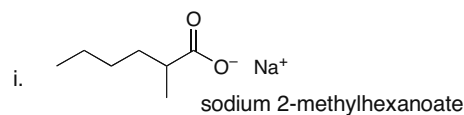
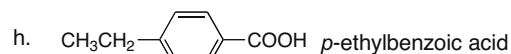
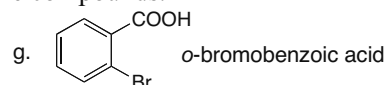
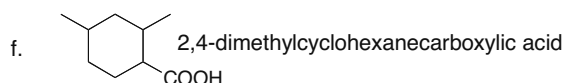
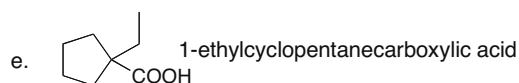
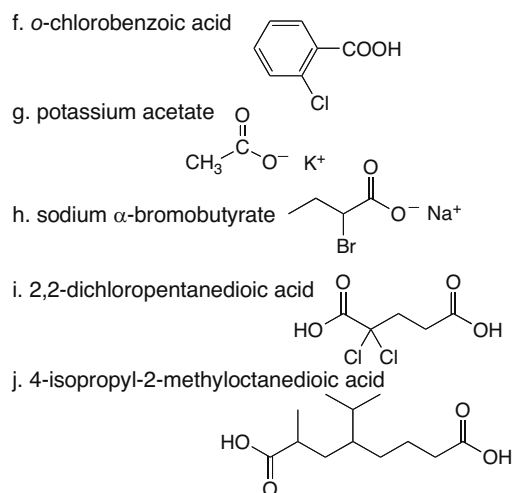
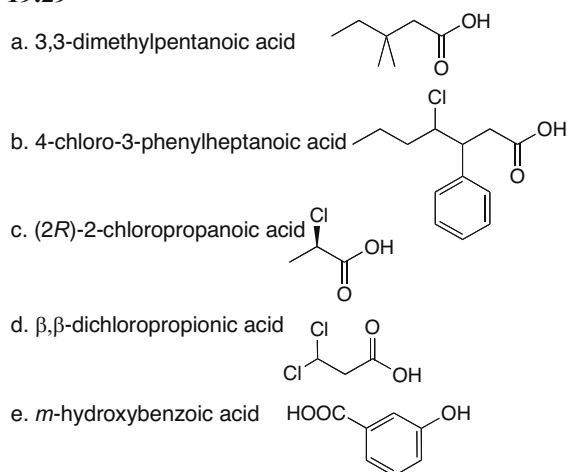
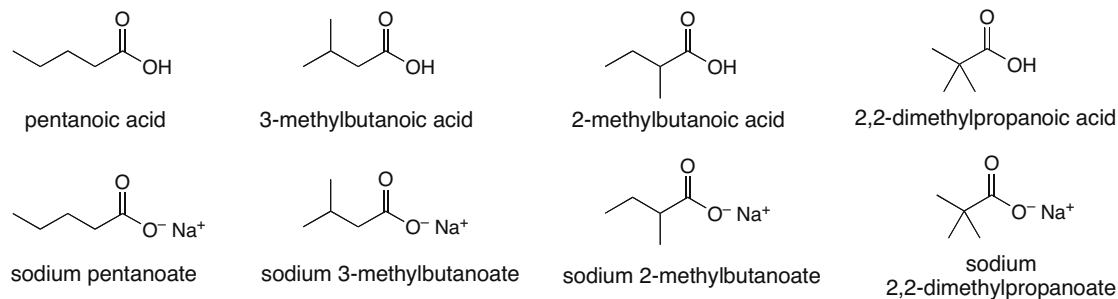
Carboxylic Acids and the Acidity of the O–H Bond 19–9

19.28 Use the directions from Answer 19.1 to name the compounds.

- a. $(\text{CH}_3)_2\text{CHCH}_2\text{CH}_2\text{CO}_2\text{H}$ 4-methylpentanoic acid
 b. BrCH_2COOH 2-bromoacetic acid
 or 2-bromoethanoic acid

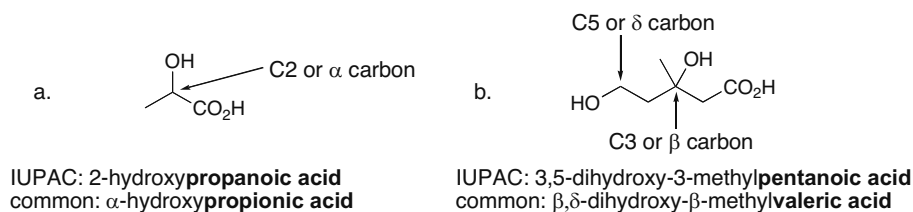


- d. $\text{CH}_3\text{CH}_2\text{CH}_2\text{COO}^-\text{Li}^+$ lithium butanoate

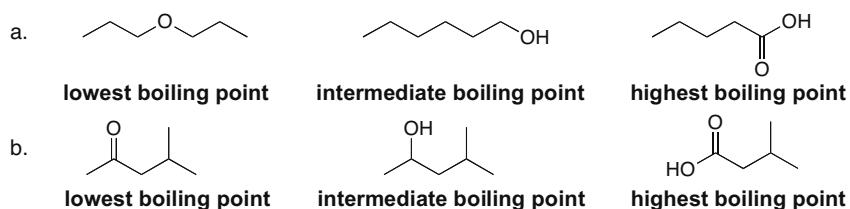
**19.29****19.30**

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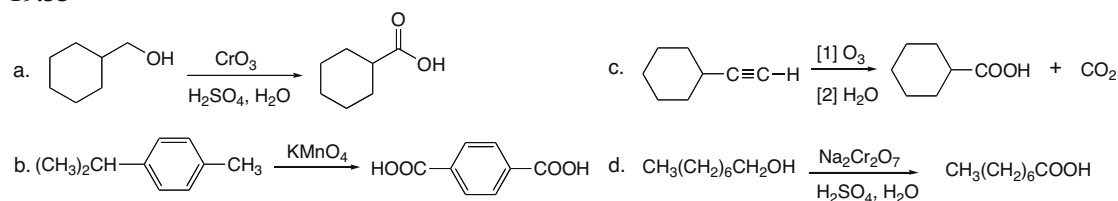
19.31



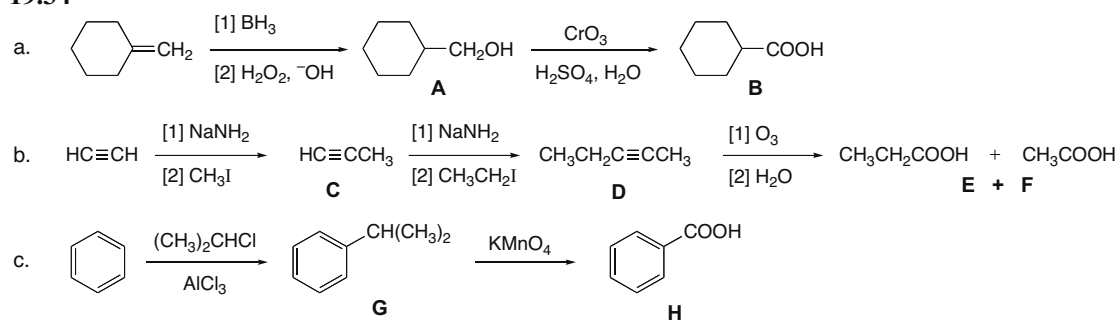
19.32



19.33

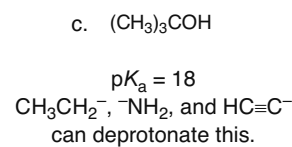
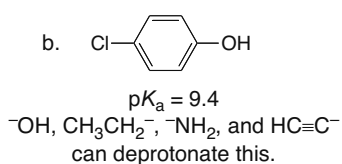
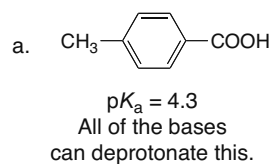


19.34



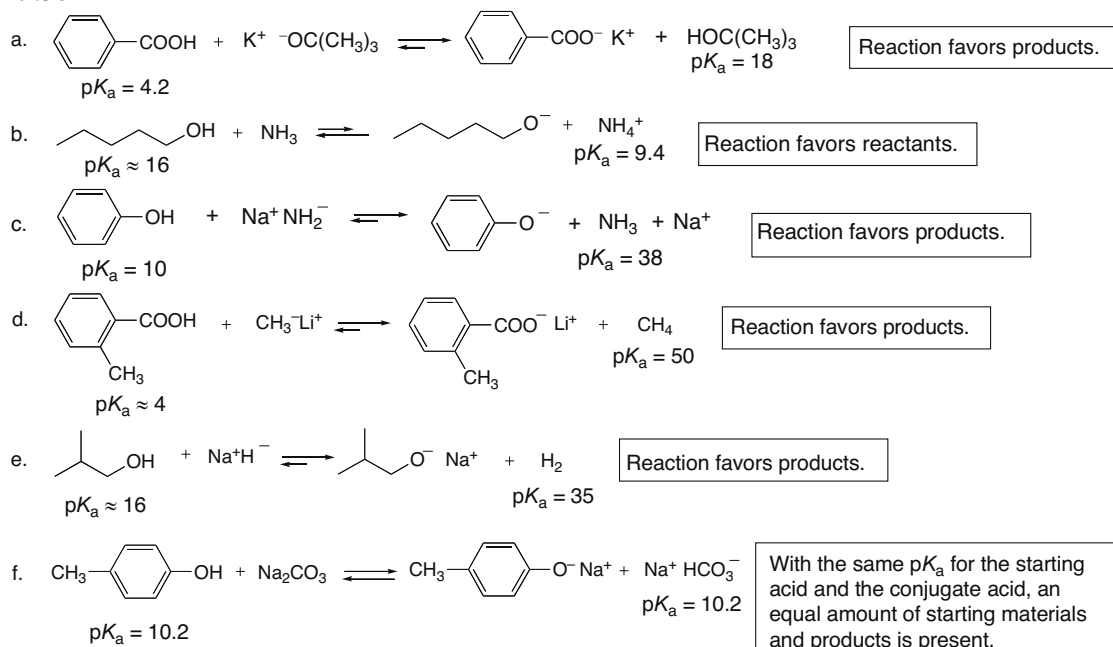
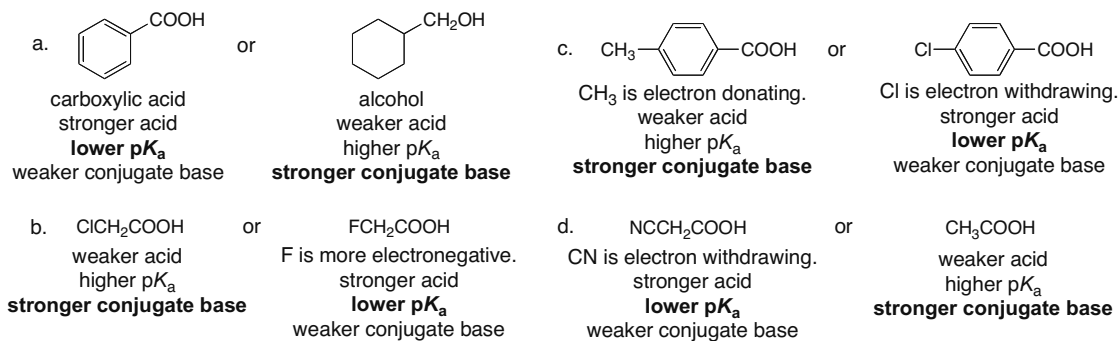
19.35

Bases: [1] OH^- $pK_a(\text{H}_2\text{O}) = 15.7$; [2] CH_3CH_2^- $pK_a(\text{CH}_3\text{CH}_3) = 50$; [3] NH_2^- $pK_a(\text{NH}_3) = 38$;
[4] NH_3 $pK_a(\text{NH}_4^+) = 9.4$; [5] $\text{HC}\equiv\text{C}^-$ $pK_a(\text{HC}\equiv\text{CH}) = 25$.

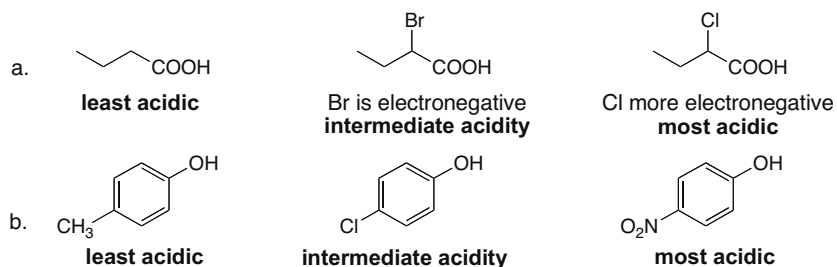


Carboxylic Acids and the Acidity of the O–H Bond 19–11

19.36

19.37 The stronger acid has a lower $\text{p}K_{\text{a}}$ and a weaker conjugate base.

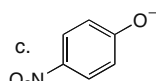
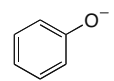
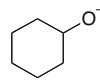
19.38

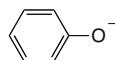
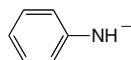
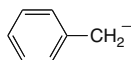


Chapter 19–12

19.39

a. $\text{BrCH}_2\text{COO}^-$ $\text{BrCH}_2\text{CH}_2\text{COO}^-$ $(\text{CH}_3)_3\text{CCOO}^-$
weakest base **intermediate basicity** **strongest base**

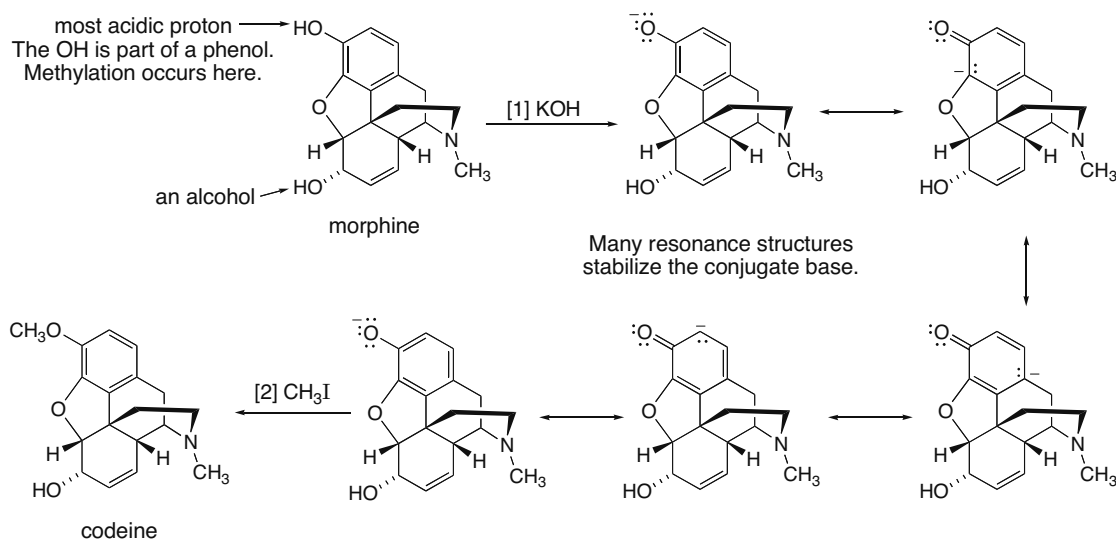
c.   
weakest base **intermediate basicity** **strongest base**

b.   
weakest base **intermediate basicity** **strongest base**

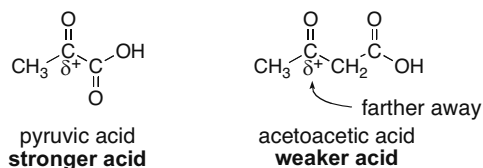
19.40

	Increasing acidity				
pK_a values	ICH_2COOH least acidic 3.12	BrCH_2COOH 2.86	FCH_2COOH 2.66	F_2CHCOOH 1.24	F_3CCOOH most acidic 0.28

19.41 The OH of the phenol group in morphine is more acidic than the OH of the alcohol ($\text{pK}_a \approx 10$ versus $\text{pK}_a \approx 16$). KOH is basic enough to remove the phenolic OH, the most acidic proton.



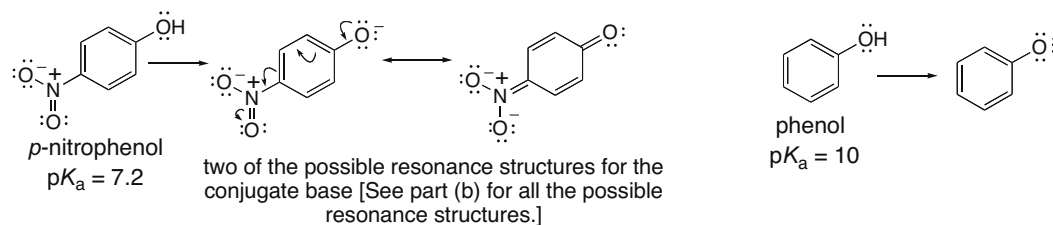
19.42 The closer the electron-withdrawing $\text{CH}_3\text{CO}-$ group is to the carboxylic acid, the more it will stabilize the conjugate base, making the acid stronger.



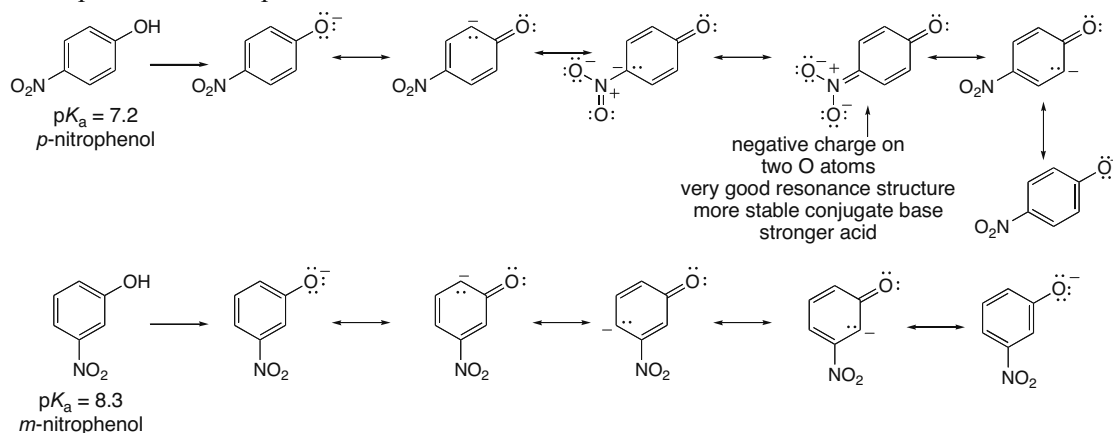
Carboxylic Acids and the Acidity of the O–H Bond 19–13

19.43

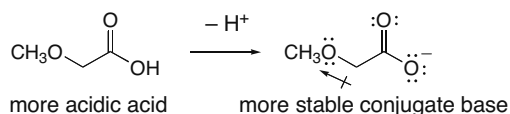
- a. The negative charge on the conjugate base of *p*-nitrophenol is delocalized on the NO₂ group, stabilizing the conjugate base, and making *p*-nitrophenol more acidic than phenol (where the negative charge is delocalized only around the benzene ring).



- b. In the para isomer, the negative charge of the conjugate base is delocalized over both the benzene ring and onto the NO₂ group, whereas in the meta isomer it cannot be delocalized onto the NO₂ group. This makes the conjugate base from the para isomer more highly resonance stabilized, and the para substituted phenol more acidic than its meta isomer.

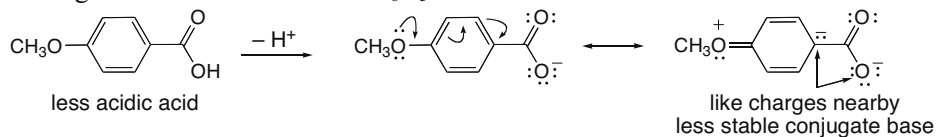


- 19.44 A CH₃O group has an electron-withdrawing inductive effect and an electron-donating resonance effect. In 2-methoxyacetic acid, the OCH₃ group is bonded to an *sp*³ hybridized C, so there is no way to donate electron density by resonance. The CH₃O group withdraws electron density because of the electronegative O atom, stabilizing the conjugate base, and making CH₃OCH₂COOH a stronger acid than CH₃COOH.

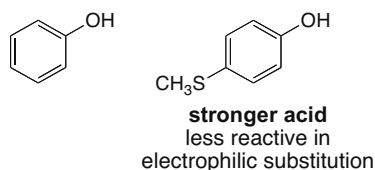


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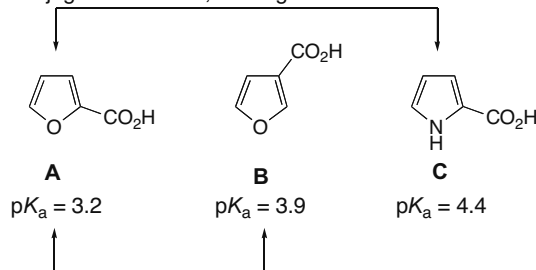
In *p*-methoxybenzoic acid, the CH₃O group is bonded to an *sp*² hybridized C, so it can donate electron density by a resonance effect. This destabilizes the conjugate base, making the starting material less acidic than C₆H₅COOH.



- 19.45** Phenol has a pK_a of 10, making *p*-methylthiophenol ($pK_a = 9.53$) the stronger acid. A substituent that increases the acidity of a phenol must withdraw electron density to stabilize the negative charge of the conjugate base. An electron-withdrawing substituent deactivates a benzene ring towards electrophilic aromatic substitution, making *p*-methylthiophenol less reactive than phenol.

**19.46**

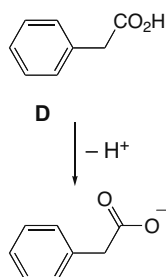
The O in **A** is more electronegative than the N in **C** so there is a stronger electron-withdrawing inductive effect. This stabilizes the conjugate base of **A**, making **A** more acidic than **C**.



Since the O in **A** is closer to the COOH group than the O atom in **B**, there is a stronger electron-withdrawing inductive effect. This makes **A** more acidic than **B**.

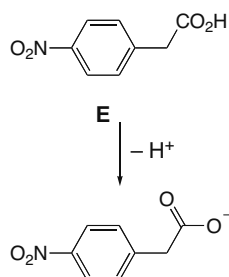
Carboxylic Acids and the Acidity of the O–H Bond 19–15

19.47



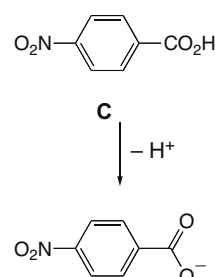
Since the benzene ring is bonded to the α carbon (not the carbonyl carbon), this compound is not much different than any alkyl-substituted carboxylic acid.

least acidic



The electron-withdrawing inductive effect of the NO_2 group helps stabilize the COO^- group.

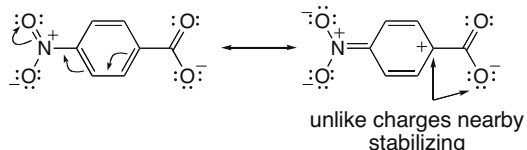
intermediate acidity



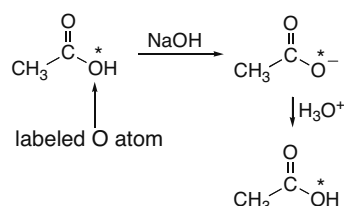
Since the NO_2 group is bonded to a benzene ring that is bonded directly to the carbonyl group, inductive effects and resonance effects stabilize the conjugate base. For example, a resonance structure can be drawn that places a (+) charge close to the COO^- group.

most acidic

Two of the resonance structures for the conjugate base of **C**:



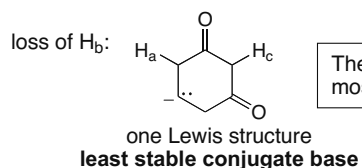
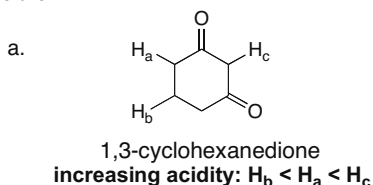
19.48



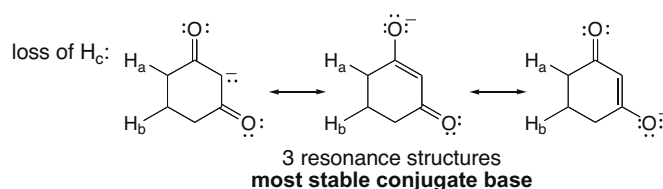
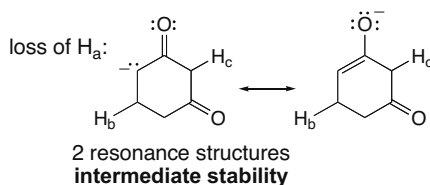
The resonance-stabilized carboxylate anion can now be protonated on either O atom, the one with the label and the one without the label.

The label is now in two different locations.

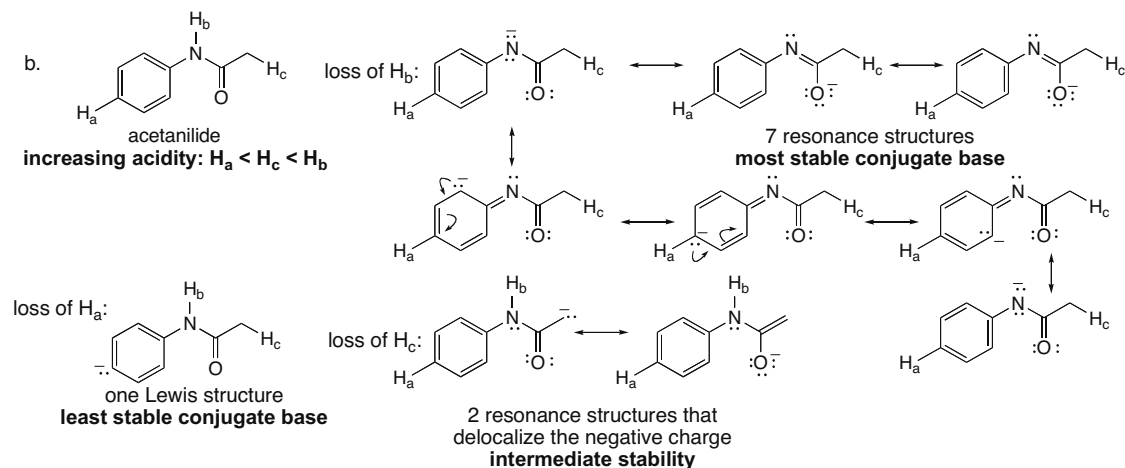
19.49



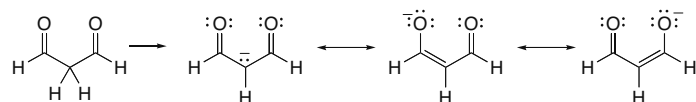
The most acidic proton forms the most stable conjugate base.



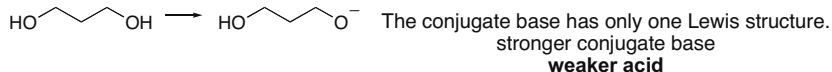
Chapter 19–16



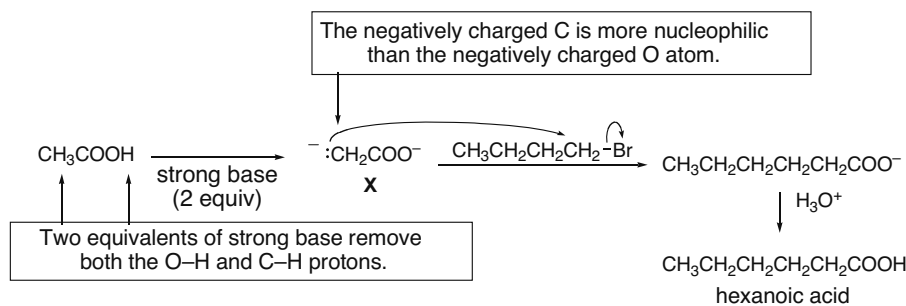
19.50



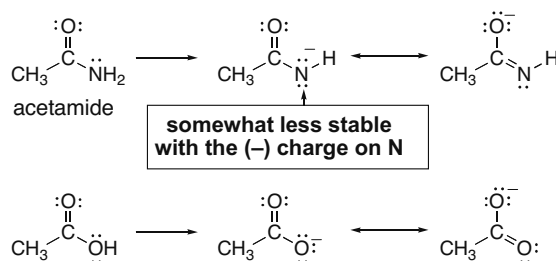
The conjugate base is resonance stabilized. Two of the structures place a negative charge on an O atom.
weaker conjugate base
stronger acid



19.51



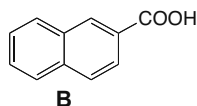
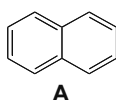
19.52



O is more electronegative than N, making the conjugate base of CH_3COOH more stable than the conjugate base of acetamide. Therefore, acetamide is less acidic.

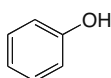
Carboxylic Acids and the Acidity of the O–H Bond 19–17

19.53

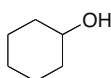


- Dissolve both compounds in CH_2Cl_2 .
- Add 10% NaHCO_3 solution. This makes a carboxylate anion ($\text{C}_{10}\text{H}_7\text{COO}^-$) from **B**, which dissolves in the aqueous layer. The other compound (**A**) remains in the CH_2Cl_2 .
- Separate the layers.

19.54



and

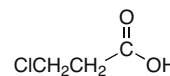


- Dissolve both compounds in CH_2Cl_2 .
- Add 10% NaOH solution. This converts $\text{C}_6\text{H}_5\text{OH}$ into a phenoxide anion, $\text{C}_6\text{H}_5\text{O}^-$, which dissolves in the aqueous solution. The alcohol remains in the organic layer (neutral) since it is not acidic enough to be deprotonated to any significant extent by NaOH .
- Separate the layers.

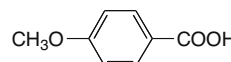
19.55 To separate two compounds in an aqueous extraction, one must be water soluble (or be able to be converted into a water-soluble ionic compound by an acid–base reaction), and the other insoluble. 1-Octanol has greater than 5 C's, making it insoluble in water. Octane is an alkane, also insoluble in water. Neither compound is acidic enough to be deprotonated by a base in aqueous solution. Since their solubility properties are similar, they cannot be separated by an extraction procedure.

19.56

a. Molecular formula: $\text{C}_3\text{H}_5\text{ClO}_2$ $\longrightarrow$ one double bond or ring
 IR: $3500\text{--}2500\text{ cm}^{-1}$, 1714 cm^{-1} $\longrightarrow$ C=O and O–H
 NMR data: 2.87 (triplet, 2 H), 3.76 (triplet, 2 H), and 11.8 (singlet, 1 H) ppm

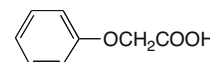


b. Molecular formula: $\text{C}_8\text{H}_8\text{O}_3$ $\longrightarrow$ 5 double bonds or rings
 IR: $3500\text{--}2500\text{ cm}^{-1}$, 1688 cm^{-1} $\longrightarrow$ C=O and O–H
 NMR data: 3.8 (singlet, 3 H), 7.0 (doublet, 2 H), 7.9 (doublet, 2 H), and 12.7 (singlet, 1 H) ppm



para disubstituted benzene ring

c. Molecular formula: $\text{C}_8\text{H}_8\text{O}_3$ $\longrightarrow$ 5 double bonds or rings
 IR: $3500\text{--}2500\text{ cm}^{-1}$, 1710 cm^{-1} $\longrightarrow$ C=O and O–H
 NMR data: 4.7 (singlet, 2 H), 6.9–7.3 (multiplet, 5 H), and 11.3 (singlet, 1 H) ppm



monosubstituted benzene ring

Chapter 19–18

19.57

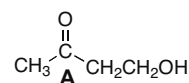
Compound **A**: Molecular formula $C_4H_8O_2$ (one degree of unsaturation)

IR absorptions at 3600–3200 (O–H), 3000–2800 (C–H), and 1700 (C=O) cm^{-1}

^1H NMR data:

Absorption	ppm	# of H's	Explanation
singlet	2.2	3	a CH_3 group
singlet	2.55	1	1 H adjacent to none or OH
triplet	2.7	2	2 H's adjacent to 2 H's
triplet	3.9	2	2 H's adjacent to 2 H's

Structure:



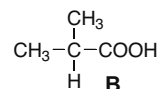
Compound **B**: Molecular formula $C_4H_8O_2$ (one degree of unsaturation)

IR absorptions at 3500–2500 (O–H) and 1700 (C=O) cm^{-1}

^1H NMR data:

Absorption	ppm	# of H's	Explanation
doublet	1.6	6	6 H's adjacent to 1 H
septet	2.3	1	1 H adjacent to 6 H's
singlet (very broad)	10.7	1	OH of $RCOOH$

Structure:



19.58

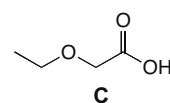
Compound **C**: Molecular formula $C_4H_8O_3$ (one degree of unsaturation)

IR absorptions at 3600–2500 (O–H) and 1734 (C=O) cm^{-1}

^1H NMR data:

Absorption	ppm	# of H's	Explanation
triplet	1.2	3	a CH_3 group adjacent to 2 H's
quartet	3.6	2	2 H's adjacent to 3 H's
singlet	4.1	2	2 H's
singlet	11.3	1	OH of $COOH$

Structure:



19.59

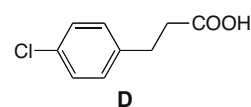
Compound **D**: Molecular formula $C_9H_9ClO_2$ (five degrees of unsaturation)

^{13}C NMR data: 30, 36, 128, 130, 133, 139, 179 = 7 different types of C's

^1H NMR data:

Absorption	ppm	# of H's	Explanation
triplet	2.7	2	2 H's adjacent to 2 H's
triplet	2.9	2	2 H's adjacent to 2 H's
two signals	7.2	4	on benzene ring
singlet	11.7	1	OH of $COOH$

Structure:



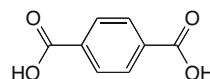
19.60

Molecular formula: $C_8H_6O_4$: 6 degrees of unsaturation

IR 1692 cm^{-1} (C=O)

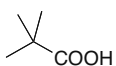
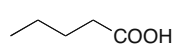
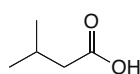
^1H NMR 8.2 and 10.0 ppm (singlets)

↑ ↑
aromatic H COOH



Carboxylic Acids and the Acidity of the O–H Bond 19–19

19.61

- A**  3 different C's
Spectrum [2]: peaks at 27, 39, 186 ppm
- B**  5 different C's
Spectrum [1]: peaks at 14, 22, 27, 34, 181 ppm
- C**  4 different C's
Spectrum [3]: peaks at 22, 26, 43, 180 ppm

19.62

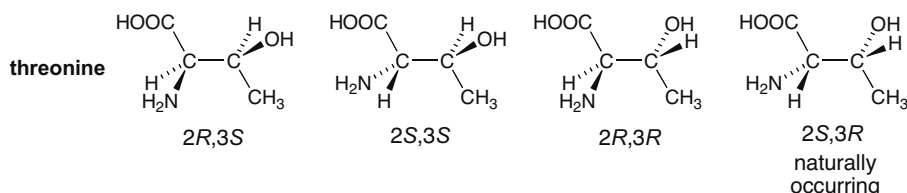
GBL: Molecular formula $C_4H_6O_2$ (two degrees of unsaturation)

IR absorption at $1770\text{ (C=O)}\text{ cm}^{-1}$

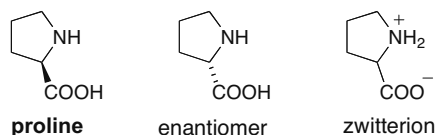
^1H NMR data:

Absorption	ppm	# of H's	Explanation	Structure:
multiplet	2.28	2	2 H's adjacent to several H's	
triplet	2.48	2	2 H's adjacent to 2 H's	
triplet	4.35	2	2 H's adjacent to 2 H's	

19.63

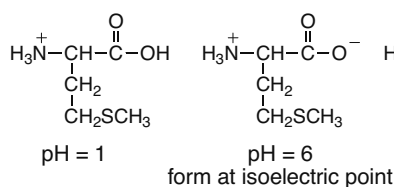


19.64

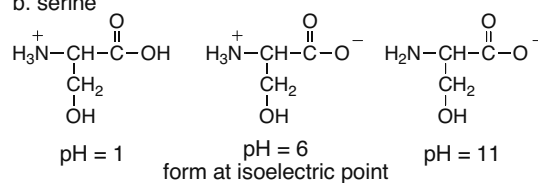


19.65

a. methionine



b. serine



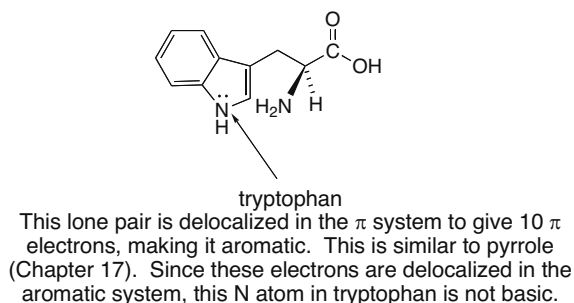
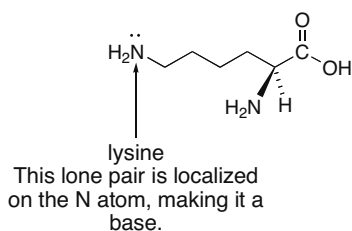
19.66

a. cysteine $pI = \frac{pK_a(\text{COOH}) + pK_a(\text{NH}_3^+)}{2} = (2.05) + (10.25) / 2 = 6.15$

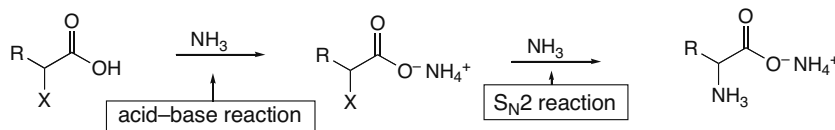
b. methionine $pI = \frac{pK_a(\text{COOH}) + pK_a(\text{NH}_3^+)}{2} = (2.28) + (9.21) / 2 = 5.75$

Chapter 19–20

19.67

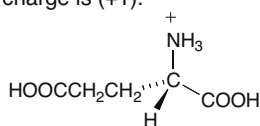


- 19.68** The first equivalent of NH_3 acts as a base to remove a proton from the carboxylic acid. A second equivalent then acts as a nucleophile to displace X to form the ammonium salt of the amino acid.

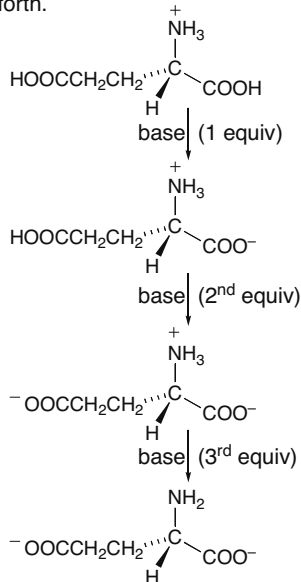


19.69

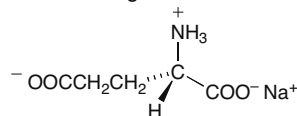
- a. At pH = 1, the net charge is (+1).



- b. increasing pH: As base is added, the most acidic proton is removed first, then the next most acidic proton, and so forth.

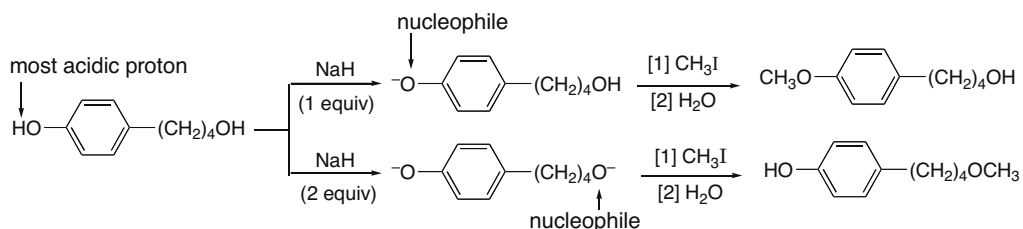


- c. monosodium glutamate

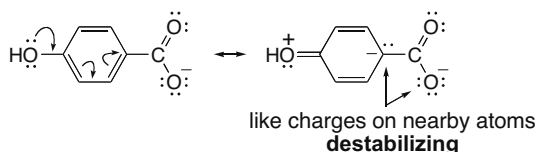
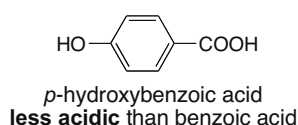


- 19.70** The first equivalent of NaH removes the most acidic proton—that is, the OH proton on the phenol. The resulting phenoxide can then act as a nucleophile to displace I to form a substitution product. With two equivalents, both OH protons are removed. In this case the more nucleophilic O atom is the stronger base—that is, the alkoxide derived from the alcohol (not the phenoxide), so this negatively charged O atom reacts first in a nucleophilic substitution reaction.

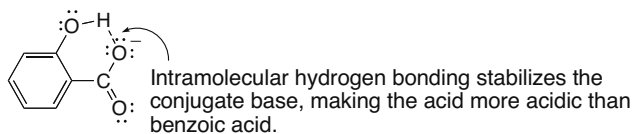
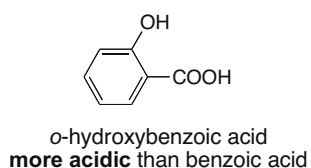
Carboxylic Acids and the Acidity of the O–H Bond 19–21



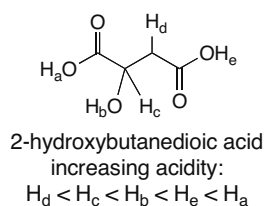
19.71



The OH group donates electron density by its resonance effect and this destabilizes the conjugate base, making the acid less acidic than benzoic acid.



19.72

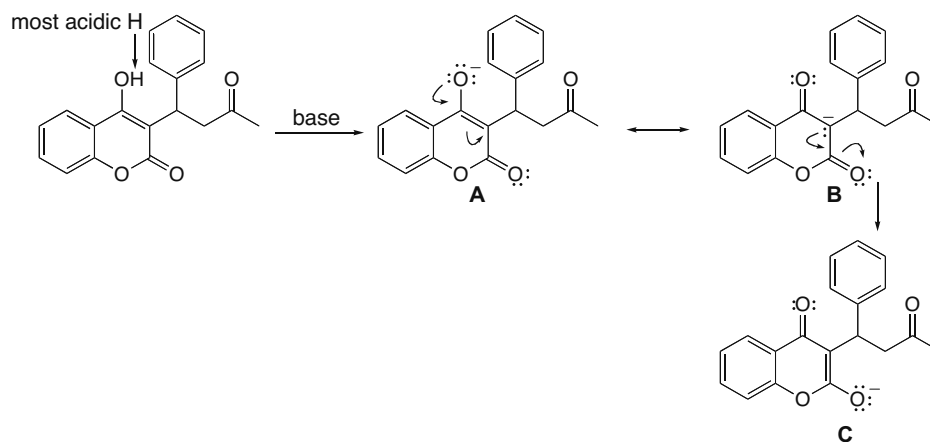


H_a and H_e must be the two most acidic protons since they are part of carboxylic acids. Loss of a proton forms a resonance-stabilized carboxylate anion that has the negative charge delocalized on two O atoms. H_a is more acidic than H_e because the nearby OH group on the α carbon increases acidity by an electron-withdrawing inductive effect. H_b is the next most acidic proton because the conjugate base places a negative charge on the electronegative O atom, but it is not resonance stabilized.

The least acidic H's are H_c and H_d since these H's are bonded to C atoms. The electronegative O atom further acidifies H_c by an electron-withdrawing inductive effect.

Chapter 19-22

19.73



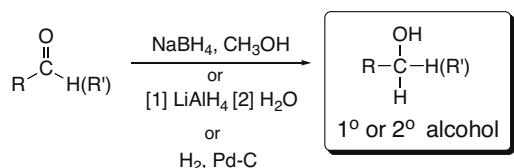
The conjugate base has three resonance structures, two of which place a negative charge on the oxygens. In this way the conjugate base resembles a carboxylate anion. In addition, the C=C's in **A** and **C** are conjugated.

Chapter 20 Introduction to Carbonyl Chemistry

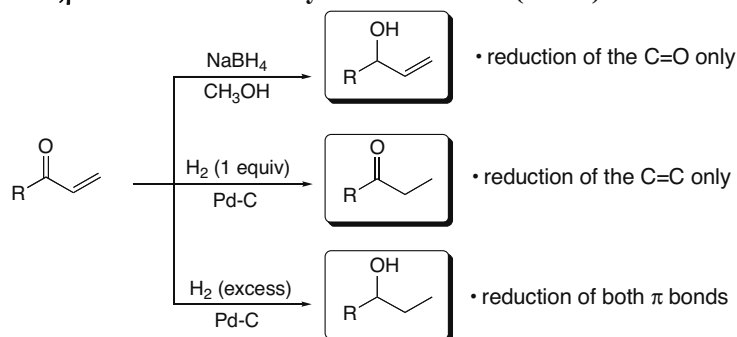
Chapter Review

Reduction reactions

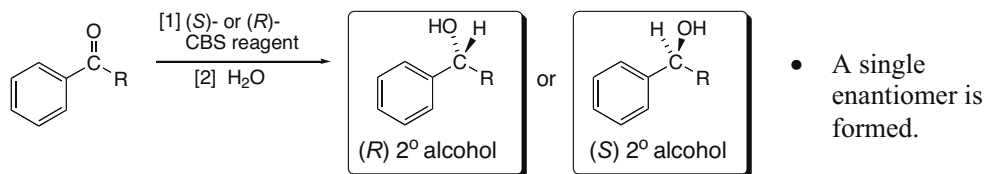
[1] Reduction of aldehydes and ketones to 1° and 2° alcohols (20.4)



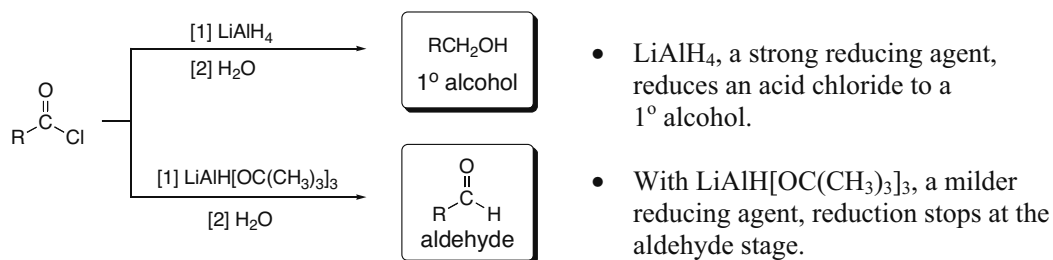
[2] Reduction of α,β -unsaturated aldehydes and ketones (20.4C)



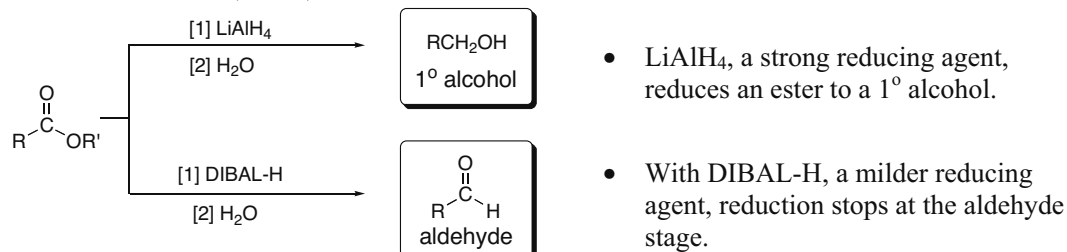
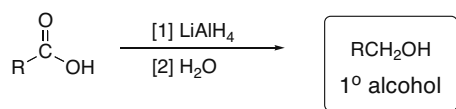
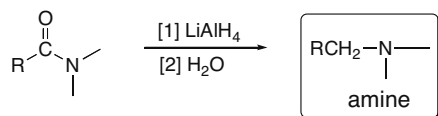
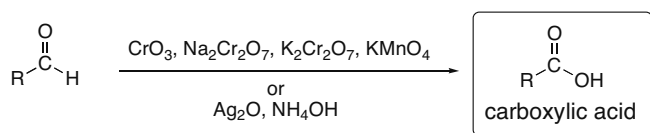
[3] Enantioselective ketone reduction (20.6)



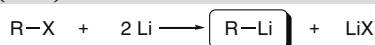
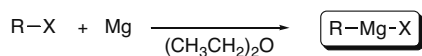
[4] Reduction of acid chlorides (20.7A)



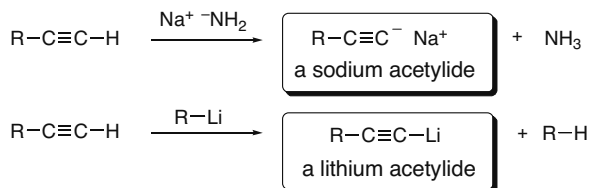
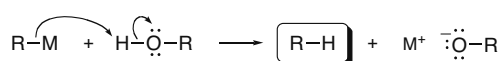
Chapter 20-2

[5] Reduction of esters (20.7A)**[6] Reduction of carboxylic acids to 1° alcohols (20.7B)****[7] Reduction of amides to amines (20.7B)****Oxidation reactions****Oxidation of aldehydes to carboxylic acids (20.8)**

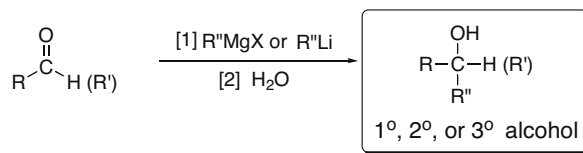
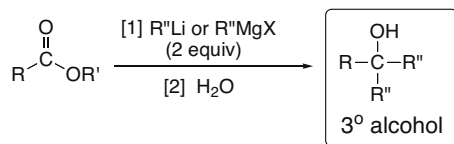
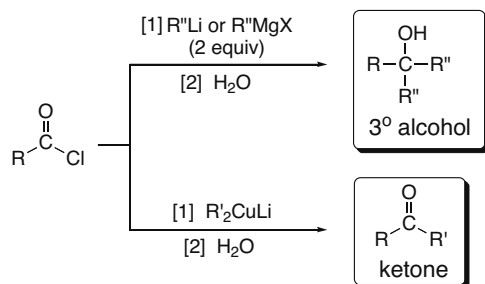
- All Cr⁶⁺ reagents except PCC oxidize RCHO to RCOOH.
- Tollens reagent (Ag₂O + NH₄OH) oxidizes RCHO only. Primary (1°) and secondary (2°) alcohols do not react with Tollens reagent.

Preparation of organometallic reagents (20.9)**[1] Organolithium reagents:****[2] Grignard reagents:****[3] Organocuprate reagents:**

Introduction to Carbonyl Chemistry 20-3

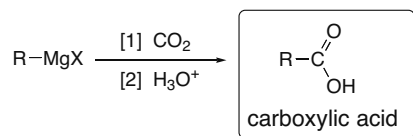
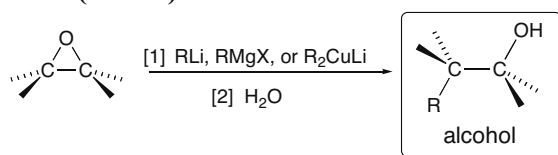
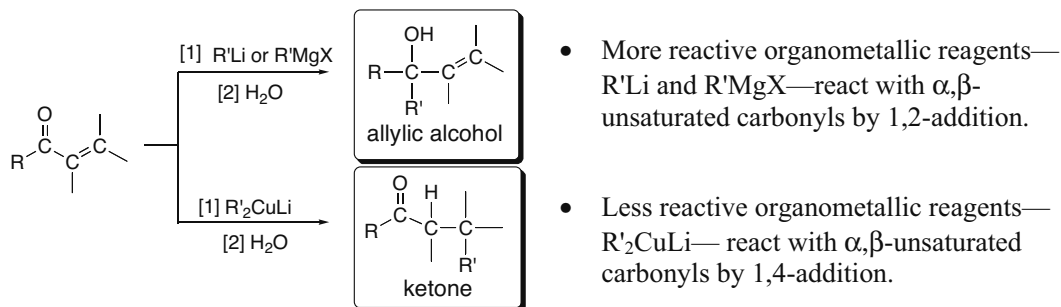
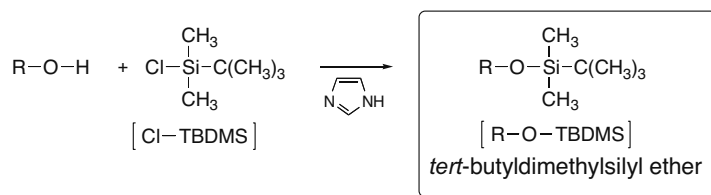
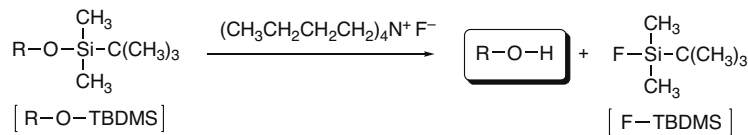
[4] Lithium and sodium acetylides:**Reactions with organometallic reagents****[1] Reaction as a base (20.9C)**

- $\text{RM} = \text{RLi}, \text{RMgX}, \text{R}_2\text{CuLi}$
- This acid-base reaction occurs with H_2O , ROH , RNH_2 , R_2NH , RSH , RCOOH , RCONH_2 , and RCONHR .

[2] Reaction with aldehydes and ketones to form 1°, 2°, and 3° alcohols (20.10)**[3] Reaction with esters to form 3° alcohols (20.13A)****[4] Reaction with acid chlorides (20.13)**

- More reactive organometallic reagents— $\text{R}''\text{Li}$ and $\text{R}''\text{MgX}$ —add two equivalents of R'' to an acid chloride to form a 3° alcohol with two identical R'' groups.
- Less reactive organometallic reagents— $\text{R}'_2\text{CuLi}$ —add only one equivalent of R' to an acid chloride to form a ketone.

Chapter 20-4

[5] Reaction with carbon dioxide—Carboxylation (20.14A)**[6] Reaction with epoxides (20.14B)****[7] Reaction with α,β -unsaturated aldehydes and ketones (20.15B)****Protecting groups (20.12)****[1] Protecting an alcohol as a *tert*-butyldimethylsilyl ether****[2] Deprotecting a *tert*-butyldimethylsilyl ether to re-form an alcohol**

Introduction to Carbonyl Chemistry 20–5

Practice Test on Chapter Review

1. Which compounds undergo nucleophilic addition and which undergo substitution?



2. What product is formed when $\text{CH}_3\text{CH}_2\text{CH}_2\text{Li}$ reacts with each compound, followed by quenching with water and acid?

a. $\text{CH}_3\text{CH}_2\text{CHO}$	e. CO_2
b. $(\text{CH}_3)_2\text{CO}$	f. $\text{CH}_2=\text{CHCOCH}_3$
c. $\text{CH}_3\text{CH}_2\text{CO}_2\text{CH}_3$	g. ethylene oxide
d. $\text{CH}_3\text{CH}_2\text{COCl}$	h. CH_3COOH

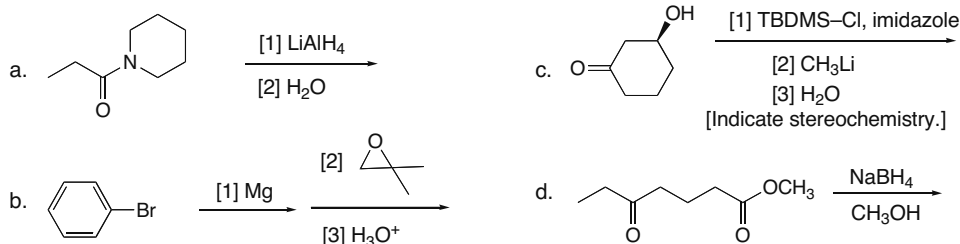
3. What product is formed when $\text{HO}(\text{CH}_2)_4\text{CHO}$ is treated with each reagent?

a. NaBH_4 , CH_3OH	c. Ag_2O , NH_4OH
b. PCC	d. $\text{Na}_2\text{Cr}_2\text{O}_7$, H_2SO_4 , H_2O

4. What reagent is needed to convert $(\text{CH}_3\text{CH}_2)_2\text{CHCOCl}$ into each compound?

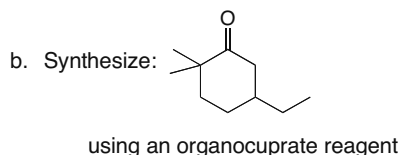
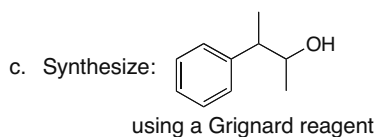
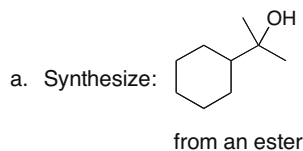
a. $(\text{CH}_3\text{CH}_2)_2\text{CHCOCH}_2\text{CH}_3$	c. $(\text{CH}_3\text{CH}_2)_2\text{CHC}(\text{OH})(\text{CH}_2\text{CH}_3)_2$
b. $(\text{CH}_3\text{CH}_2)_2\text{CHCHO}$	d. $(\text{CH}_3\text{CH}_2)_2\text{CHCH}_2\text{OH}$

5. Draw the organic products formed in the following reactions.



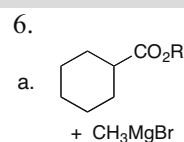
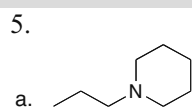
Chapter 20–6

6. What starting materials are needed to synthesize each compound using the indicated reagent or functional group?

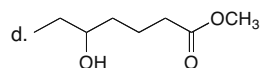
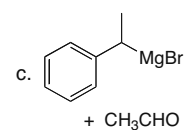
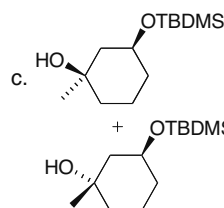
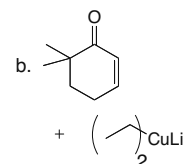
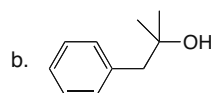


Answers to Practice Test

1. a. addition
b. substitution
c. substitution
d. addition
- 4.a. $(\text{CH}_3\text{CH}_2)_2\text{CuLi}$
b. DIBAL-H
c. $\text{CH}_3\text{CH}_2\text{MgBr}$
d. LiAlH_4



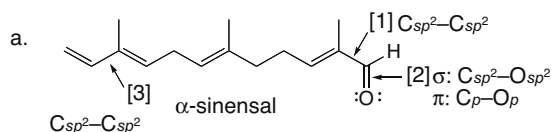
2. a. $\text{CH}_3\text{CH}_2\text{CH}(\text{OH})\text{CH}_2\text{CH}_2\text{CH}_3$
b. $(\text{CH}_3)_2\text{C}(\text{OH})\text{CH}_2\text{CH}_2\text{CH}_3$
c. $(\text{CH}_3\text{CH}_2)_3\text{COH}$
d. $(\text{CH}_3\text{CH}_2)_3\text{COH}$
e. $\text{CH}_3\text{CH}_2\text{CH}_2\text{CO}_2\text{H}$
f. $\text{CH}_2=\text{CHC}(\text{OH})(\text{CH}_3)\text{CH}_2\text{CH}_2\text{CH}_3$
g. $\text{CH}_3(\text{CH}_2)_4\text{OH}$
h. $\text{CH}_3\text{CH}_2\text{CH}_3 + \text{CH}_3\text{CO}_2\text{H}$



3. a. $\text{HO}(\text{CH}_2)_5\text{OH}$
b. $\text{OHC}(\text{CH}_2)_3\text{CHO}$
c. $\text{HO}(\text{CH}_2)_4\text{CO}_2\text{H}$
d. $\text{HO}_2\text{C}(\text{CH}_2)_3\text{CO}_2\text{H}$

Answers to Problems

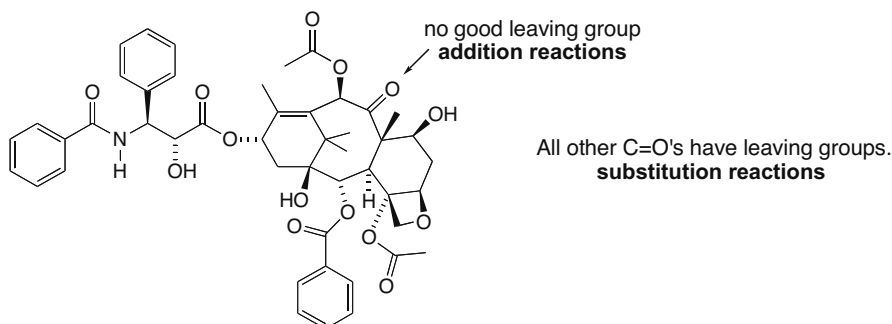
20.1



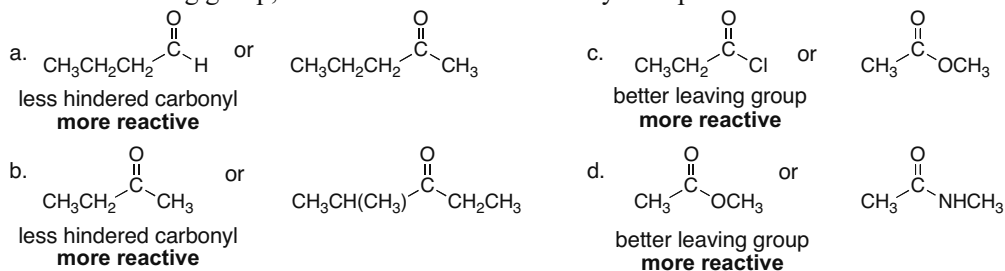
- b. The O is sp^2 hybridized.
Both lone pairs occupy sp^2 hybrid orbitals.

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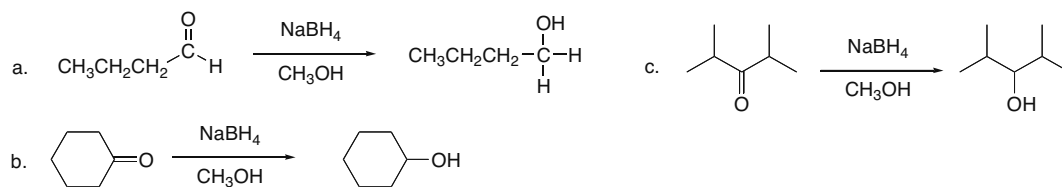
- 20.2** A carbonyl compound with a reasonable leaving group (NR_2 or OR bonded to the $\text{C}=\text{O}$) undergoes substitution reactions. Those without good leaving groups undergo addition.



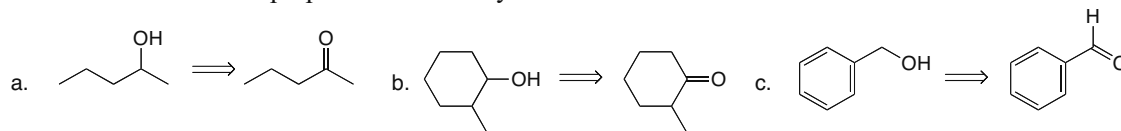
- 20.3** Aldehydes are more reactive than ketones. In carbonyl compounds with leaving groups, the better the leaving group, the more reactive the carbonyl compound.



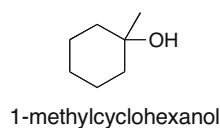
- 20.4** NaBH_4 reduces aldehydes to 1° alcohols and ketones to 2° alcohols.



- 20.5** 1° Alcohols are prepared from aldehydes and 2° alcohols are from ketones.



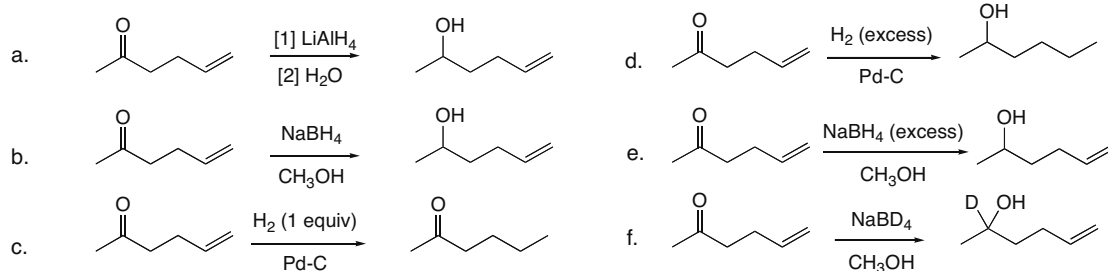
- 20.6**



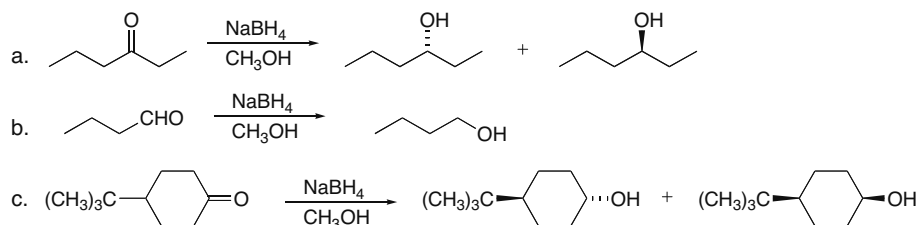
3° Alcohols cannot be made by reduction of a carbonyl group, because they do not contain a H on the C with the OH.

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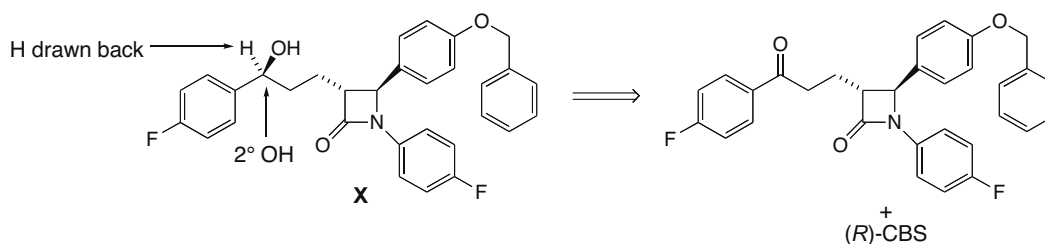
20.7



20.8

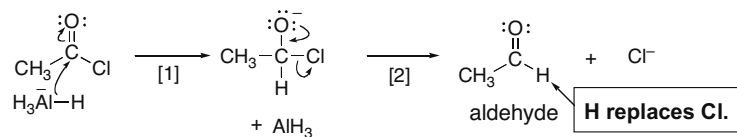
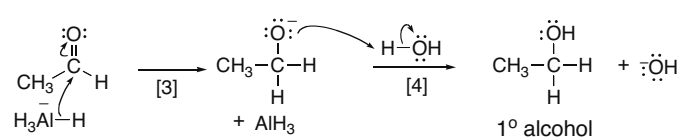


20.9 The 2° alcohol comes from a carbonyl group. Since hydride was delivered from the back side, the (*R*)-CBS reagent must be used.



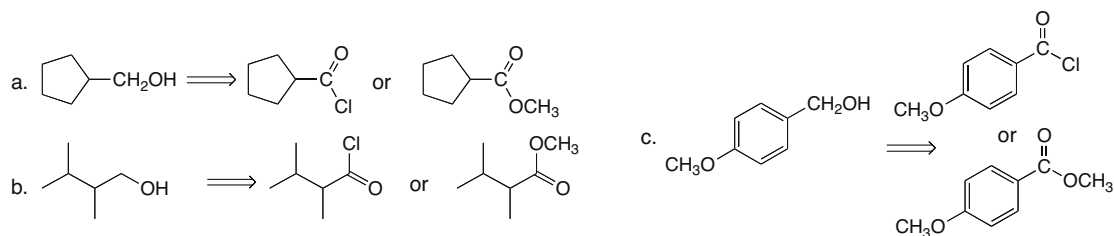
20.10

Part [1]: Nucleophilic substitution of H for Cl

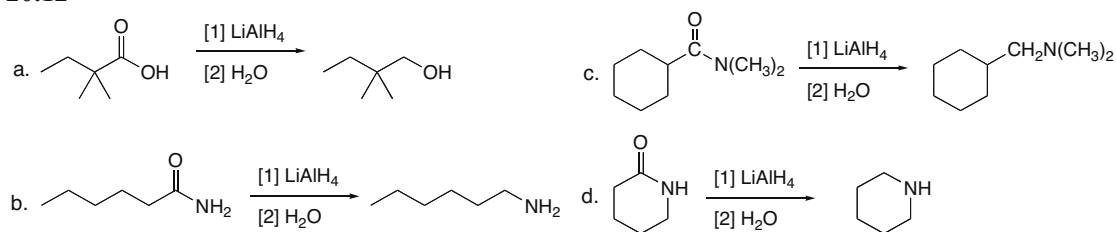
Part [2]: Nucleophilic addition of H⁻ to form an alcohol

20.11 Acid chlorides and esters can be reduced to 1° alcohols. Keep the carbon skeleton the same in drawing an ester and acid chloride precursor.

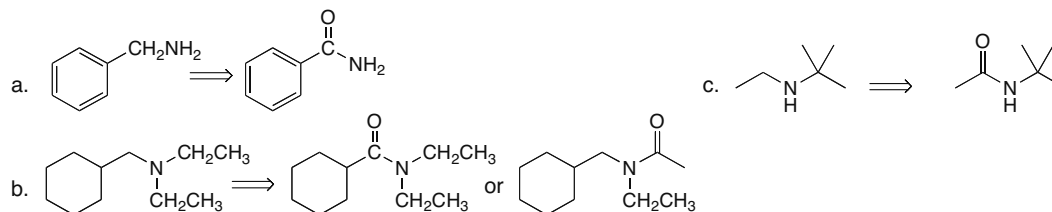
Introduction to Carbonyl Chemistry 20-9



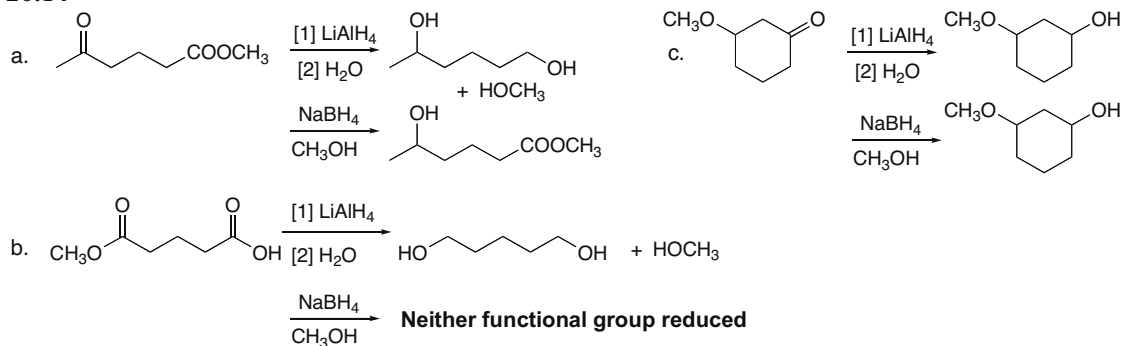
20.12



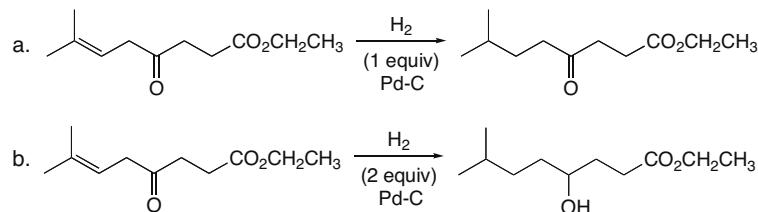
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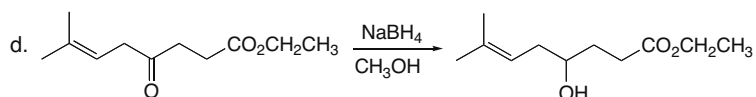
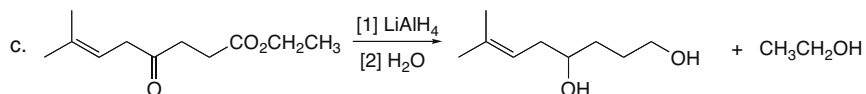
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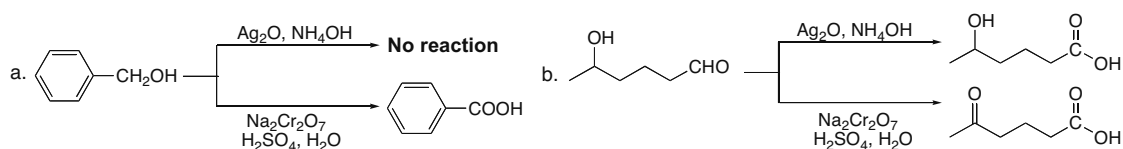
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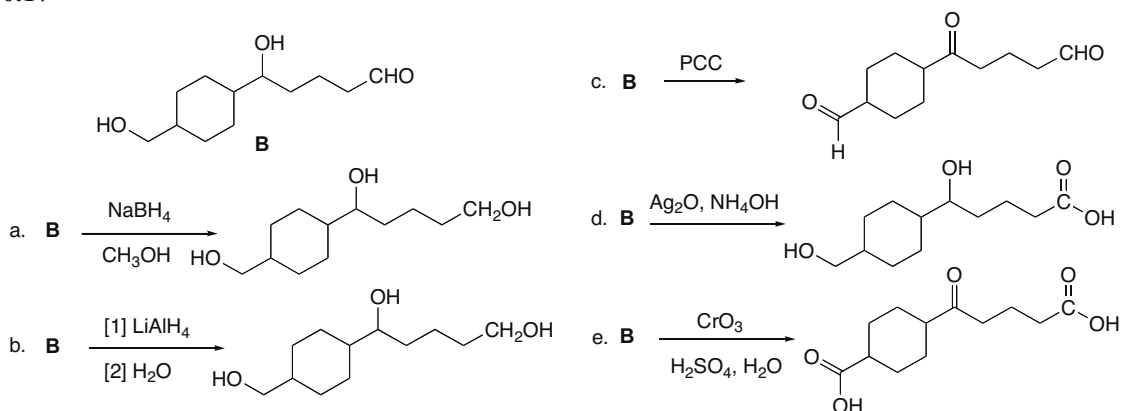
Chapter 20–10



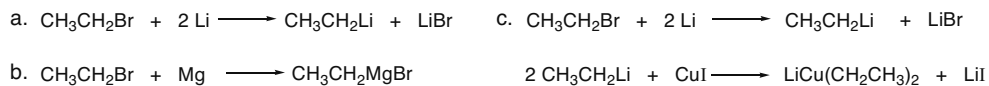
20.16 Tollens reagent reacts only with aldehydes.



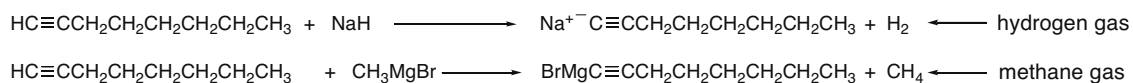
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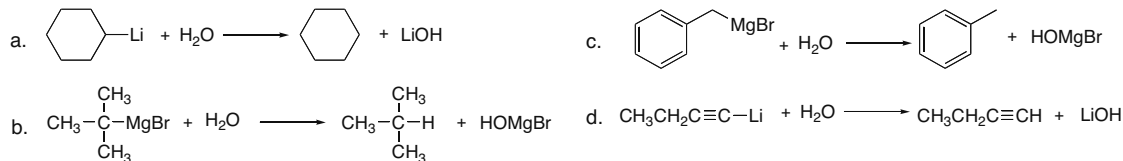
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20.19

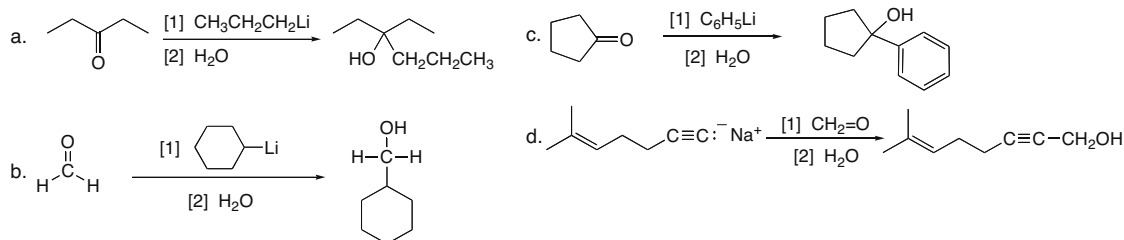


20.20

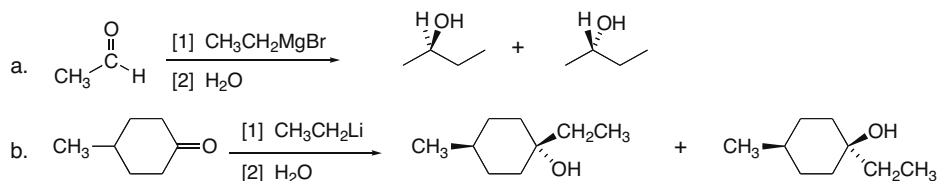
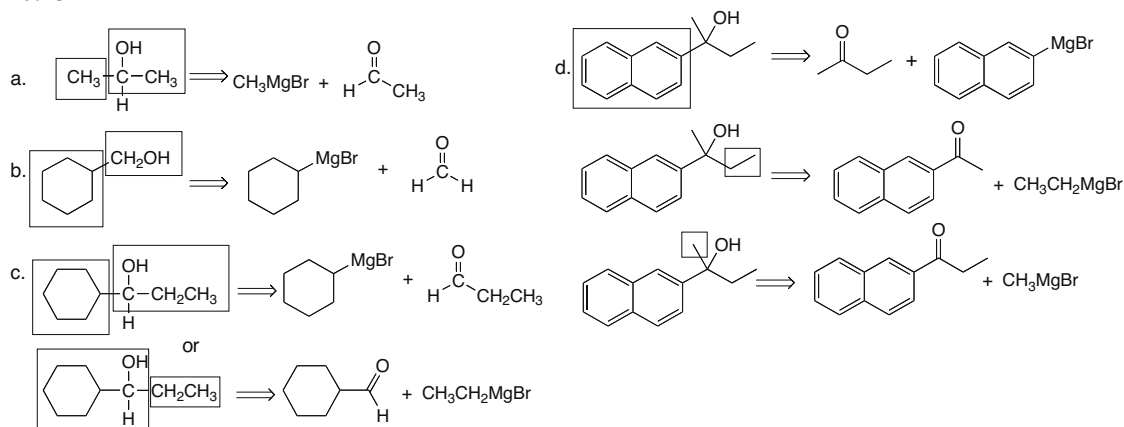
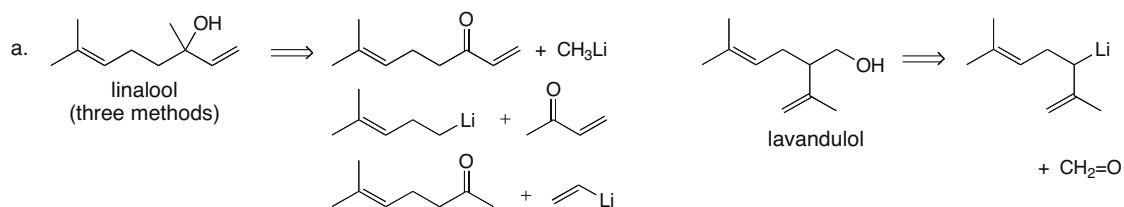


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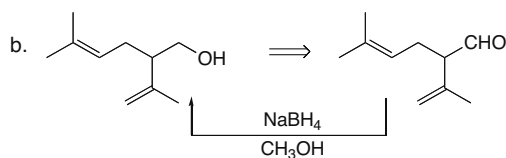
20.21 To draw the products, add the alkyl or phenyl group to the carbonyl carbon and protonate the oxygen.



20.22 Addition of RM always occurs from above and below the plane of the molecule.

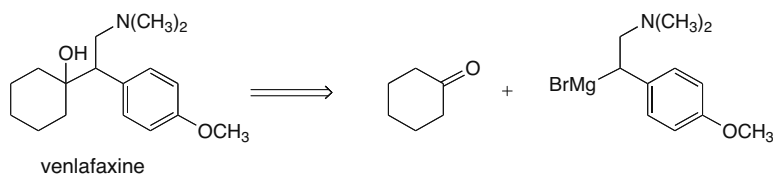
**20.23****20.24**

Chapter 20–12

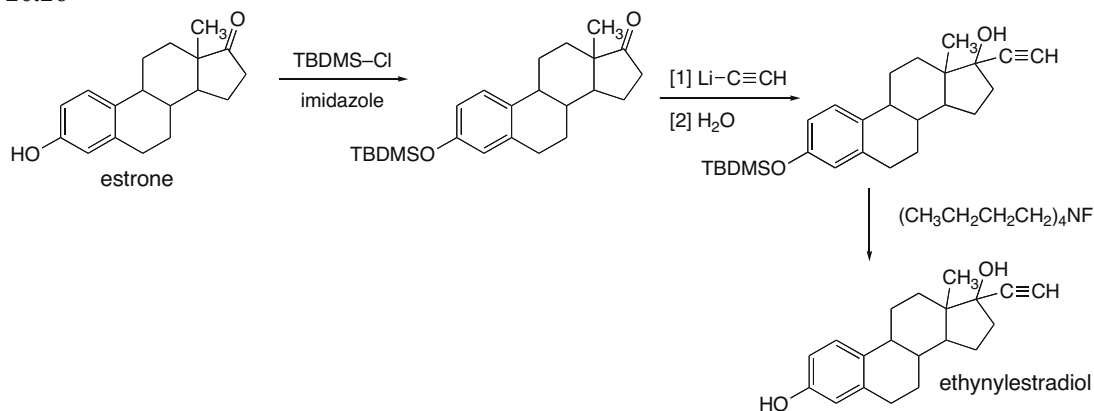


c. Linalool is a 3° ROH. Therefore, it has no H on the carbon with the OH group, and cannot be prepared by reduction of a carbonyl compound.

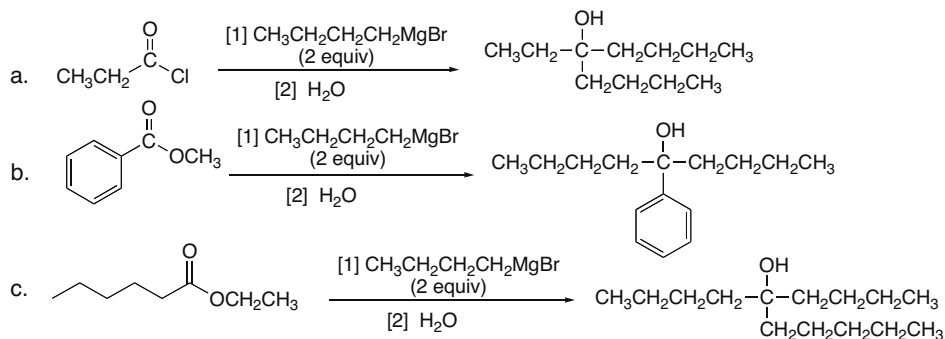
20.25



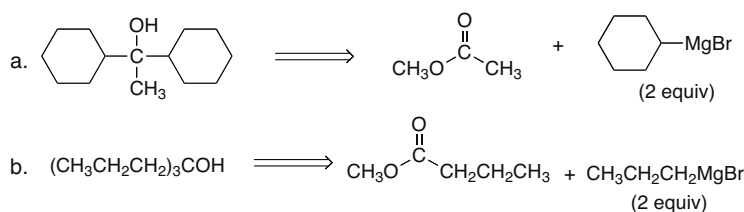
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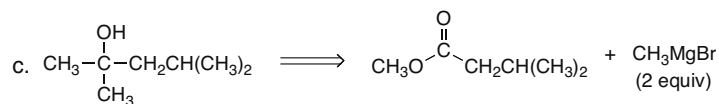
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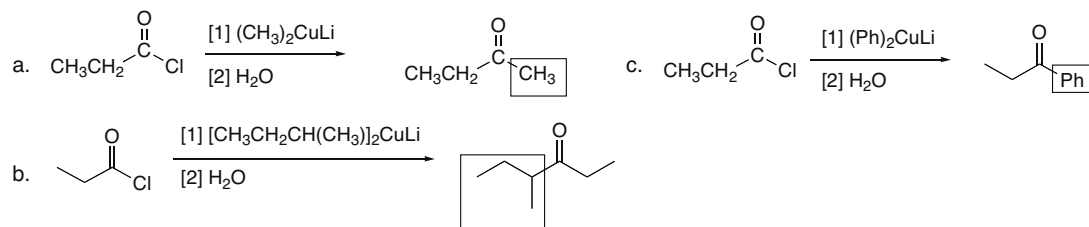
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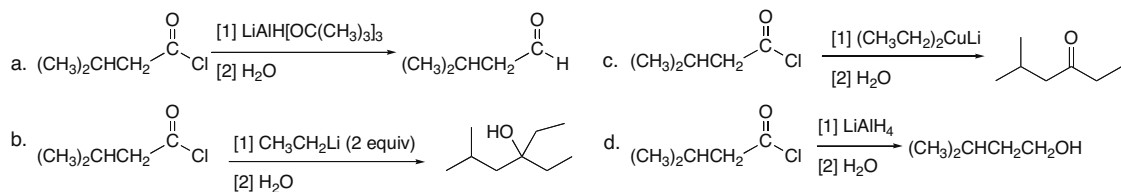
Introduction to Carbonyl Chemistry 20–13



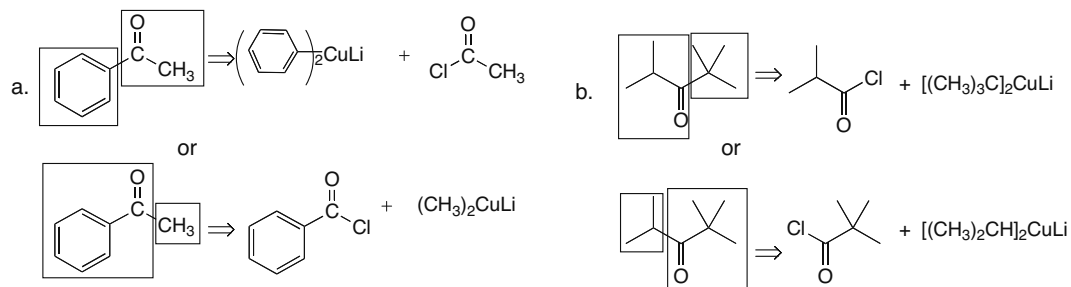
20.29 The R group of the organocuprate has replaced the Cl on the acid chloride.



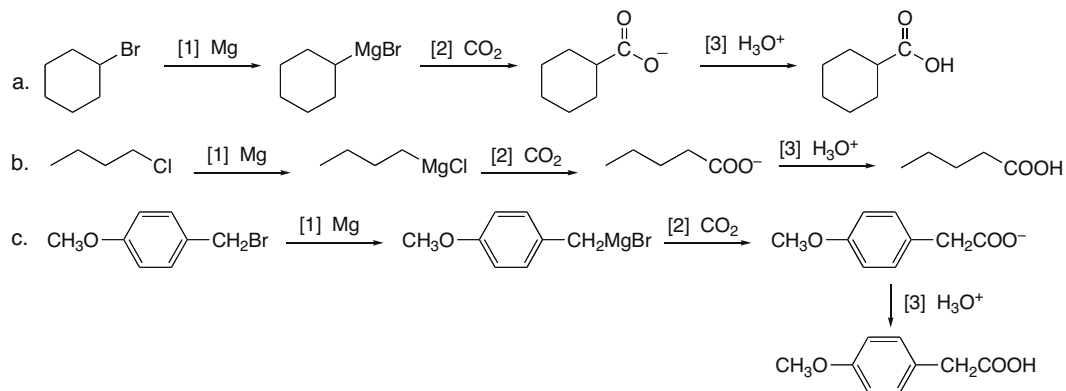
20.30



20.31

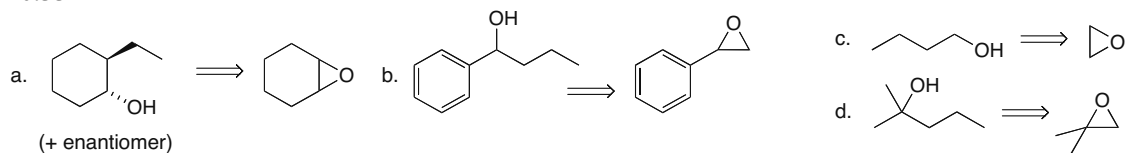


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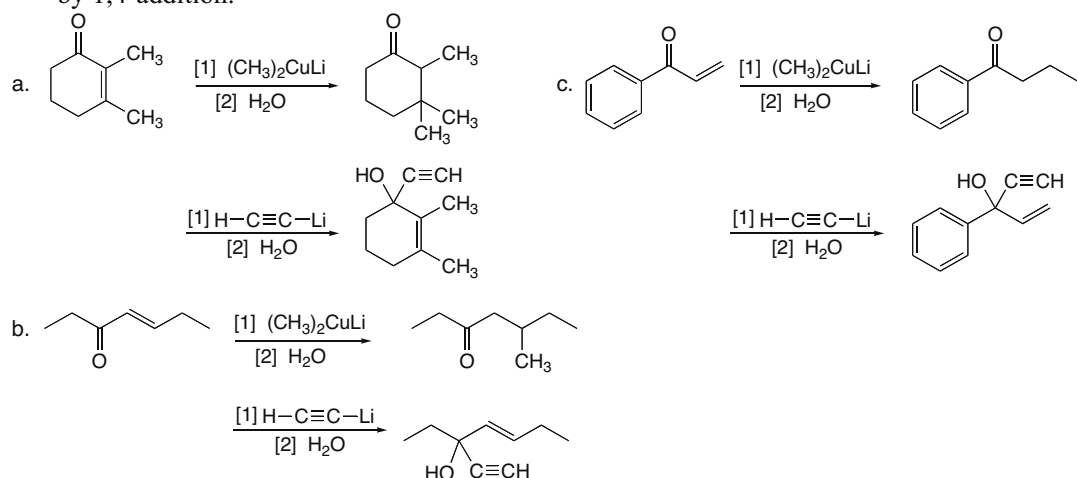


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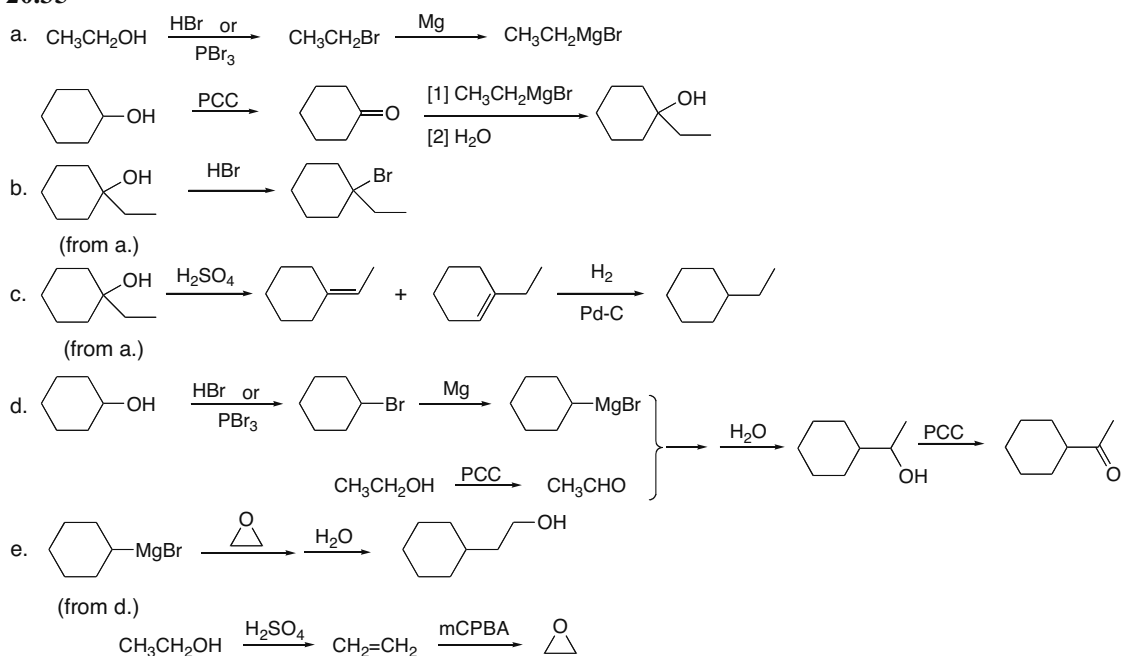
20.33



20.34 The characteristic reaction of α,β -unsaturated carbonyl compounds is nucleophilic addition. Grignard and organolithium reagents react by 1,2-addition and organocuprate reagents react by 1,4-addition.

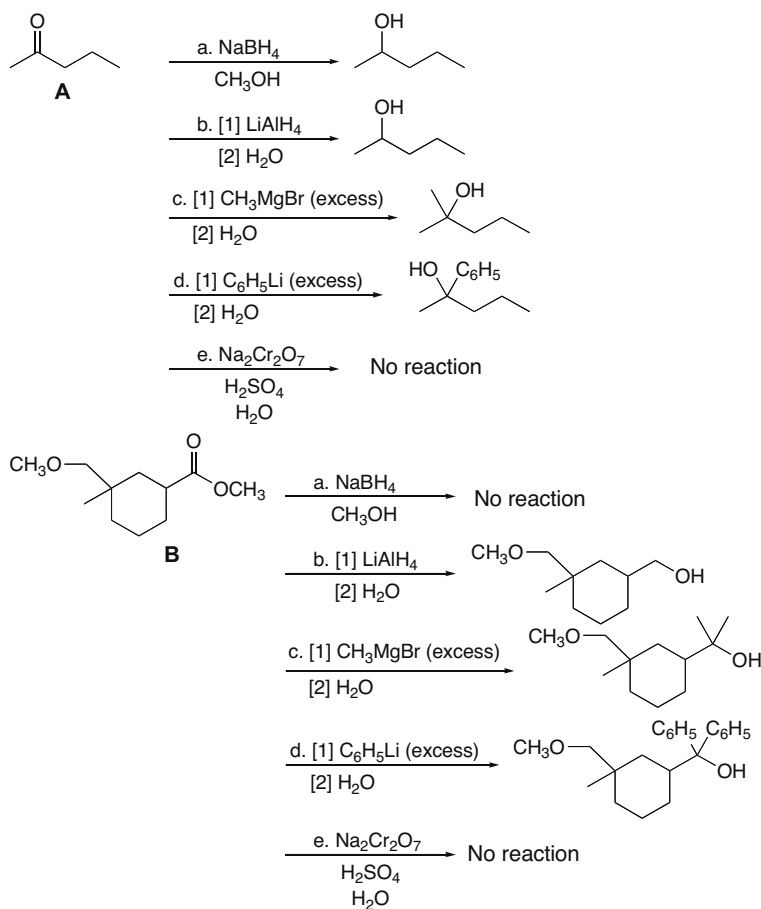


20.35

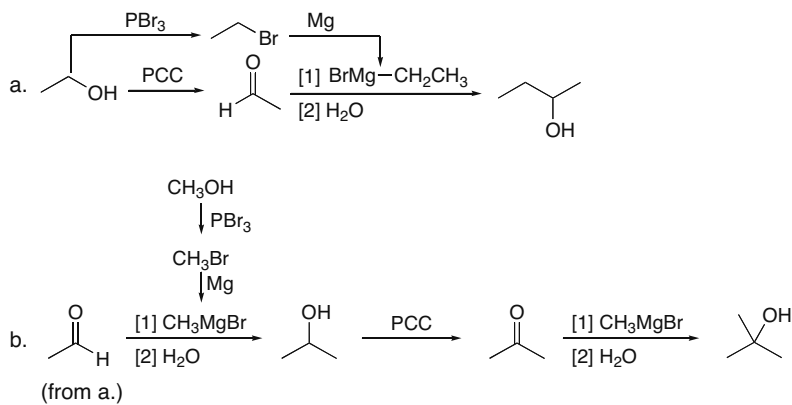


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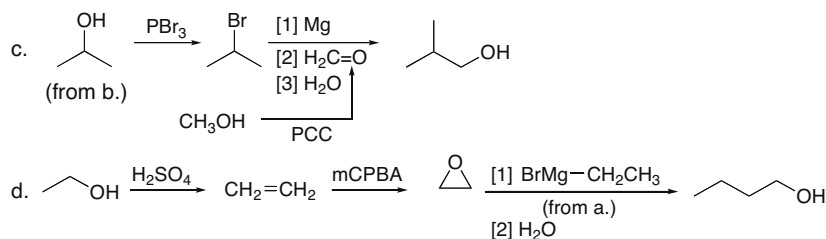
20.36



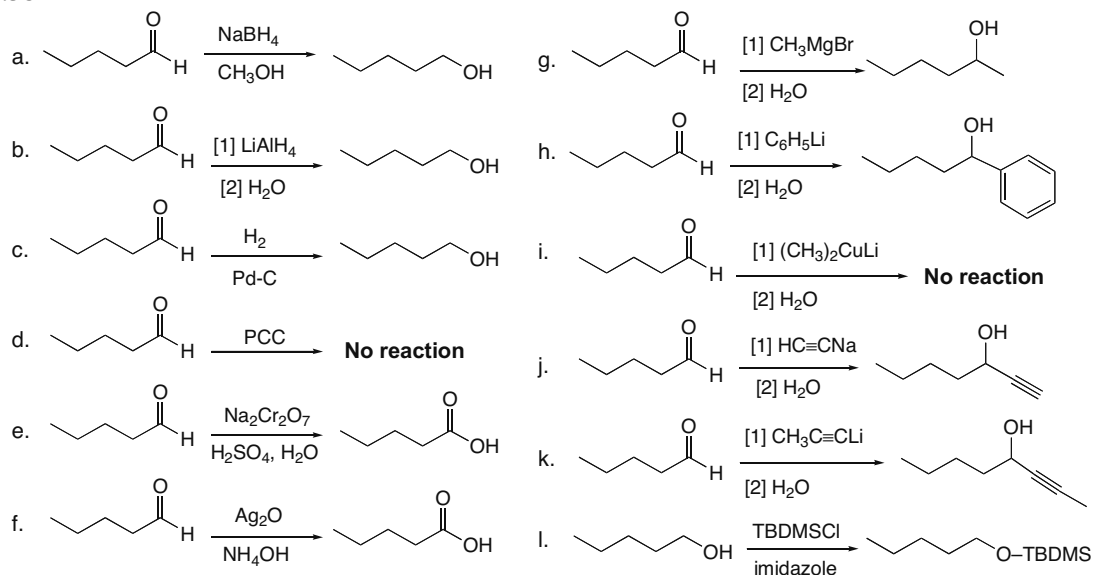
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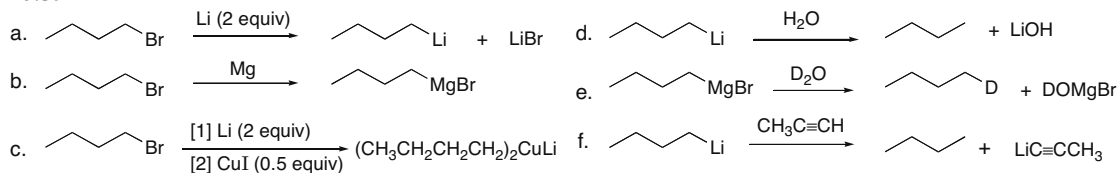
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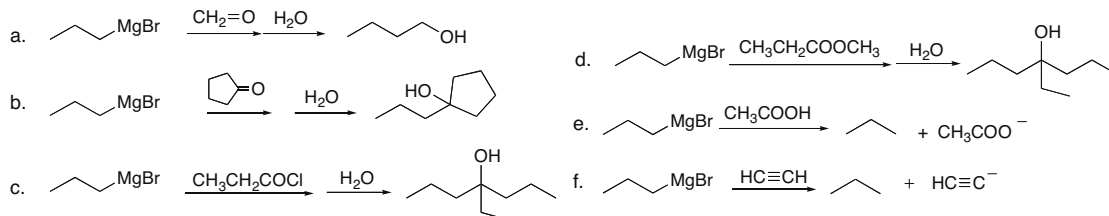
20.38



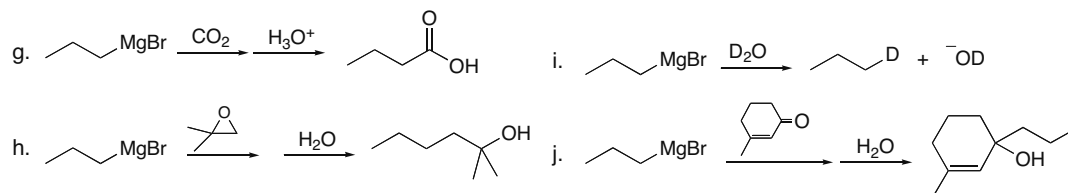
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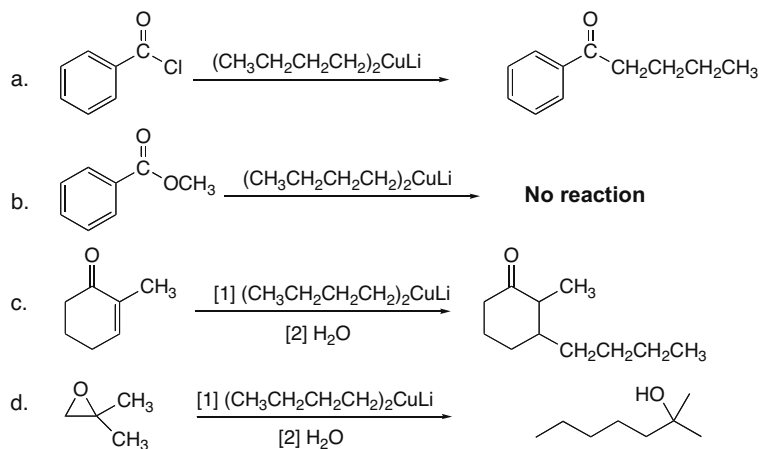
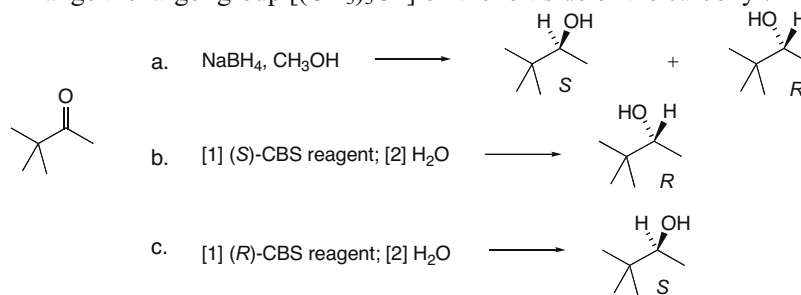
20.40



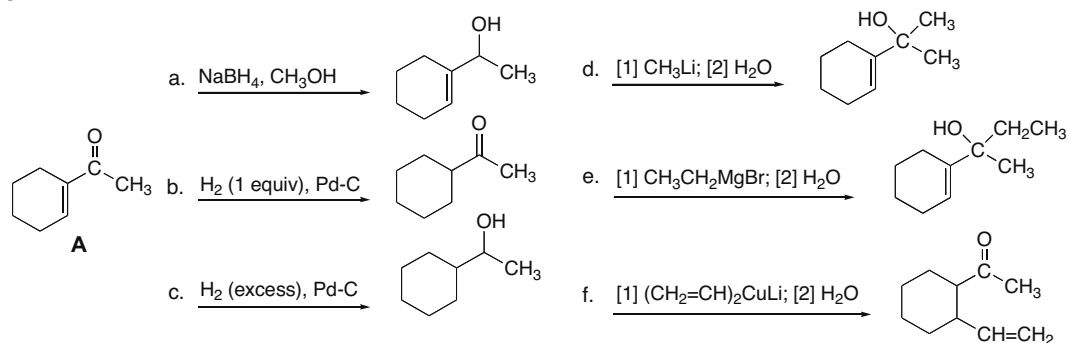
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20.41

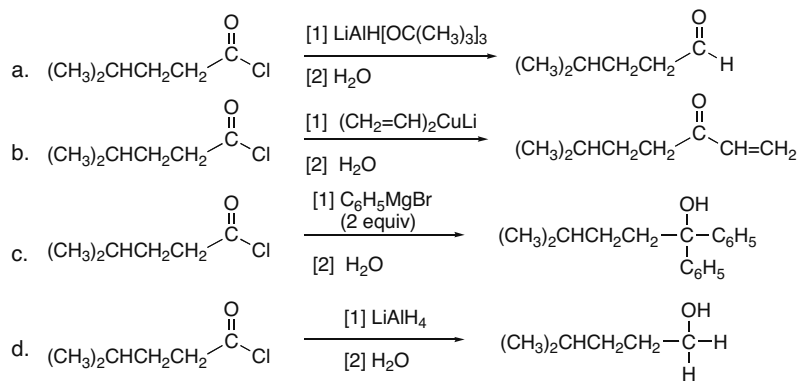
20.42 Arrange the larger group [(CH₃)₃C-] on the left side of the carbonyl.

20.43

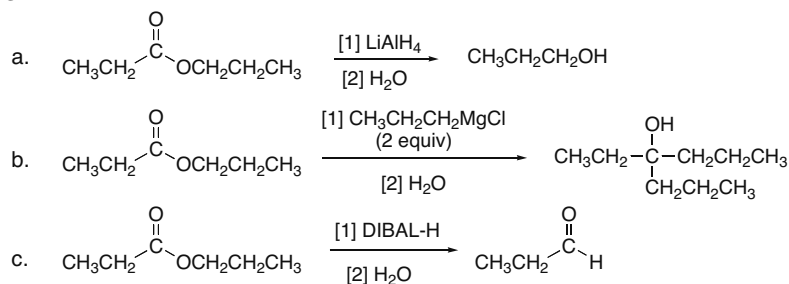


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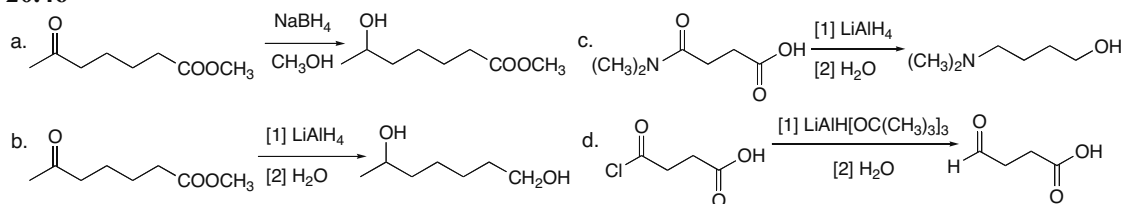
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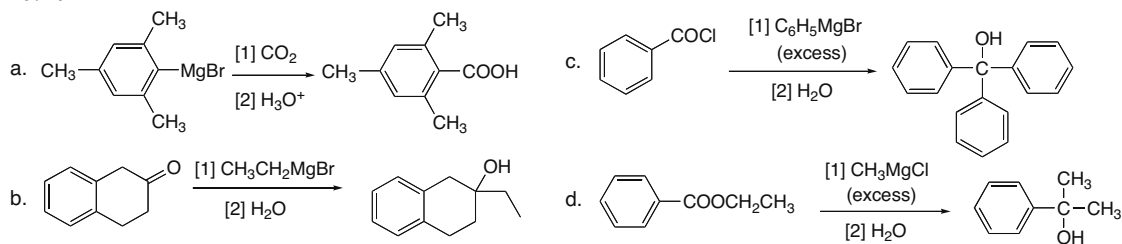
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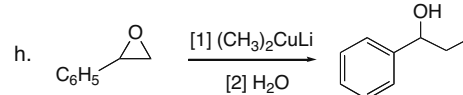
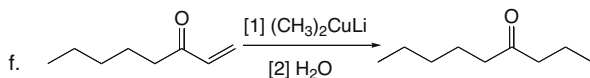
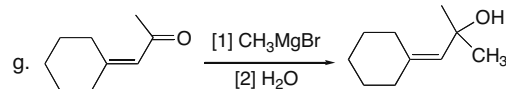
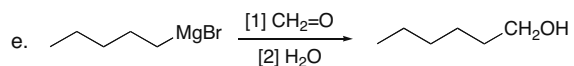
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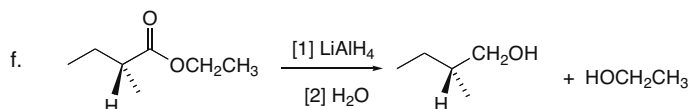
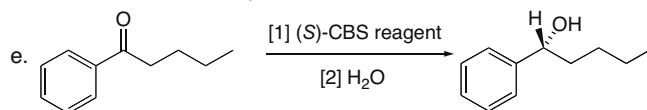
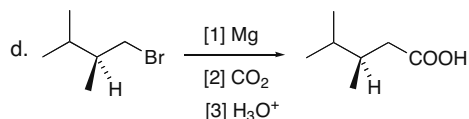
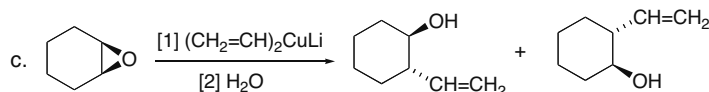
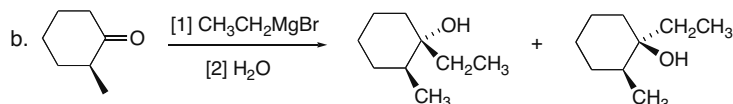
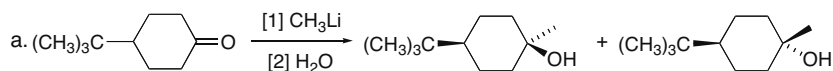
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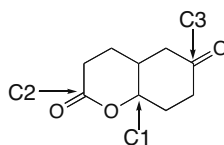
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20.48

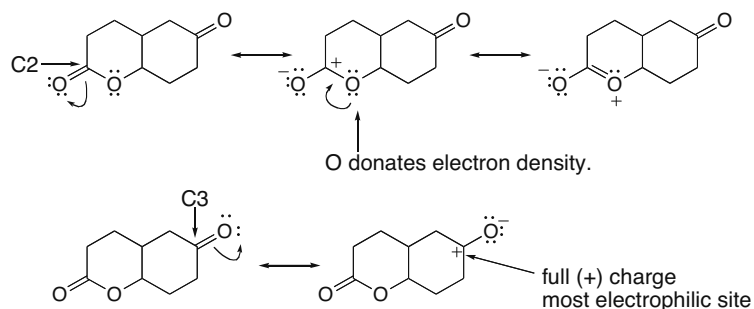


20.49 Three carbons bear a δ^+ because they are bonded to electronegative O atoms.

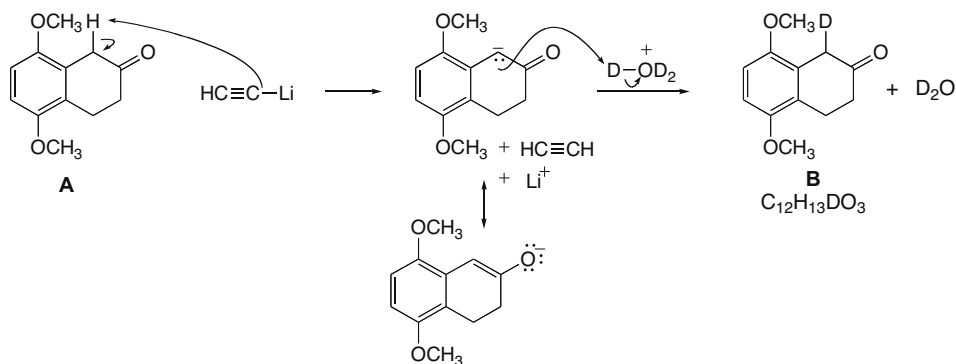


C1 is an sp^3 hybridized C bonded to an O so it bears a δ^+ . There are no additional resonance structures that affect C1. C2 is part of a carbonyl that has three resonance structures, only one of which places a (+) charge on C. The O atom of the ester donates its electron pair, making the carbonyl C less electrophilic than C3. C3 is most electrophilic. Its carbonyl is stabilized by two resonance structures, one of which places a (+) charge on carbon.

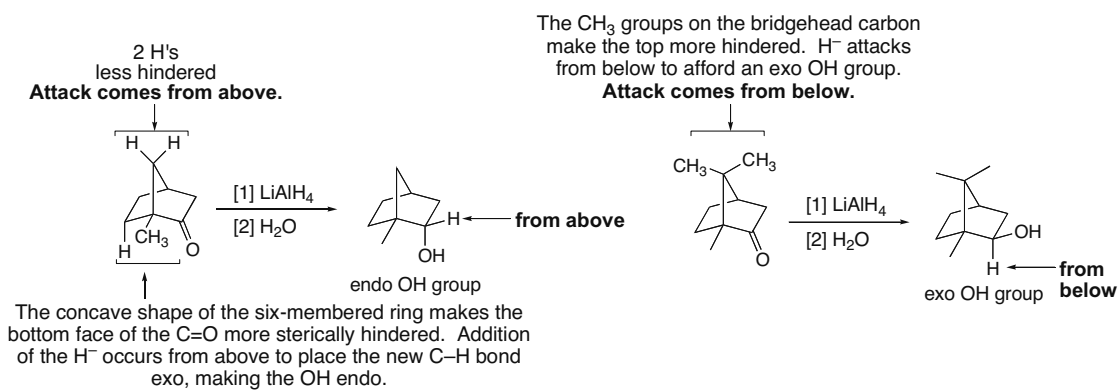
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20.50 The organolithium reagent is a nucleophile and a base. As a base it can remove the most acidic proton (between the benzene ring and C=O) to form an enolate that is protonated by D_3O^+ .

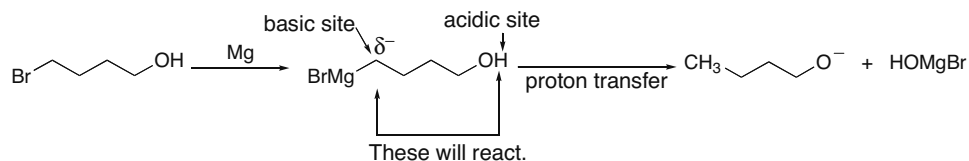


20.51 Both ketones are chiral molecules with carbonyl groups that have one side more sterically hindered than the other. In both reductions, hydride approaches from the less hindered side.

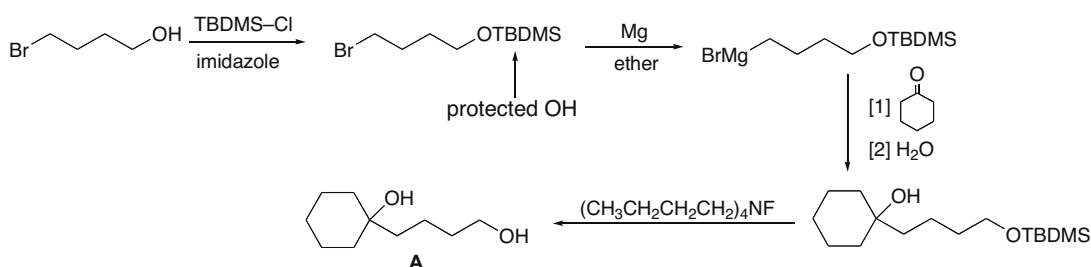


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- 20.52** Since a Grignard reagent contains a carbon atom with a partial negative charge, it acts as a base and reacts with the OH of the starting halide, $\text{BrCH}_2\text{CH}_2\text{CH}_2\text{CH}_2\text{OH}$. This acid–base reaction destroys the Grignard reagent so that addition cannot occur. To get around this problem, the OH group can be protected as a *tert*-butyldimethylsilyl ether, from which a Grignard reagent can be made.

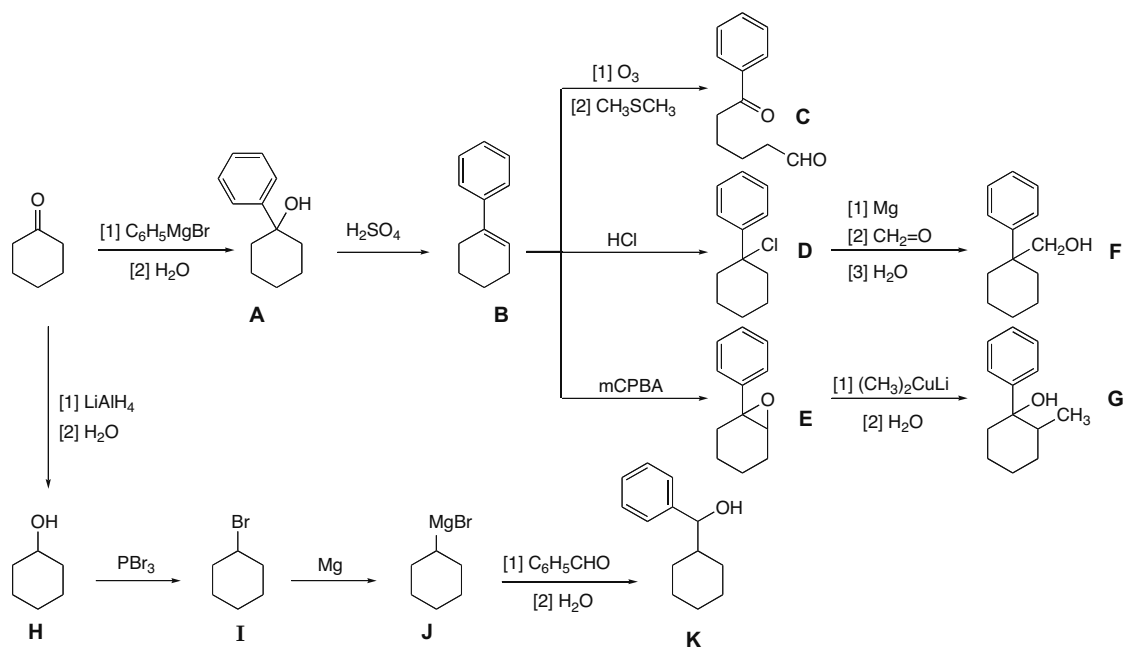


INSTEAD: Use a protecting group.

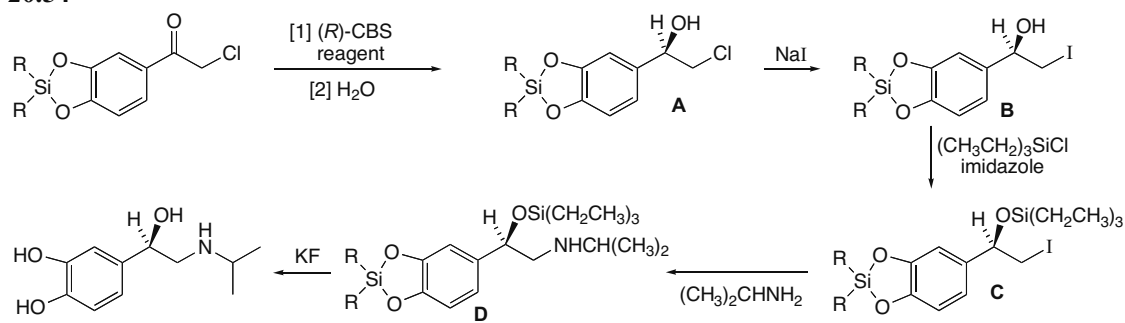


- 20.53** Compounds **F**, **G**, and **K** are all alcohols with aromatic rings so there will be many similarities in their proton NMR spectra. These compounds will, however, show differences in absorptions due to the CH protons on the carbon bearing the OH group. **F** has a CH_2OH group, which will give a singlet in the 3–4 ppm region of the spectrum. **G** is a 3° alcohol that has no protons on the C bonded to the OH group so it will have no peak in the 3–4 ppm region of the spectrum. **K** is a 2° alcohol that will give a doublet in the 3–4 ppm region of the spectrum for the CH proton on the carbon with the OH group.

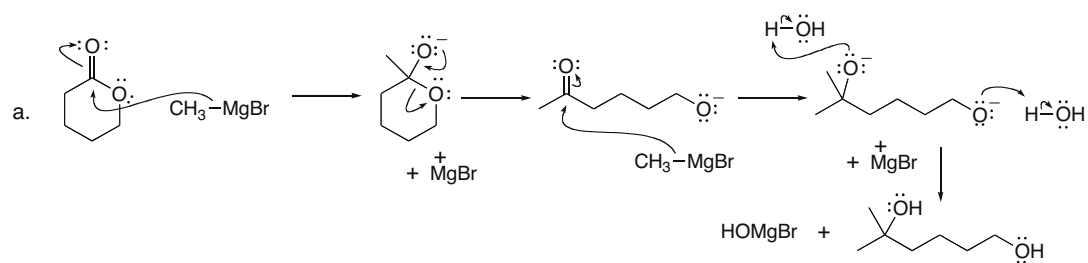
Chapter 20–22



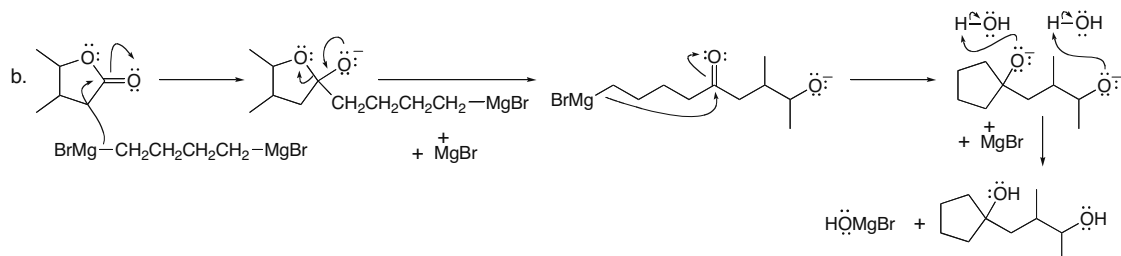
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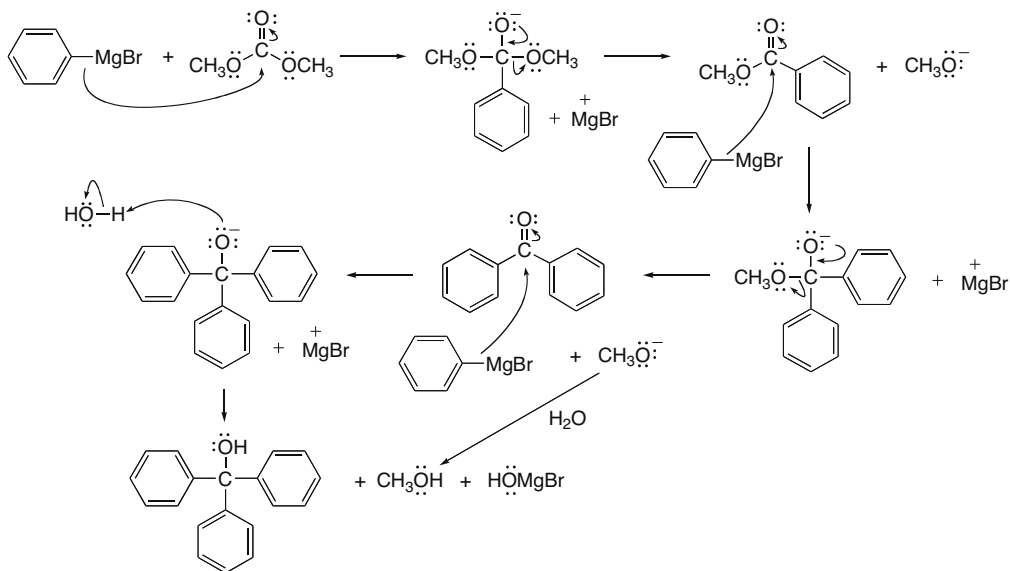
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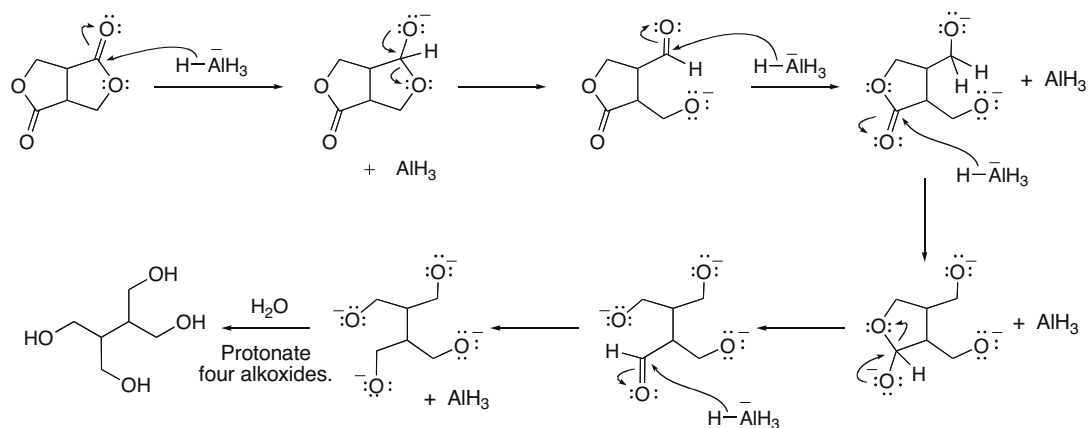
Introduction to Carbonyl Chemistry 20–23



20.56

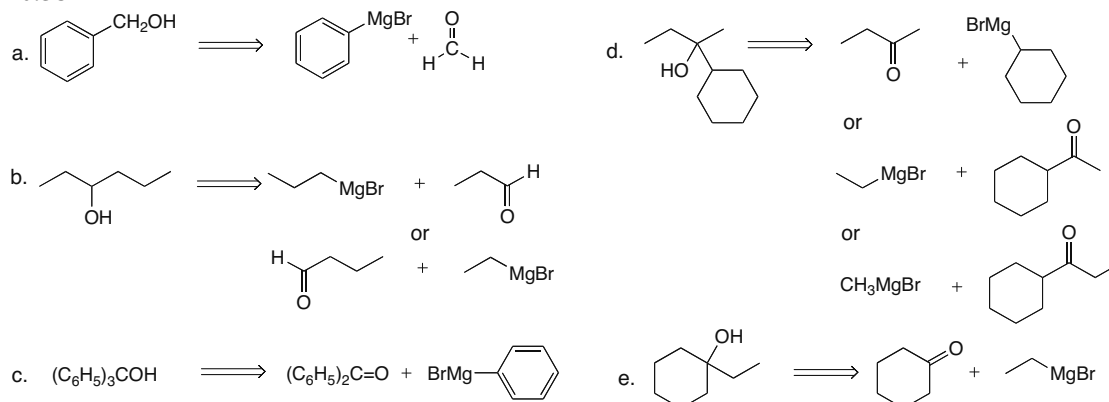


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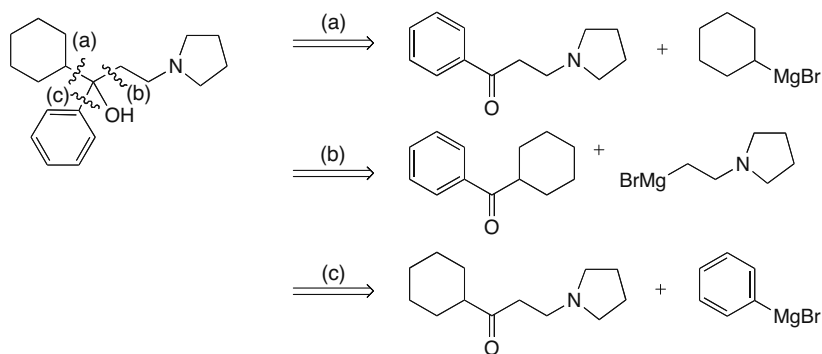


Chapter 20–24

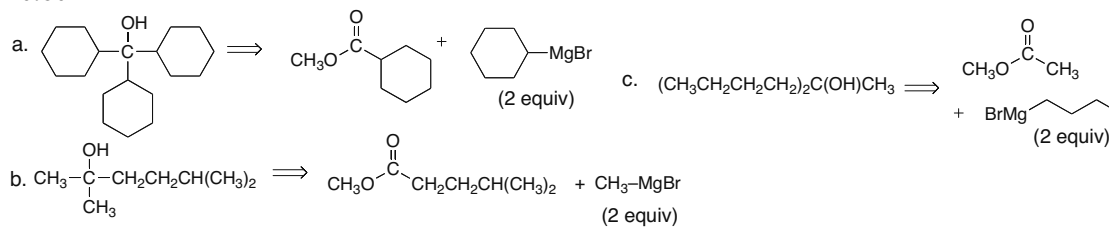
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20.59

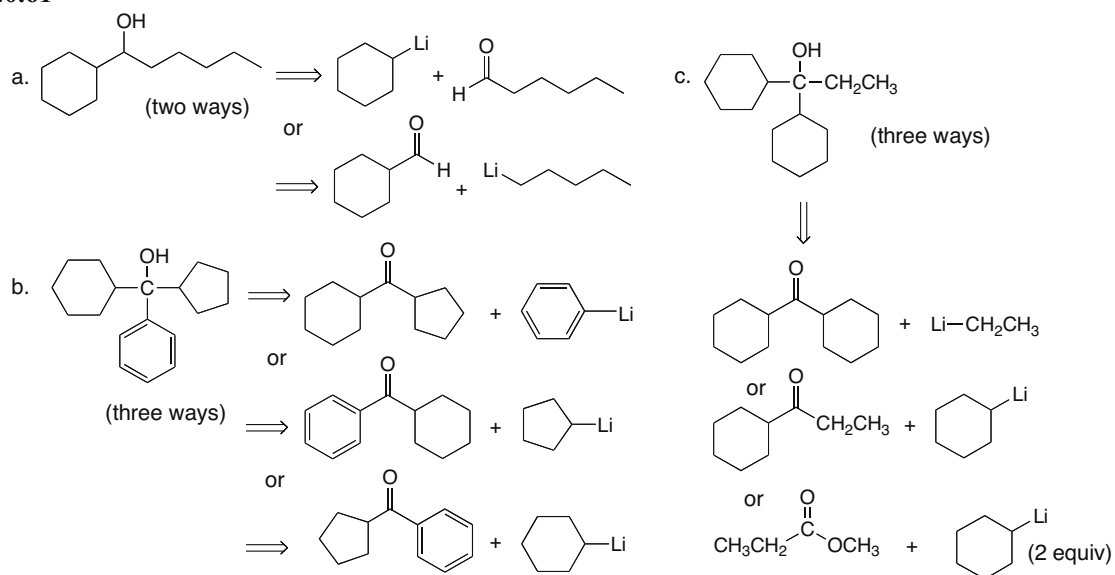


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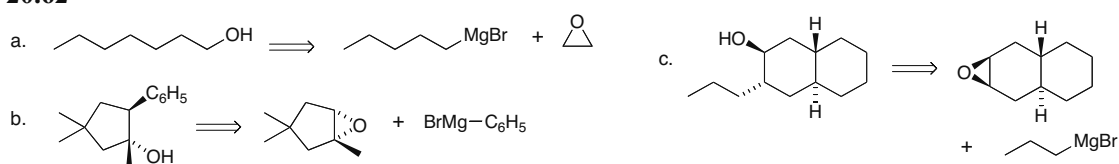


Introduction to Carbonyl Chemistry 20–25

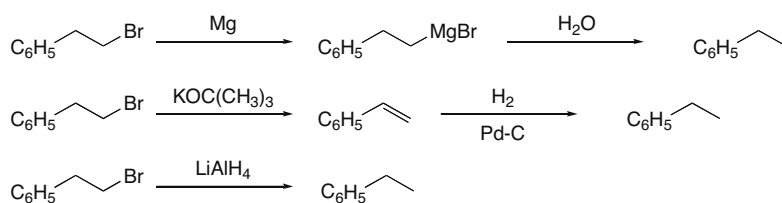
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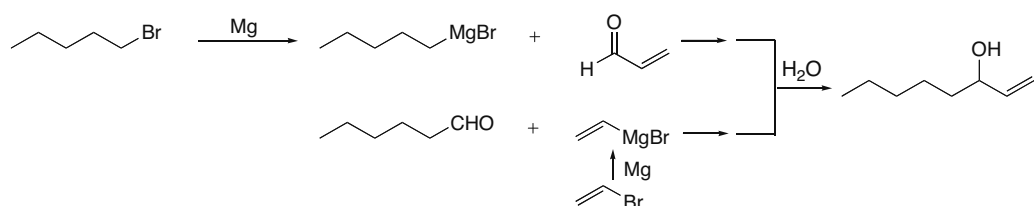
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20.63

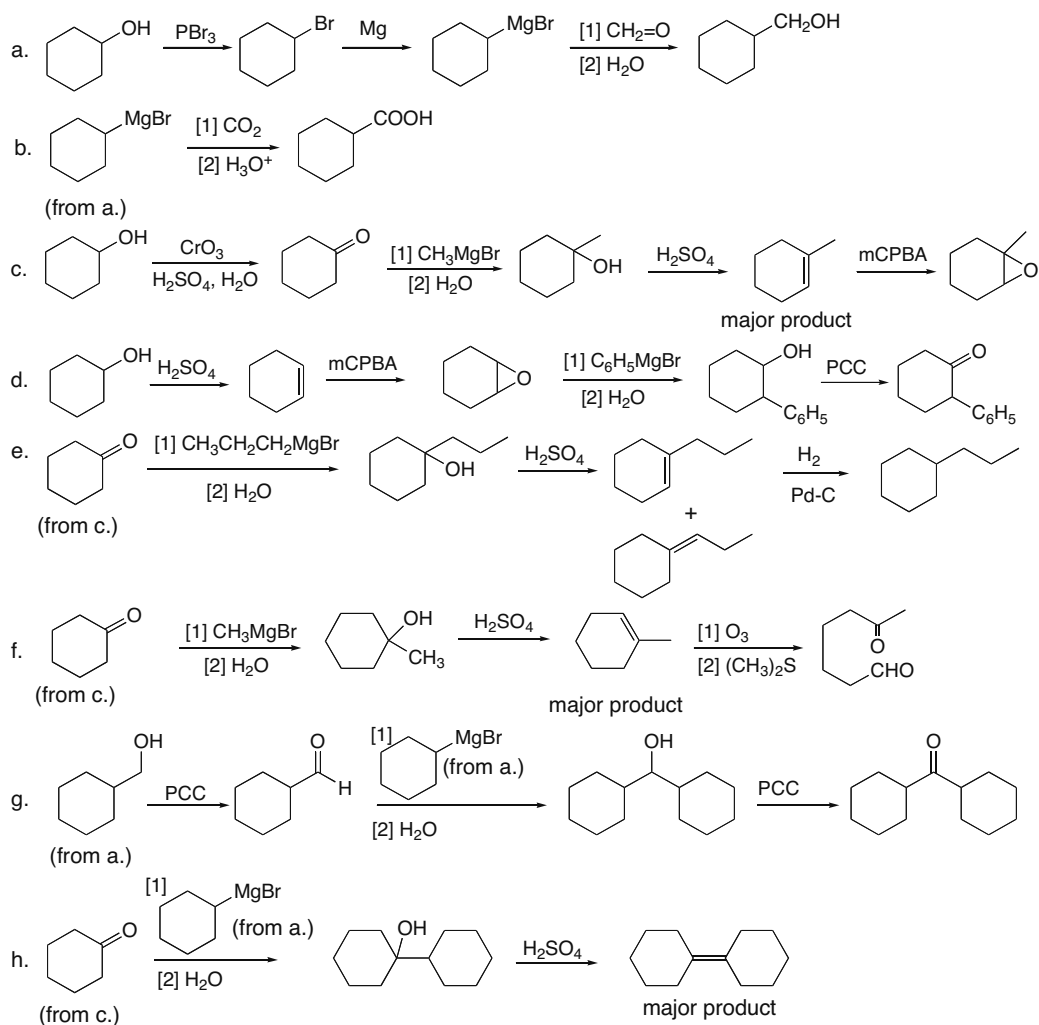


20.64

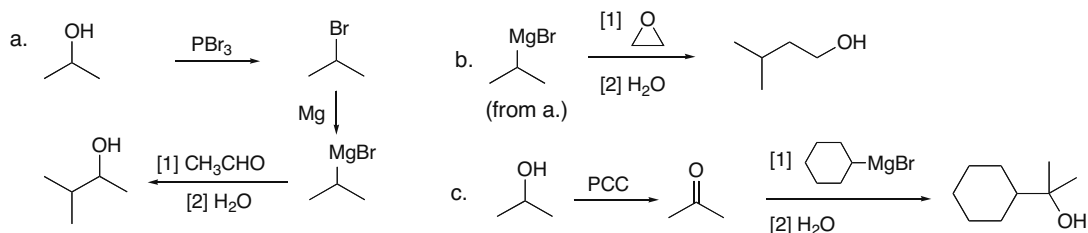


Chapter 20–26

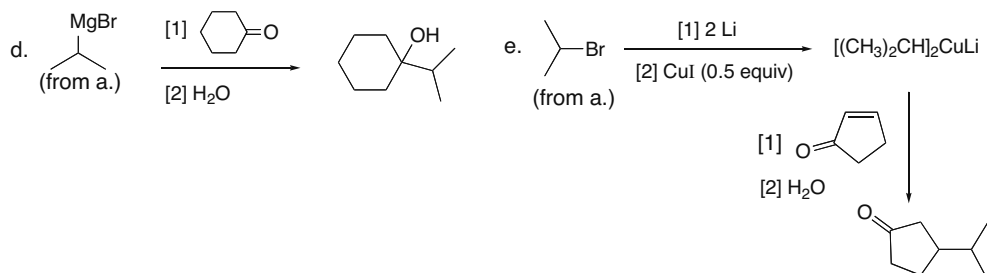
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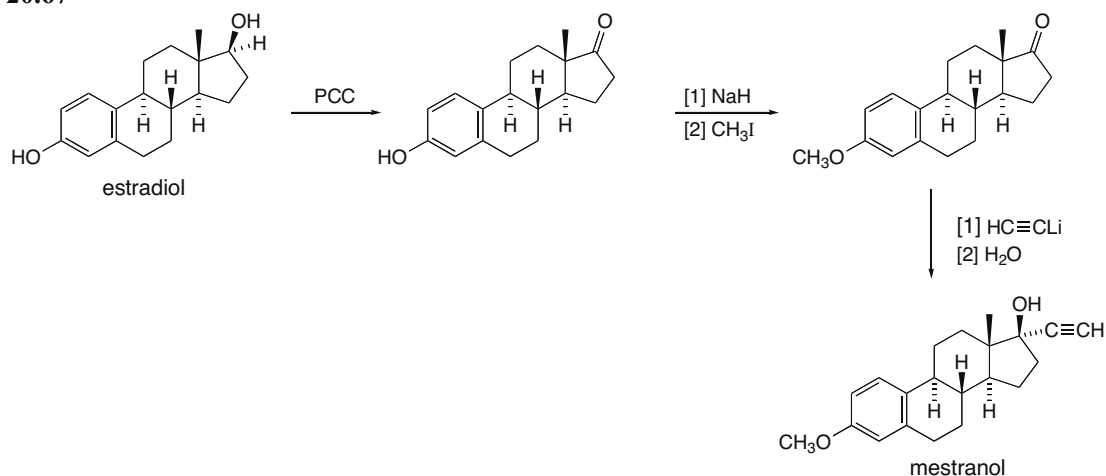
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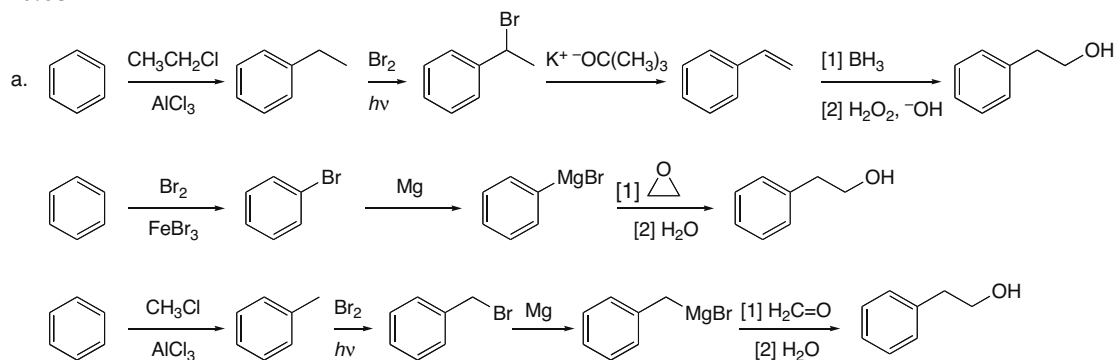
Introduction to Carbonyl Chemistry 20–27



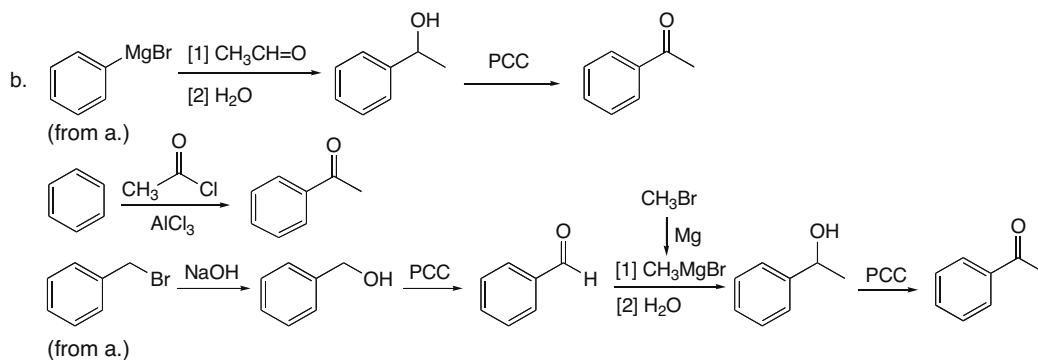
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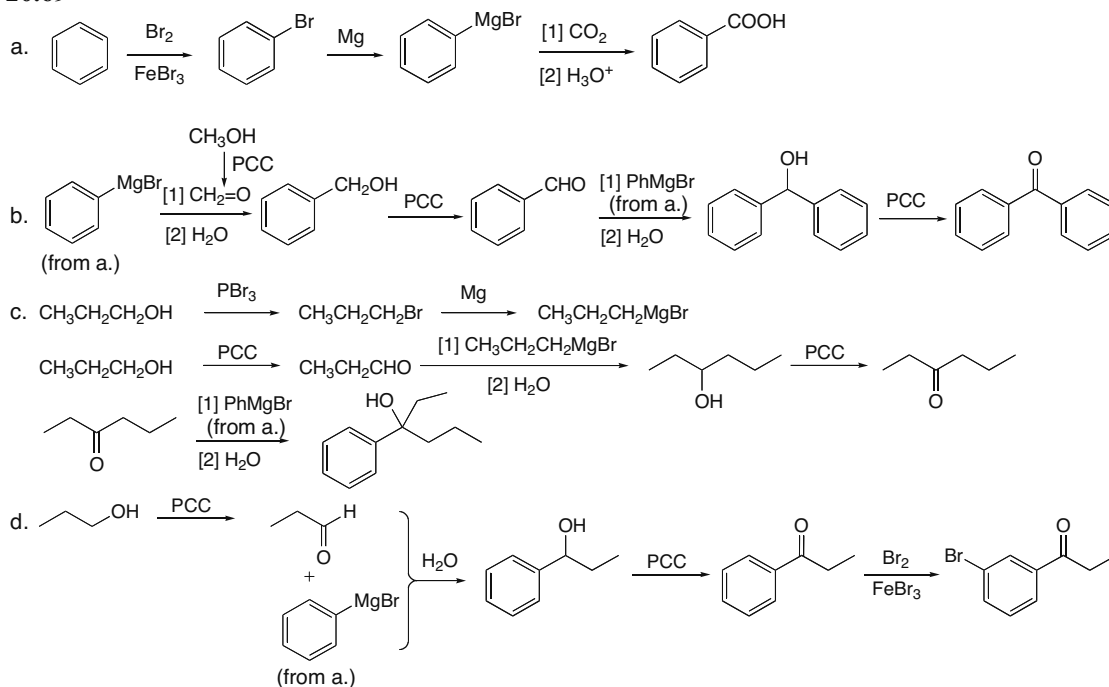
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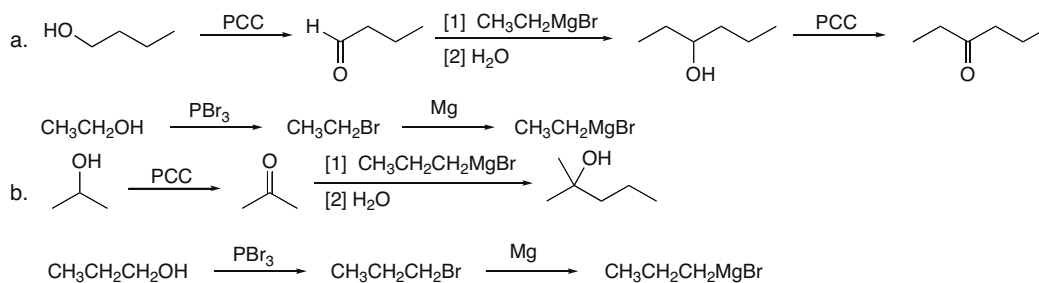
Chapter 20–28



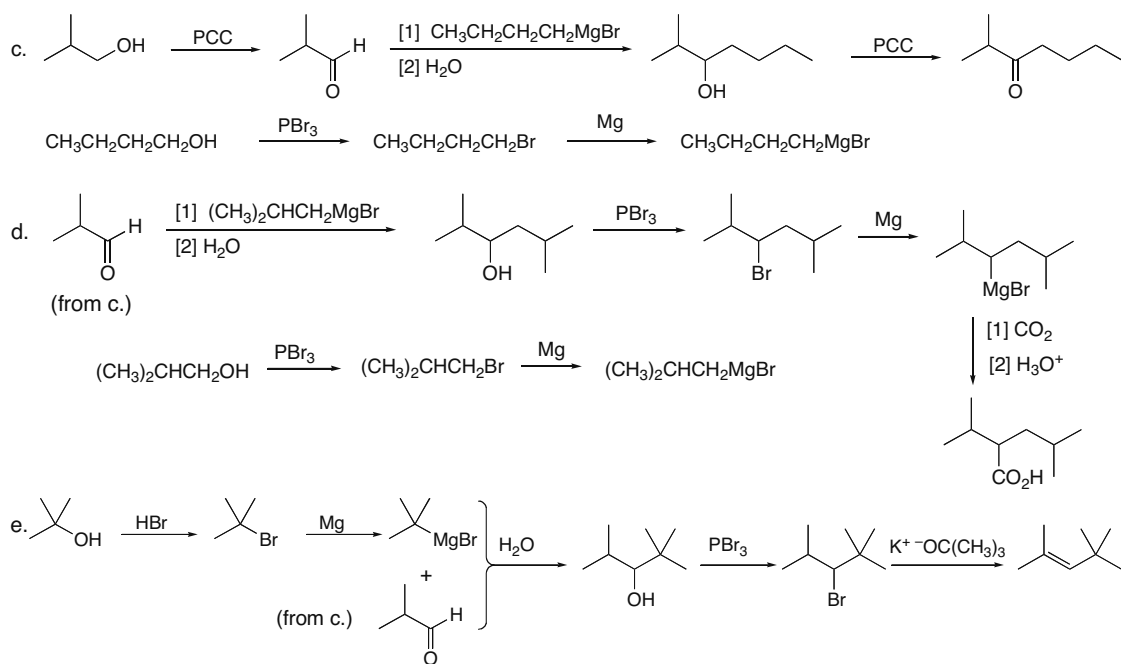
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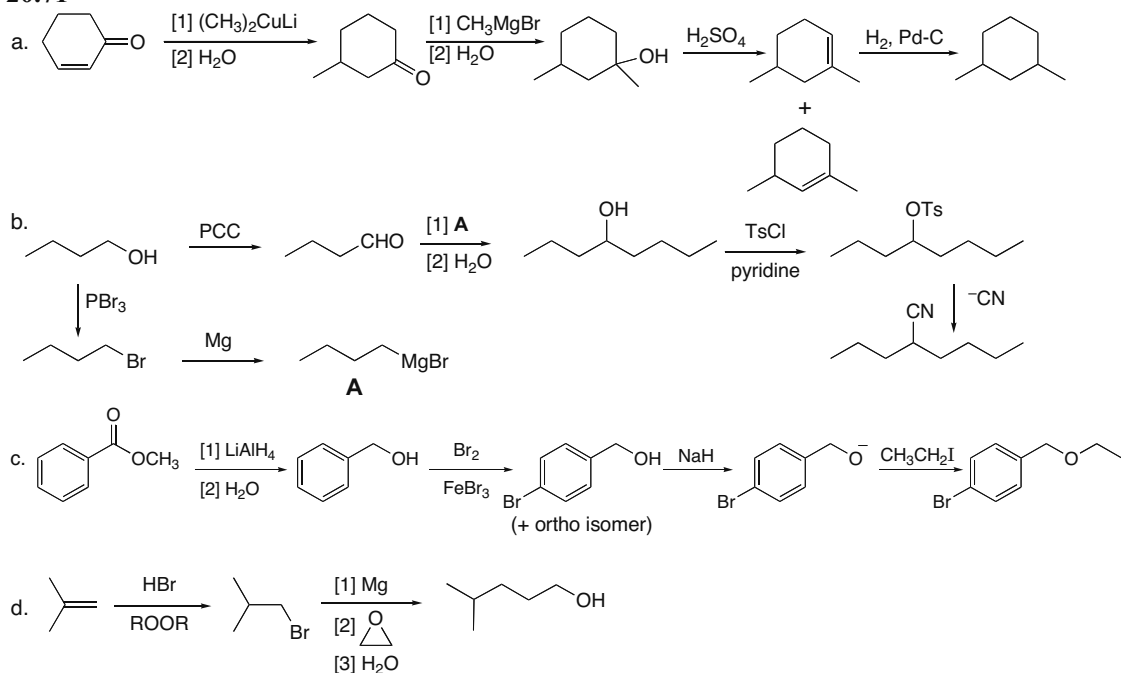
20.70



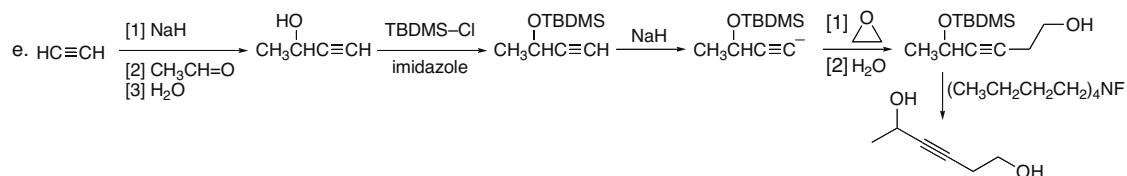
Introduction to Carbonyl Chemistry 20–29



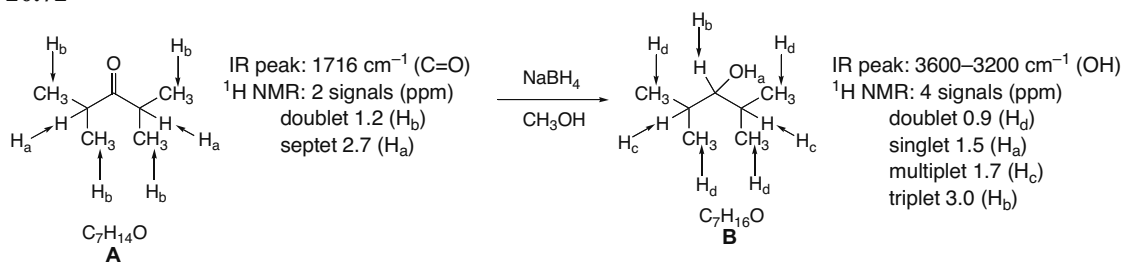
20.71



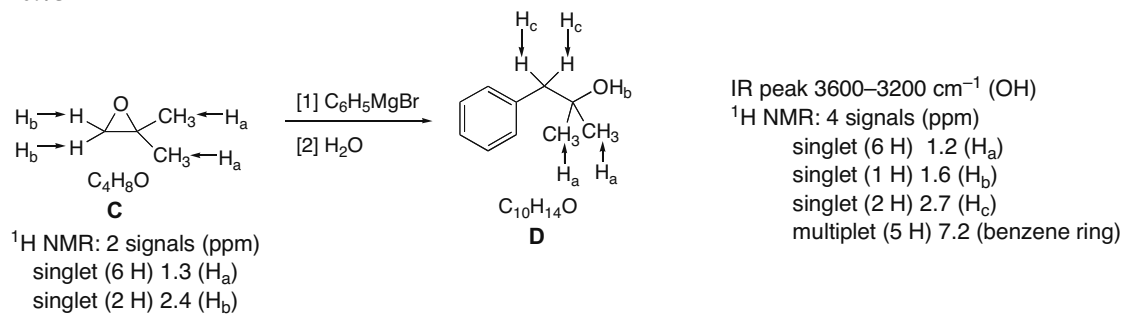
Chapter 20–30



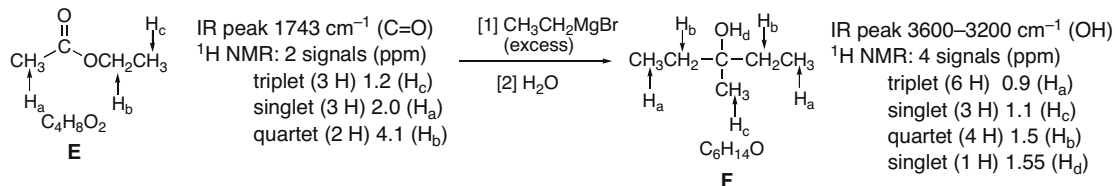
20.72



20.73



20.74



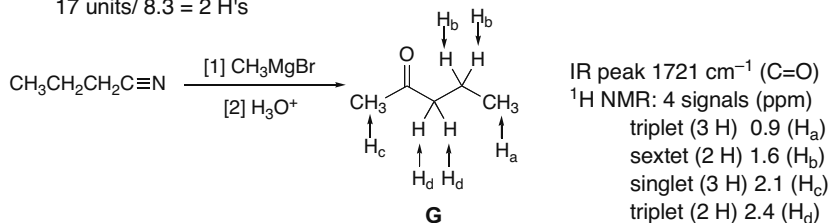
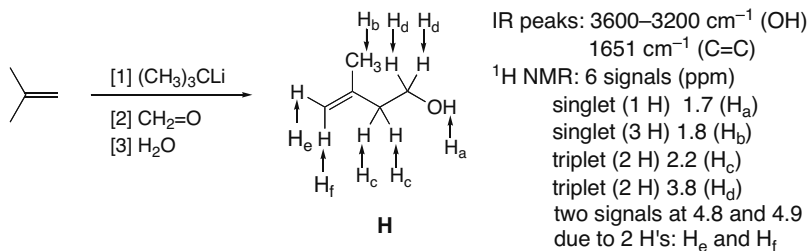
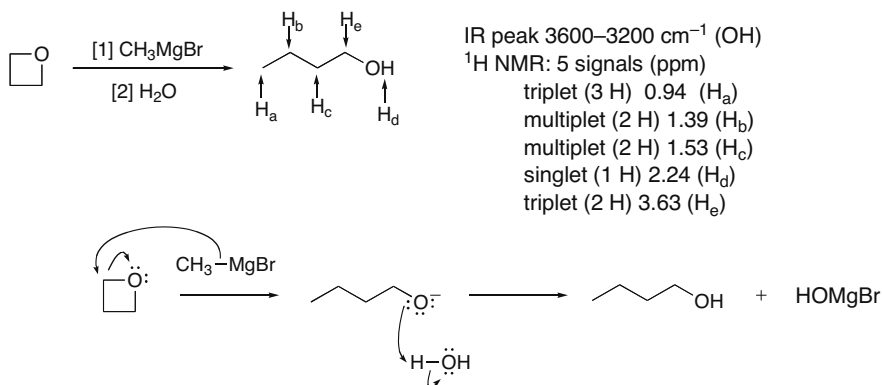
Introduction to Carbonyl Chemistry 20–31

20.75 Molecular ion at $m/z = 86$: $C_5H_{10}O$ (possible molecular formula).

Determine the number of integration units per H:

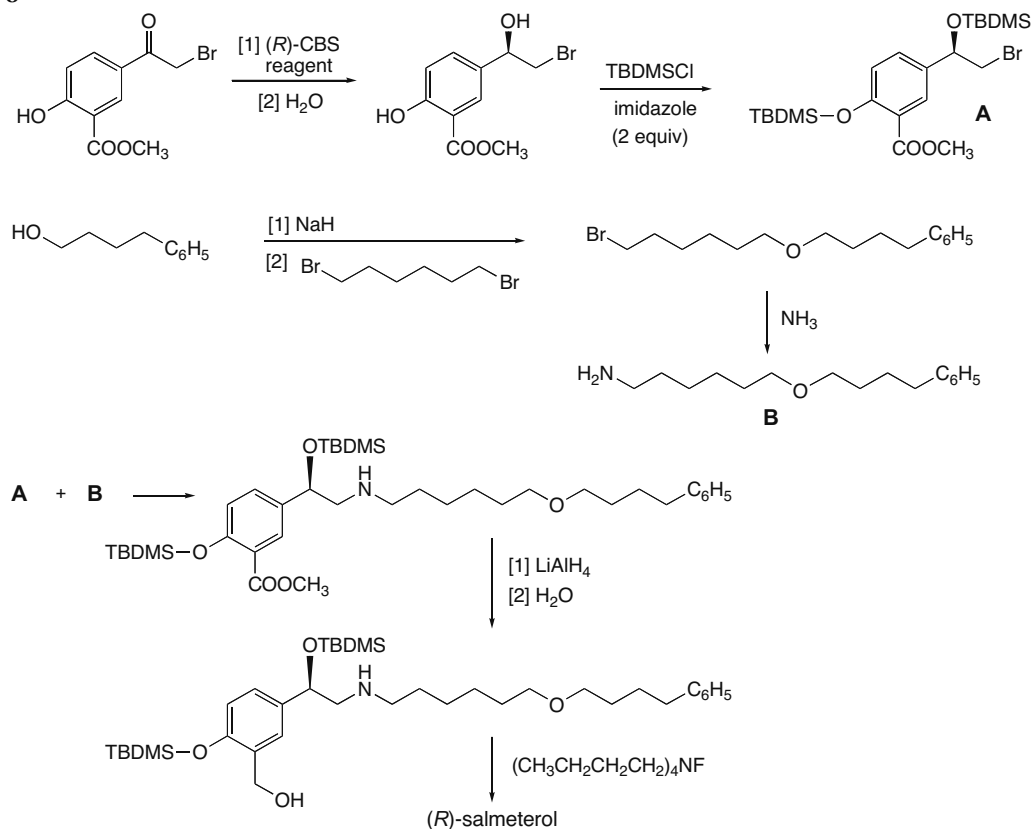
Total number of integration units: $25 + 17 + 24 + 17 = 83$ $83 \text{ units}/10 \text{ H's} = 8.3 \text{ units per H}$

Divide each integration value by 8.3 to determine the number of H's per signal:

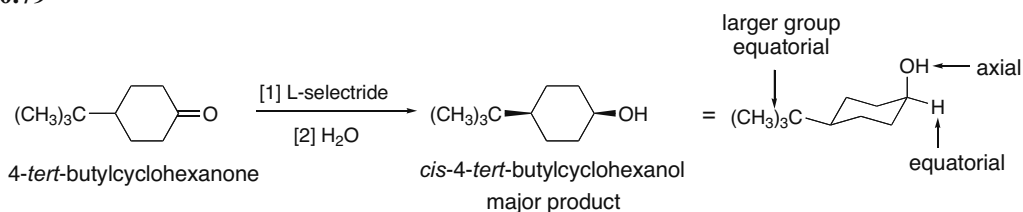
 $25 \text{ units}/8.3 = 3 \text{ H's}$ $24 \text{ units}/8.3 = 3 \text{ H's}$ $17 \text{ units}/8.3 = 2 \text{ H's}$ **20.76** Molecular ion at $m/z = 86$: $C_5H_{10}O$ (possible molecular formula).**20.77**

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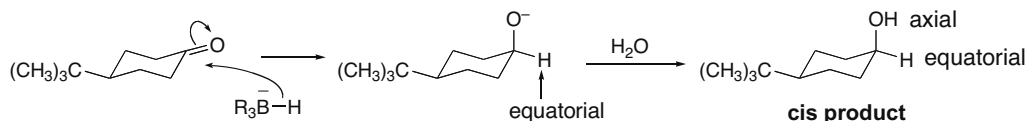
20.78



20.79

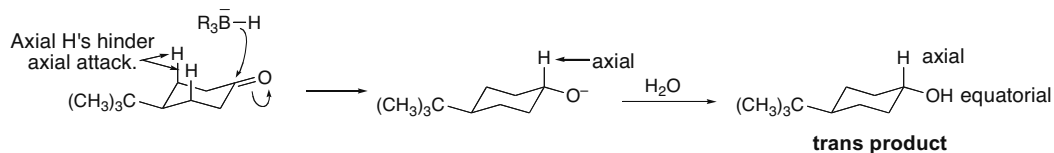


L-Selectride adds H^- to a $\text{C}=\text{O}$ group. There are two possible reduction products—*cis* and *trans* isomers—but the *cis* isomer is favored. The key element is that the three *sec*-butyl groups make L-selectride a large, bulky reducing agent that attacks the carbonyl group from the less hindered direction.



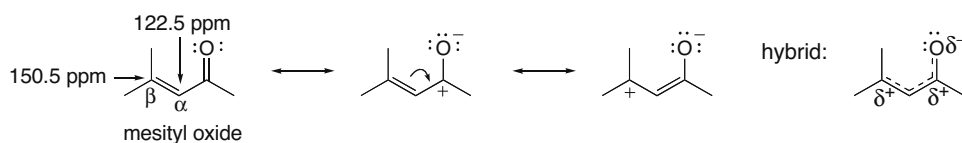
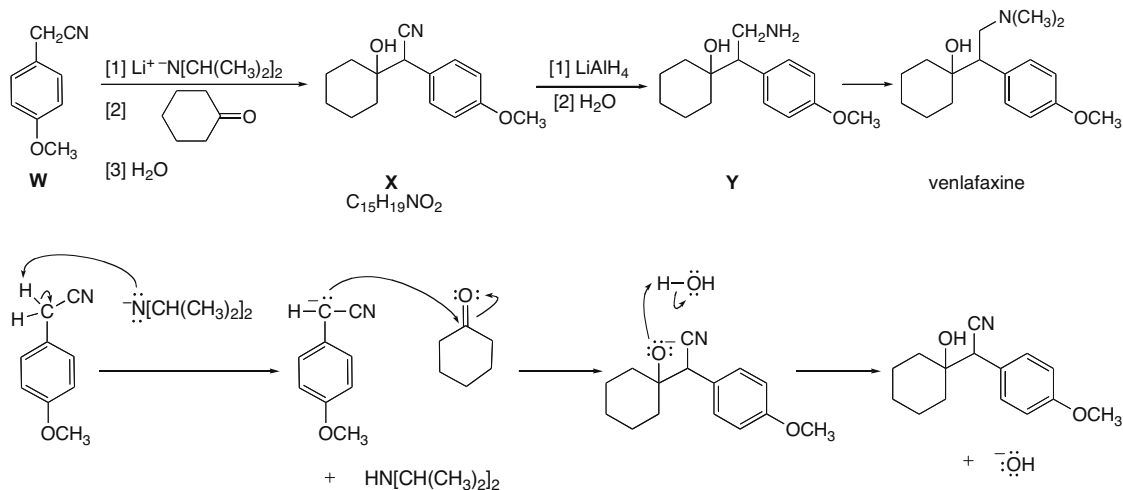
When H^- adds from the equatorial direction, the product has an axial OH and a new equatorial H. Since the equatorial direction is less hindered, this mode of attack is favored with large bulky reducing agents like L-selectride. In this case, the product is *cis*.

Introduction to Carbonyl Chemistry 20–33



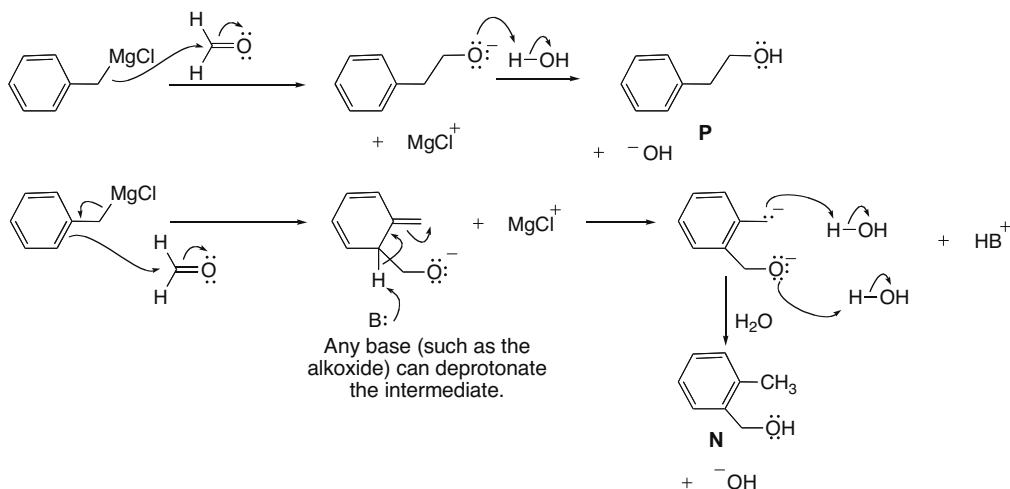
The axial H's hinder H^- attack from the axial direction. As a result, this mode of attack is more difficult with larger reducing agents. In this case the product is trans. This product is not formed to any appreciable extent.

- 20.80** The β carbon of an α,β -unsaturated carbonyl compound absorbs farther downfield in the ^{13}C NMR spectrum than the α carbon, because the β carbon is deshielded and bears a partial positive charge as a result of resonance. Since three resonance structures can be drawn for an α,β -unsaturated carbonyl compound, one of which places a positive charge on the β carbon, the decrease of electron density at this carbon deshields it, shifting the ^{13}C absorption downfield. This is not the case for the α carbon.

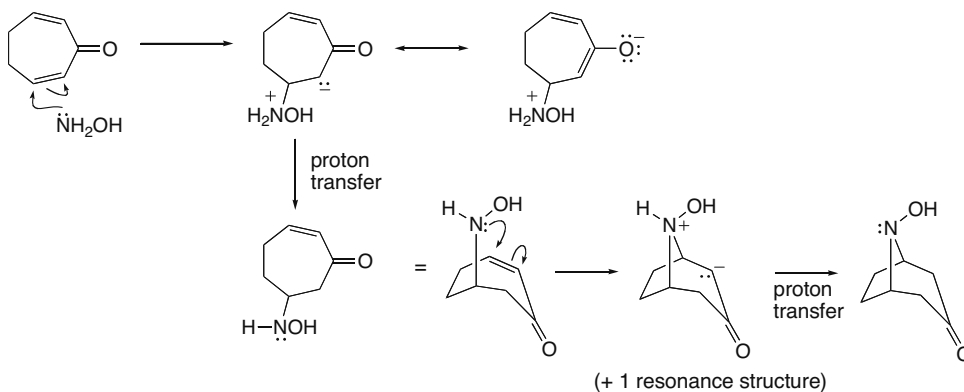
**20.81**

Chapter 20–34

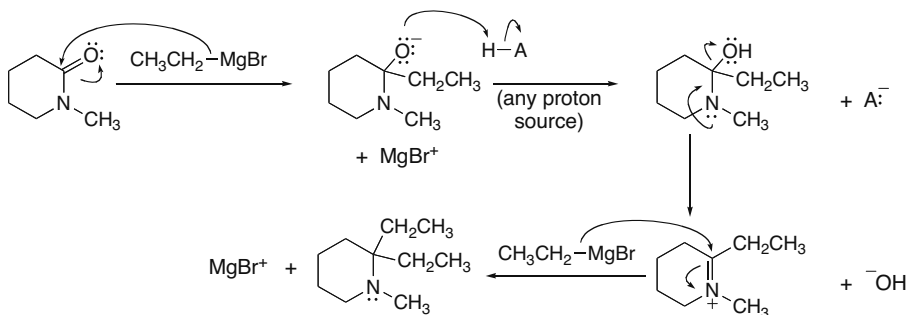
20.82



20.83



20.84



Chapter 21 Aldehydes and Ketones—Nucleophilic Addition

Chapter Review

General facts

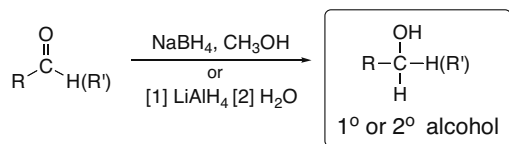
- Aldehydes and ketones contain a carbonyl group bonded to only H atoms or R groups. The carbonyl carbon is sp^2 hybridized and trigonal planar (21.1).
- Aldehydes are identified by the suffix *-al*, while ketones are identified by the suffix *-one* (21.2).
- Aldehydes and ketones are polar compounds that exhibit dipole–dipole interactions (21.3).

Summary of spectroscopic absorptions of RCHO and R₂CO (21.4)

IR absorptions	C=O	~1715 cm ⁻¹ for ketones
		increasing frequency with decreasing ring size
		~1730 cm ⁻¹ for aldehydes
		For both RCHO and R₂CO, the frequency decreases with conjugation.
¹ H NMR absorptions	C _{sp} ² -H of CHO	~2700–2830 cm ⁻¹ (one or two peaks)
	CHO	9–10 ppm (highly deshielded proton)
	C-H α to C=O	2–2.5 ppm (somewhat deshielded C _{sp} ³ -H)
¹³ C NMR absorption	C=O	190–215 ppm

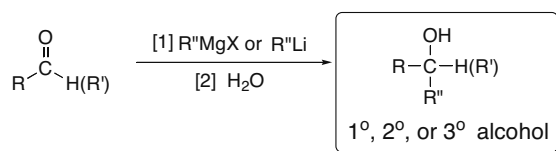
Nucleophilic addition reactions

[1] Addition of hydride (H⁻) (21.8)



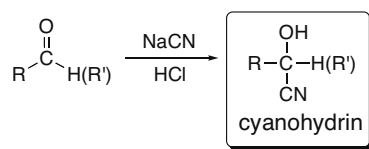
- The mechanism has two steps.
- H⁻ adds to the planar C=O from both sides.

[2] Addition of organometallic reagents (R⁻) (21.8)



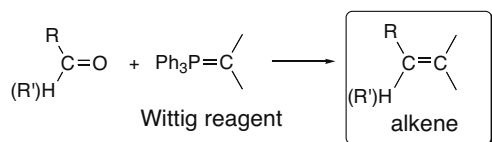
- The mechanism has two steps.
- R⁻ adds to the planar C=O from both sides.

[3] Addition of cyanide (CN⁻) (21.9)

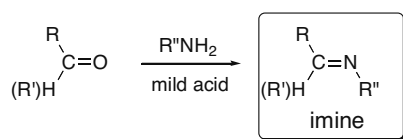


- The mechanism has two steps.
- CN⁻ adds to the planar C=O from both sides.

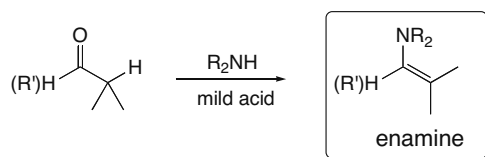
Chapter 21-2

[4] Wittig reaction (21.10)

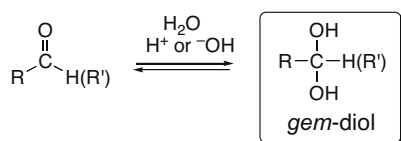
- The reaction forms a new C–C σ bond and a new C–C π bond.
- $\text{Ph}_3\text{P}=\text{O}$ is formed as by-product.

[5] Addition of 1° amines (21.11)

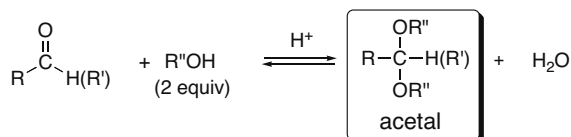
- The reaction is fastest at pH 4–5.
- The intermediate carbinolamine is unstable, and loses H_2O to form the $\text{C}=\text{N}$.

[6] Addition of 2° amines (21.12)

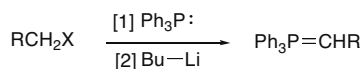
- The reaction is fastest at pH 4–5.
- The intermediate carbinolamine is unstable, and loses H_2O to form the $\text{C}=\text{C}$.

[7] Addition of H_2O —Hydration (21.13)

- The reaction is reversible. Equilibrium favors the product only with less stable carbonyl compounds (e.g., H_2CO and Cl_3CCHO).
- The reaction is catalyzed with either H^+ or ^-OH .

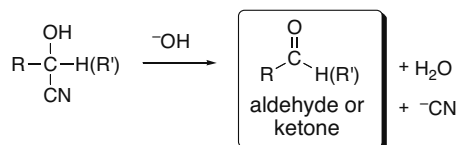
[8] Addition of alcohols (21.14)

- The reaction is reversible.
- The reaction is catalyzed with acid.
- Removal of H_2O drives the equilibrium to favor the products.

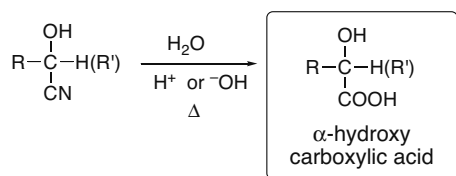
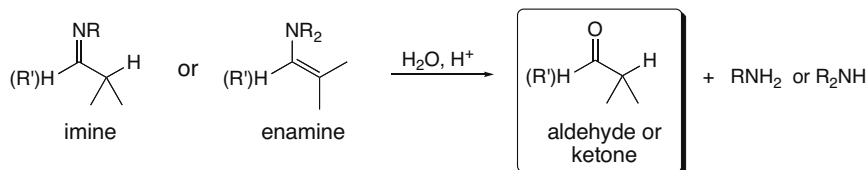
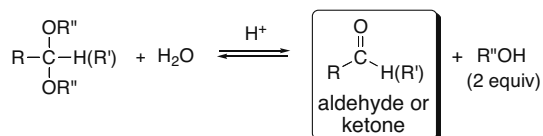
Other reactions**[1] Synthesis of Wittig reagents (21.10A)**

- Step [1] is best with CH_3X and RCH_2X since the reaction follows an $\text{S}_\text{N}2$ mechanism.
- A strong base is needed for proton removal in Step [2].

Aldehydes and Ketones—Nucleophilic Addition 21-3

[2] Conversion of cyanohydrins to aldehydes and ketones (21.9)

- This reaction is the reverse of cyanohydrin formation.

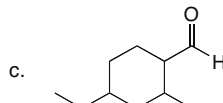
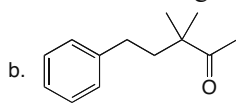
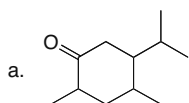
[3] Hydrolysis of nitriles (21.9)**[4] Hydrolysis of imines and enamines (21.12)****[5] Hydrolysis of acetals (21.14)**

- The reaction is acid catalyzed and is the reverse of acetal synthesis.
- A large excess of H_2O drives the equilibrium to favor the products.

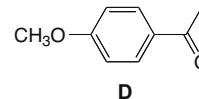
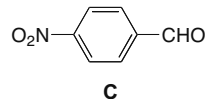
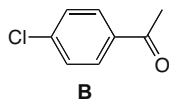
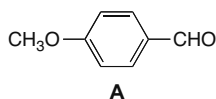
Chapter 21–4

Practice Test on Chapter Review

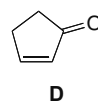
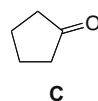
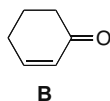
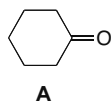
1. Give the IUPAC name for the following compounds.



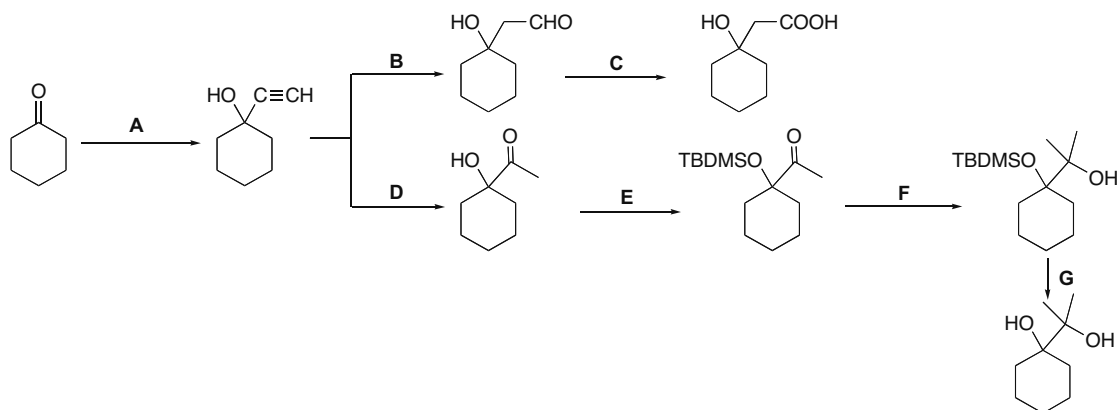
2. (a) Considering compounds **A–D**, which compound forms the smallest amount of hydrate?
(b) Which compound forms the largest amount of hydrate?



3. (a) Considering compounds **A–D**, which compound absorbs at the *lowest* wavenumber in its IR spectrum? (b) Which compound absorbs at the *highest* wavenumber in its IR spectrum?

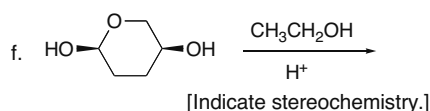
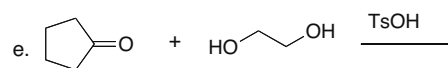
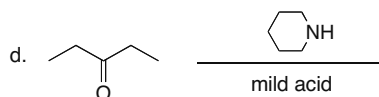
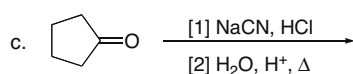
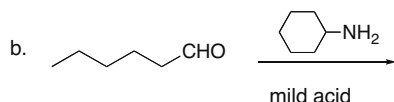
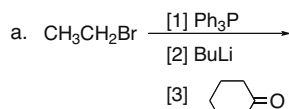


4. Fill in the lettered reagents (**A–G**) in the following reaction scheme.



Aldehydes and Ketones—Nucleophilic Addition 21–5

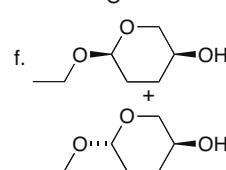
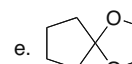
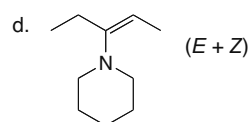
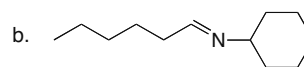
5. Draw the organic products formed in the following reactions.



Answers to Practice Test

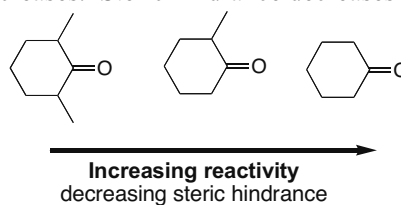
- 1.a. 5-isopropyl-2,4-dimethylcyclohexanone
b. 3,3-dimethyl-5-phenyl-2-pentanone
c. 4-ethyl-2-methylcyclohexanecarbaldehyde
2. a. **D**
b. **C**
3. a. **B**
b. **C**
4.
A = [1] $\text{LiC}\equiv\text{CH}$; [2] H_2O
B = [1] R_2BH ; [2] $\text{H}_2\text{O}_2, ^-\text{OH}$
C = $\text{Ag}_2\text{O}, \text{NH}_4\text{OH}$
D = $\text{H}_2\text{O}, \text{H}_2\text{SO}_4, \text{HgSO}_4$
E = $\text{TBDMS-Cl, pyridine}$
F = [1] CH_3Li ; [2] H_2O
G = $(\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2)_4\text{N}^+\text{F}^-$

5.



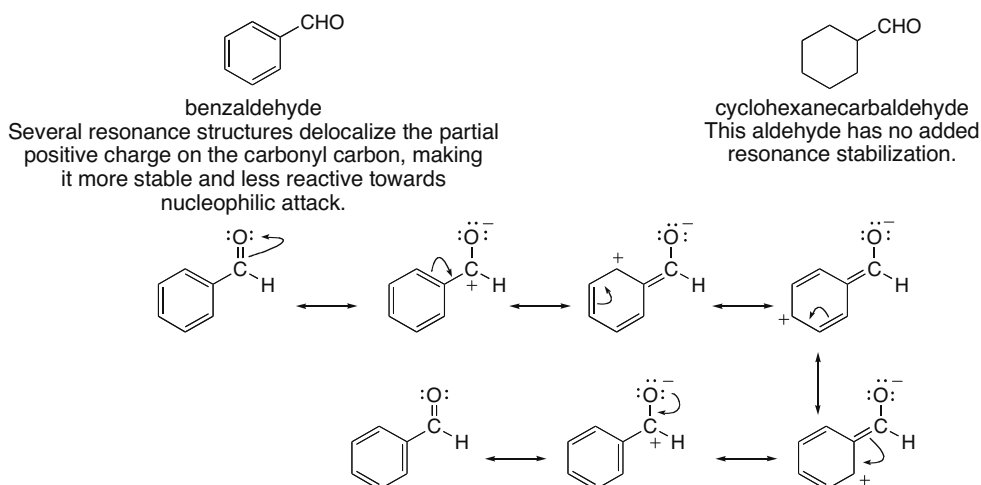
Answers to Problems

21.1 As the number of R groups bonded to the carbonyl C increases, reactivity towards nucleophilic attack decreases. Steric hindrance decreases reactivity as well.

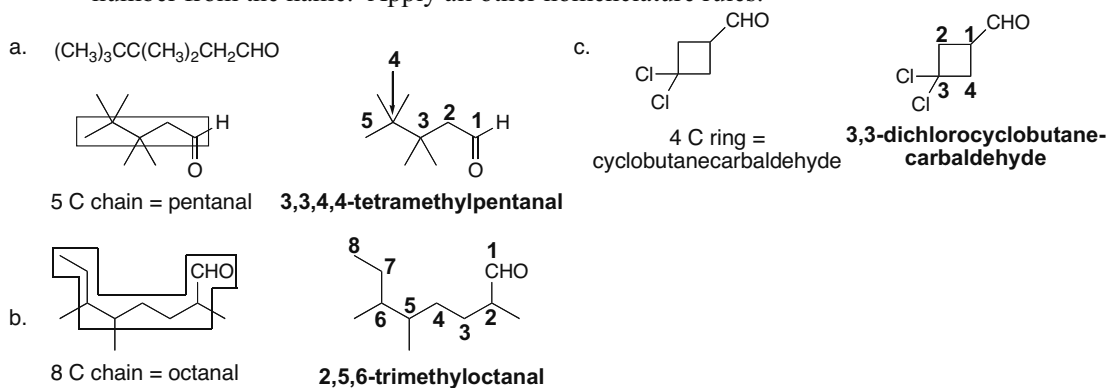


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21.2 More stable aldehydes are less reactive towards nucleophilic attack.

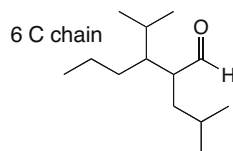


- 21.3**
- To name an aldehyde with a chain of atoms: [1] Find the longest chain with the CHO group and change the *-e* ending to *-al*. [2] Number the carbon chain to put the CHO at C1, but omit this number from the name. Apply all other nomenclature rules.
 - To name an aldehyde with the CHO bonded to a ring: [1] Name the ring and add the suffix *-carbaldehyde*. [2] Number the ring to put the CHO group at C1, but omit this number from the name. Apply all other nomenclature rules.

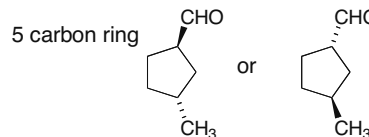


- 21.4** Work backwards from the name to the structure, referring to the nomenclature rules in Answer 21.3.

a. 2-isobutyl-3-isopropylhexanal



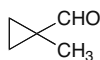
b. *trans*-3-methylcyclopentanecarbaldehyde



Aldehydes and Ketones—Nucleophilic Addition 21–7

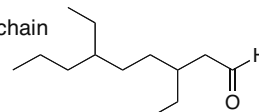
c. 1-methylcyclopropanecarbaldehyde

3 carbon ring

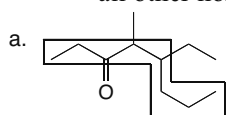
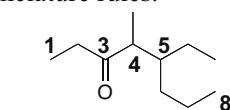
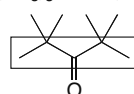
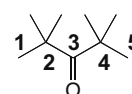
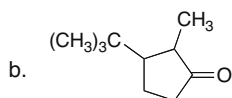
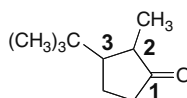


d. 3,6-diethylnonanal

9 C chain

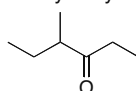


- 21.5**
- To name an acyclic ketone: [1] Find the longest chain with the carbonyl group and change the *-e* ending to *-one*. [2] Number the carbon chain to give the carbonyl C the lower number. Apply all other nomenclature rules.
 - To name a cyclic ketone: [1] Name the ring and change the *-e* ending to *-one*. [2] Number the C's to put the carbonyl C at C1 and give the next substituent the lower number. Apply all other nomenclature rules.

8 C chain =
octanone**5-ethyl-4-methyl-3-octanone**c. $(\text{CH}_3)_3\text{CCOC}(\text{CH}_3)_3$ 5 C chain =
pentanone**2,2,4,4-tetramethyl-3-pentanone**5 C ring =
cyclopentanone**3-tert-butyl-2-methylcyclopentanone**

- 21.6** Most common names are formed by naming both alkyl groups on the carbonyl C, arranging them alphabetically, and adding the word ketone.

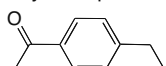
a. sec-butyl ethyl ketone



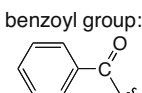
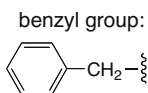
b. methyl vinyl ketone



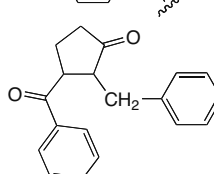
c. p-ethylacetophenone



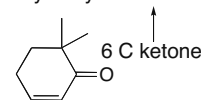
d. 3-benzoyl-2-benzylcyclopentanone



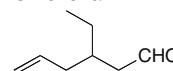
5 C ketone



e. 6,6-dimethyl-2-cyclohexenone

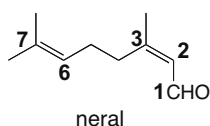


f. 3-ethyl-5-hexenal

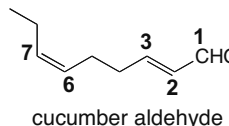


- 21.7** Compounds with both a C–C double bond and an aldehyde are named as enals.

a. (2Z)-3,7-dimethyl-2,6-octadienal



b. (2E,6Z)-2,6-nonadienal



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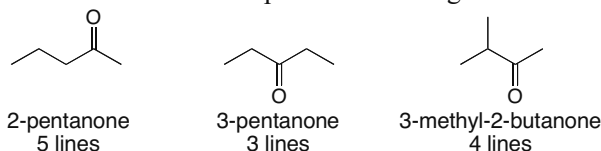
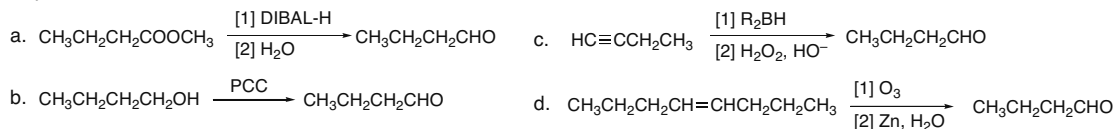
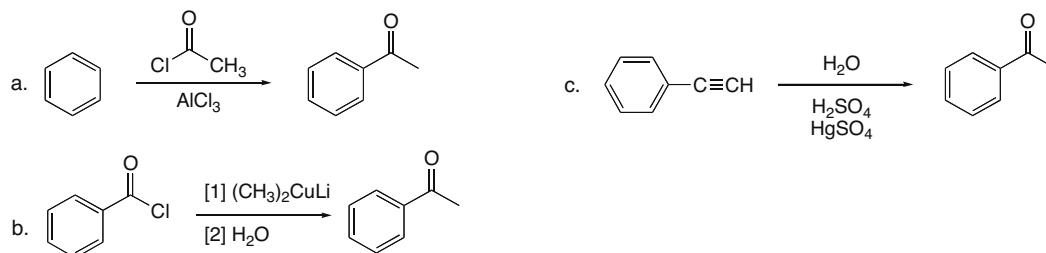
- 21.8** Even though both compounds have polar C–O bonds, the electron pairs around the sp^3 hybridized O atom of diethyl ether are more crowded and less able to interact with electron-deficient sites in other diethyl ether molecules. The O atom of the carbonyl group of 2-butanone extends out from the carbon chain, making it less crowded. The lone pairs of electrons on the O atom can more readily interact with the electron-deficient sites in the other molecules, resulting in stronger forces and a higher boiling point.



- 21.9** For cyclic ketones, the carbonyl absorption shifts to higher wavenumber as the size of the ring decreases and the ring strain increases. Conjugation of the carbonyl group with a C=C or a benzene ring shifts the absorption to lower wavenumber.

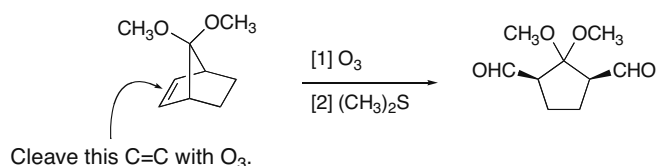


- 21.10** The number of lines in their ^{13}C NMR spectra can distinguish the constitutional isomers.

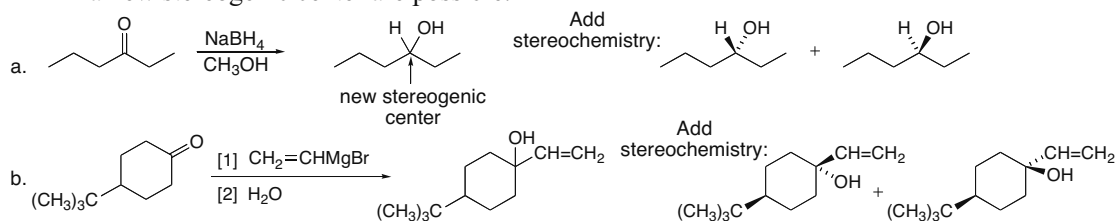
**21.11****21.12**

Aldehydes and Ketones—Nucleophilic Addition 21–9

21.13



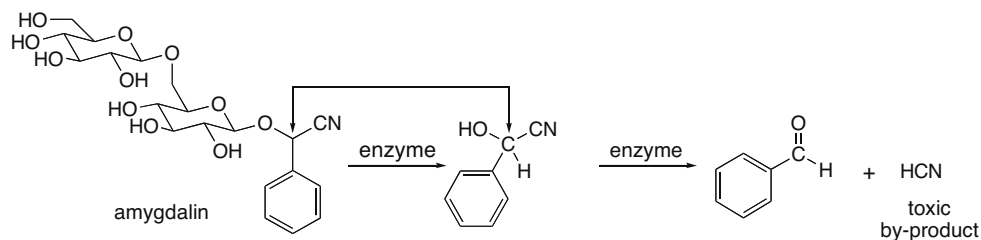
21.14 Addition of hydride or R–M occurs at a planar carbonyl C, so two different configurations at a new stereogenic center are possible.



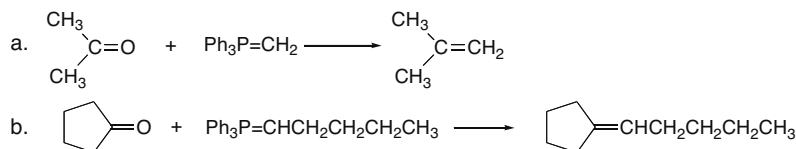
21.15 Treatment of an aldehyde or ketone with NaCN, HCl adds HCN across the double bond. Cyano groups are hydrolyzed by H_3O^+ to replace the three C–N bonds with three C–O bonds.



21.16

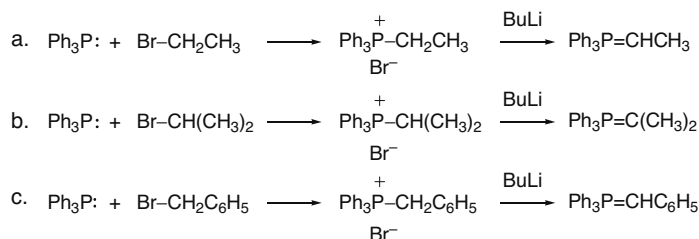


21.17

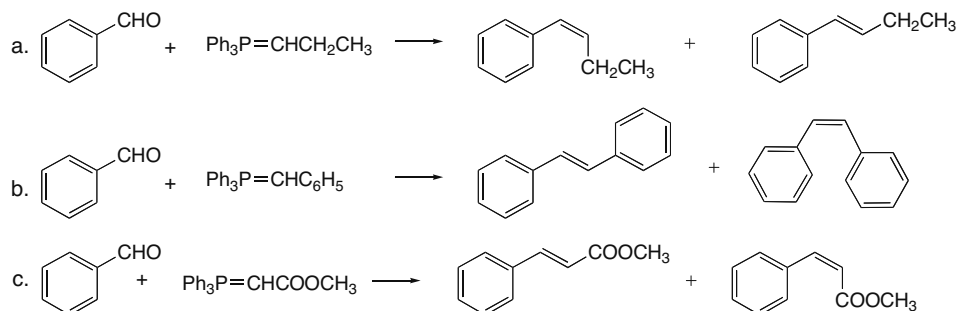


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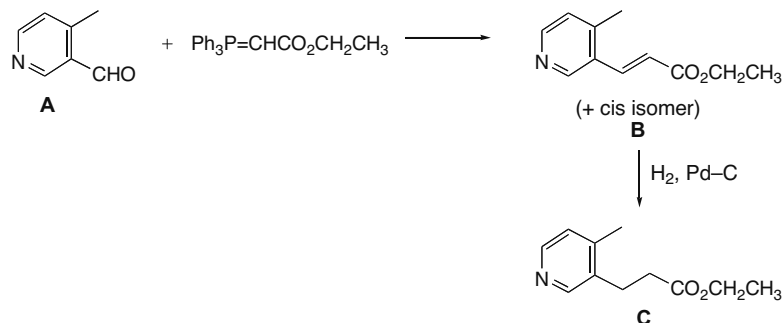
21.18



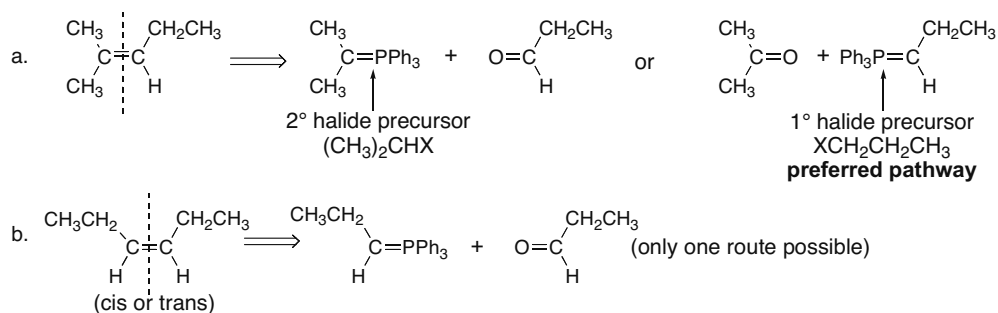
21.19



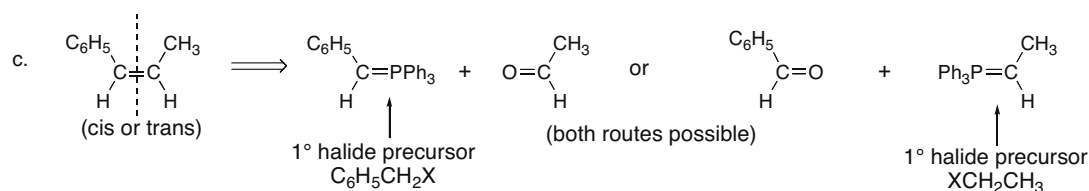
21.20



21.21 To draw the starting materials of the Wittig reactions, find the C=C and cleave it. Replace it with a C=O in one half of the molecule and a C=PPh₃ in the other half. The preferred pathway uses a Wittig reagent derived from a less hindered alkyl halide.

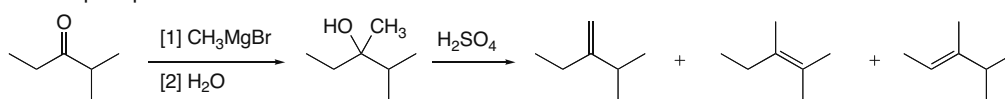


Aldehydes and Ketones—Nucleophilic Addition 21–11

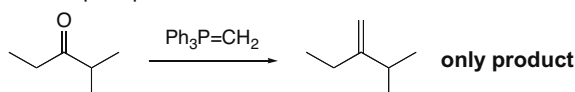


21.22

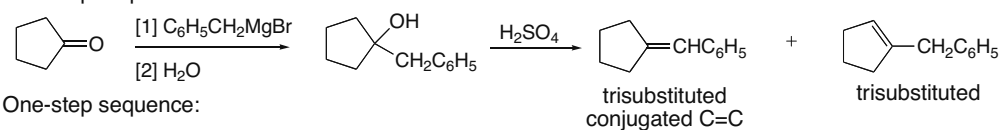
a. Two-step sequence:



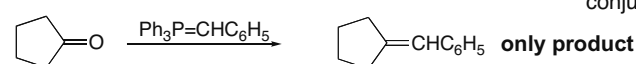
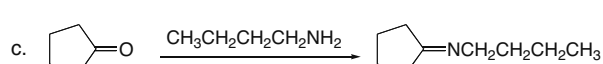
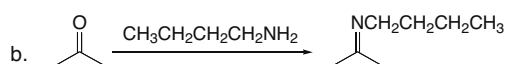
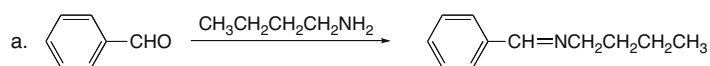
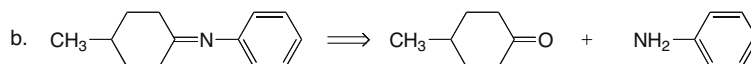
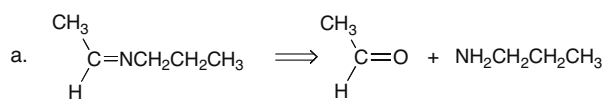
One-step sequence:



b. Two-step sequence:



One-step sequence:

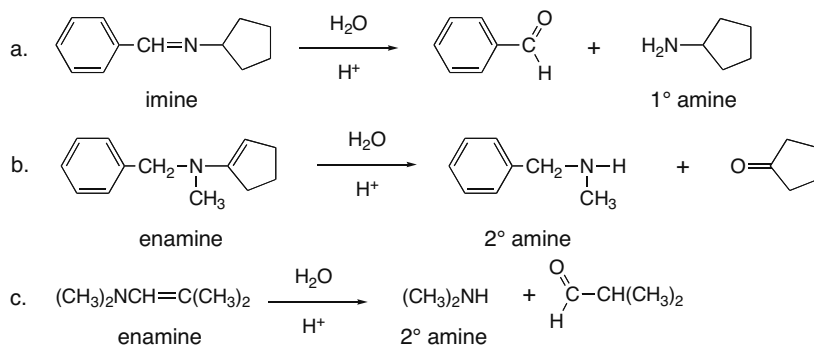
21.23 When a 1° amine reacts with an aldehyde or ketone, the $\text{C}=\text{O}$ is replaced by $\text{C}=\text{NR}$.21.24 Remember that the $\text{C}=\text{NR}$ is formed from a $\text{C}=\text{O}$ and an NH_2 group of a 1° amine.

21.25

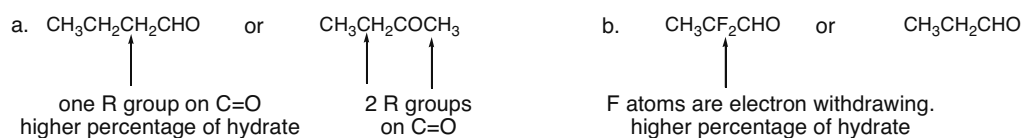
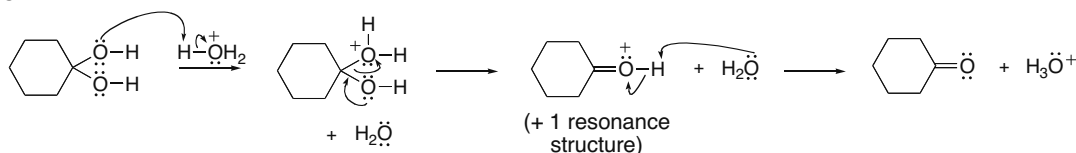


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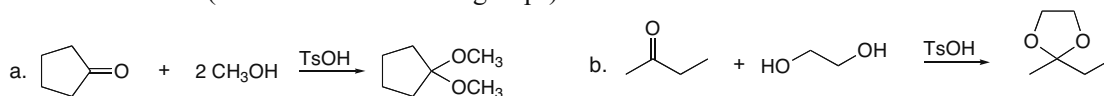
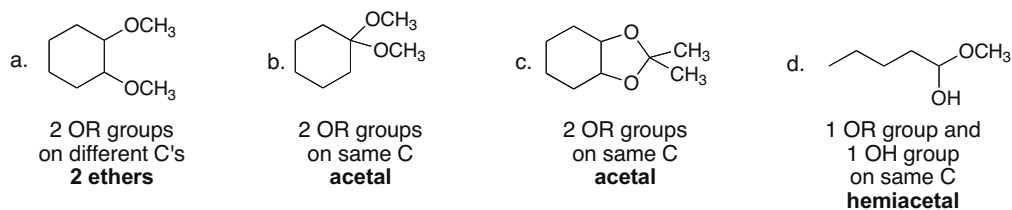
- 21.26**
- Imines are hydrolyzed to 1° amines and a carbonyl compound.
 - Enamines are hydrolyzed to 2° amines and a carbonyl compound.



- 21.27**
- A substituent that **donates** electron density to the carbonyl C stabilizes it, **decreasing** the percentage of hydrate at equilibrium.
 - A substituent that **withdraws** electron density from the carbonyl C destabilizes it, **increasing** the percentage of hydrate at equilibrium.

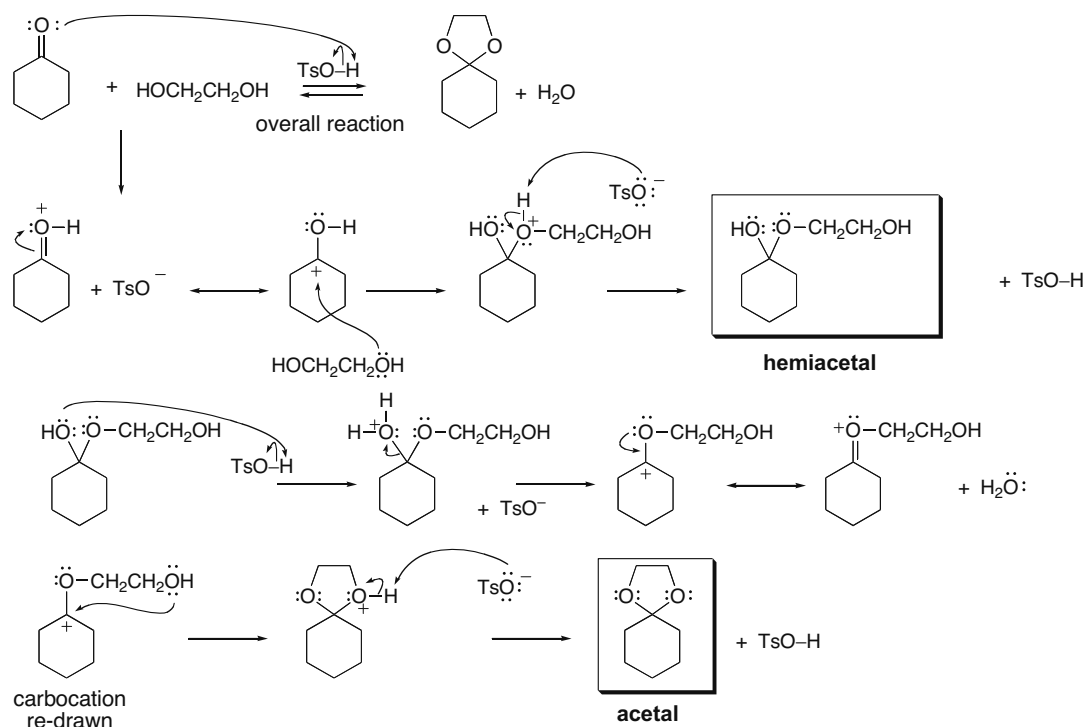
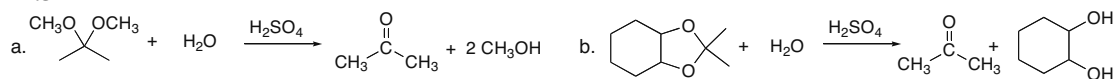
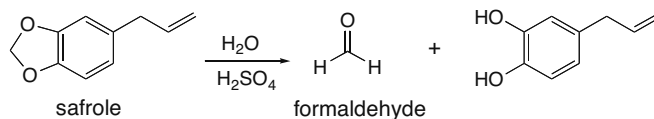
**21.28**

- 21.29** Treatment of an aldehyde or ketone with two equivalents of alcohol results in the formation of an acetal (a C bonded to two OR groups).

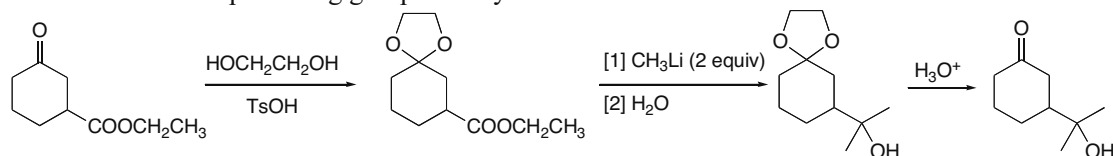
**21.30**

Aldehydes and Ketones—Nucleophilic Addition 21–13

- 21.31** The mechanism has two parts: [1] nucleophilic addition of ROH to form a hemiacetal;
[2] conversion of the hemiacetal to an acetal.

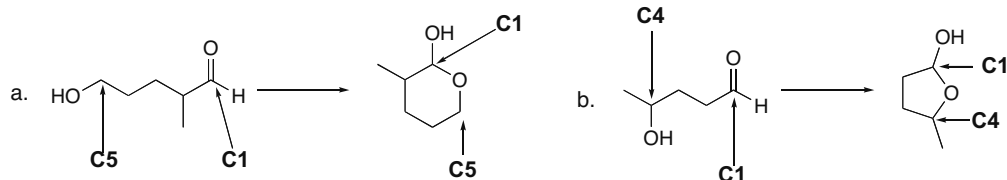
**21.32****21.33**

- 21.34** Use an acetal protecting group to carry out the reaction.

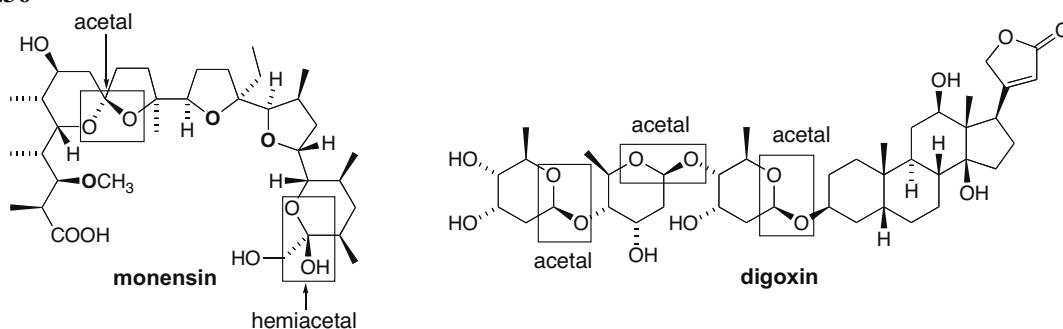


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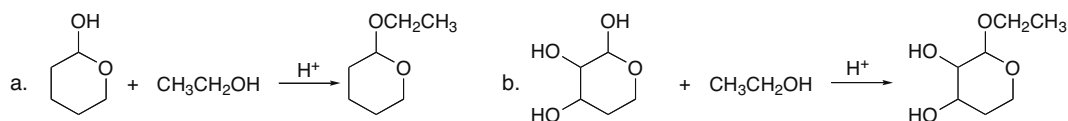
21.35



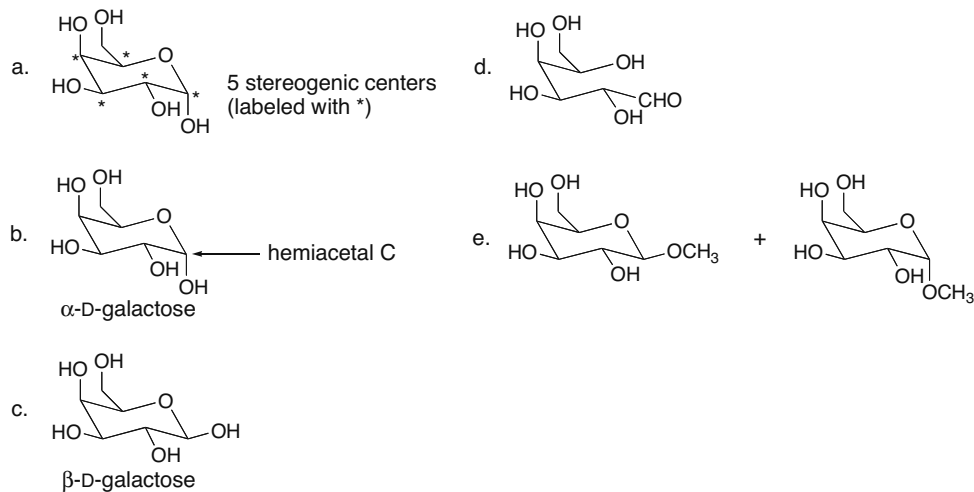
21.36

Ether **O** atoms are indicated in **bold**.

21.37 The hemiacetal OH is replaced by an OR group to form an acetal.

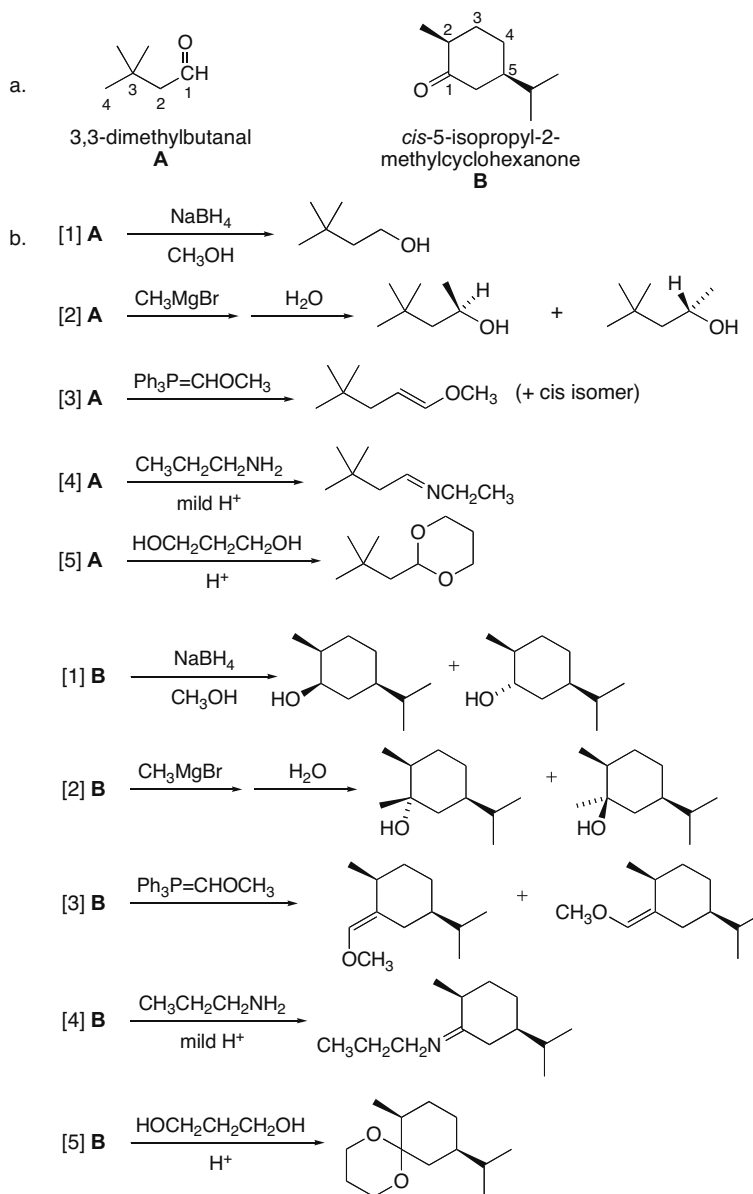


21.38

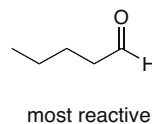
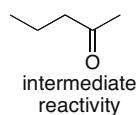
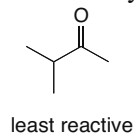


Aldehydes and Ketones—Nucleophilic Addition 21–15

21.39

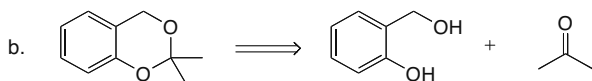
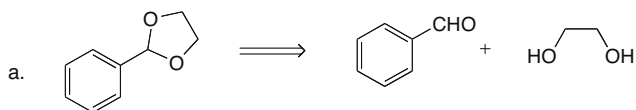


21.40 The least hindered carbonyl group is the most reactive.

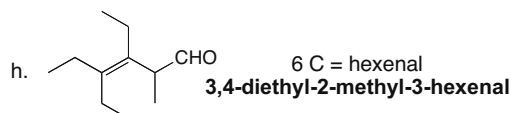
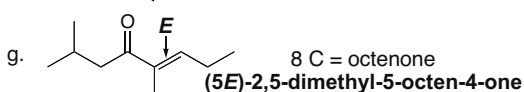
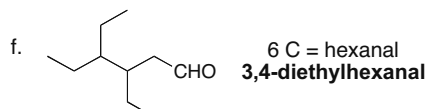
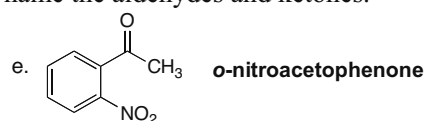
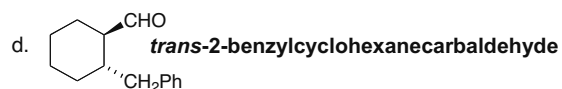
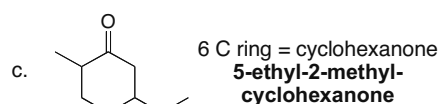
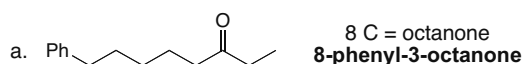


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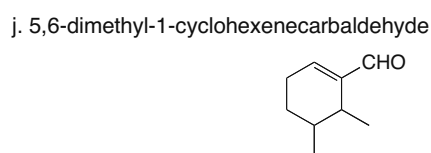
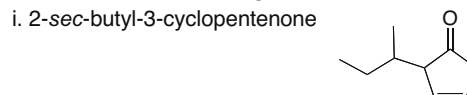
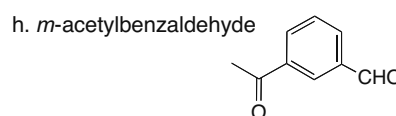
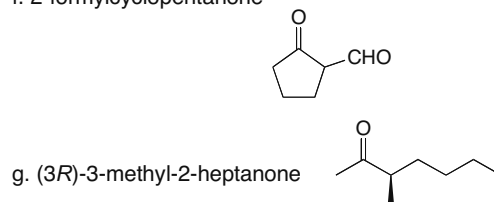
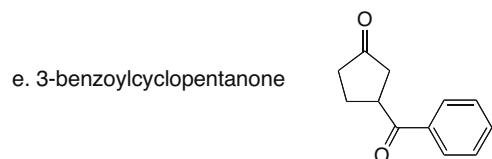
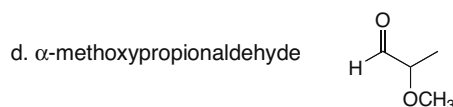
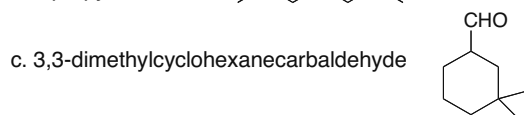
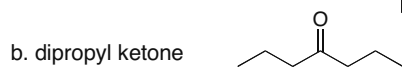
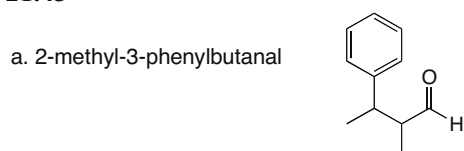
21.41



21.42 Use the rules from Answers 21.3 and 21.5 to name the aldehydes and ketones.

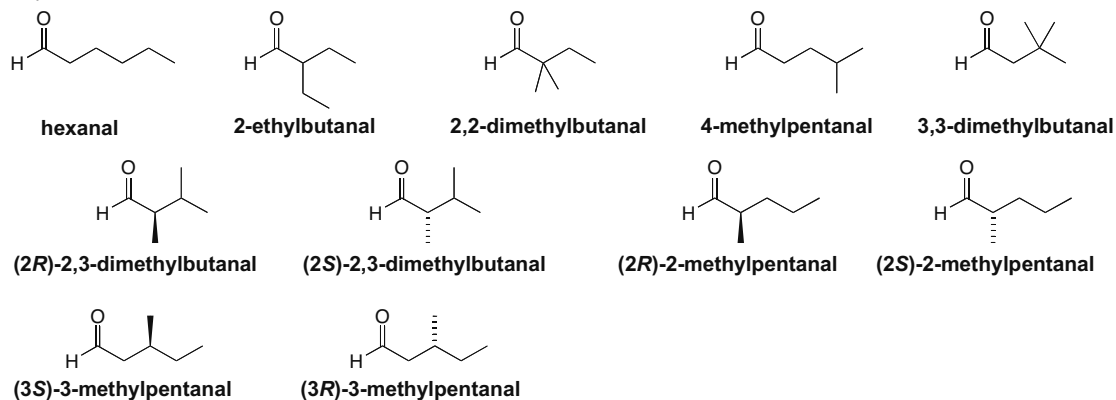


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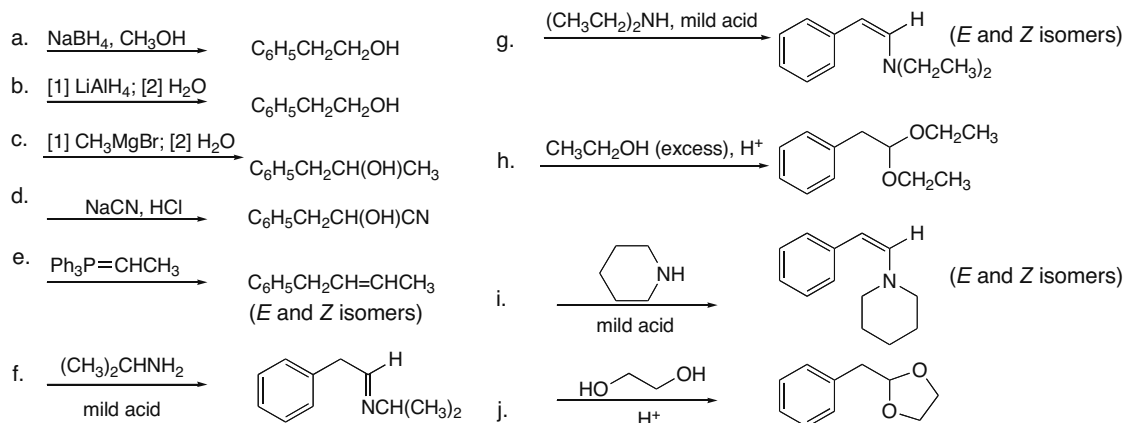
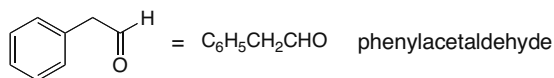


Aldehydes and Ketones—Nucleophilic Addition 21–17

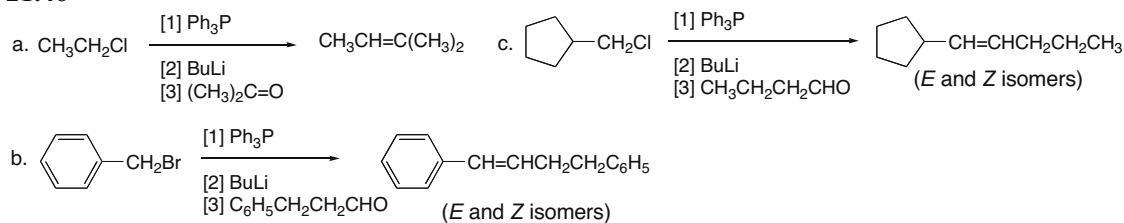
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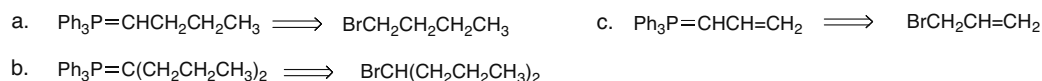
21.45



21.46

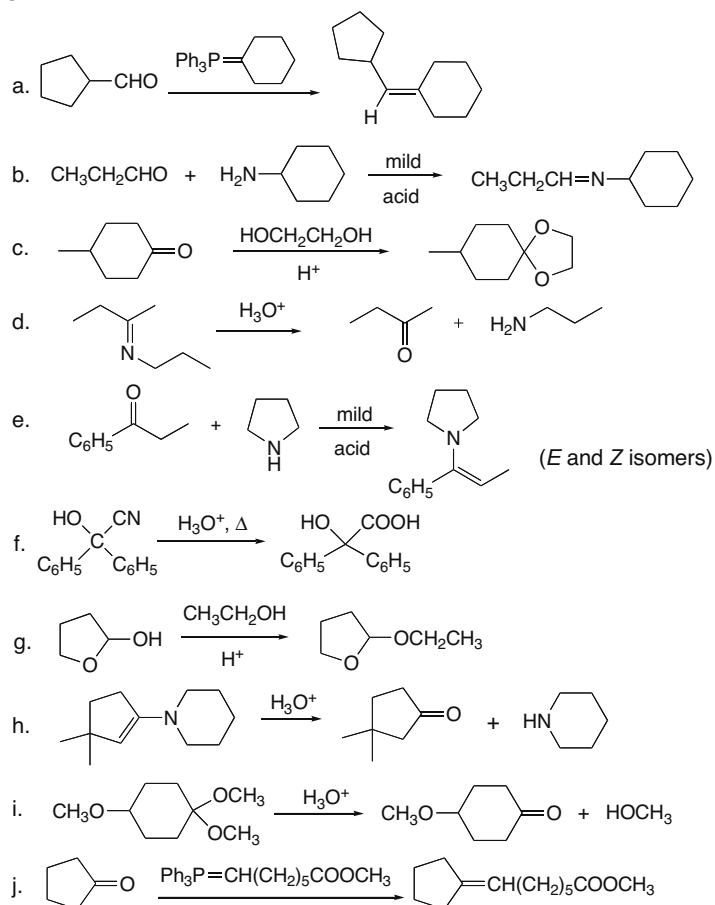


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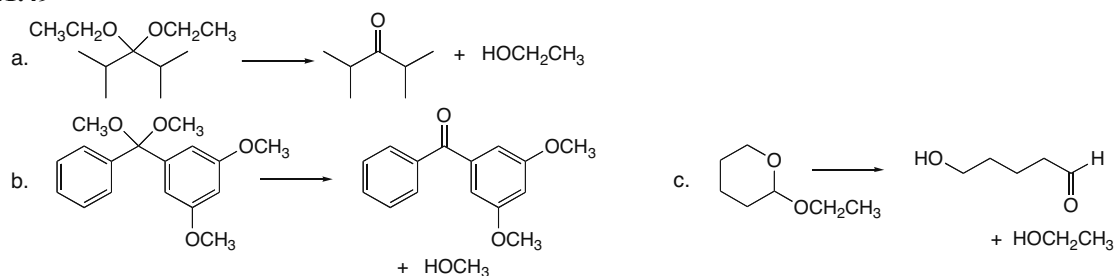


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21.48

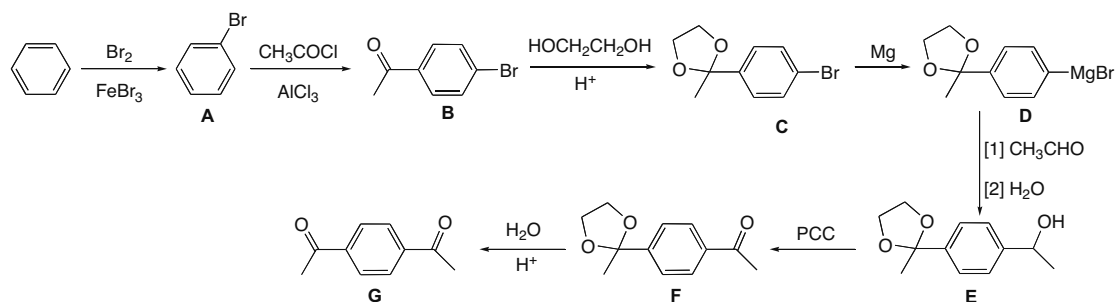


21.49

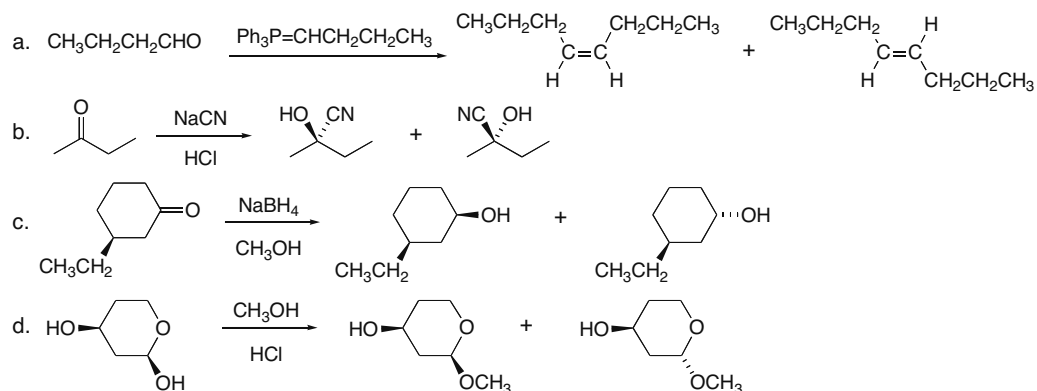


Aldehydes and Ketones—Nucleophilic Addition 21–19

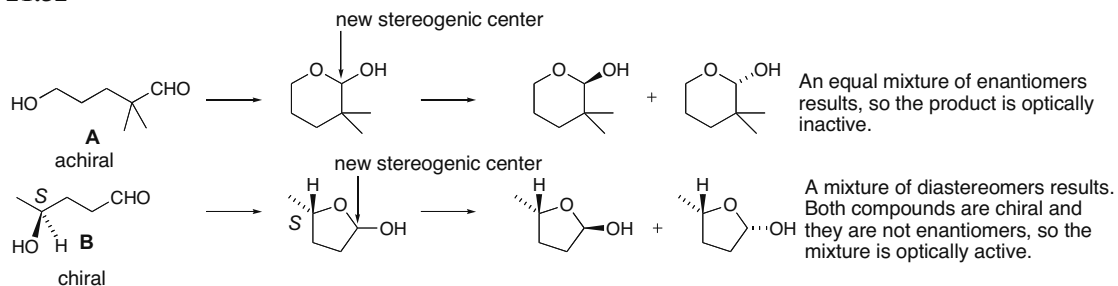
21.50 Consider para product only, when an ortho, para mixture can result.



21.51

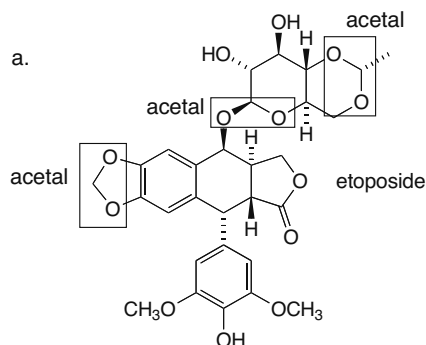


21.52

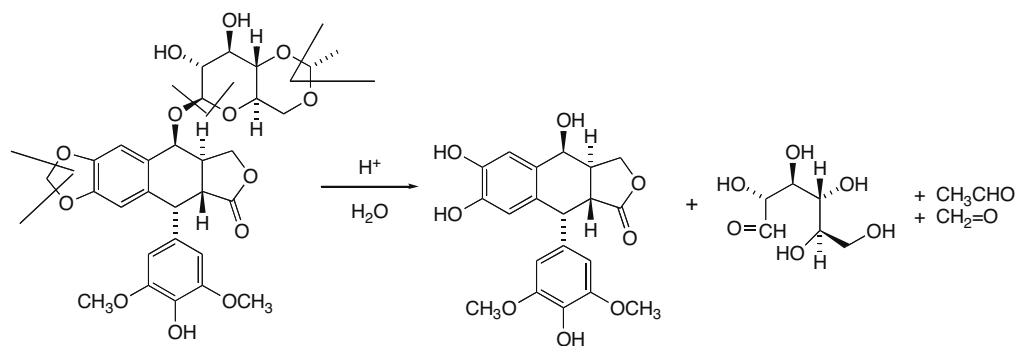


Chapter 21–20

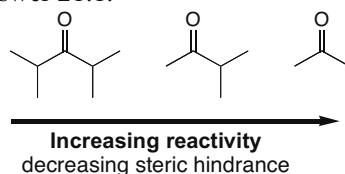
21.53



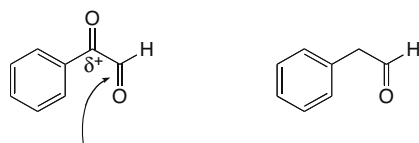
b. Lines of cleavage are drawn in.



21.54 Use the rules from Answer 21.1.



21.55 The less stable carbonyl compound forms the higher percentage of hydrate.



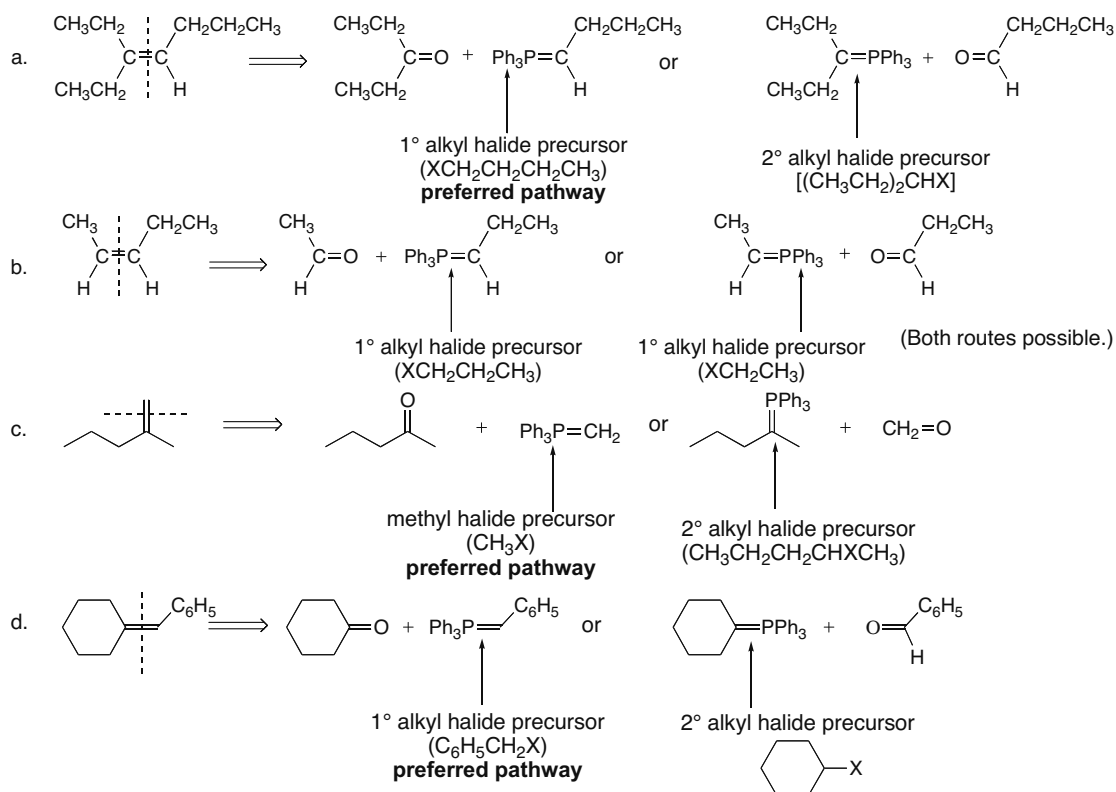
The aldehyde is destabilized since there is a δ^+ on its adjacent carbon, which is part of a C=O. Thus, PhCOCHO has the higher concentration of hydrate.

21.56 Electron-donating groups decrease the amount of hydrate at equilibrium by stabilizing the carbonyl starting material. Electron-withdrawing groups increase the amount of hydrate at equilibrium by destabilizing the carbonyl starting material. Electron-donating groups make the IR absorption of the C=O shift to lower wavenumber because they stabilize the charge-separated resonance form, giving the C=O more single bond character.

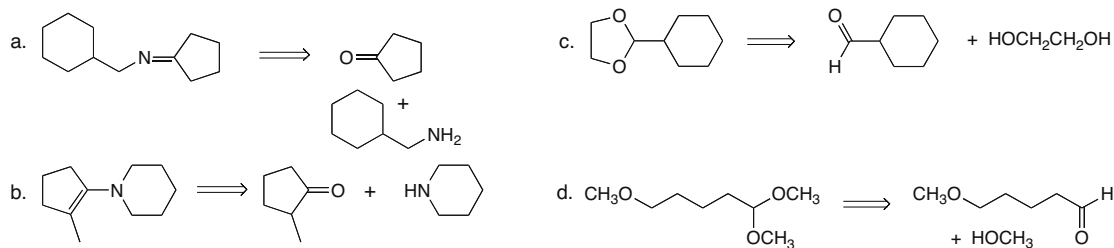
Aldehydes and Ketones—Nucleophilic Addition 21–21

<i>p</i> -nitroacetophenone	<i>p</i> -methoxyacetophenone
a. NO ₂ withdrawing group less stable	CH ₃ O donating group more stable
b. higher percentage of hydrate	lower percentage of hydrate
c. higher wavenumber	lower wavenumber

21.57 Use the principles from Answer 21.21.

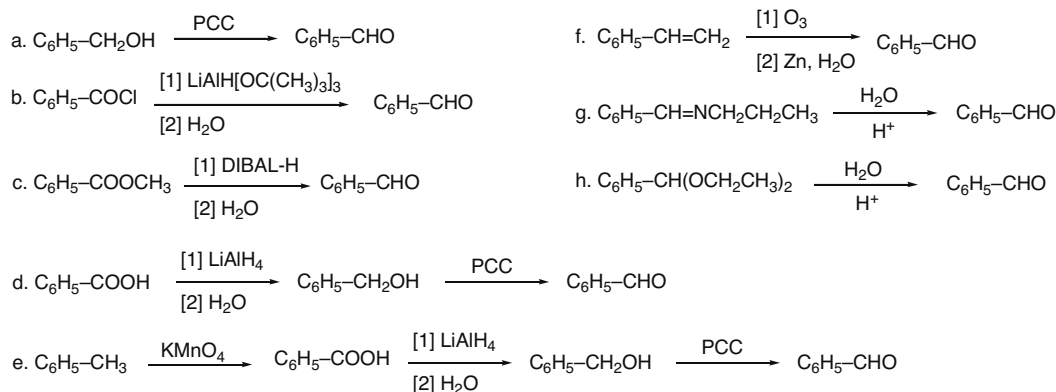


21.58

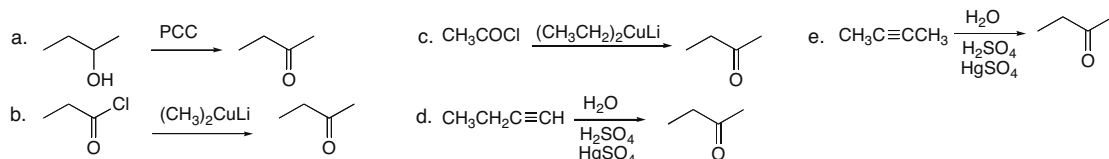


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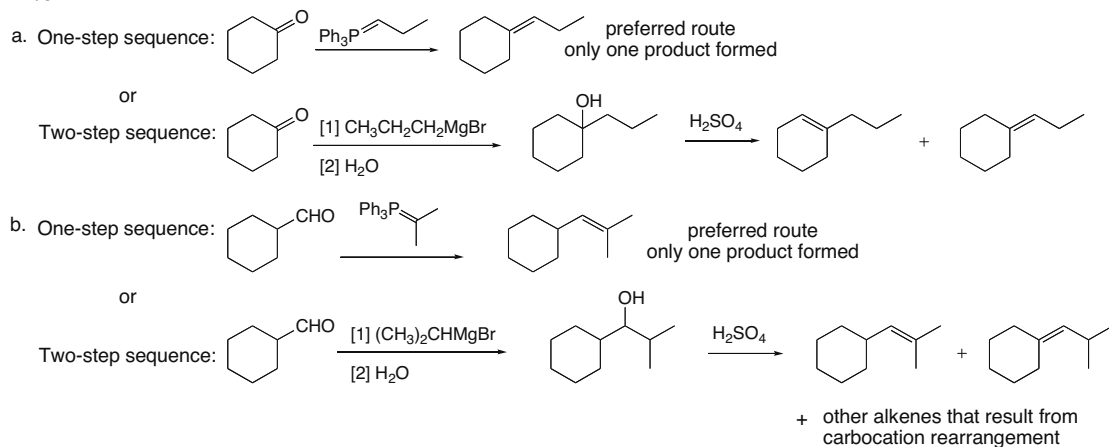
21.59



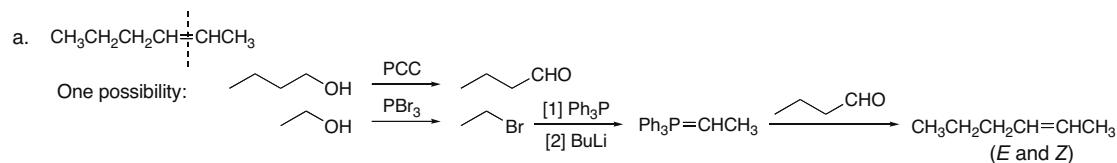
21.60



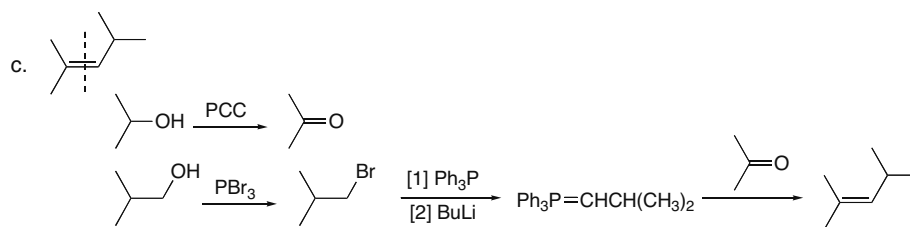
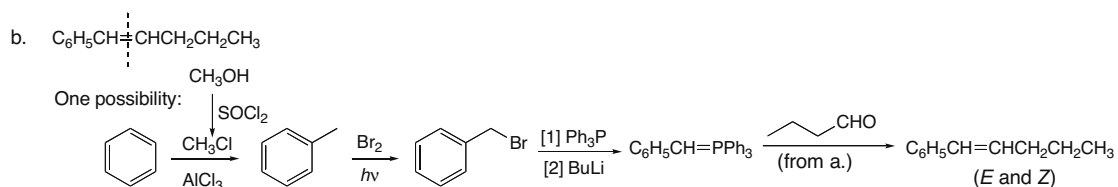
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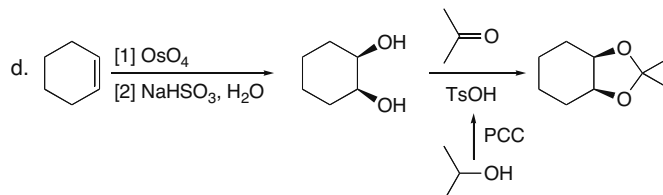
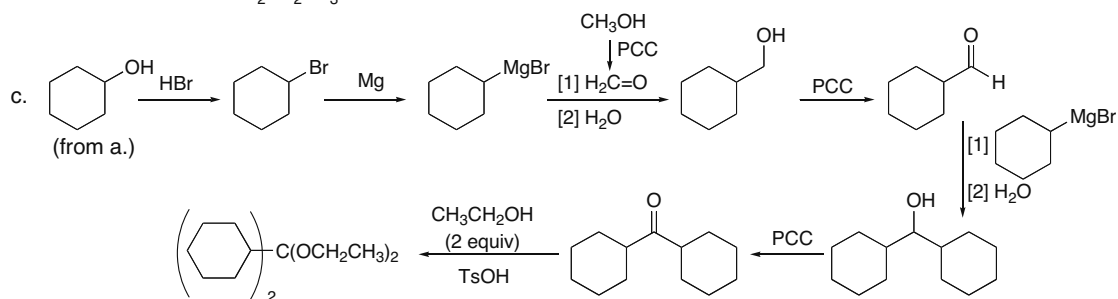
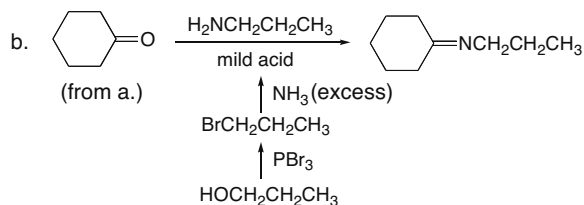
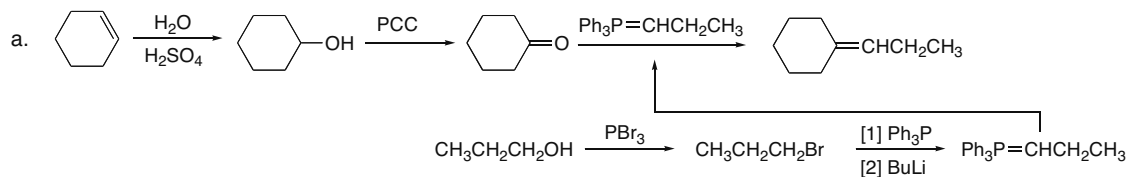
21.62



Aldehydes and Ketones—Nucleophilic Addition 21–23

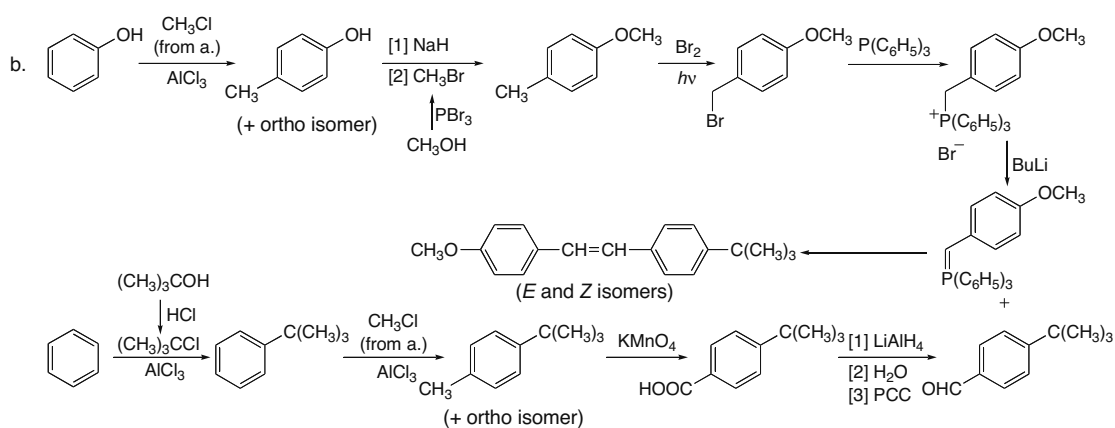
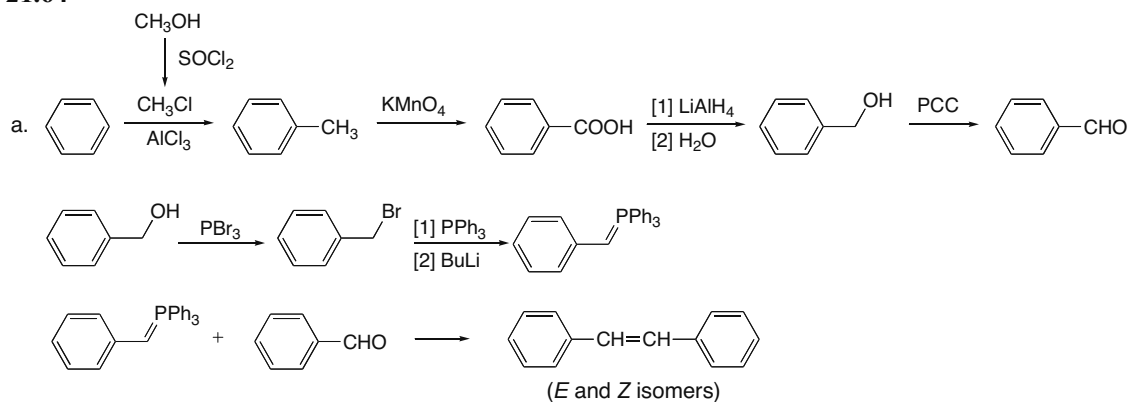


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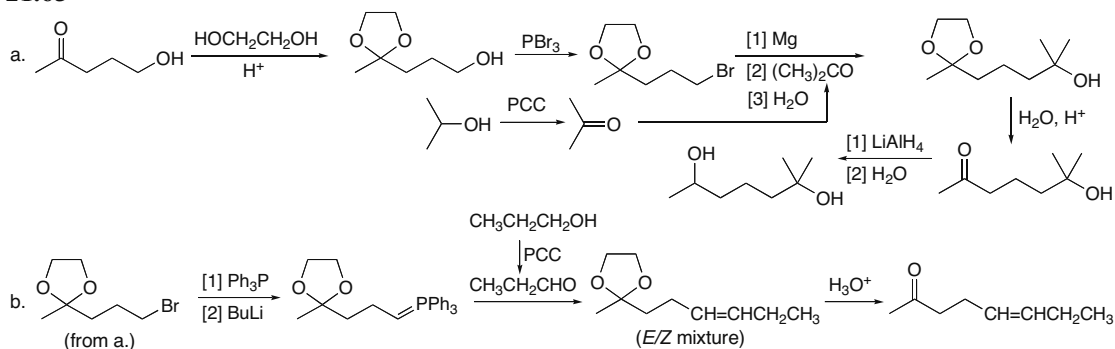


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21.64

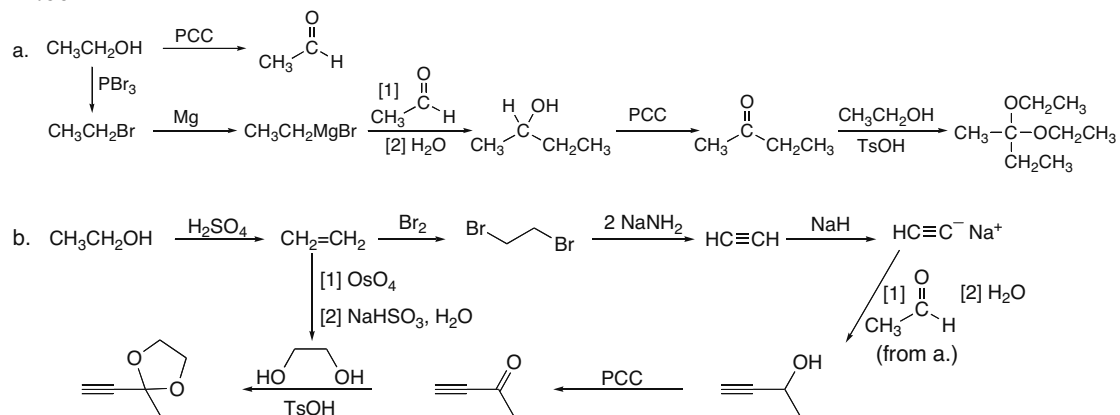


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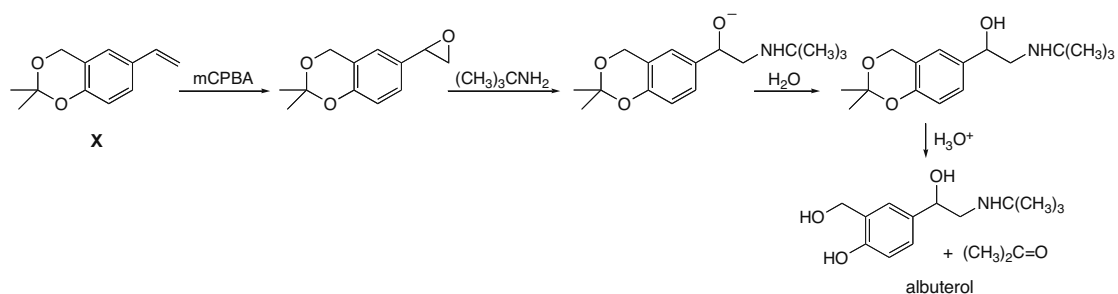


Aldehydes and Ketones—Nucleophilic Addition 21–25

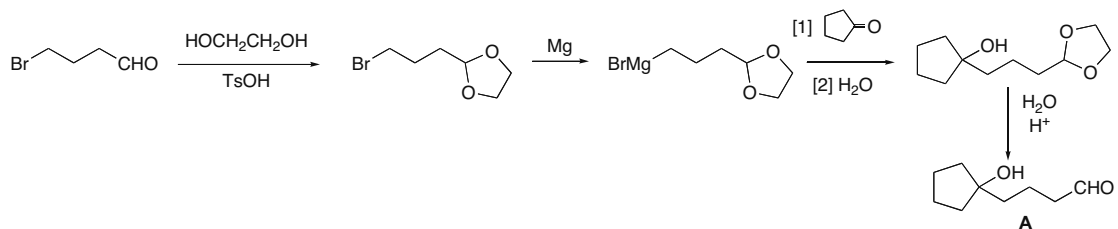
21.66



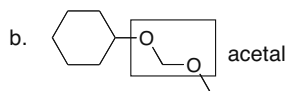
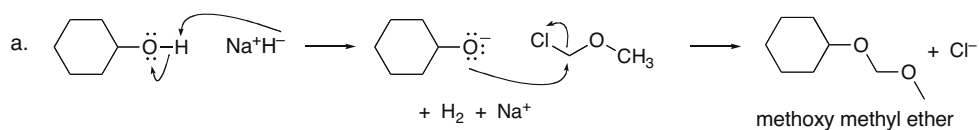
21.67



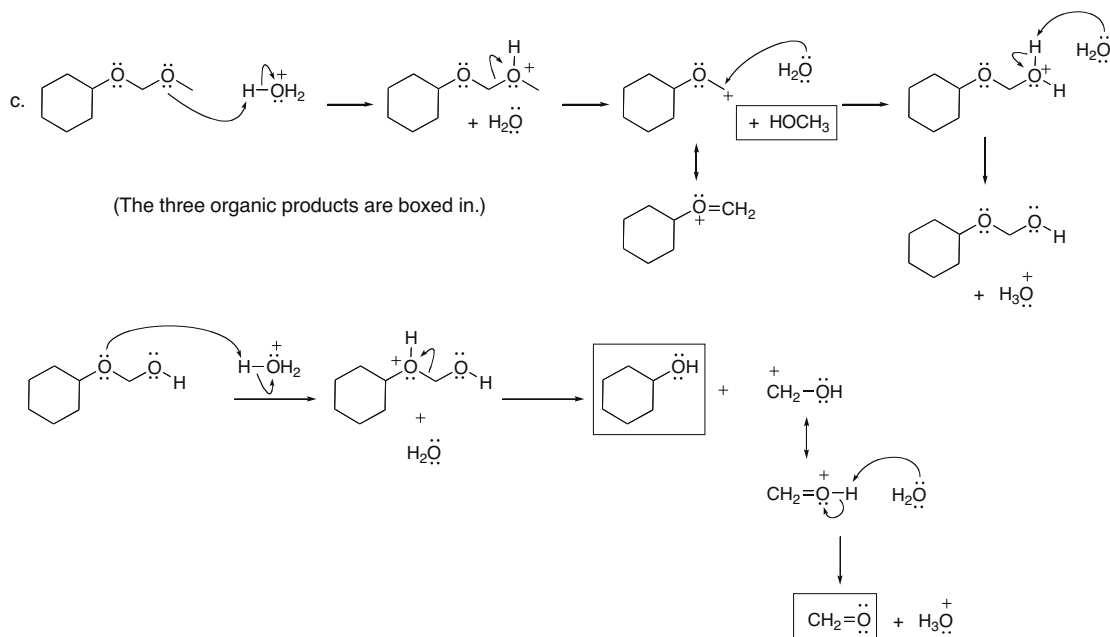
21.68



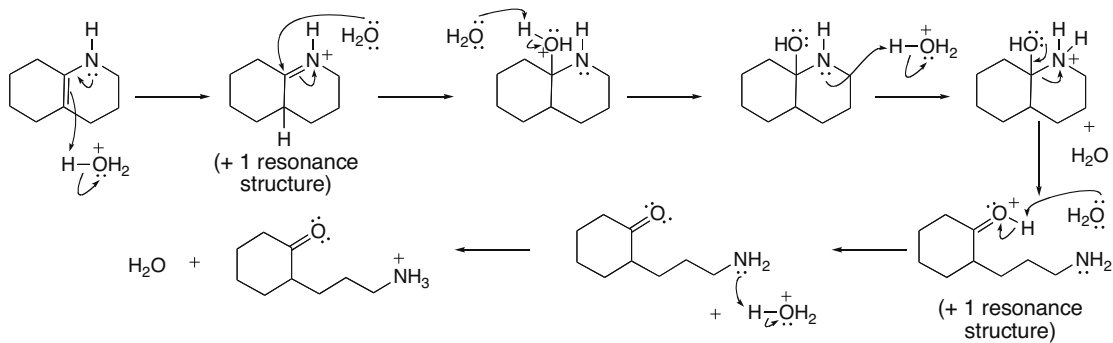
21.69



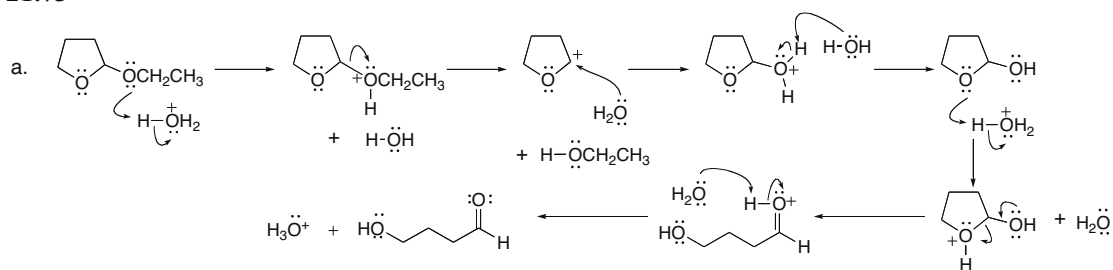
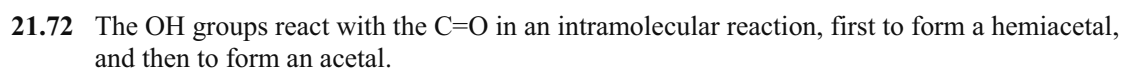
Chapter 21-26



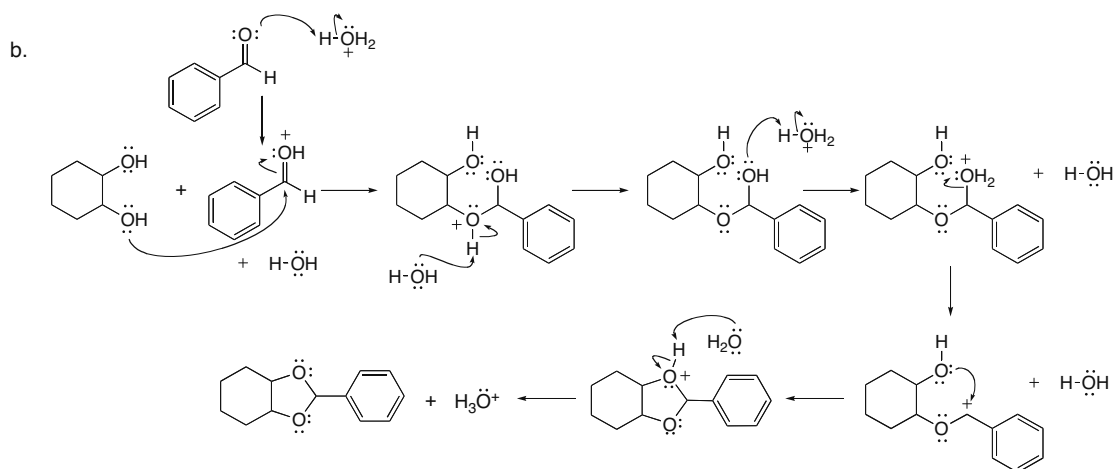
21.70



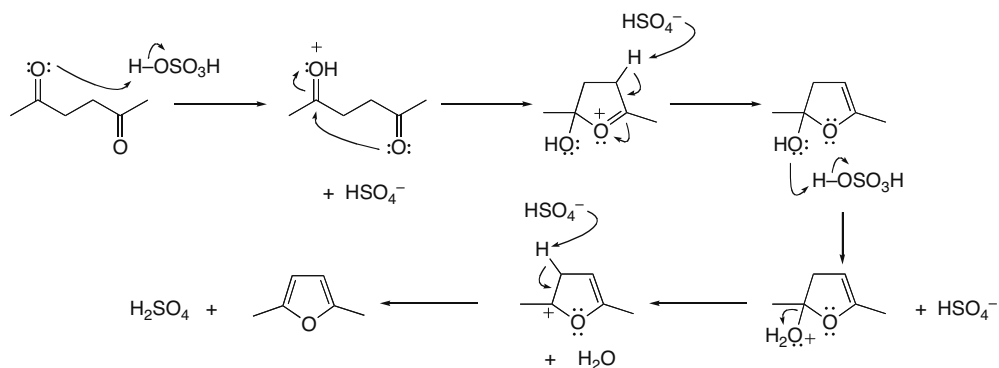
21.71



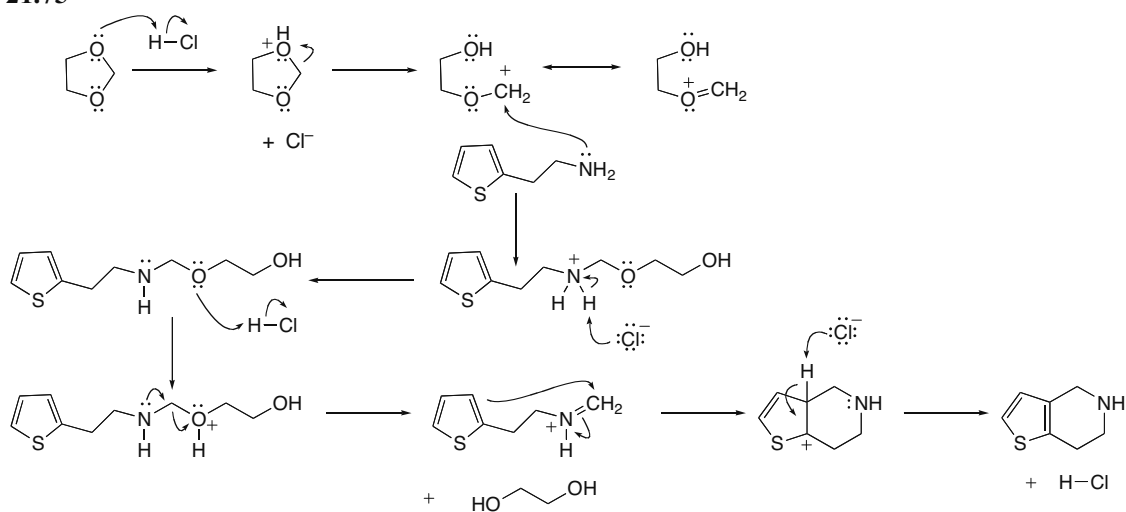
Chapter 21–28



21.74

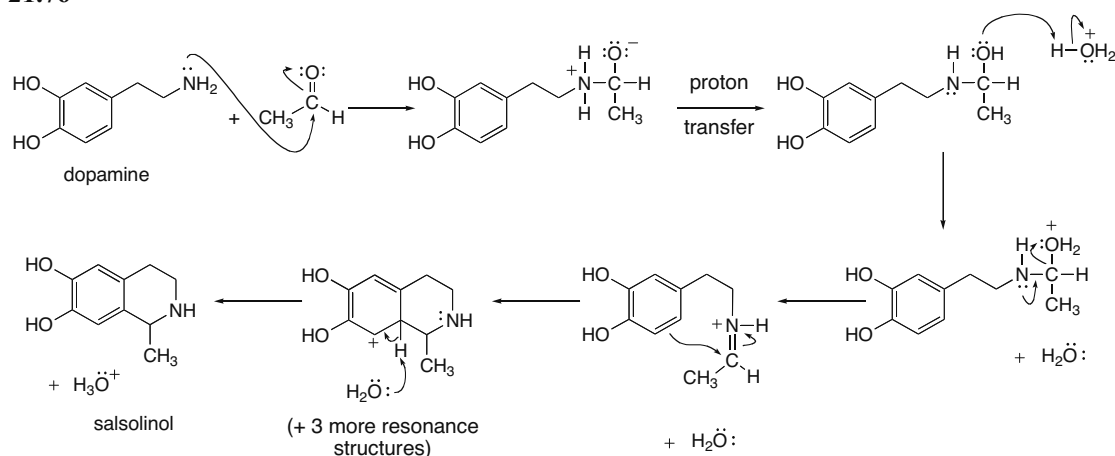


21.75

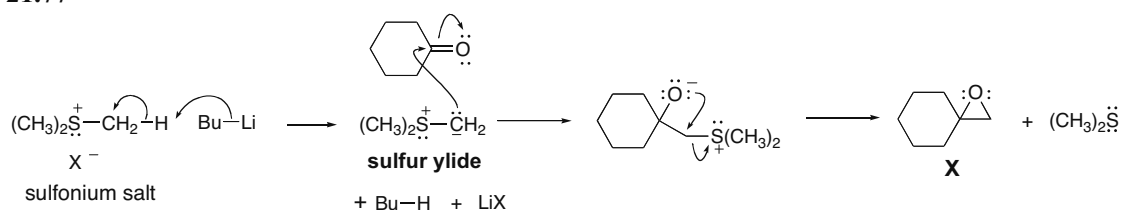


Aldehydes and Ketones—Nucleophilic Addition 21–29

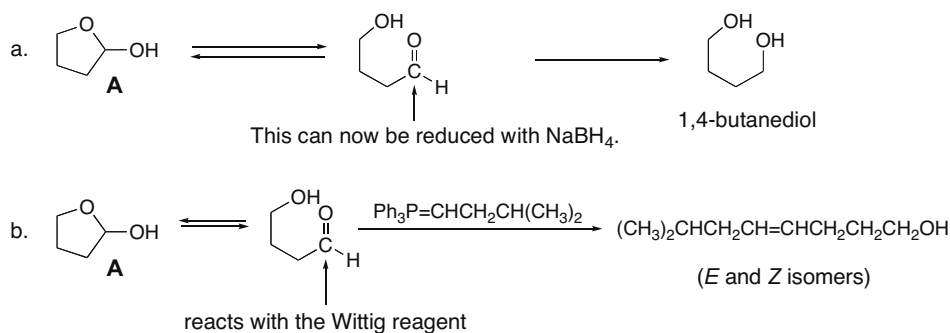
21.76



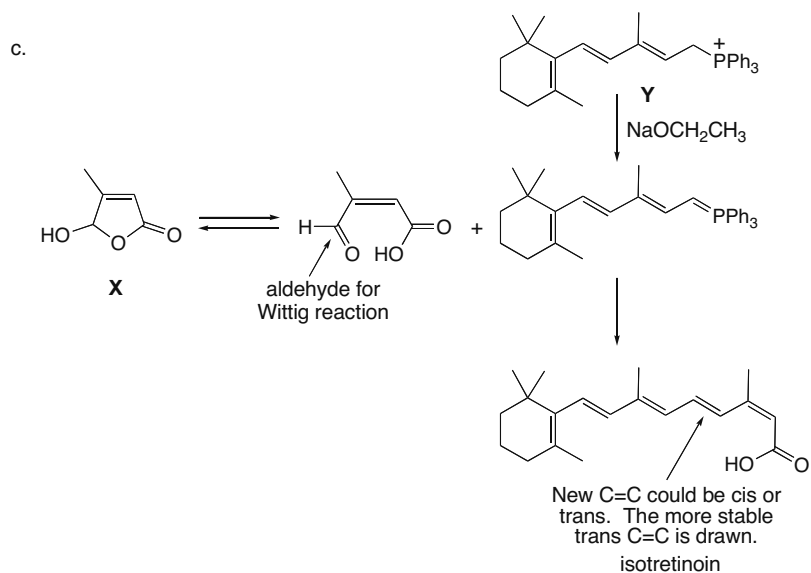
21.77



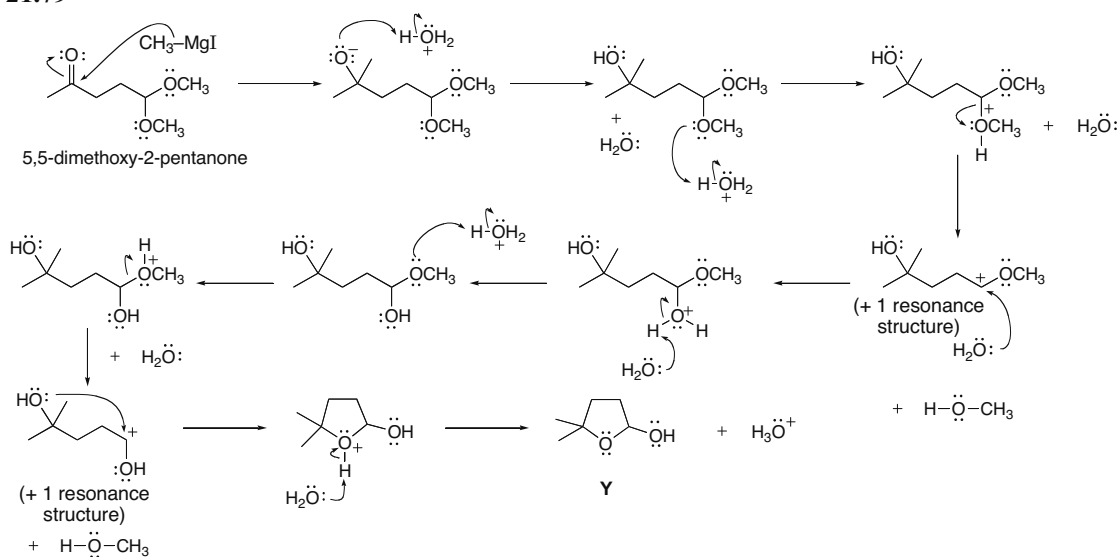
21.78 Hemiacetal **A** is in equilibrium with its acyclic hydroxy aldehyde. The aldehyde can undergo hydride reduction to form 1,4-butanediol and a Wittig reaction to form an alkene.



Chapter 21–30

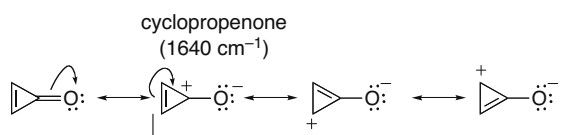


21.79

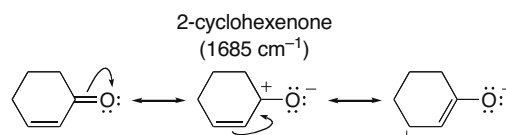


Aldehydes and Ketones—Nucleophilic Addition 21–31

21.80



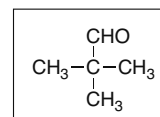
These three resonance structures include an aromatic ring; $4n + 2 = 2\pi$ electrons. Although they are charge separated, the stabilized aromatic ring makes these three structures contribute to the hybrid more than usual. Since these three resonance contributors have a C–O single bond, the absorption is shifted to a lower wavenumber.



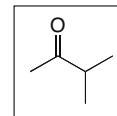
There are three resonance structures for 2-cyclohexenone, but the charge-separated resonance structures are not aromatic so they contribute less to the resonance hybrid. The C=O absorbs in the usual region for a conjugated carbonyl.

21.81

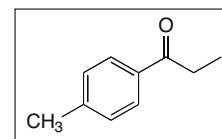
- A. Molecular formula $\text{C}_5\text{H}_{10}\text{O}$ $\longrightarrow$ 1 degree of unsaturation
 IR absorptions at 1728, 2791, 2700 cm^{-1} $\longrightarrow$ C=O, CHO
 NMR data: singlet at 1.08 (9 H) $\longrightarrow$ 3 CH_3 groups
 singlet at 9.48 (1 H) ppm $\longrightarrow$ CHO



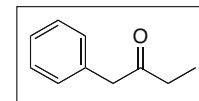
- B. Molecular formula $\text{C}_5\text{H}_{10}\text{O}$ $\longrightarrow$ 1 degree of unsaturation
 IR absorption at 1718 cm^{-1} $\longrightarrow$ C=O
 NMR data: doublet at 1.10 (6 H) $\longrightarrow$ 2 CH_3 's adjacent to H
 singlet at 2.14 (3 H) $\longrightarrow$ CH_3
 septet at 2.58 (1 H) ppm $\longrightarrow$ CH adjacent to 2 CH_3 's



- C. Molecular formula $\text{C}_{10}\text{H}_{12}\text{O}$ $\longrightarrow$ 5 degrees of unsaturation (4 due to a benzene ring)
 IR absorption at 1686 cm^{-1} $\longrightarrow$ C=O
 NMR data: triplet at 1.21 (3 H) $\longrightarrow$ CH_3 adjacent to 2 H's
 singlet at 2.39 (3 H) $\longrightarrow$ CH_3
 quartet at 2.95 (2 H) $\longrightarrow$ CH_2 adjacent to 3 H's
 doublet at 7.24 (2 H) $\longrightarrow$ 2 H's on benzene ring
 doublet at 7.85 (2 H) ppm $\longrightarrow$ 2 H's on benzene ring



- D. Molecular formula $\text{C}_{10}\text{H}_{12}\text{O}$ $\longrightarrow$ 5 degrees of unsaturation (4 due to a benzene ring)
 IR absorption at 1719 cm^{-1} $\longrightarrow$ C=O
 NMR data: triplet at 1.02 (3 H) $\longrightarrow$ CH_3 adjacent 2 H's
 quartet at 2.45 (2 H) $\longrightarrow$ 2 H's adjacent to 3 H's
 singlet at 3.67 (2 H) $\longrightarrow$ CH_2
 multiplet at 7.06–7.48 (5 H) ppm $\longrightarrow$ a monosubstituted benzene ring



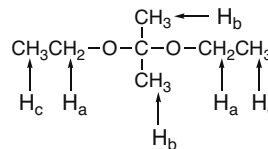
21.82

$\text{C}_7\text{H}_{16}\text{O}_2$: 0 degrees of unsaturation

IR: 3000 cm^{-1} : C–H bonds

NMR data (ppm):

- H_a : quartet at 3.5 (4 H), split by 3 H's
 H_b : singlet at 1.4 (6 H)
 H_c : triplet at 1.2 (6 H), split by 2 H's



Chapter 21–32

21.83

A. Molecular formula $C_9H_{10}O$

5 degrees of unsaturation

IR absorption at $1700\text{ cm}^{-1} \rightarrow C=O$ IR absorption at $\sim 2700\text{ cm}^{-1} \rightarrow CH$ of RCHO

NMR data (ppm):

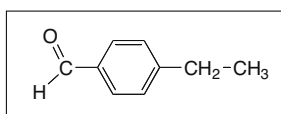
triplet at 1.2 (2 H's adjacent)

quartet at 2.7 (3 H's adjacent)

doublet at 7.3 (2 H's on benzene)

doublet at 7.7 (2 H's on benzene)

singlet at 9.9 (CHO)

B. Molecular formula $C_9H_{10}O$

5 degrees of unsaturation

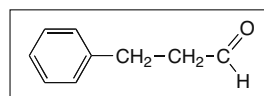
IR absorption at $1720\text{ cm}^{-1} \rightarrow C=O$ IR absorption at $\sim 2700\text{ cm}^{-1} \rightarrow CH$ of RCHO

NMR data (ppm):

2 triplets at 2.85 and 2.95 (suggests $-CH_2CH_2-$)

multiplet at 7.2 (benzene H's)

signal at 9.8 (CHO)



21.84

C. Molecular formula $C_6H_{12}O_3$

1 degree of unsaturation

IR absorption at $1718\text{ cm}^{-1} \rightarrow C=O$

To determine the number of H's that give rise to each signal, first find the number of integration units per H by dividing the total number of integration units ($7 + 40 + 14 + 21 = 82$) by the number of H's (12); $82/12 = 6.8$. Then divide each integration unit by this number (6.8).

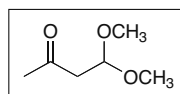
NMR data (ppm):

singlet at 2.2 (3 H's)

doublet at 2.7 (2 H's)

singlet at 3.2 (6 H's – 2 OCH_3 groups)

triplet at 4.8 (1 H)



21.85

D. Molecular ion at $m/z = 150$: $C_9H_{10}O_2$ (possible molecular formula)

5 degrees of unsaturation

IR absorption at $1692\text{ cm}^{-1} \rightarrow C=O$

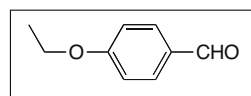
NMR data (ppm):

triplet at 1.5 (3 H's – CH_3CH_2)quartet at 4.1 (2 H's – CH_3CH_2)

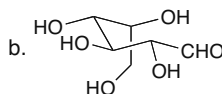
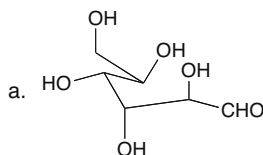
doublet at 7.0 (2 H's – on benzene ring)

doublet at 7.8 (2 H's – on benzene ring)

singlet at 9.9 (1 H – on aldehyde)

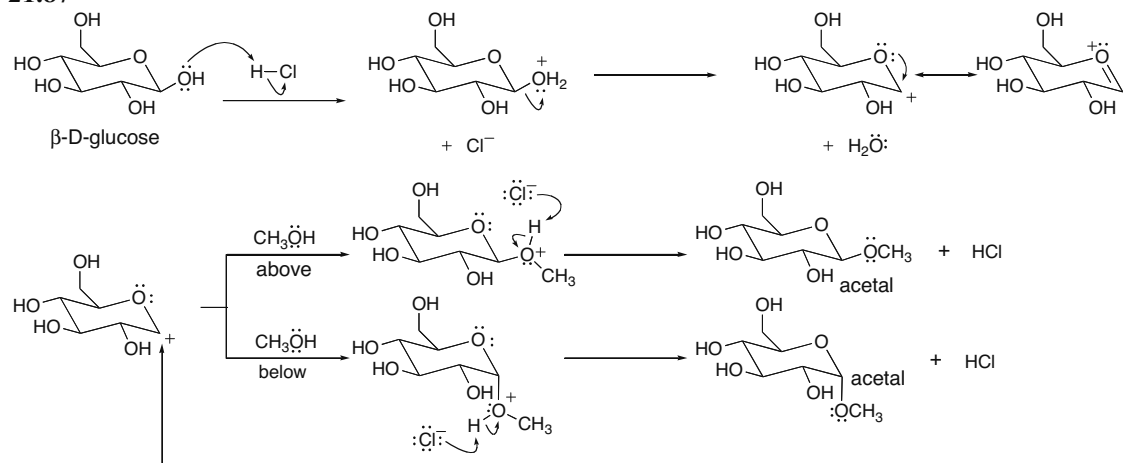


21.86



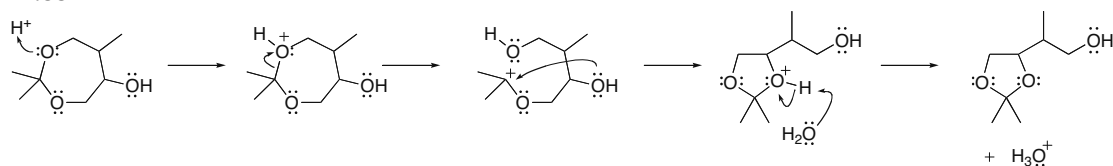
Aldehydes and Ketones—Nucleophilic Addition 21–33

21.87

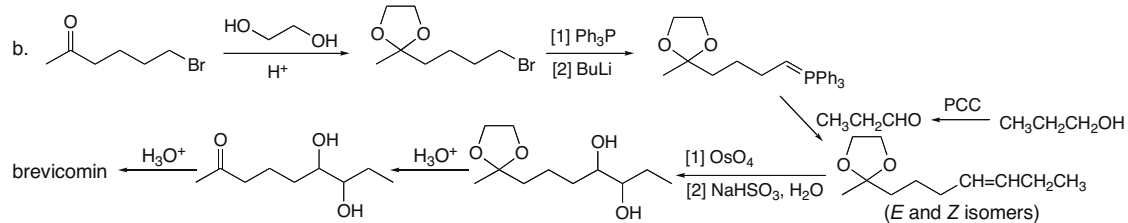
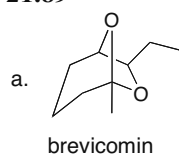


The carbocation is trigonal planar, so CH_3OH attacks from two different directions, and two different acetals are formed.

21.88

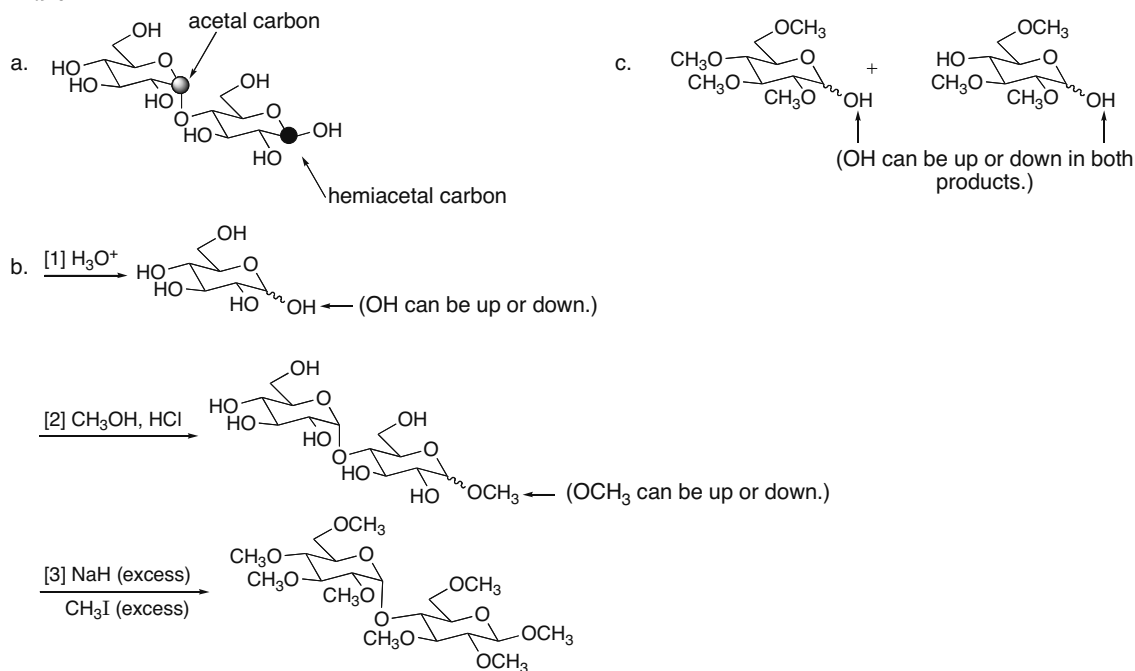


21.89

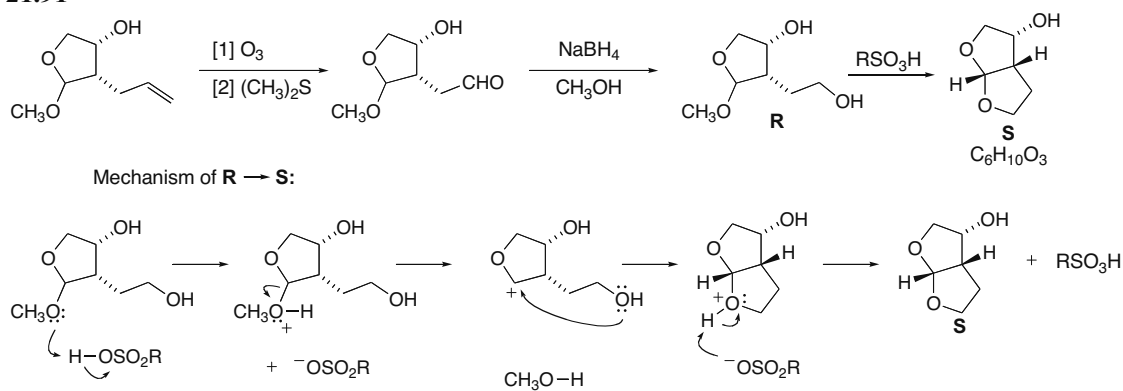


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21.90

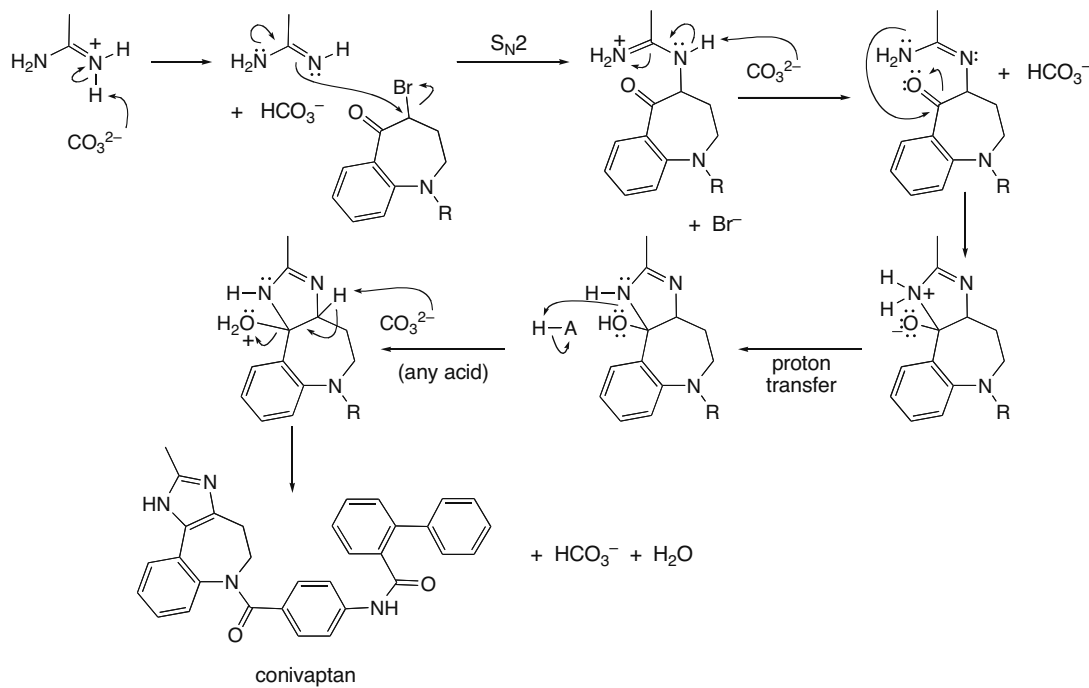


21.91



Aldehydes and Ketones—Nucleophilic Addition 21–35

21.92 The mechanism involves S_N2 displacement of Br, followed by intramolecular enamine formation.



Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 22–1

Chapter 22 Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution**Chapter Review****Summary of spectroscopic absorptions of RCOZ (22.5)****IR absorptions**

- All RCOZ compounds have a C=O absorption in the region 1600–1850 cm^{-1} .
 - RCOCl : 1800 cm^{-1}
 - $(\text{RCO})_2\text{O}$: 1820 and 1760 cm^{-1} (two peaks)
 - RCOOR' : 1735–1745 cm^{-1}
 - RCONR'_2 : 1630–1680 cm^{-1}
- Additional amide absorptions occur at 3200–3400 cm^{-1} (N–H stretch) and 1640 cm^{-1} (N–H bending).
- Decreasing the ring size of a cyclic lactone, lactam, or anhydride increases the frequency of the C=O absorption.
- Conjugation shifts the C=O to lower wavenumber.

 ^1H NMR absorptions

- C–H α to the C=O absorbs at 2–2.5 ppm.
- N–H of an amide absorbs at 7.5–8.5 ppm.

 ^{13}C NMR absorption

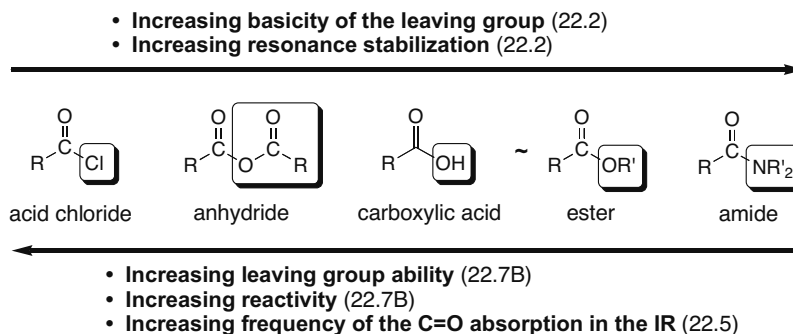
- C=O absorbs at 160–180 ppm.

Summary of spectroscopic absorptions of RCN (22.5)**IR absorption**

- $\text{C}\equiv\text{N}$ absorption at 2250 cm^{-1}

 ^{13}C NMR absorption

- $\text{C}\equiv\text{N}$ absorbs at 115–120 ppm.

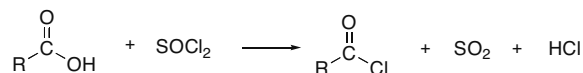
Summary: The relationship between the basicity of Z^- and the properties of RCOZ**General features of nucleophilic acyl substitution**

- The characteristic reaction of compounds having the general structure RCOZ is nucleophilic acyl substitution (22.1).
- The mechanism consists of two steps (22.7A):
 - [1] Addition of a nucleophile to form a tetrahedral intermediate
 - [2] Elimination of a leaving group
- More reactive acyl compounds can be used to prepare less reactive acyl compounds. The reverse is not necessarily true (22.7B).

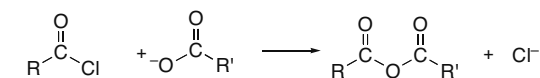
Chapter 22-2

Nucleophilic acyl substitution reactions**[1] Reaction that synthesizes acid chlorides (RCOCl)**

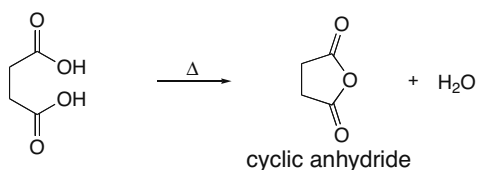
From RCOOH
(22.10A):

**[2] Reactions that synthesize anhydrides [(RCO)₂O]**

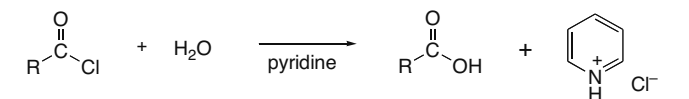
[a] From RCOCl
(22.8):



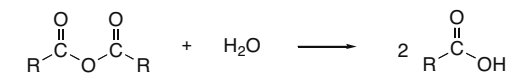
[b] From dicarboxylic acids (22.10B):

**[3] Reactions that synthesize carboxylic acids (RCOOH)**

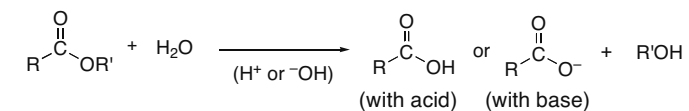
[a] From RCOCl
(22.8):



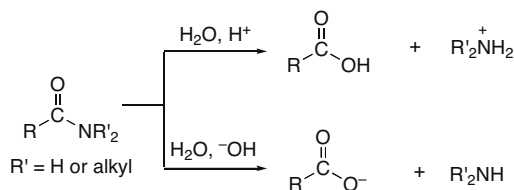
[b] From (RCO)₂O
(22.9):



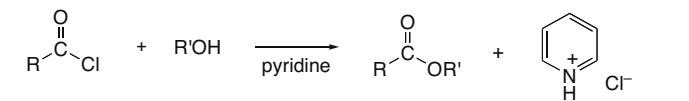
[c] From RCOOR'
(22.11):



[d] From RCONR'₂ (R' = H or alkyl, 22.13):

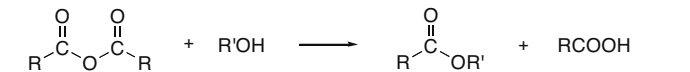
**[4] Reactions that synthesize esters (RCOOR')**

[a] From RCOCl
(22.8):

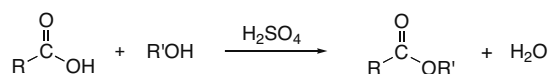


Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 22–3

[b] From $(\text{RCO})_2\text{O}$
(22.9):

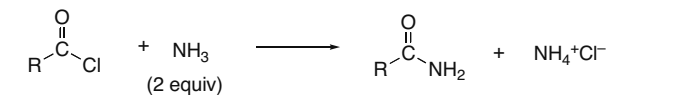


[c] From RCOOH
(22.10C):

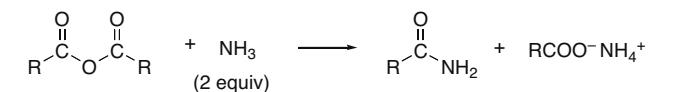


[5] Reactions that synthesize amides (RCONH_2) [The reactions are written with NH_3 as the nucleophile to form RCONH_2 . Similar reactions occur with $\text{R}'\text{NH}_2$ to form RCONHR' , and with $\text{R}'_2\text{NH}$ to form RCONR'_2 .]

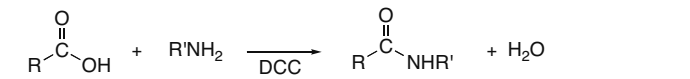
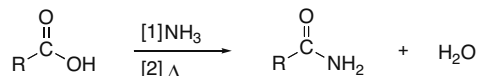
[a] From RCOCl
(22.8):



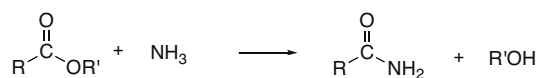
[b] From $(\text{RCO})_2\text{O}$
(22.9):



[c] From RCOOH
(22.10D):

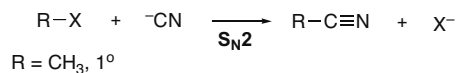


[d] From RCOOR'
(22.11):



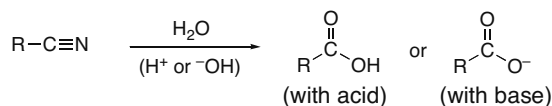
Nitrile synthesis (22.18)

Nitriles are prepared by $\text{S}_{\text{N}}2$ substitution using unhindered alkyl halides as starting materials.

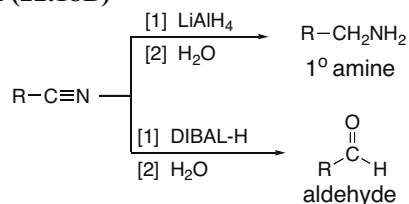
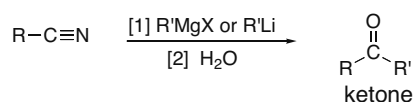


Reactions of nitriles

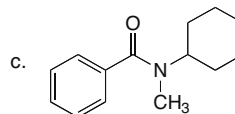
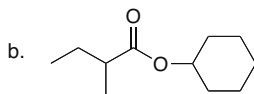
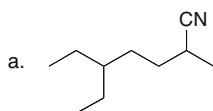
[1] Hydrolysis (22.18A)



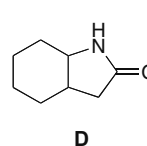
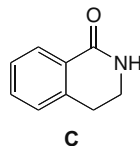
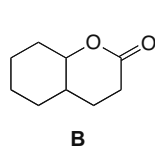
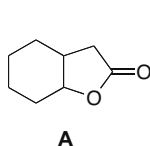
Chapter 22-4

[2] Reduction (22.18B)**[3] Reaction with organometallic reagents (22.18C)****Practice Test on Chapter Review**

1. Give the IUPAC name for each of the following compounds.



2. (a) Which compound absorbs at the *lowest* wavenumber in the IR? (b) Which compound absorbs at the *highest* wavenumber?



3. a. Which of the following reaction conditions can be used to synthesize an ester?

1. $\text{RCOCl} + \text{R}'\text{OH} + \text{pyridine}$
2. $\text{RCOOH} + \text{R}'\text{OH} + \text{H}_2\text{SO}_4$
3. $\text{RCOOH} + \text{R}'\text{OH} + \text{NaOH}$
4. Both methods [1] and [2] can be used to synthesize an ester.
5. Methods [1], [2], and [3] can all be used to synthesize an ester.

b. Which of the following compounds is most reactive in nucleophilic acyl substitution?

1. CH_3COCl	3. $\text{CH}_3\text{CON}(\text{CH}_3)_2$	5. CH_3COOH
2. $\text{CH}_3\text{COOCH}_3$	4. $(\text{CH}_3\text{CO})_2\text{O}$	

Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 22–5

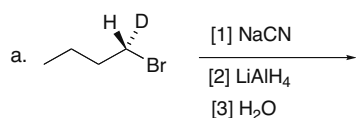
4. What reagent is needed to convert $(\text{CH}_3\text{CH}_2)_2\text{CHCOOH}$ into each compound?

- $(\text{CH}_3\text{CH}_2)_2\text{CHCOO}^-\text{Na}^+$
- $(\text{CH}_3\text{CH}_2)_2\text{CHCOCl}$
- $(\text{CH}_3\text{CH}_2)_2\text{CHCON}(\text{CH}_3)_2$
- $(\text{CH}_3\text{CH}_2)_2\text{CHCO}_2\text{CH}_2\text{CH}_3$
- $[(\text{CH}_3\text{CH}_2)_2\text{CHCO}]_2\text{O}$

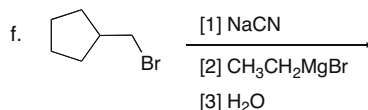
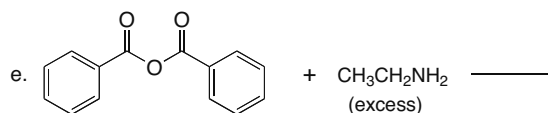
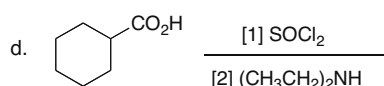
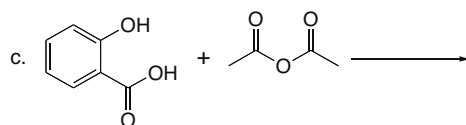
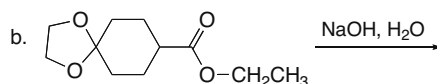
5. What reagent is needed to convert $\text{CH}_3\text{CH}_2\text{CH}_2\text{CN}$ to each compound?

- $\text{CH}_3\text{CH}_2\text{CH}_2\text{COOH}$
- $\text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{NH}_2$
- $\text{CH}_3\text{CH}_2\text{CH}_2\text{COCH}_2\text{CH}_3$
- $\text{CH}_3\text{CH}_2\text{CH}_2\text{CHO}$

6. Draw the organic products formed in the following reactions.



[Indicate stereochemistry.]



Answers to Practice Test

- 5-ethyl-2-methylheptanenitrile
 - cyclohexyl 2-methylbutanoate
 - N*-cyclohexyl-*N*-methylbenzamide

- C
 - A

- 4
 - 1

- NaOH
 - SOCl_2
 - $\text{HN}(\text{CH}_3)_2$, DCC
 - $\text{CH}_3\text{CH}_2\text{OH}$, H_2SO_4
 - heat

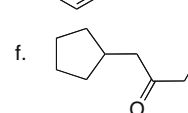
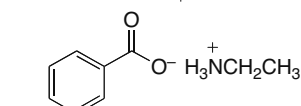
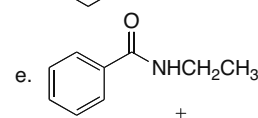
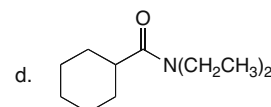
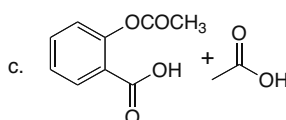
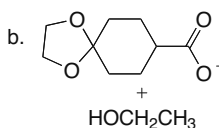
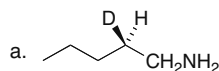
5. a. H_3O^+

b. [1] LiAlH_4 ; [2] H_2O

c. [1] $\text{CH}_3\text{CH}_2\text{Li}$; [2] H_2O

d. [1] DIBAL-H; [2] H_2O

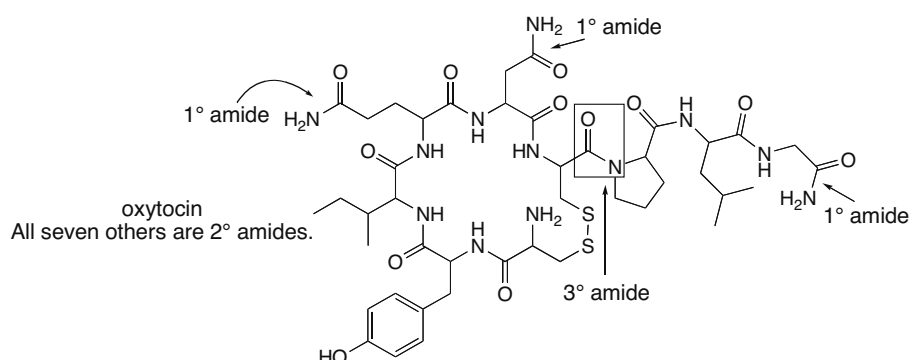
6.



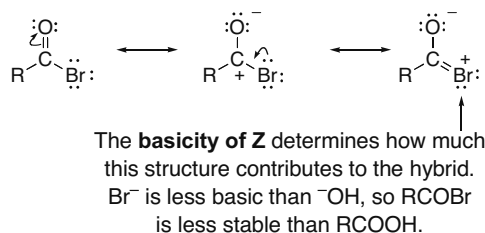
Chapter 22–6

Answers to Problems

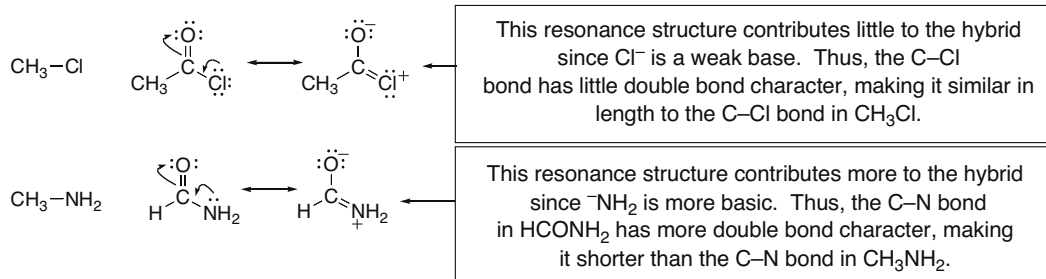
22.1 The number of C–N bonds determines the classification as a 1°, 2°, or 3° amide.



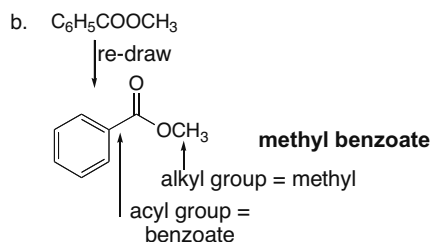
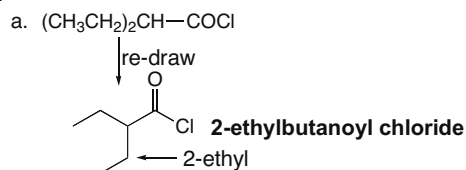
22.2 As the basicity of Z increases, the stability of RCOZ increases because of added resonance stabilization.



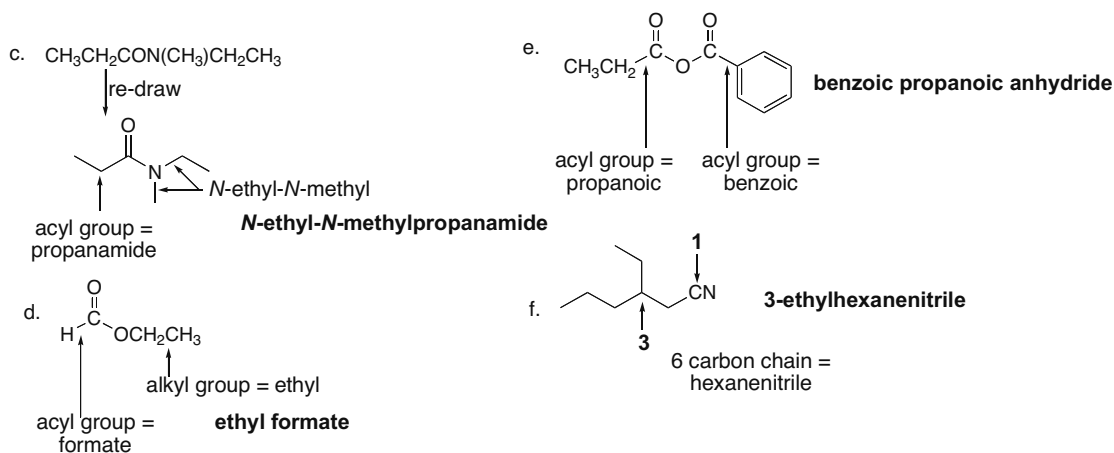
22.3



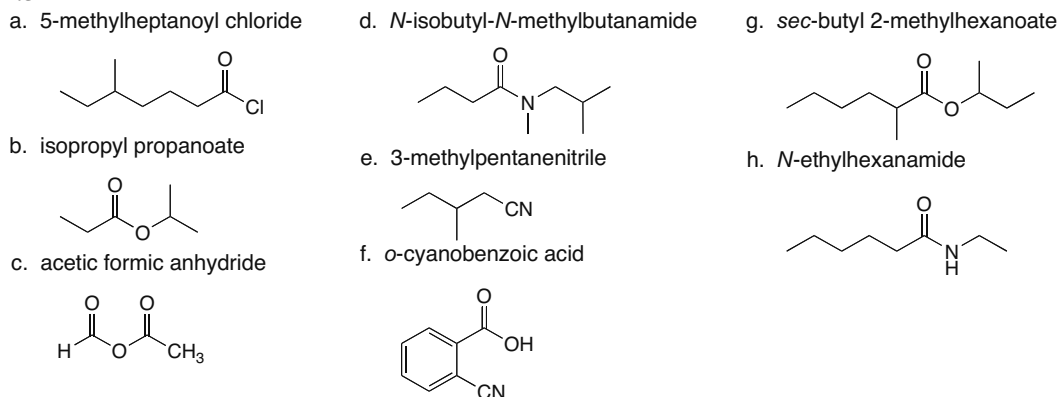
22.4



Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 22–7

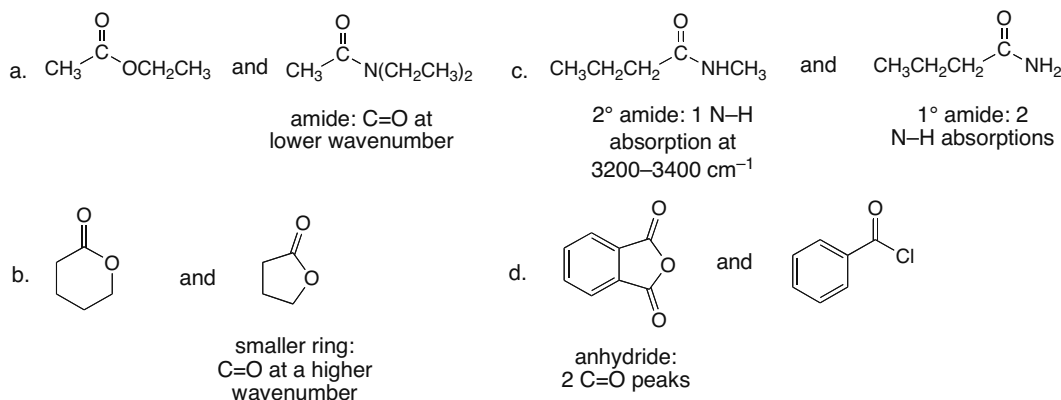


22.5



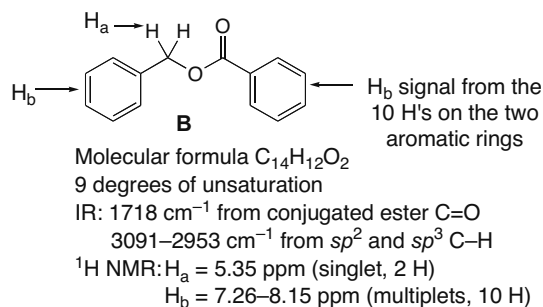
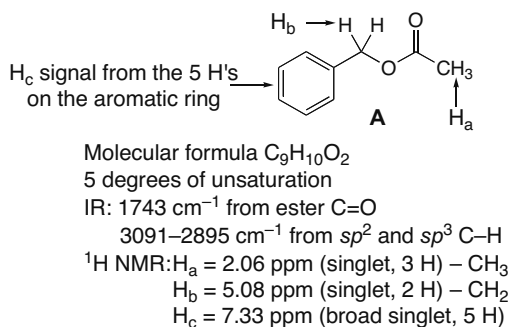
22.6 CH_3CONH_2 has two H's bonded to N that can hydrogen bond. $\text{CH}_3\text{CON}(\text{CH}_3)_2$ does not have any H's capable of hydrogen bonding. This means CH_3CONH_2 has much stronger intermolecular forces, which leads to a higher boiling point.

22.7

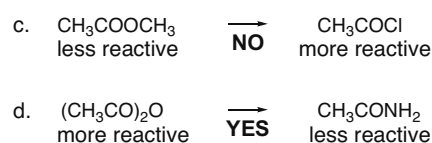
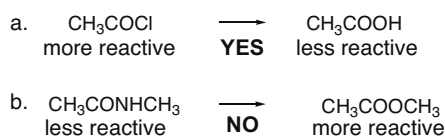


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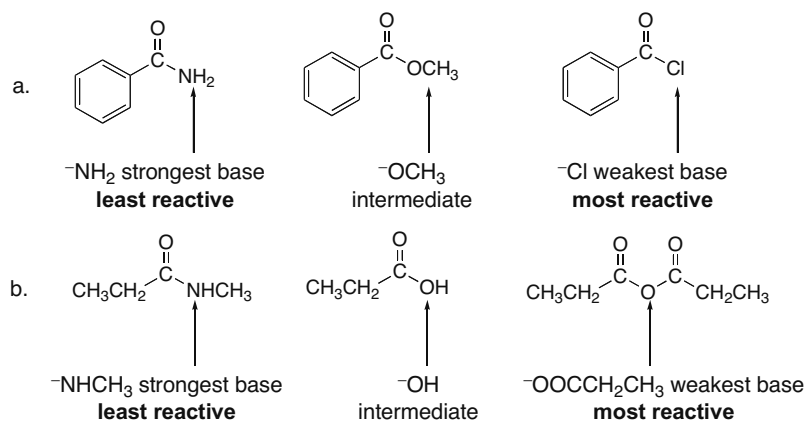
22.8



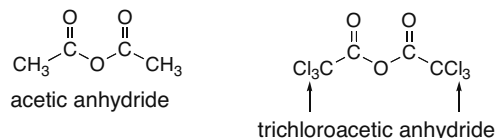
22.9 More reactive acyl compounds can be converted to less reactive acyl compounds.



22.10 The better the leaving group is, the more reactive the carboxylic acid derivative. The weakest base is the best leaving group.



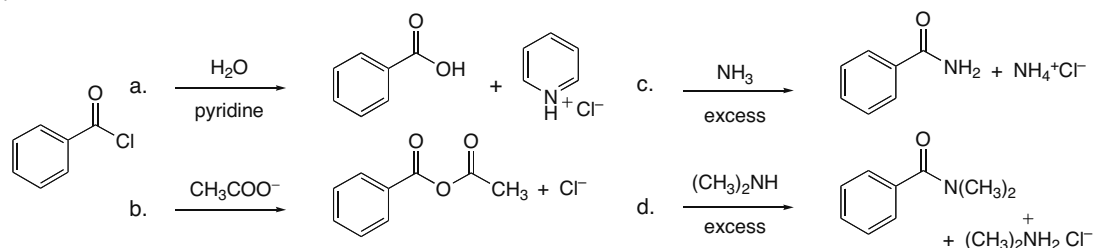
22.11



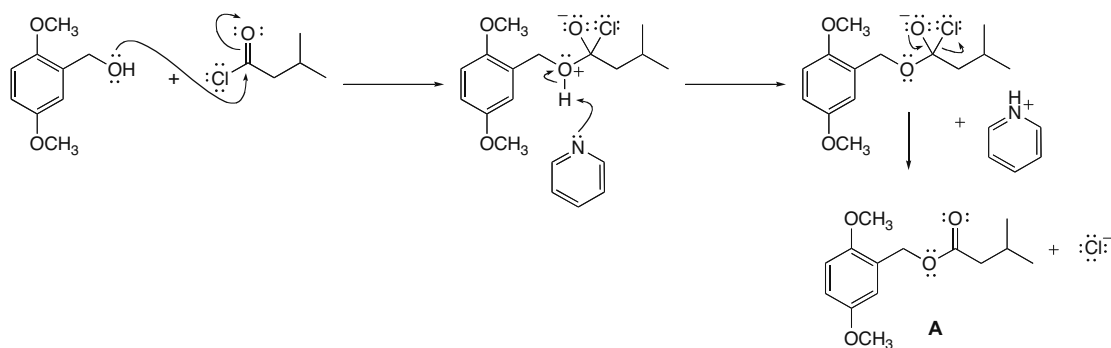
The Cl atoms are electron withdrawing, which makes the conjugate base (the leaving group, CCl_3COO^-) weaker and more stable.

Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 22–9

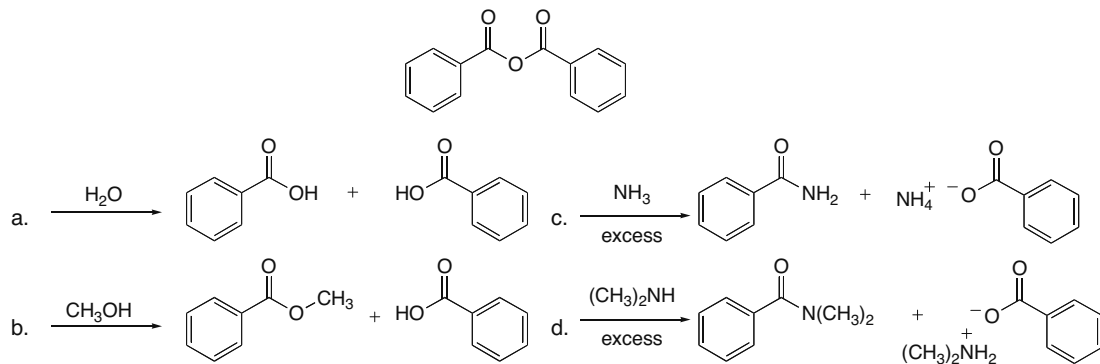
22.12



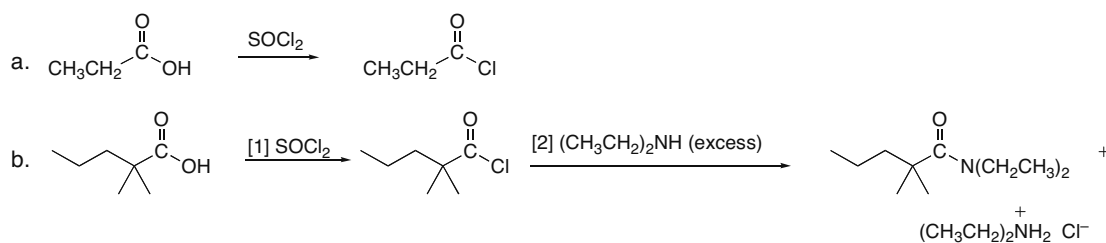
22.13 The mechanism has three steps: [1] nucleophilic attack by O; [2] proton transfer; [3] elimination of the Cl^- leaving group to form the product.



22.14

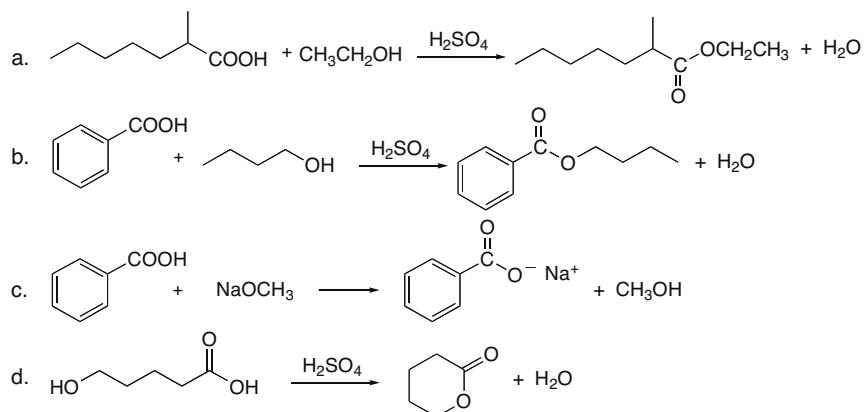


22.15 Reaction of a carboxylic acid with thionyl chloride converts it to an acid chloride.

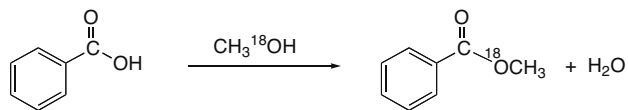


Chapter 22–10

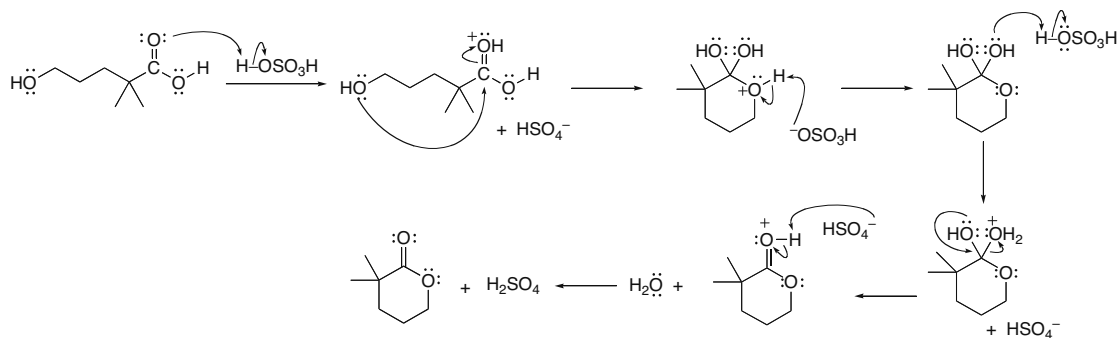
22.16



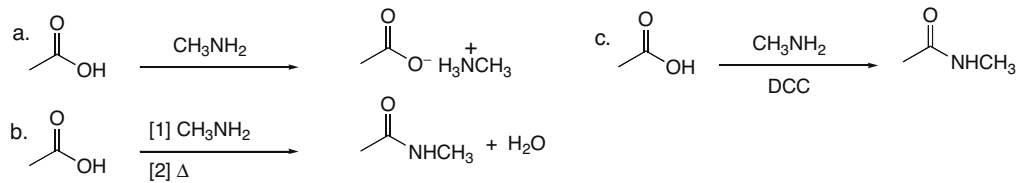
22.17



22.18

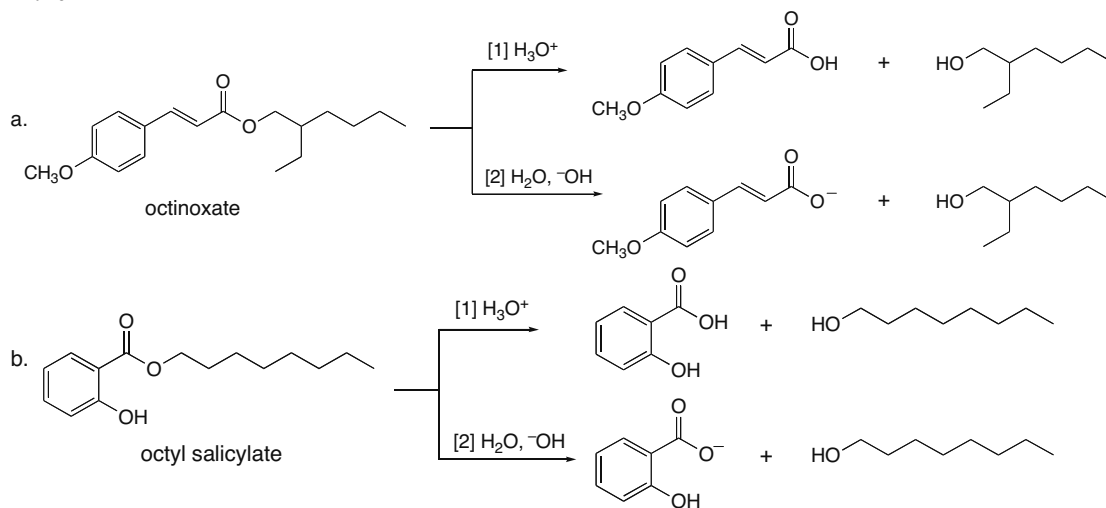


22.19

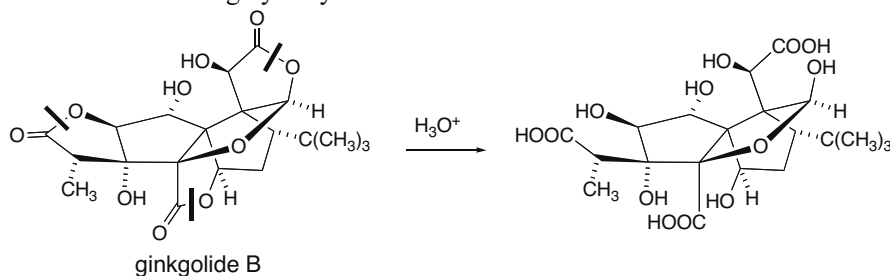


Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 22–11

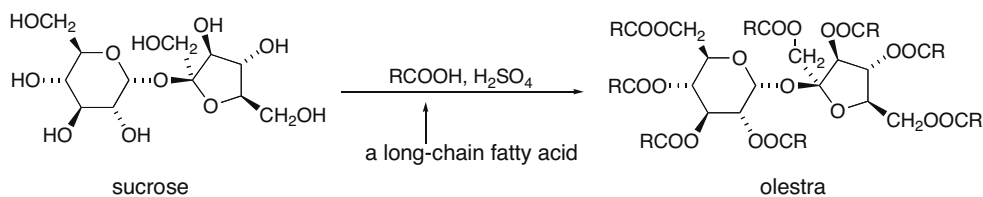
22.20



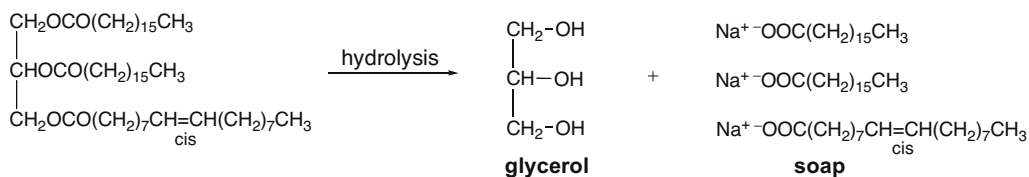
22.21 Bonds broken during hydrolysis are indicated.



22.22

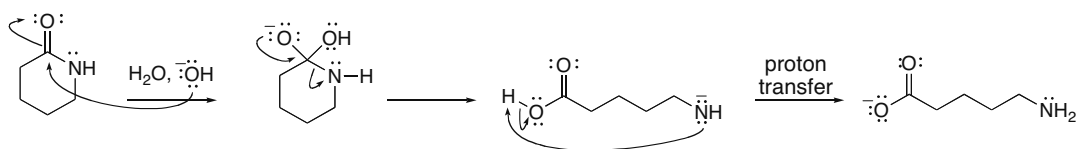


22.23



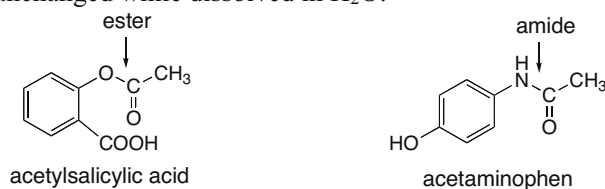
Chapter 22–12

22.24

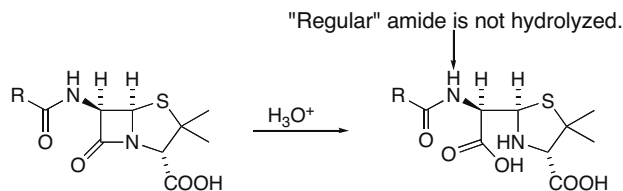


22.25 Aspirin has an ester, a more reactive acyl group, whereas acetaminophen has an amide, a less reactive acyl group.

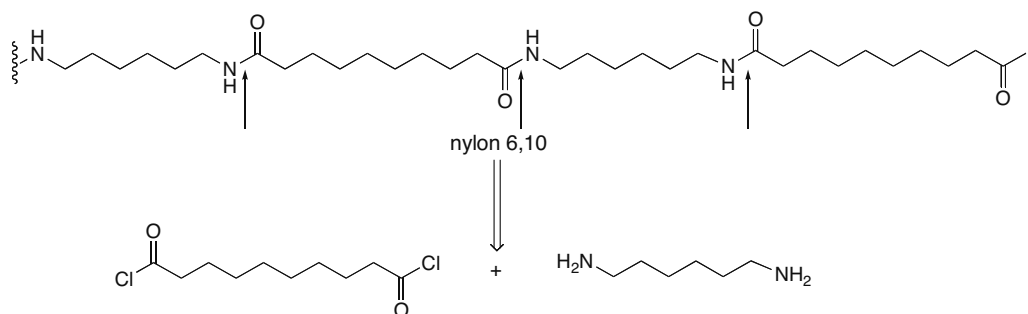
- The ester makes aspirin more easily hydrolyzed with water from the air than acetaminophen. Therefore, Tylenol can be kept for many years, whereas aspirin decomposes.
- Similarly, aspirin will be hydrolyzed and decompose in the aqueous medium of a liquid medication, but acetaminophen is stable due to the less reactive amide group, allowing it to remain unchanged while dissolved in H_2O .



22.26

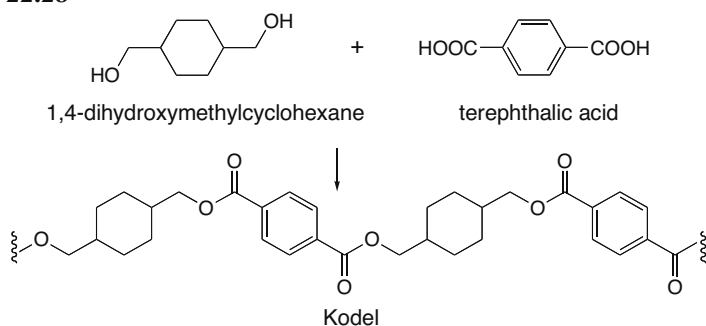


22.27



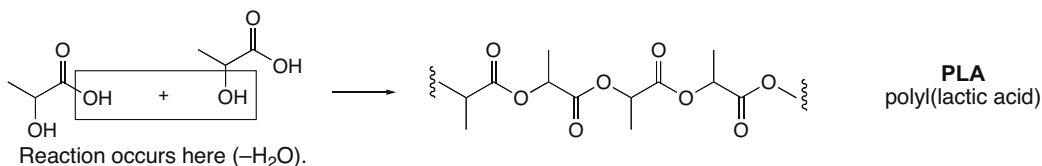
Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 22–13

22.28

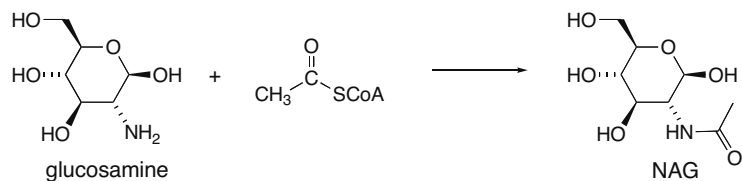


In the polyester Kodel, most of the bonds in the polymer backbone are part of a ring, so there are fewer degrees of freedom. Fabrics made from Kodel are stiff and crease resistant, due to these less flexible polyester fibers.

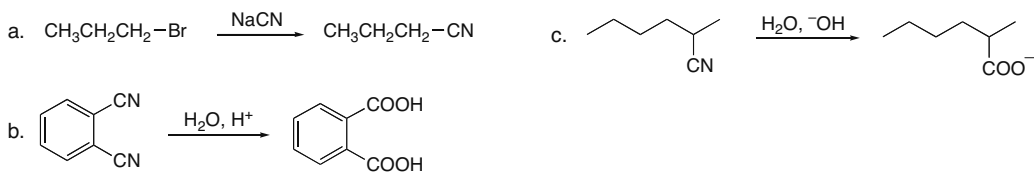
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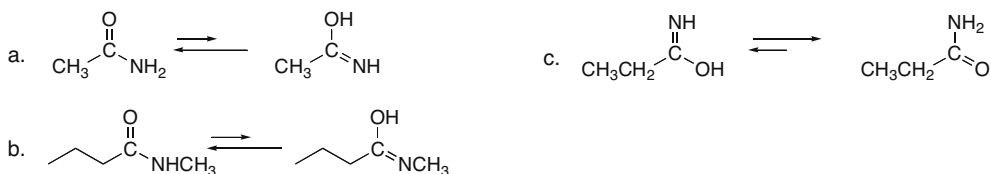
22.30 Acetyl CoA acetylates the NH_2 group of glucosamine, since the NH_2 group is the most nucleophilic site.



22.31

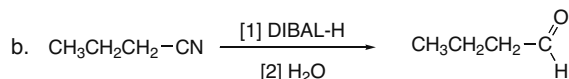
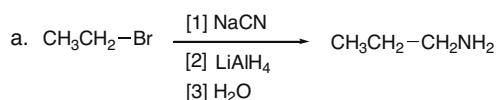


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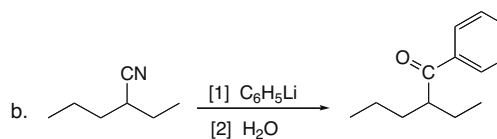
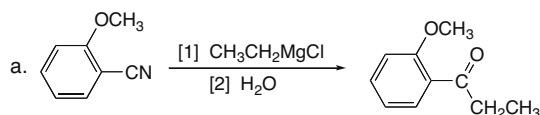


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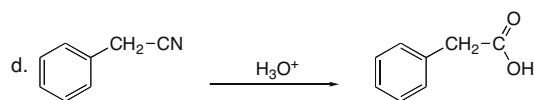
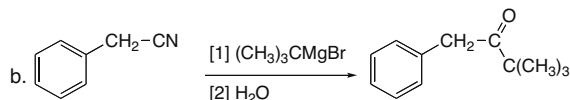
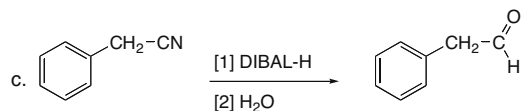
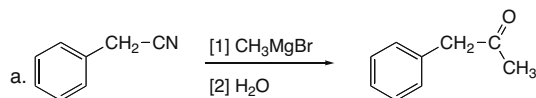
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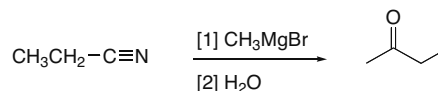
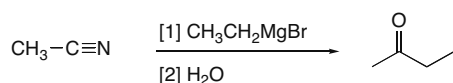
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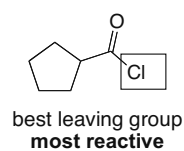
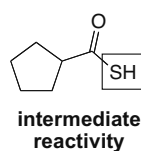
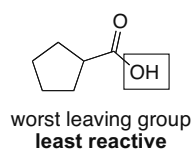
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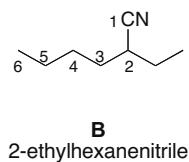
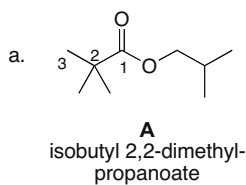
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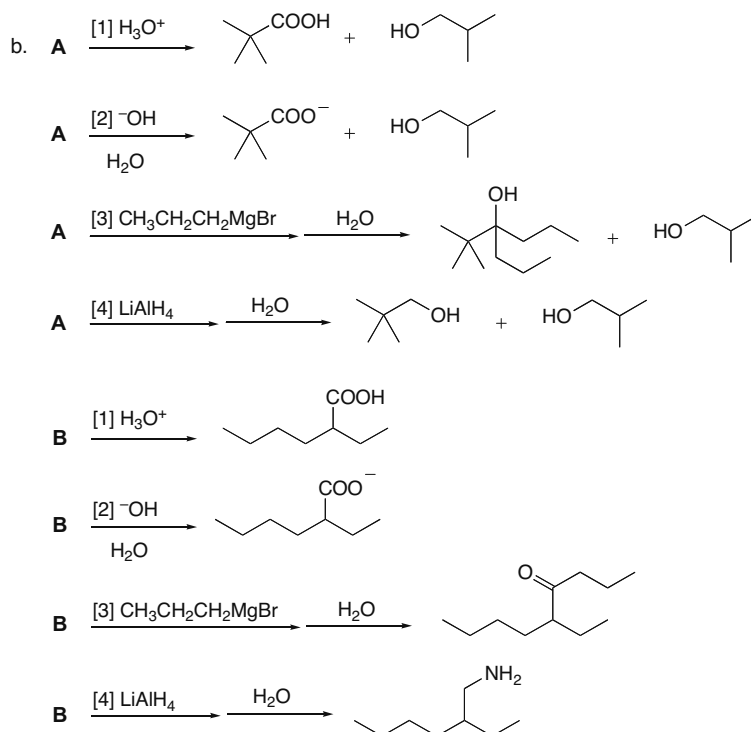
22.37 The better the leaving group, the more reactive the acyl compound.



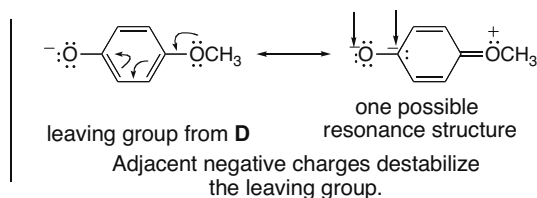
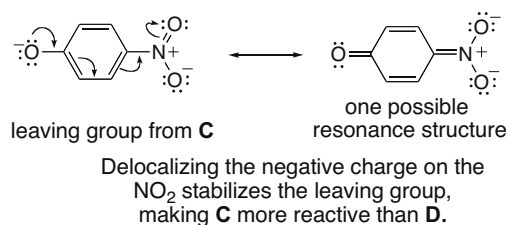
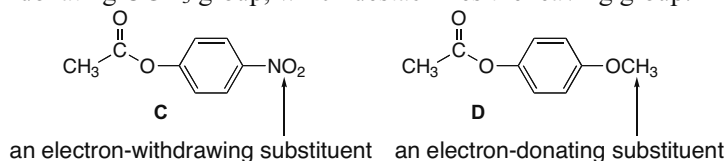
22.38



Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 22–15

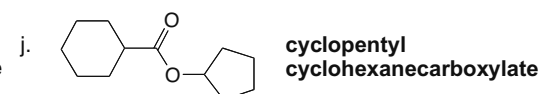
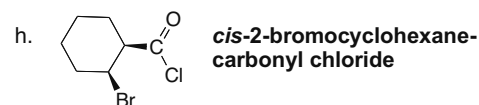
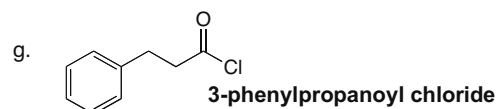
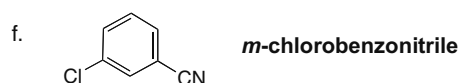
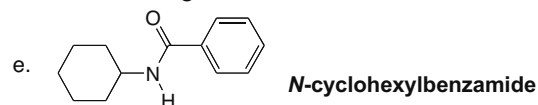
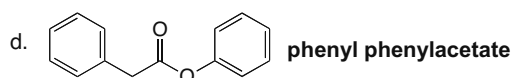
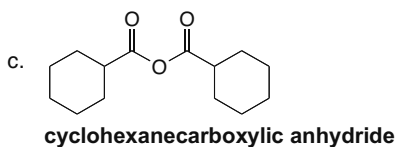
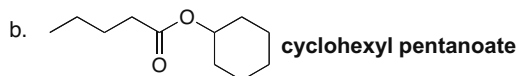


22.39 Better leaving groups make acyl compounds more reactive. **C** has an electron-withdrawing NO_2 group, which stabilizes the negative charge of the leaving group, whereas **D** has an electron-donating OCH_3 group, which destabilizes the leaving group.



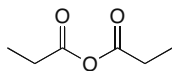
Chapter 22–16

22.40

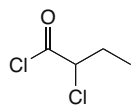


22.41

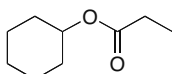
a. propanoic anhydride



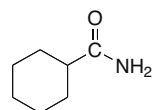
b. α -chlorobutyryl chloride



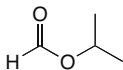
c. cyclohexyl propanoate



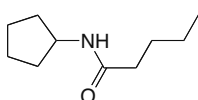
d. cyclohexanecarboxamide



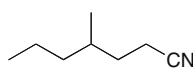
e. isopropyl formate



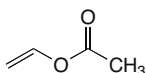
f. N-cyclopentylpentanamide



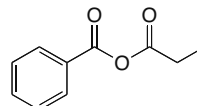
g. 4-methylheptanenitrile



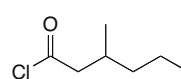
h. vinyl acetate



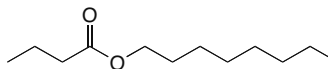
i. benzoic propanoic anhydride



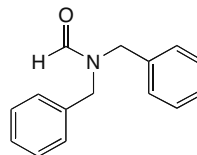
j. 3-methylhexanoyl chloride



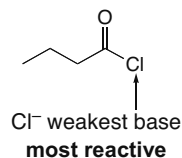
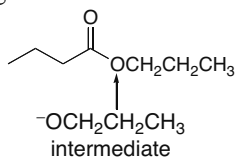
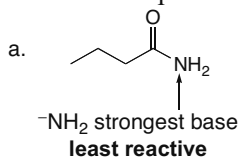
k. octyl butanoate



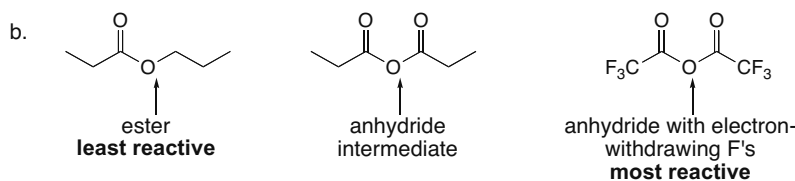
l. N,N-dibenzylformamide



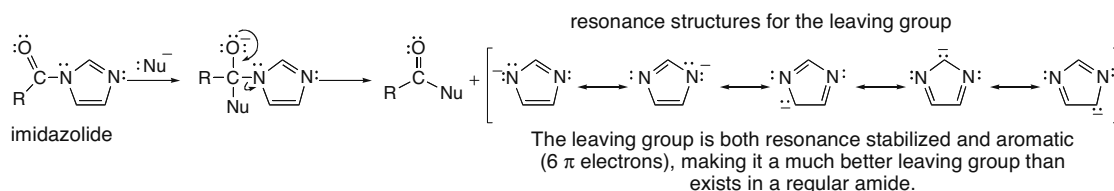
22.42 Rank the compounds using the rules from Answer 22.10.



Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 22–17

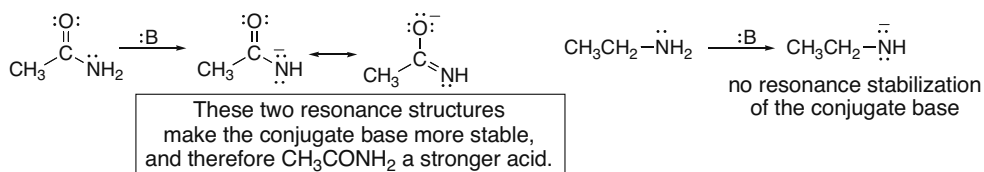


22.43

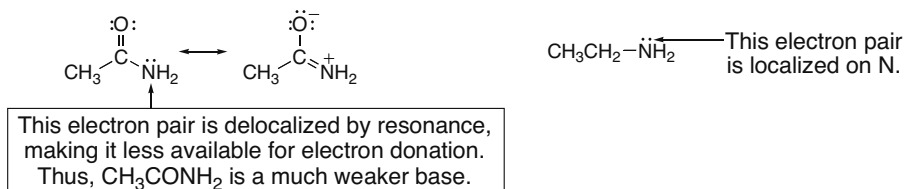


22.44

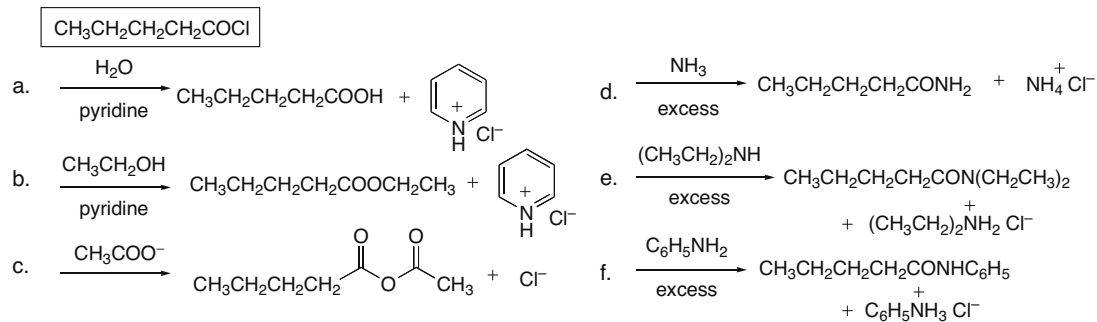
Reaction as an acid:



Reaction as a base:

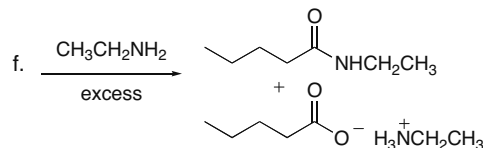
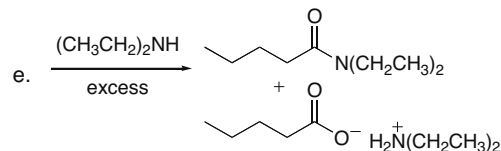
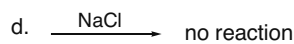
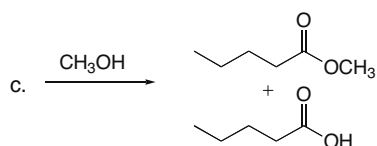
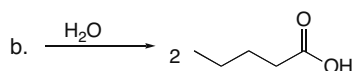
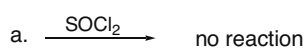
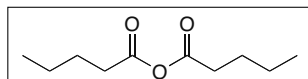


22.45

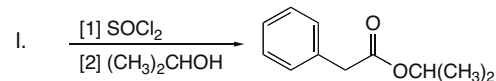
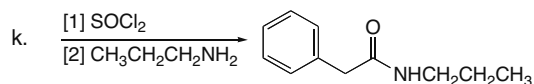
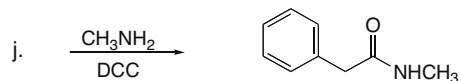
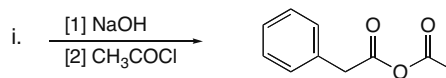
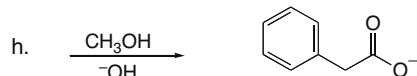
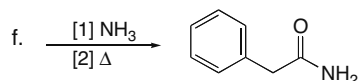
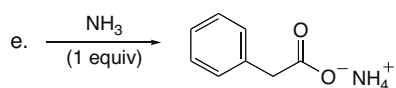
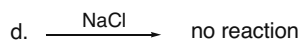
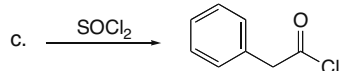
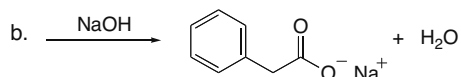
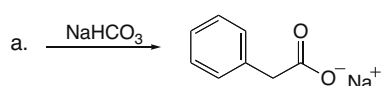
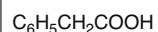


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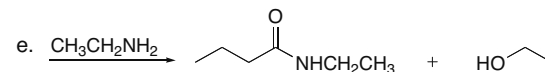
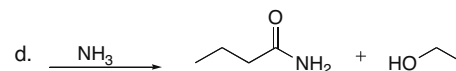
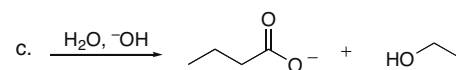
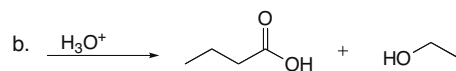
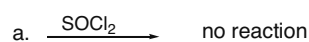
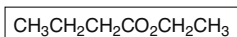
22.46



22.47

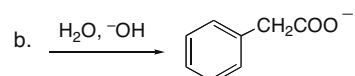
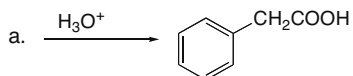
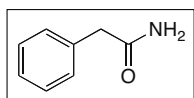


22.48

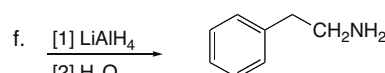
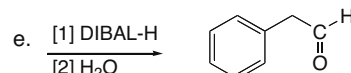
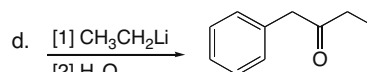
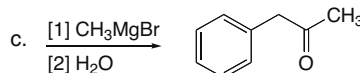
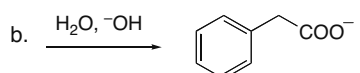
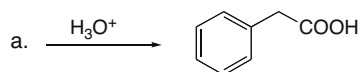
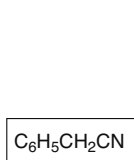


Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 22–19

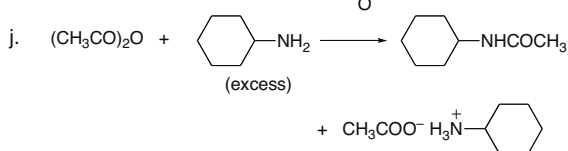
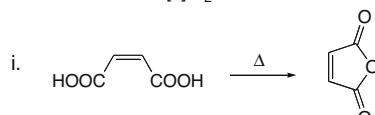
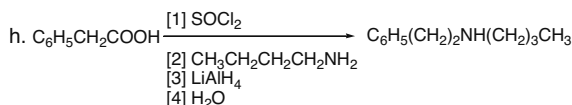
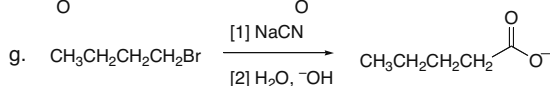
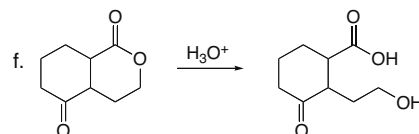
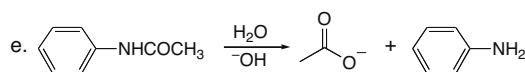
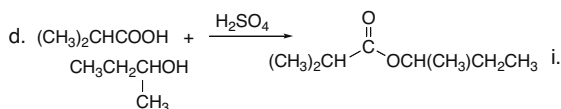
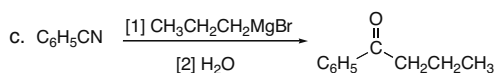
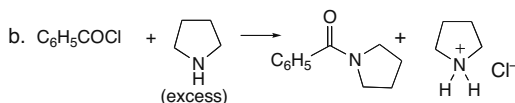
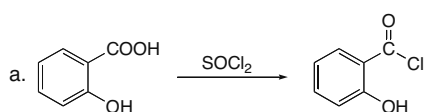
22.49



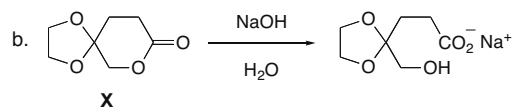
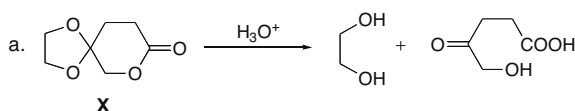
22.50



22.51

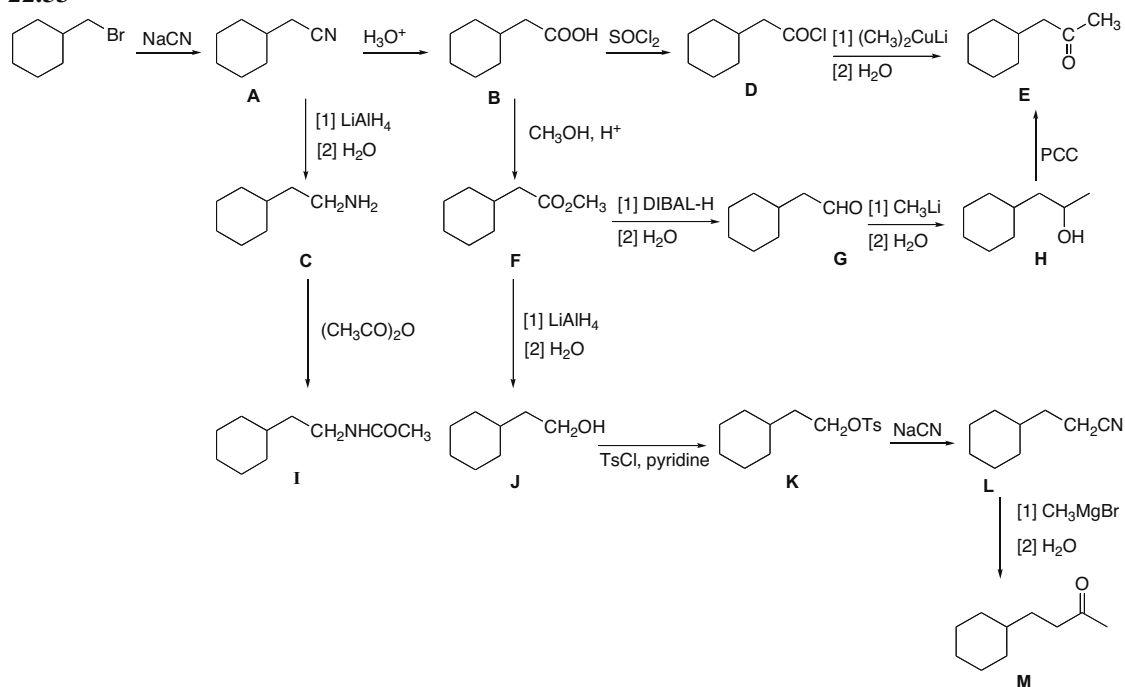


22.52 Both lactones and acetals are hydrolyzed with aqueous acid, but only lactones react with aqueous base.

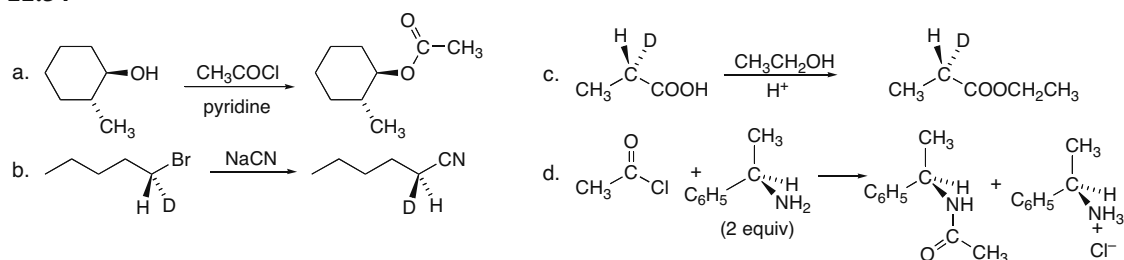


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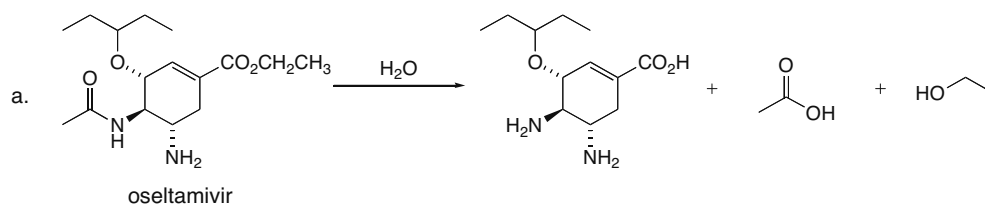
22.53



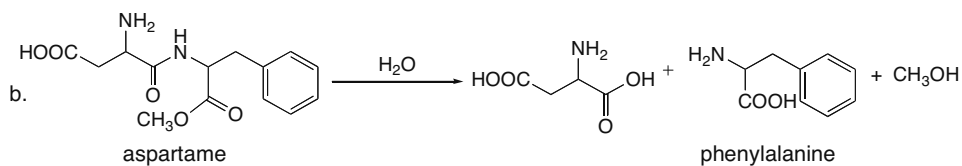
22.54



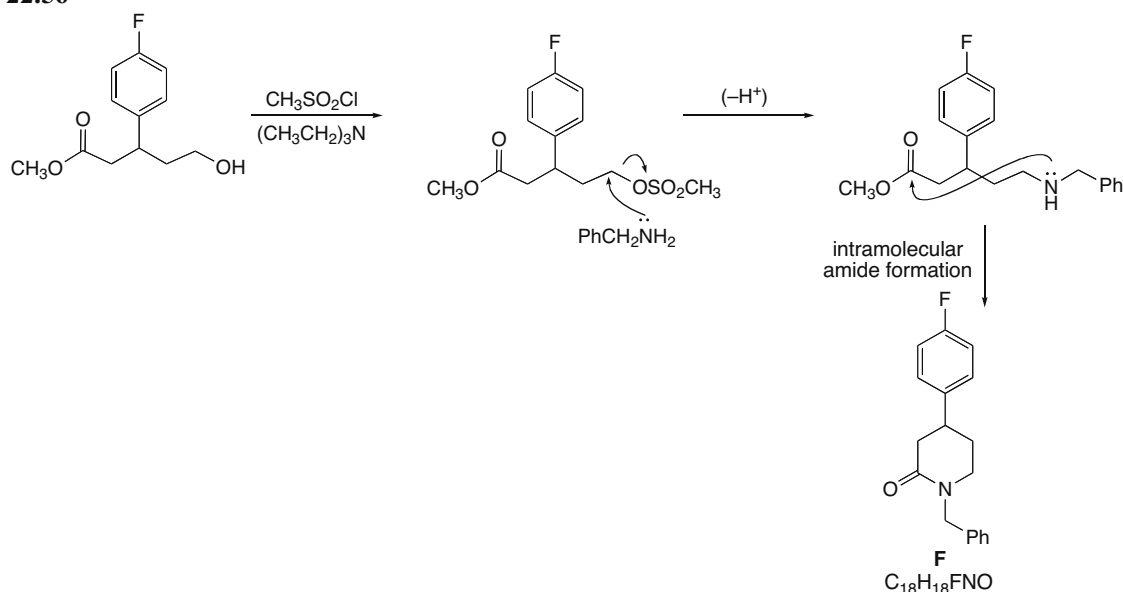
22.55 Hydrolyze the amide and ester bonds in both starting materials to draw the products.



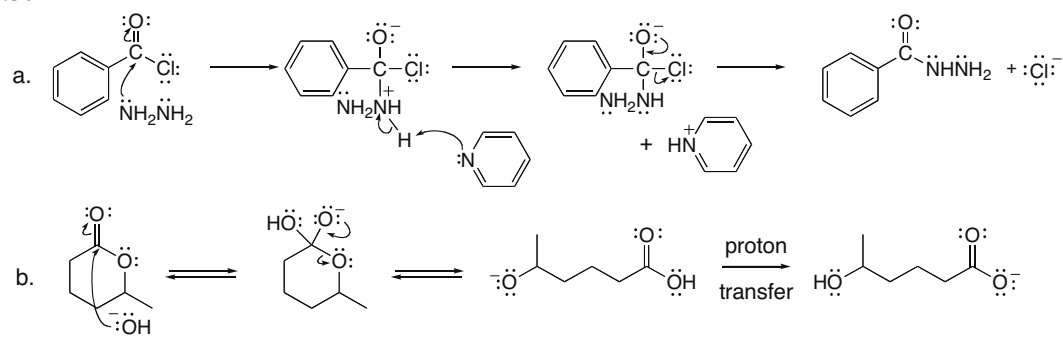
Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 22–21



22.56

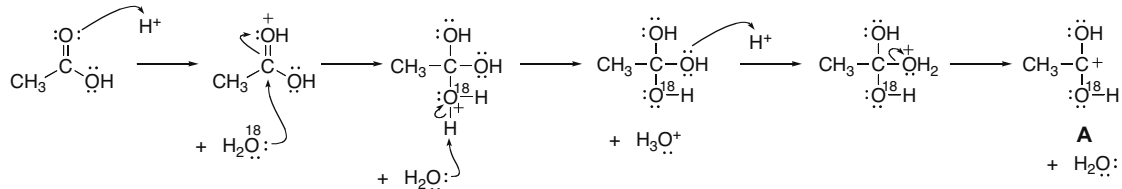
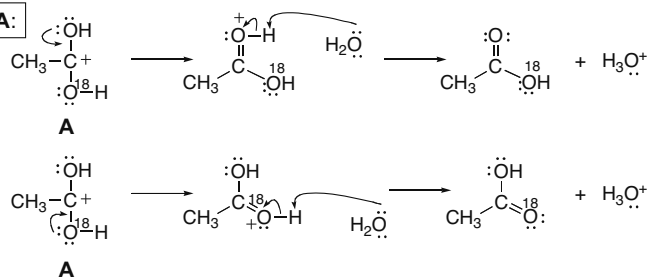


22.57

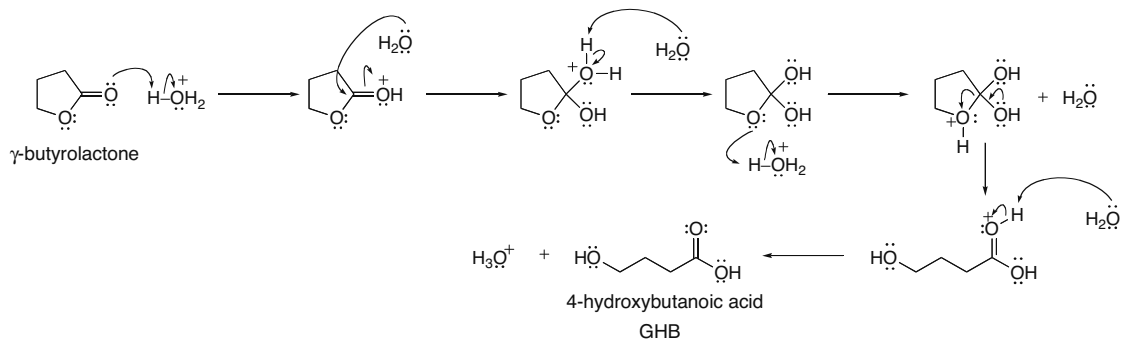


Chapter 22-22

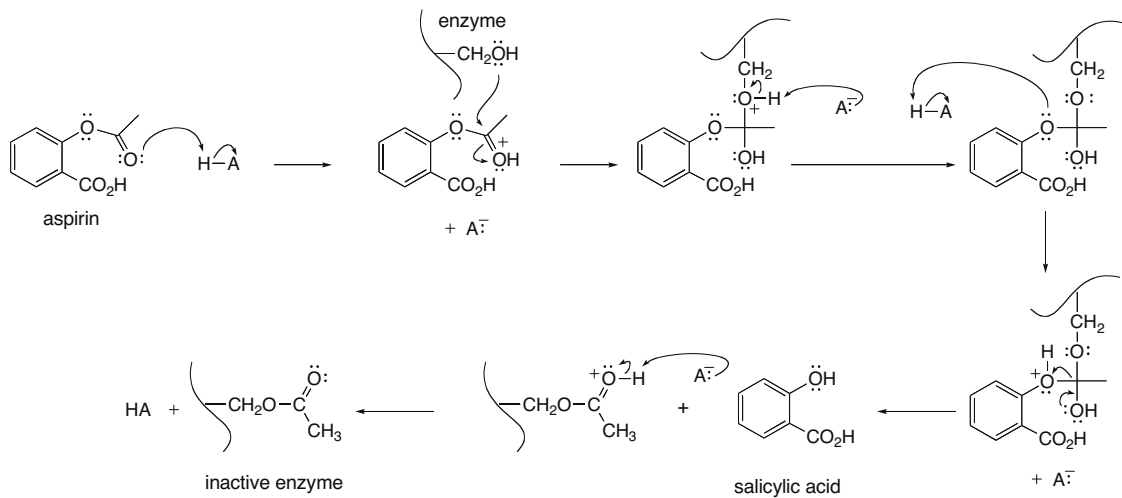
22.58

Two possibilities for **A**:

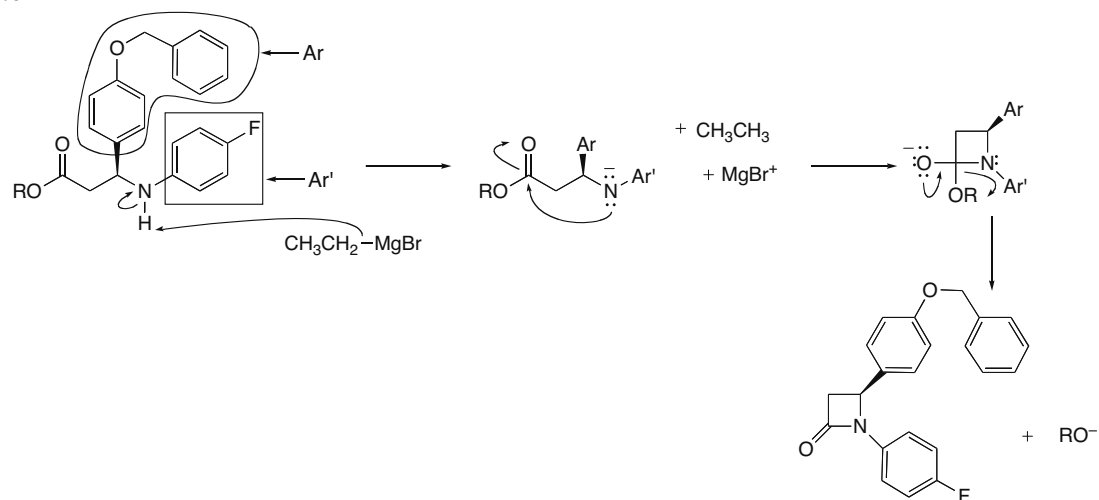
22.59



22.60



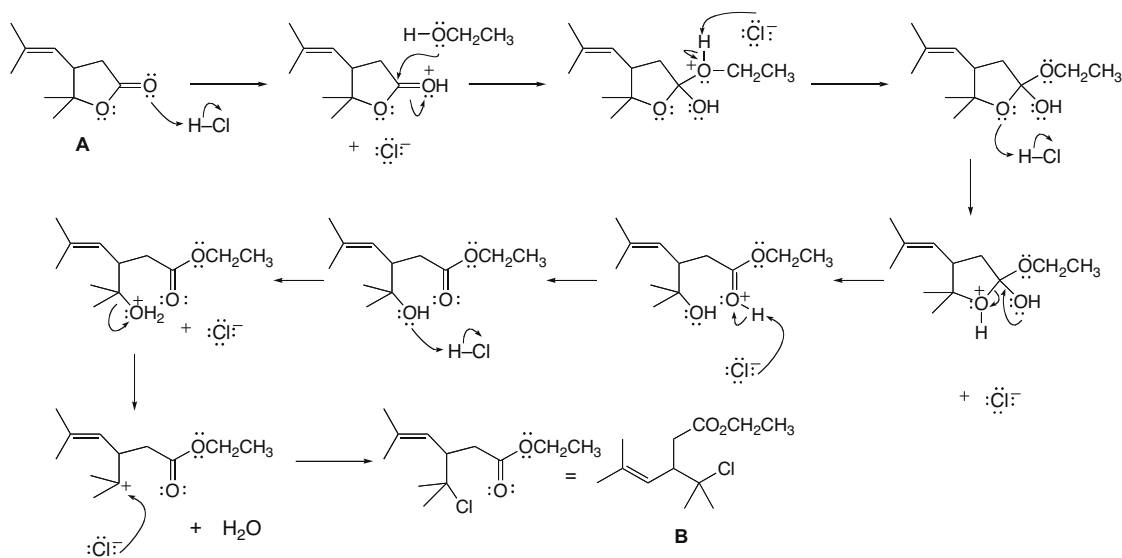
22.61



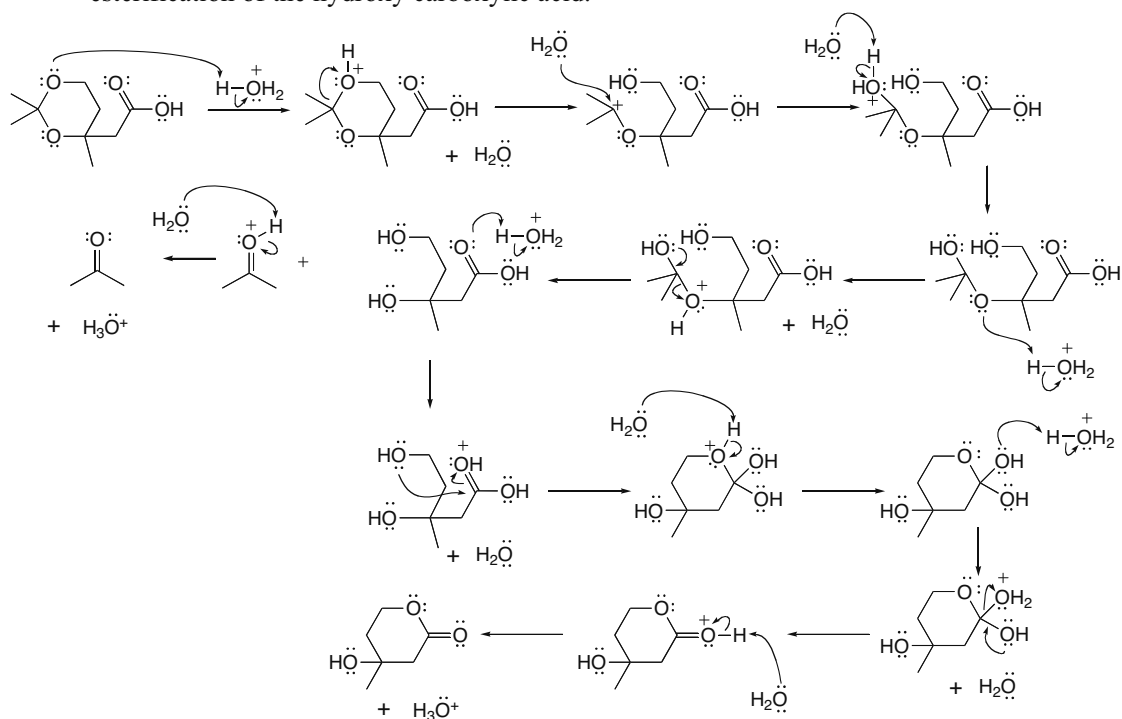
The reaction scheme illustrates the base-catalyzed ring opening of compound **1c** to form product **1d**. Compound **1c** is a bicyclic acetal with a methoxy group. Hydroxide ion (OH^-) attacks the acetal carbon, leading to ring opening and formation of a cyclic hemiacetal intermediate. This intermediate then undergoes proton transfer to yield the final product **1d**, which is a cyclopentenone derivative with a methoxy group and a hydroxyl group.

Chapter 22-24

22.63

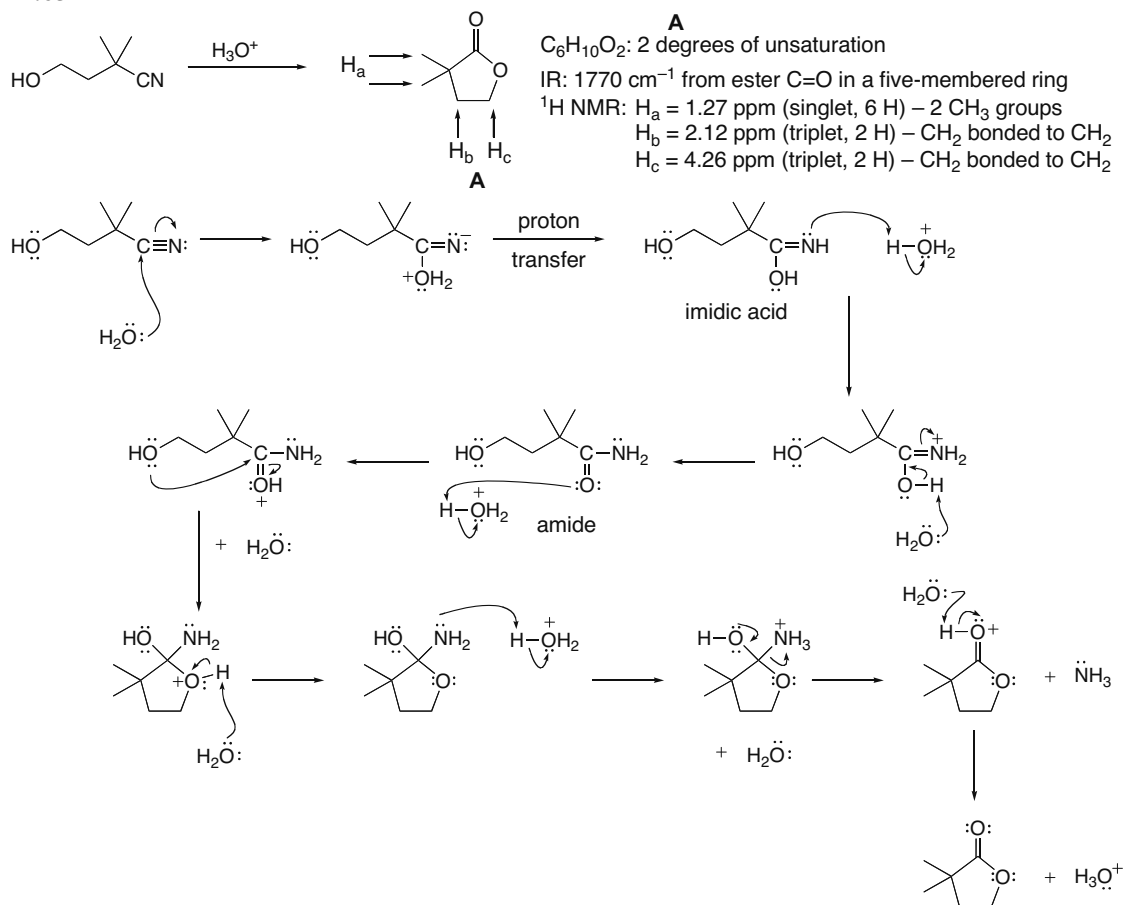


22.64 The mechanism is composed of two parts: hydrolysis of the acetal and intramolecular Fischer esterification of the hydroxy carboxylic acid.

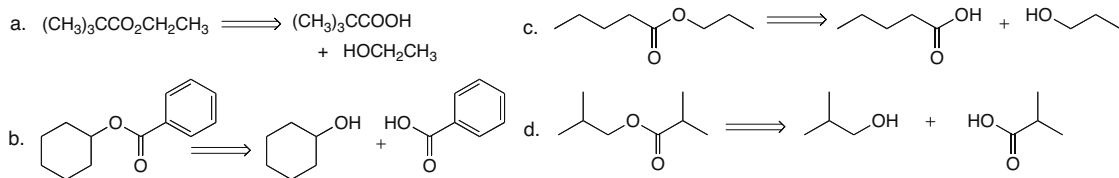


Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 22–25

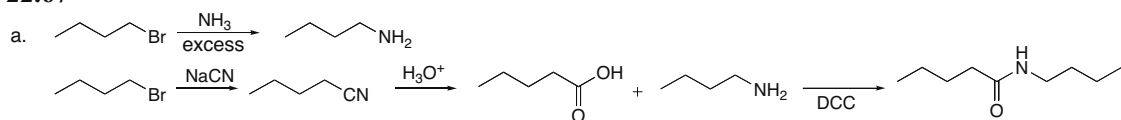
22.65



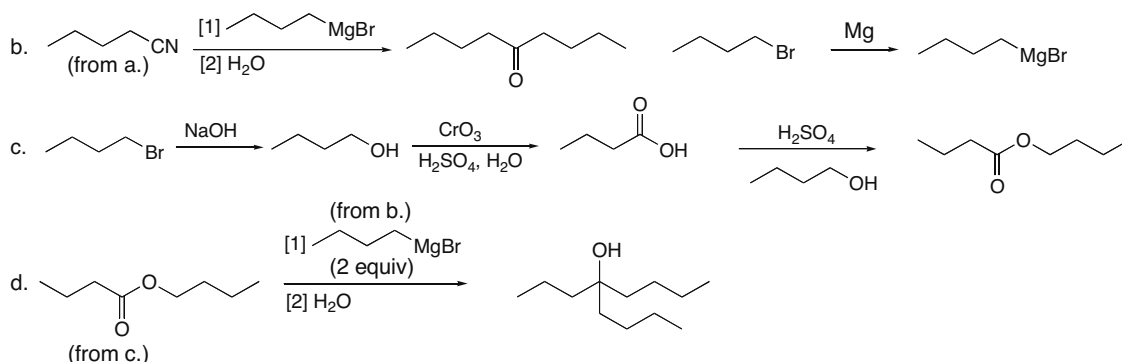
22.66 Fischer esterification is the treatment of a carboxylic acid with an alcohol in the presence of an acid catalyst to form an ester.



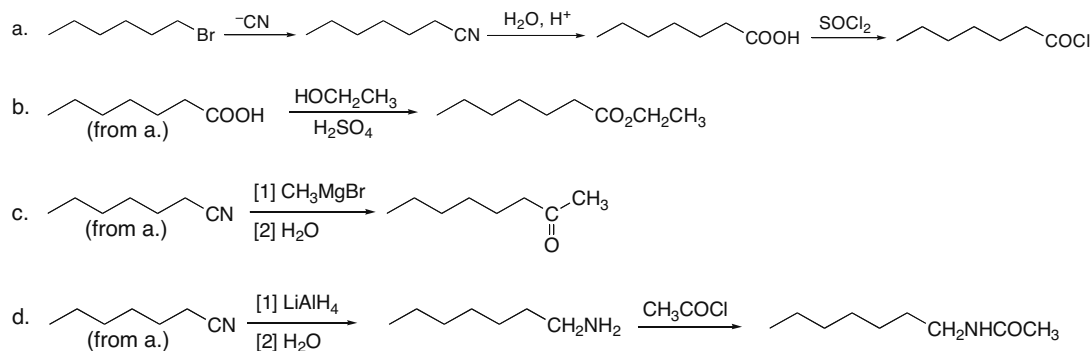
22.67



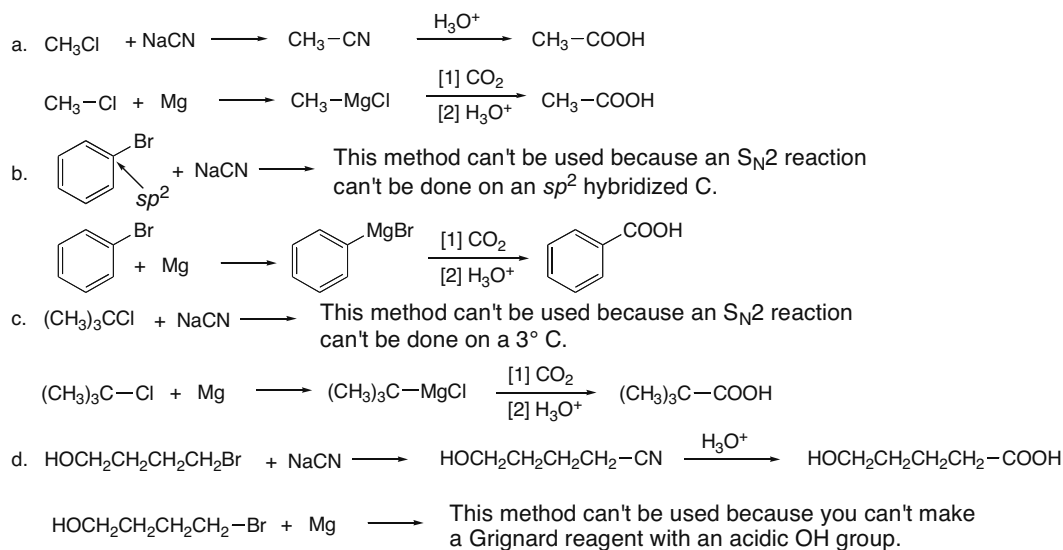
Chapter 22–26



22.68

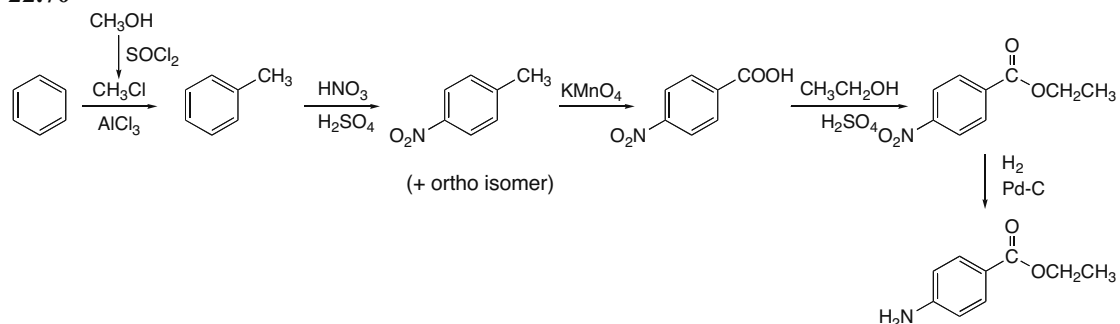


22.69

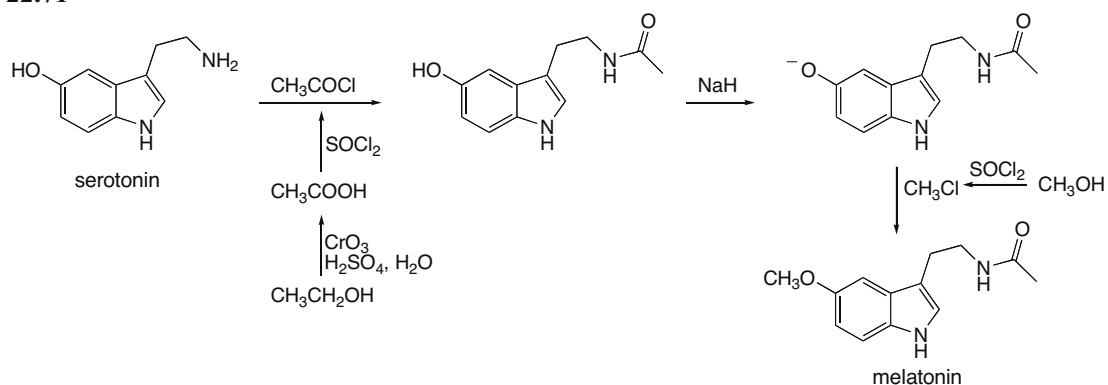


Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 22–27

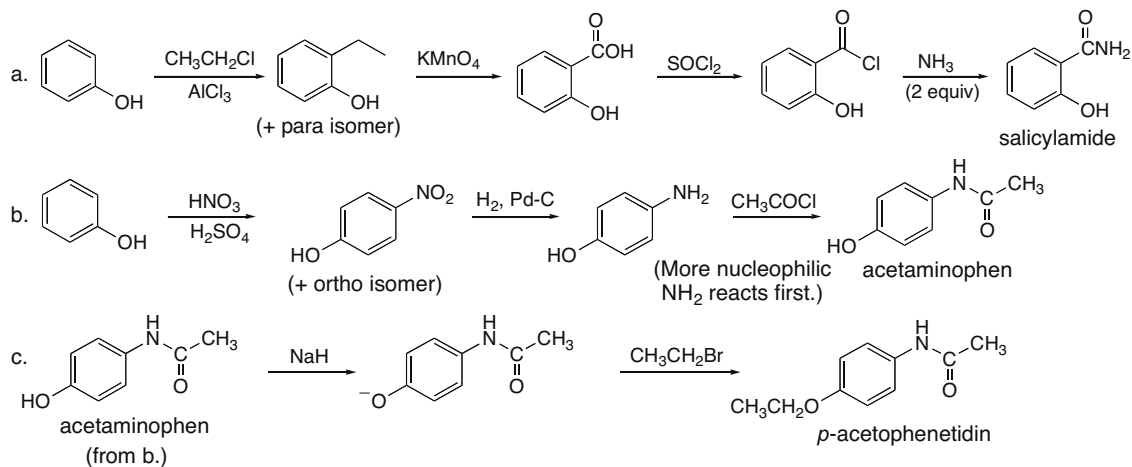
22.70



22.71

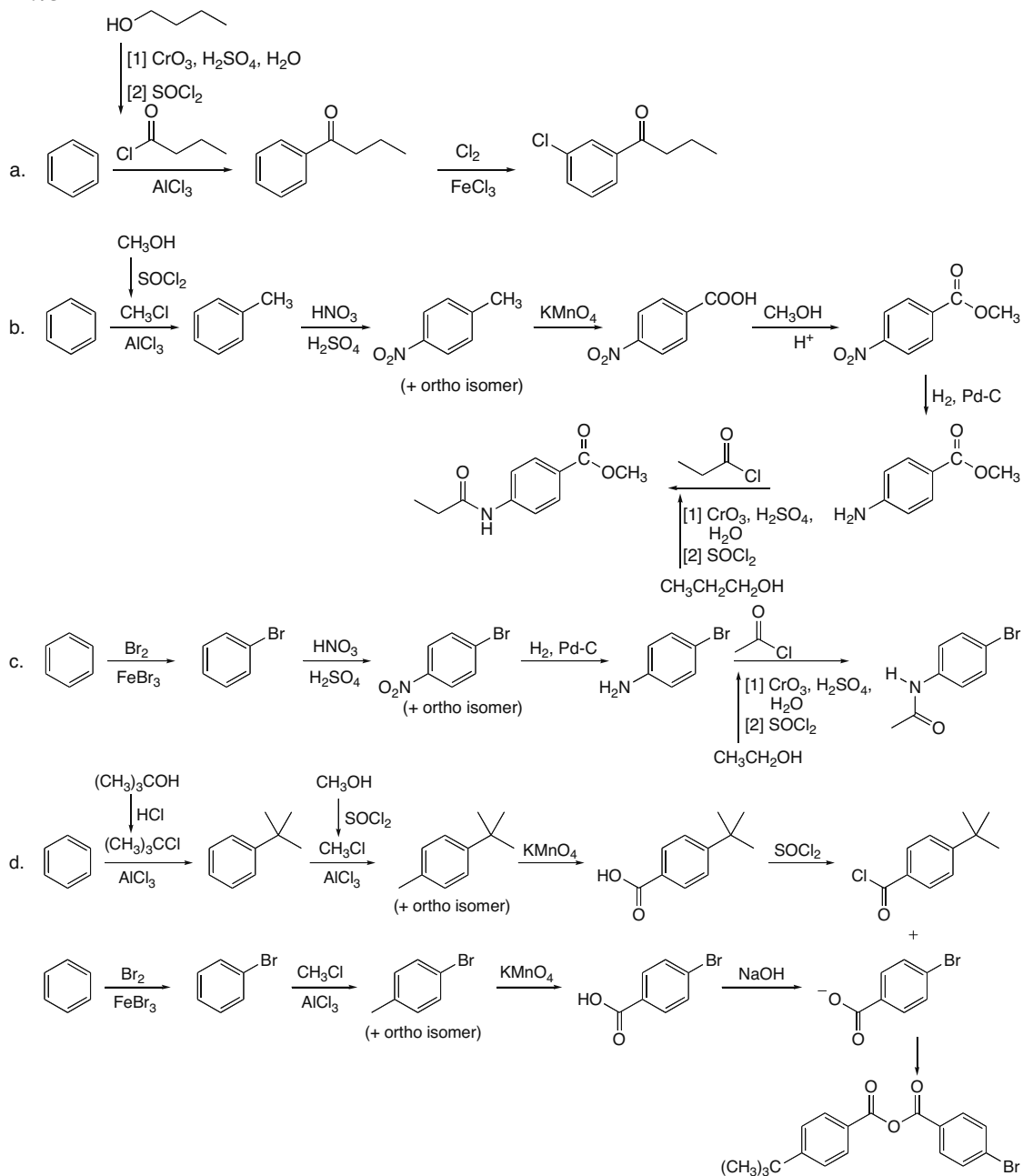


22.72



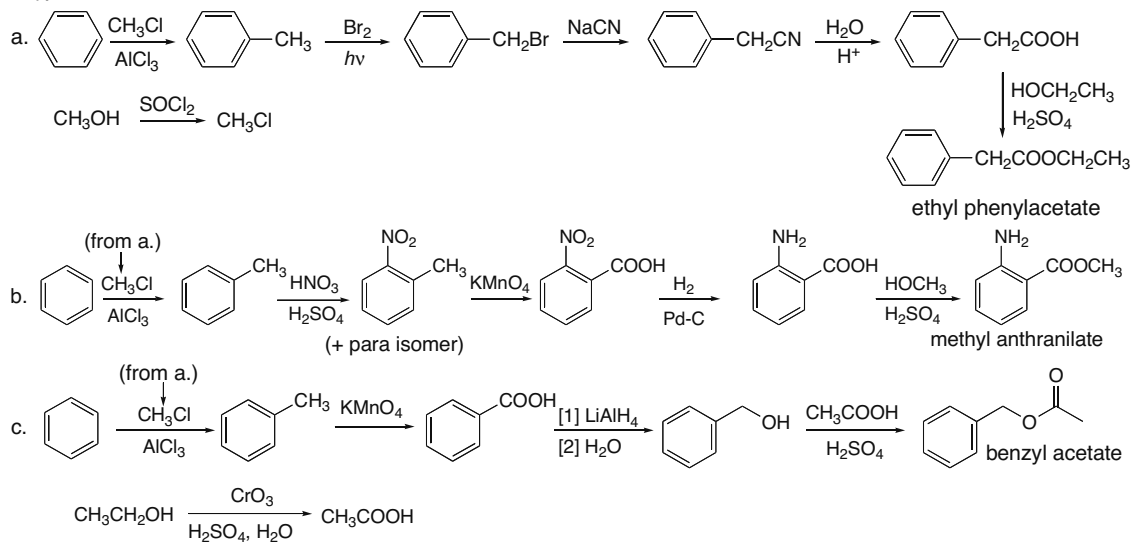
Chapter 22–28

22.73

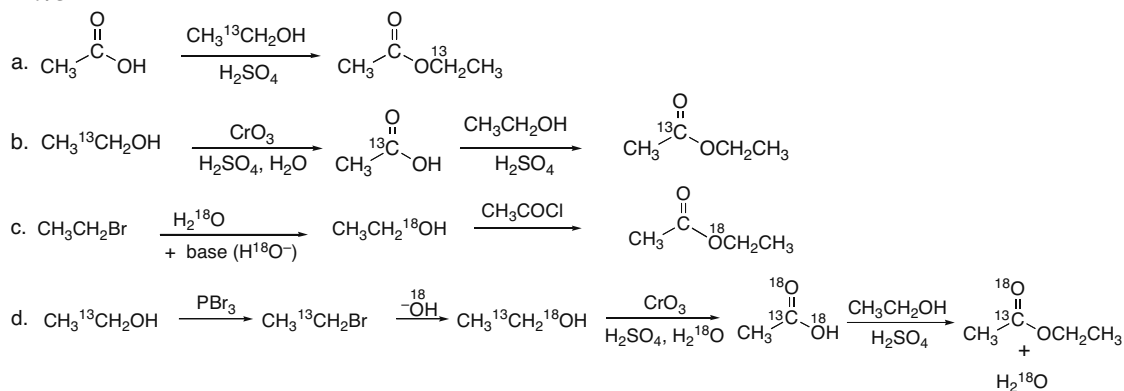


Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 22–29

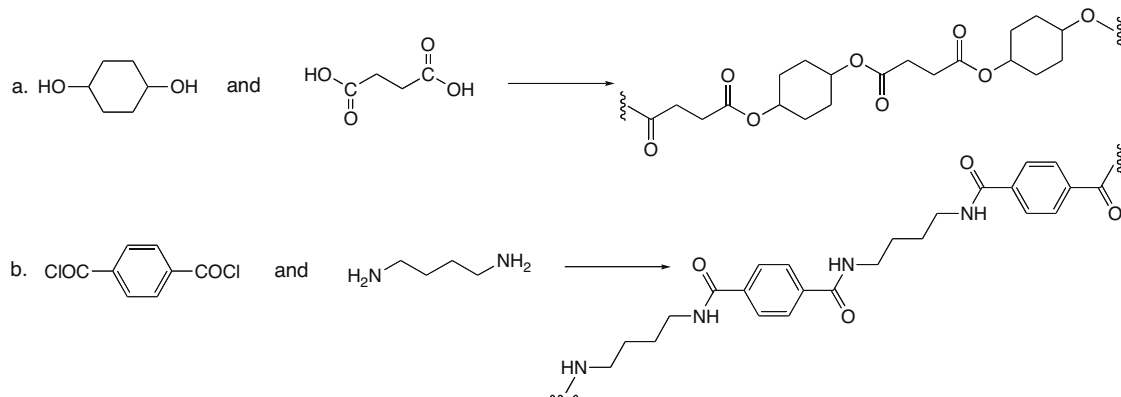
22.74



22.75

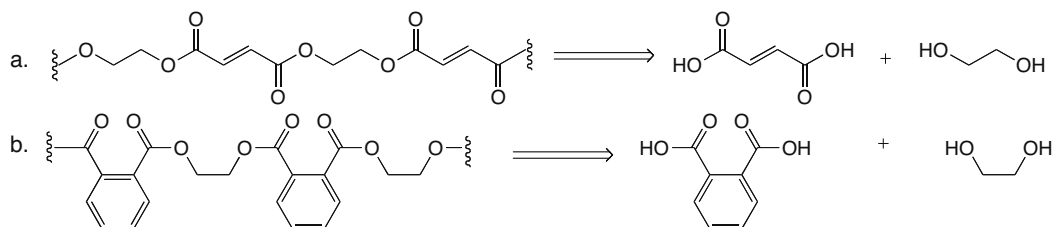


22.76



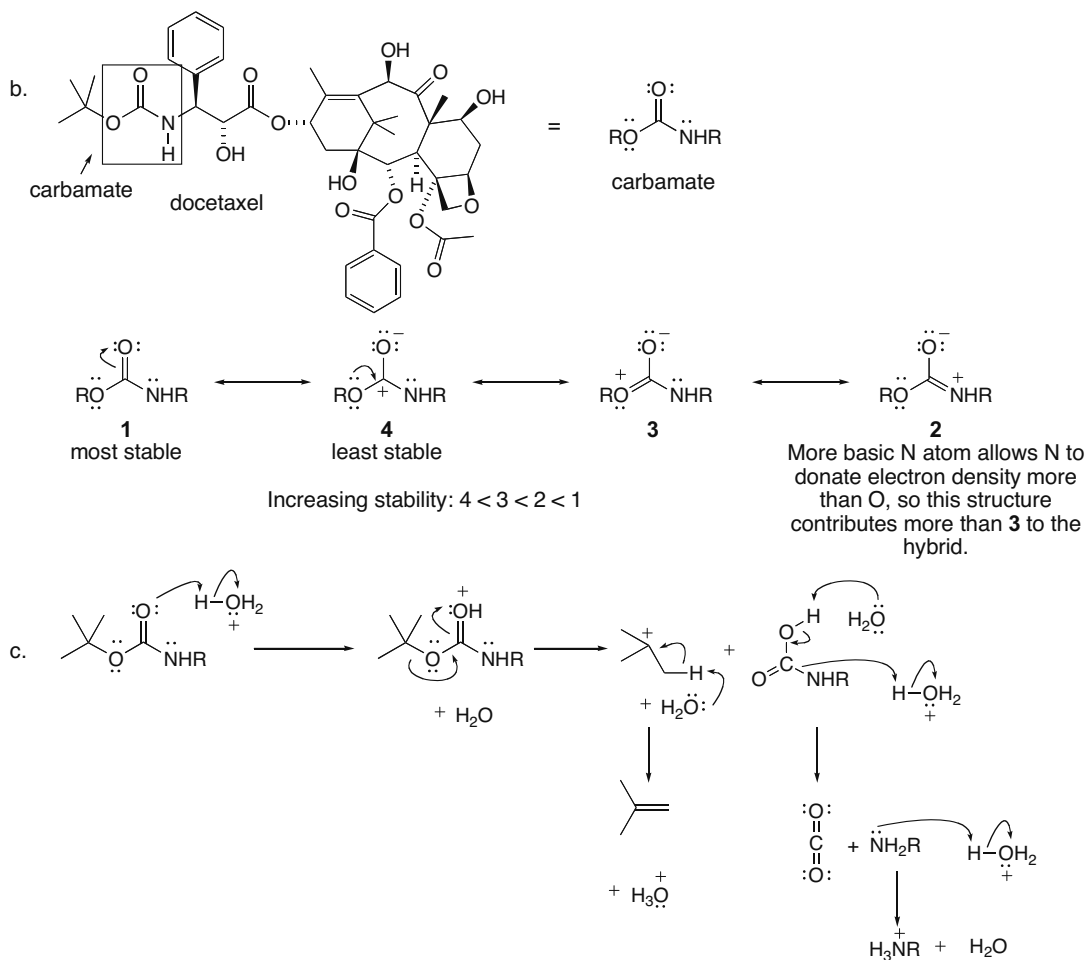
Chapter 22–30

22.77

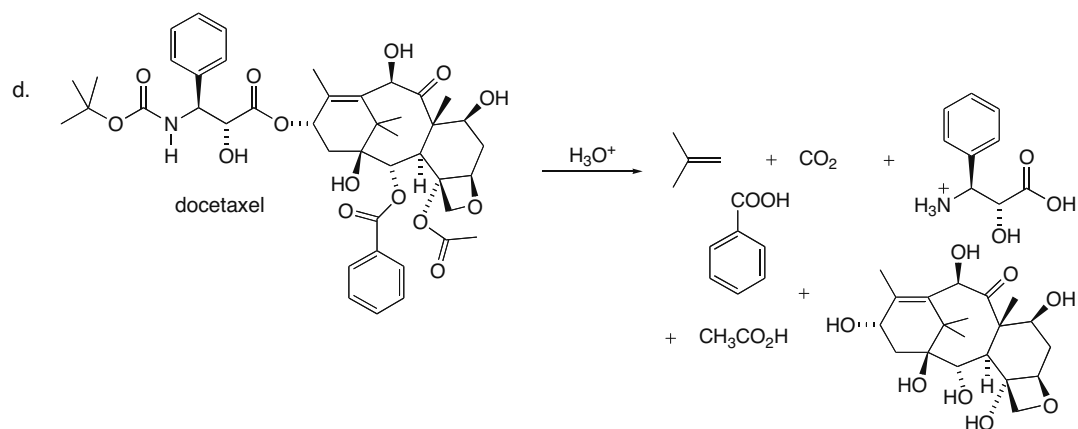


22.78

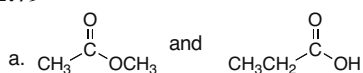
- a. Docetaxel has fewer C's and one more OH group than taxol. This makes docetaxel more water soluble than taxol.



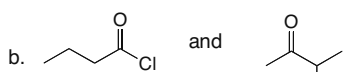
Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 22–31



22.79

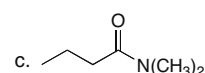


contains a broad, strong OH absorption at 3500–2500 cm^{-1}

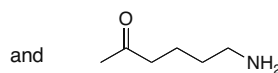


Acid chloride CO absorbs at much higher wavenumber.

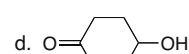
ketone



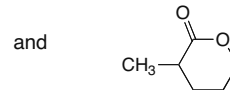
C=O at < 1700 cm^{-1} due to the stabilized amide



2 NH absorptions at 3200–3400 cm^{-1}
C=O absorption at higher wavenumber

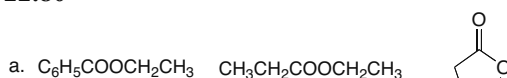


OH absorption at 3500–3200 cm^{-1} + C=O

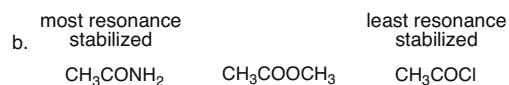


only C=O

22.80



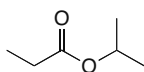
Increasing wavenumber



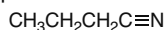
Increasing wavenumber

22.81

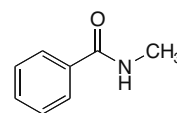
- a. $\text{C}_6\text{H}_{12}\text{O}_2 \rightarrow$ one degree of unsaturation
IR: 1738 $\text{cm}^{-1} \rightarrow \text{C}=\text{O}$
NMR: 1.12 (triplet, 3 H), 1.23 (doublet, 6 H),
2.28 (quartet, 2 H), 5.00 (septet, 1 H) ppm



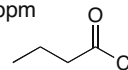
- b. $\text{C}_4\text{H}_7\text{N} \rightarrow$ triple bond
IR: 2250 $\text{cm}^{-1} \rightarrow$ triple bond
NMR: 1.08 (triplet, 3 H), 1.70 (multiplet, 2 H),
2.34 (triplet, 2 H) ppm



- c. $\text{C}_8\text{H}_9\text{NO} \rightarrow$ one degree of unsaturation
IR: 3328 (NH), 1639 (conjugated amide C=O) cm^{-1}
NMR: 2.95 (singlet, 3 H), 6.95 (singlet, 1 H),
7.3–7.7 (multiplet, 5 H) ppm

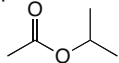


- d. $\text{C}_4\text{H}_7\text{ClO} \rightarrow$ one degree of unsaturation
IR: 1802 $\text{cm}^{-1} \rightarrow \text{C}=\text{O}$ (high wavenumber, RCOCl)
NMR: 0.95 (triplet, 3 H), 1.07 (multiplet, 2 H),
2.90 (triplet, 2 H) ppm

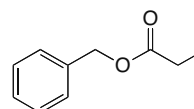


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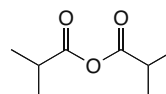
- e. $C_5H_{10}O_2 \rightarrow$ one degree of unsaturation
 IR: $1750\text{ cm}^{-1} \rightarrow C=O$
 NMR: 1.20 (doublet, 6 H), 2.00 (singlet, 3 H),
 4.95 (septet, 1 H) ppm



- f. $C_{10}H_{12}O_2 \rightarrow$ five degrees of unsaturation
 IR: $1740\text{ cm}^{-1} \rightarrow C=O$
 NMR: 1.2 (triplet, 3 H), 2.4 (quartet, 2 H),
 5.1 (singlet, 2 H), 7.1–7.5 (multiplet, 5 H) ppm



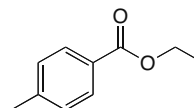
- g. $C_8H_{14}O_3 \rightarrow$ two degrees of unsaturation
 IR: $1810, 1770\text{ cm}^{-1} \rightarrow 2$ absorptions due to
 $C=O$ (anhydride)
 NMR: 1.25 (doublet, 12 H), 2.65 (septet, 2 H) ppm



22.82

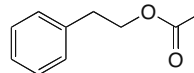
- A. Molecular formula $C_{10}H_{12}O_2 \rightarrow$ five degrees of unsaturation
 IR absorption at $1718\text{ cm}^{-1} \rightarrow C=O$
 NMR data (ppm):

triplet at 1.4 (CH_3 adjacent to 2 H's)
 singlet at 2.4 (CH_3)
 quartet at 4.4 (CH_2 adjacent to CH_3)
 doublet at 7.2 (2 H's on benzene ring)
 doublet at 7.9 (2 H's on benzene ring)



- B. IR absorption at $1740\text{ cm}^{-1} \rightarrow C=O$
 NMR data (ppm):

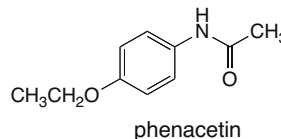
singlet at 2.0 (CH_3)
 triplet at 2.9 (CH_2 adjacent to CH_2)
 triplet at 4.4 (CH_2 adjacent to CH_2)
 multiplet at 7.3 (5 H's, monosubstituted benzene)



22.83

- Molecular formula $C_{10}H_{13}NO_2 \rightarrow$ five degrees of unsaturation
 IR absorptions at 3300 (NH) and 1680 cm^{-1} ($C=O$, amide or conjugated)
 NMR data (ppm):

triplet at 1.4 (CH_3 adjacent to CH_2)
 singlet at 2.2 ($CH_3C=O$)
 quartet at 3.9 (CH_2 adjacent to CH_3)
 doublet at 6.8 (2 H's on benzene ring)
 singlet at 7.2 (NH)
 doublet at 7.4 (2 H's on benzene ring)

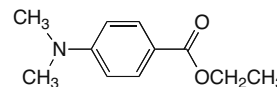


phenacetin

22.84

- Molecular formula $C_{11}H_{15}NO_2 \rightarrow$ five degrees of unsaturation
 IR absorption 1699 cm^{-1} ($C=O$, amide or conjugated)
 NMR data (ppm):

triplet at 1.3 (3 H) (CH_3 adjacent to CH_2)
 singlet at 3.0 (6 H) (2 CH_3 groups on N)
 quartet at 4.3 (2 H) (CH_2 adjacent to CH_3)
 doublet at 6.6 (2 H) (2 H's on benzene ring)
 doublet at 7.9 (2 H) (2 H's on benzene ring)

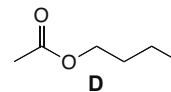


C

Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 22–33

22.85

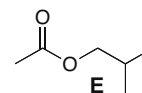
- a. Molecular formula
- $C_6H_{12}O_2 \rightarrow$
- one degree of unsaturation

IR absorption at $1743\text{ cm}^{-1} \rightarrow C=O$ ^1H NMR data (ppm):triplet at 0.9 (3 H) – CH_3 adjacent to CH_2 multiplet at 1.35 (2 H) – CH_2 multiplet at 1.60 (2 H) – CH_2 singlet at 2.1 (3 H) – from CH_3 bonded to $C=O$ triplet at 4.1 (2 H) – CH_2 adjacent to the electronegative O atom and another CH_2 

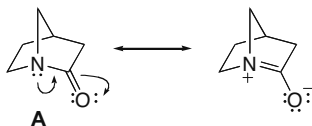
- b. Molecular formula
- $C_6H_{12}O_2 \rightarrow$
- one degree of unsaturation

IR absorption at $1746\text{ cm}^{-1} \rightarrow C=O$ ^1H NMR data (ppm):doublet at 0.9 (6 H) – 2 CH_3 's adjacent to CH

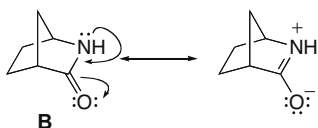
multiplet at 1.9 (1 H)

singlet at 2.1 (3 H) – CH_3 bonded to $C=O$ doublet at 3.85 (2 H) – CH_2 bonded to electronegative O and CH

- 22.86 The extent of resonance stabilization affects the position of the
- $C=O$
- absorption in the IR of an amide.

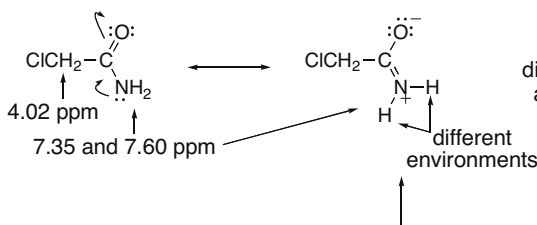


This resonance structure does not contribute significantly to the hybrid because it places a double bond at the bridgehead N, an impossible geometry in small rings. The $C=O$ has more double bond character, so the absorption is at a higher wavenumber.



This resonance structure contributes significantly to the hybrid, so the $C=O$ has more single bond character. The absorption shifts to a lower wavenumber.

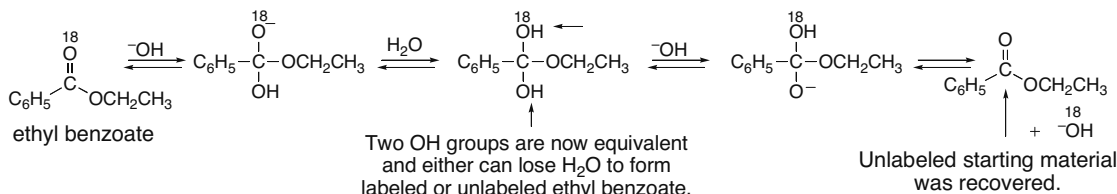
22.87



There is restricted rotation around the amide $C-N$ bond. The 2 H's are in different environments (one is cis to an O atom, and one is cis to CH_2Cl), so they give different NMR signals.

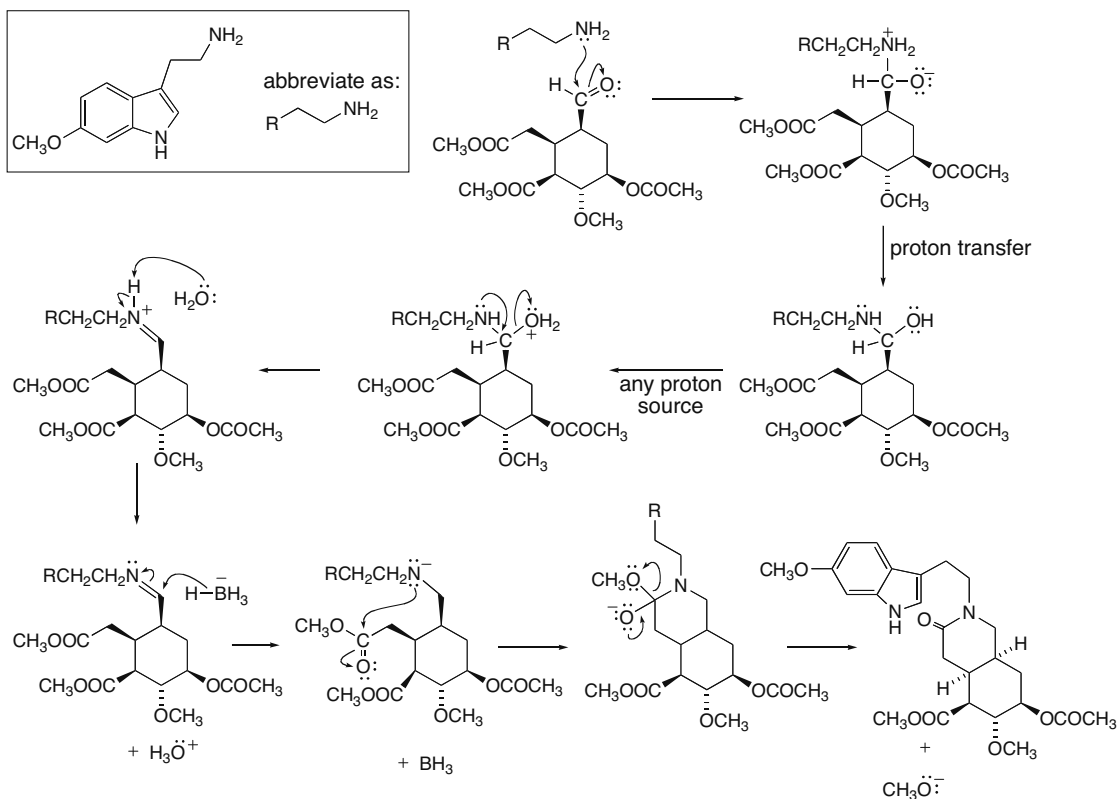
This resonance structure makes a significant contribution to the resonance hybrid.

22.88



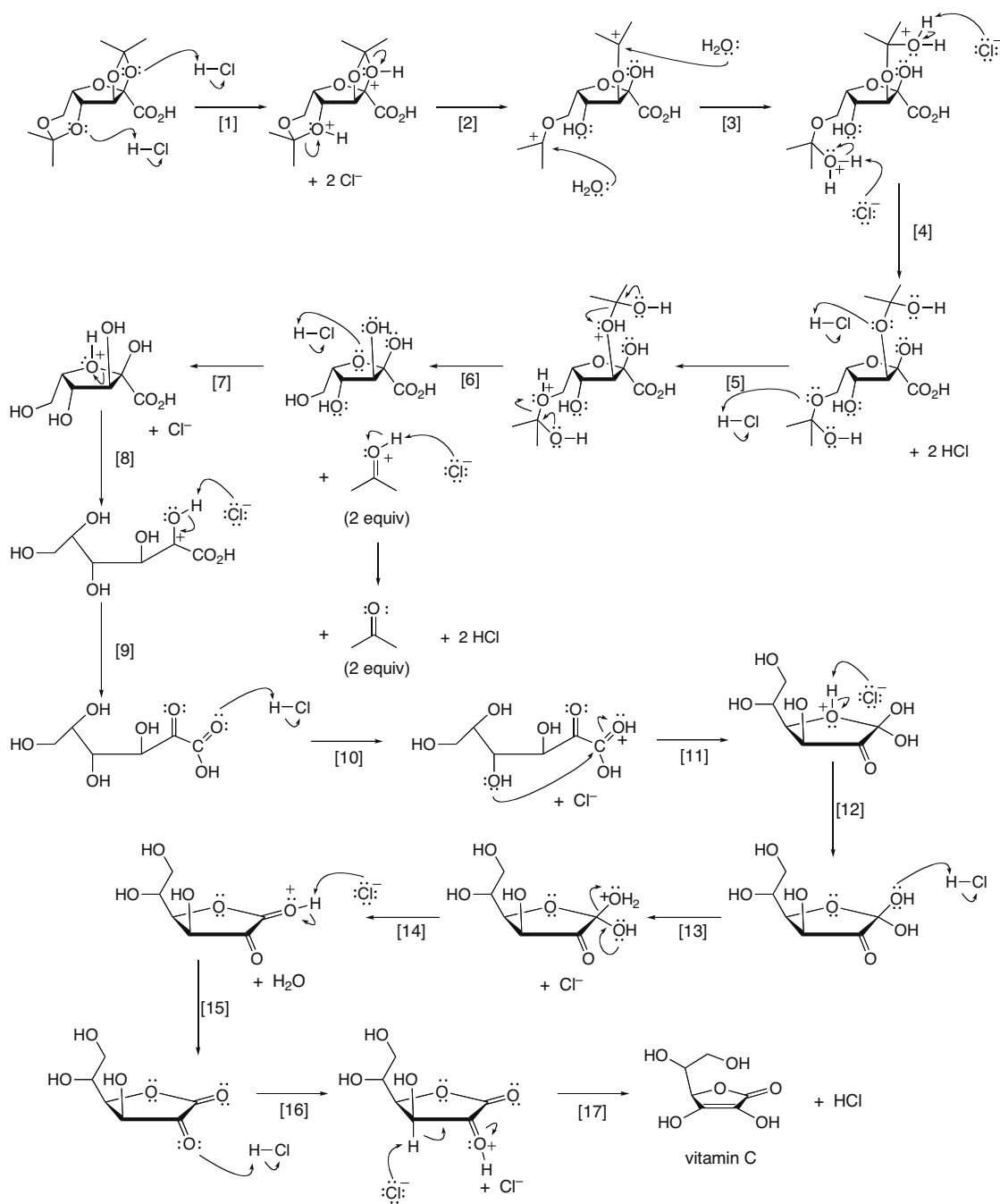
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22.89



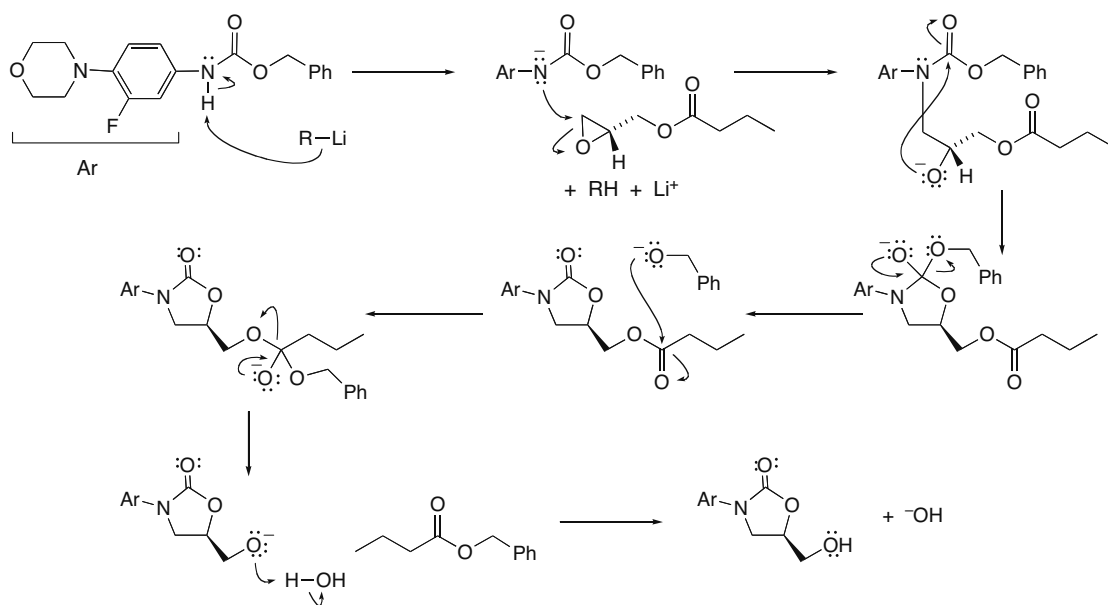
22.90 Both acetals are hydrolyzed by the usual mechanism for acetal hydrolysis (Steps [1–[6]], forming four new OH groups. Intramolecular esterification forms a lactone (Steps [10]–[15]), followed by conversion of a carbonyl tautomer to an enol (Steps [16]–[17]). Both acetals are hydrolyzed at once in the given mechanism.

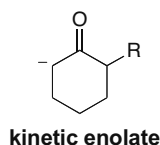
Carboxylic Acids and Their Derivatives—Nucleophilic Acyl Substitution 22–35



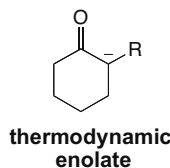
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22.91

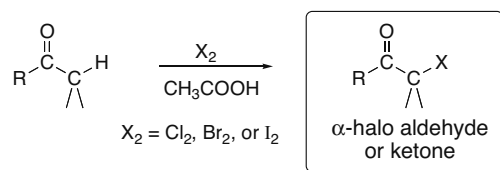


Substitution Reactions of Carbonyl Compounds at the α Carbon 23-1**Chapter 23 Substitution Reactions of Carbonyl Compounds at the α Carbon****Chapter Review****Kinetic versus thermodynamic enolates (23.4)****Kinetic enolate**

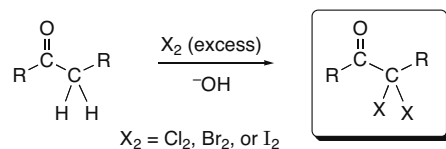
- The less substituted enolate
- Favored by strong base, polar aprotic solvent, low temperature: LDA, THF, -78°C

**Thermodynamic enolate**

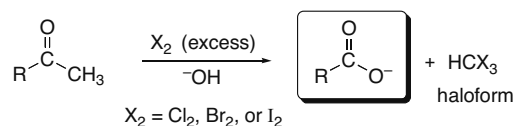
- The more substituted enolate
- Favored by strong base, protic solvent, higher temperature: $\text{NaOCH}_2\text{CH}_3$, $\text{CH}_3\text{CH}_2\text{OH}$, room temperature

Halogenation at the α carbon**[1] Halogenation in acid (23.7A)**

- The reaction occurs via enol intermediates.
- Monosubstitution of X for H occurs on the α carbon.

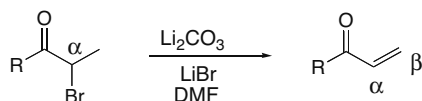
[2] Halogenation in base (23.7B)

- The reaction occurs via enolate intermediates.
- Polysubstitution of X for H occurs on the α carbon.

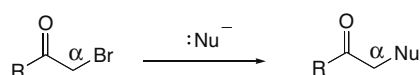
[3] Halogenation of methyl ketones in base—The haloform reaction (23.7B)

- The reaction occurs with methyl ketones and results in cleavage of a carbon-carbon σ bond.

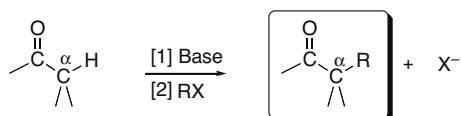
Chapter 23-2

Reactions of α -halo carbonyl compounds (23.7C)**[1] Elimination to form α,β -unsaturated carbonyl compounds**

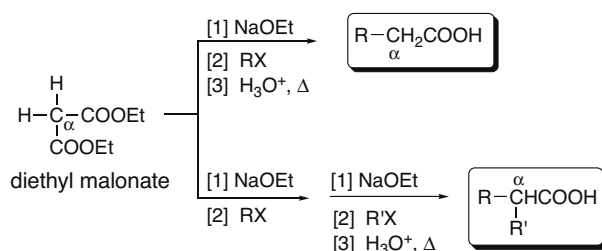
- Elimination of the elements of Br and H forms a new π bond, giving an α,β -unsaturated carbonyl compound.

[2] Nucleophilic substitution

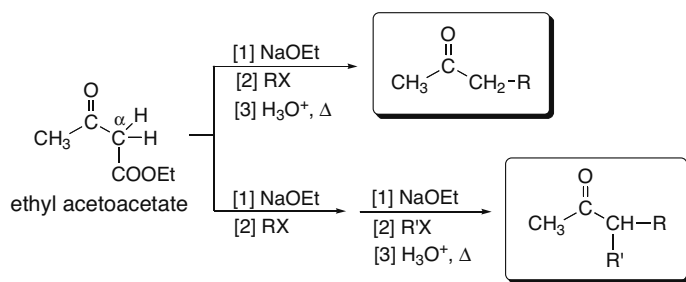
- The reaction follows an $\text{S}_{\text{N}}2$ mechanism, generating an α -substituted carbonyl compound.

Alkylation reactions at the α carbon**[1] Direct alkylation at the α carbon (23.8)**

- The reaction forms a new C–C bond to the α carbon.
- LDA is a common base used to form an intermediate enolate.
- The alkylation in Step [2] follows an $\text{S}_{\text{N}}2$ mechanism.

[2] Malonic ester synthesis (23.9)

- The reaction is used to prepare carboxylic acids with one or two alkyl groups on the α carbon.
- The alkylation in Step [2] follows an $\text{S}_{\text{N}}2$ mechanism.

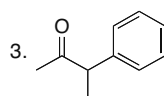
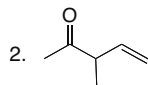
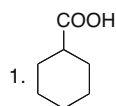
[3] Acetoacetic ester synthesis (23.10)

- The reaction is used to prepare ketones with one or two alkyl groups on the α carbon.
- The alkylation in Step [2] follows an $\text{S}_{\text{N}}2$ mechanism.

Substitution Reactions of Carbonyl Compounds at the α Carbon 23-3

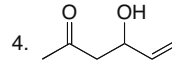
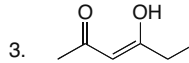
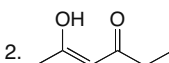
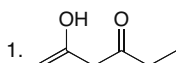
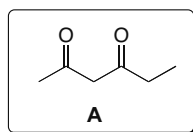
Practice Test on Chapter Review

1. a. Which of the following compounds can be prepared using either the acetoacetic ester or malonic ester syntheses?



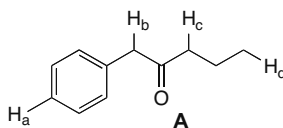
4. Both [1] and [2] can be prepared by one of these routes.
5. Compounds [1], [2], and [3] can all be prepared by these routes.

- b. Which of the following compounds is **not** an enol form of dicarbonyl compound **A**?

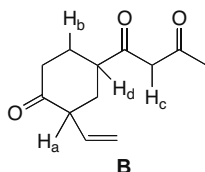


5. Compounds [1]–[4] are all enols of **A**.

2. a. Which proton in compound **A** has the *lowest* pK_a ?
b. Which proton in compound **A** has the *highest* pK_a ?



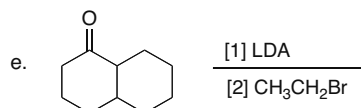
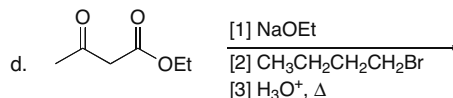
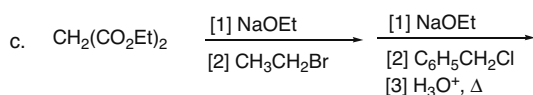
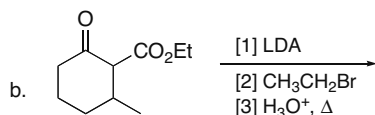
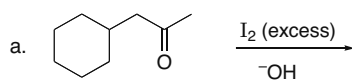
- c. What proton in compound **B** is the least acidic?
d. What proton in compound **B** is the most acidic?



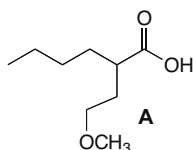
3. What reagents are needed to convert 4-heptanone to each compound?
a. 3-bromo-4-heptanone
b. 3-methyl-4-heptanone
c. 3,5-dimethyl-4-heptanone
d. 2-hepten-4-one
e. 2-methyl-4-heptanone

Chapter 23-4

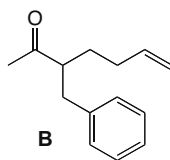
4. Draw the organic products formed in each of the following reactions.



5. a. What starting materials are needed to synthesize carboxylic acid **A** by a malonic ester synthesis?



b. What starting materials are needed to synthesize ketone **B** by the acetoacetic ester synthesis?



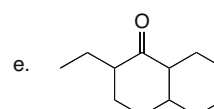
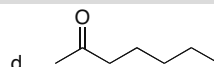
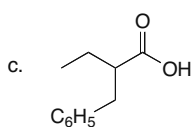
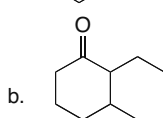
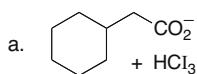
Answers to Practice Test

1. a. 1
b. 4

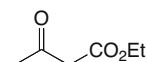
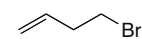
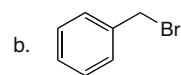
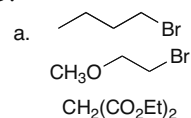
2. a. H_b
b. H_d
c. H_b
d. H_c

3. a. Br₂, CH₃CO₂H
b. [1] LDA; [2] CH₃I
c. [1] LDA; [2] CH₃I; [3] LDA; [4] CH₃I
d. [1] Br₂, CH₃CO₂H; [2] Li₂CO₃, LiBr, DMF
e. [1] Br₂, CH₃CO₂H; [2] Li₂CO₃, LiBr, DMF; [3] (CH₃)₂CuLi; [4] H₂O

4.



5.

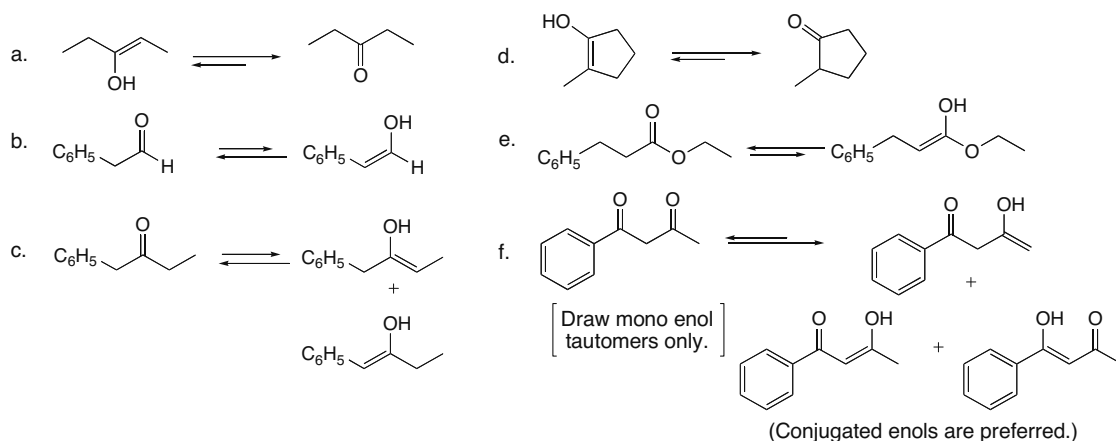


Substitution Reactions of Carbonyl Compounds at the α Carbon 23-5

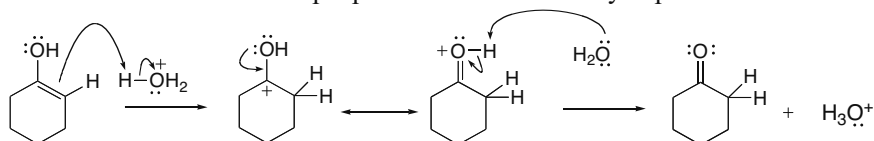
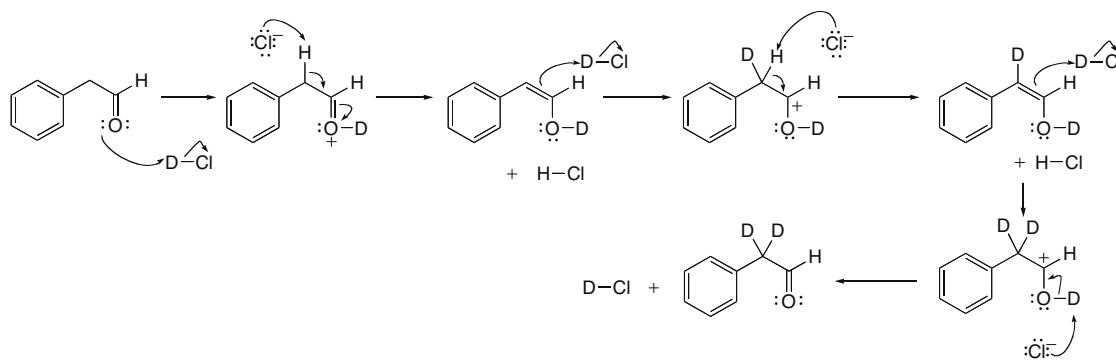
Answers to Problems

- 23.1**
- To convert a ketone to its enol tautomer, change the $C=O$ to $C-OH$, make a new double bond to an α carbon, and remove a proton at the other end of the $C=C$.
 - To convert an enol to its keto form, find the $C=C$ bonded to the OH . Change the $C-OH$ to a $C=O$, add a proton to the other end of the $C=C$, and delete the double bond.

[In cases where *E* and *Z* isomers are possible, only one stereoisomer is drawn.]

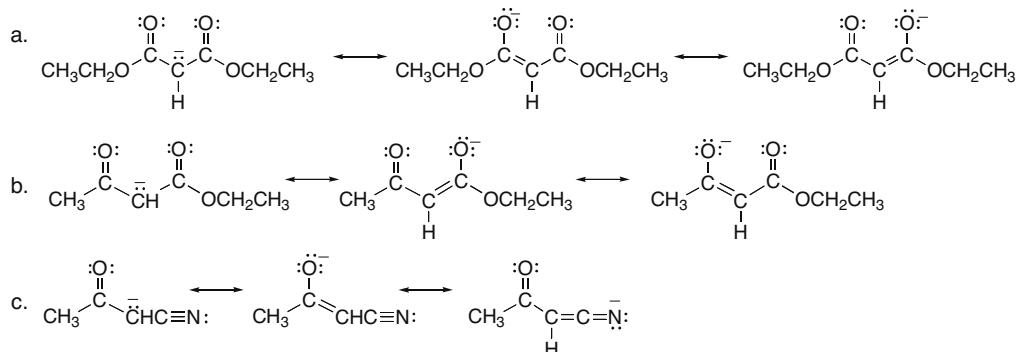


- 23.2** The mechanism has two steps: protonation followed by deprotonation.

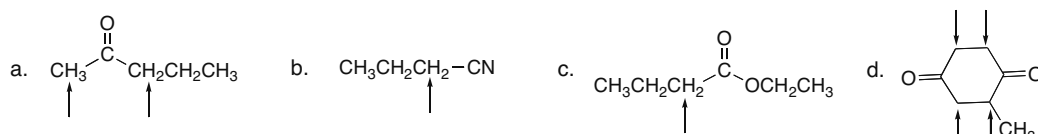
**23.3**

Chapter 23-6

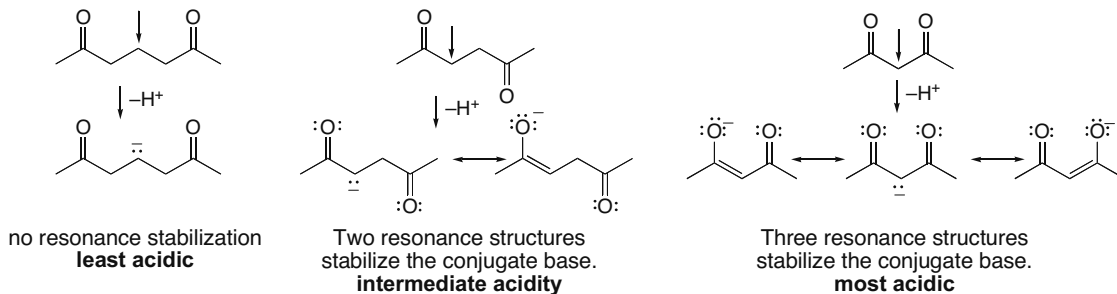
23.4



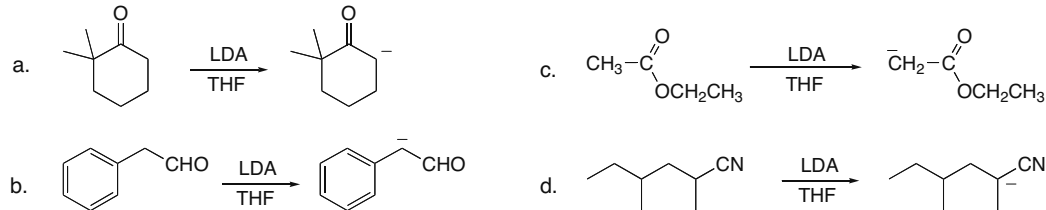
23.5 The indicated H's are α to a C=O or C $\equiv$ N group, making them more acidic because their removal forms conjugate bases that are resonance stabilized.



23.6

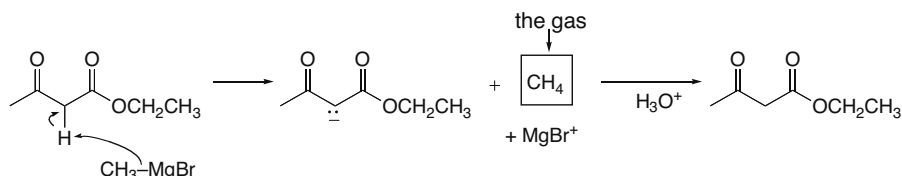


23.7 In each of the reactions, the LDA pulls off the most acidic proton.



Substitution Reactions of Carbonyl Compounds at the α Carbon 23-7

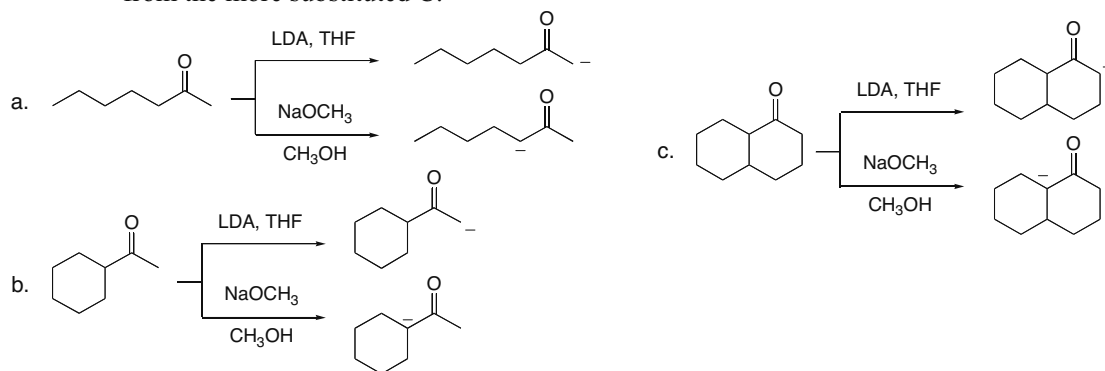
23.8



The CH_2 between the two $\text{C}=\text{O}$'s contains acidic H 's, so CH_3MgBr reacts as a base to remove a proton. Thus, proton transfer (not nucleophilic addition) occurs.

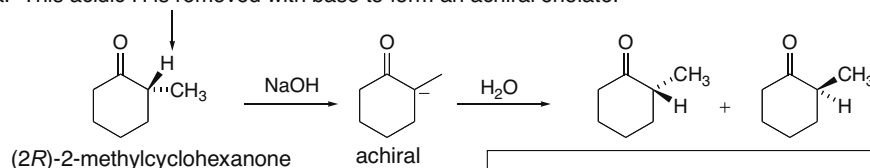
23.9 In addition to being strong bases, organolithiums are good nucleophiles that can add to a carbonyl group instead of pulling off a proton to generate an enolate.

- 23.10**
- LDA, THF forms the kinetic enolate by removing a proton from the less substituted C.
 - Treatment with NaOCH_3 , CH_3OH forms the thermodynamic enolate by removing a proton from the more substituted C.

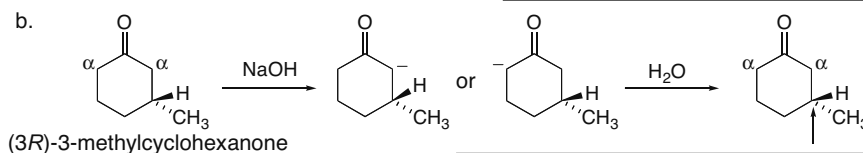


23.11

a. This acidic H is removed with base to form an achiral enolate.



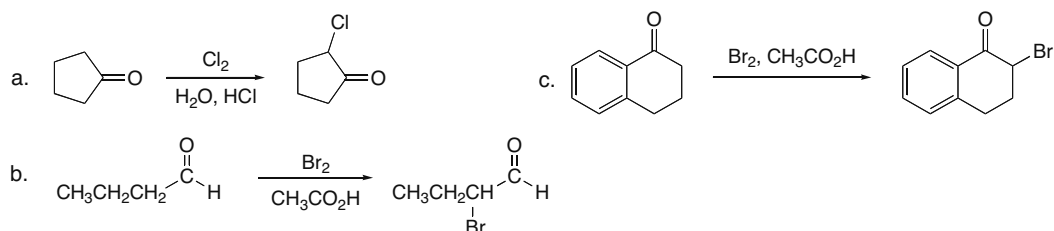
Protonation of the planar achiral enolate occurs with equal probability from two sides, so a racemic mixture is formed. The racemic mixture is optically inactive.



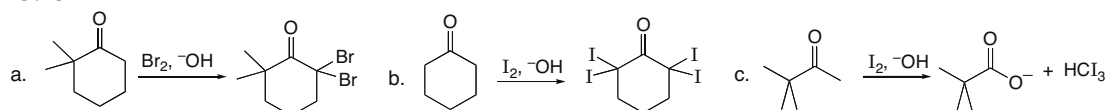
This stereogenic center is not located at the α carbon, so it is not deprotonated with base. Its configuration is retained in the product, and the product remains optically active.

Chapter 23–8

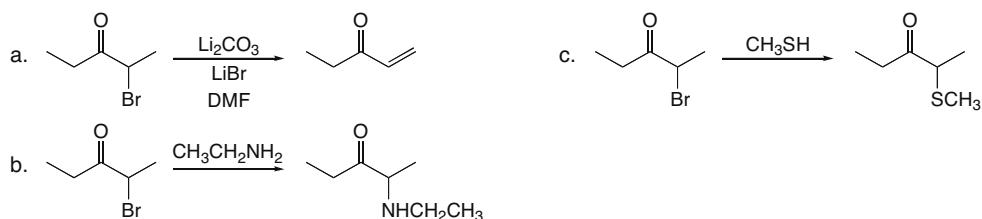
23.12



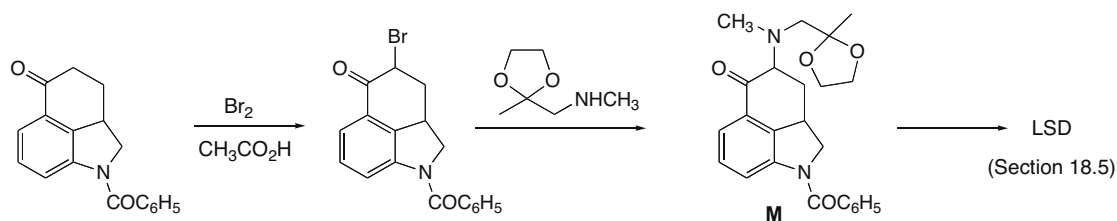
23.13



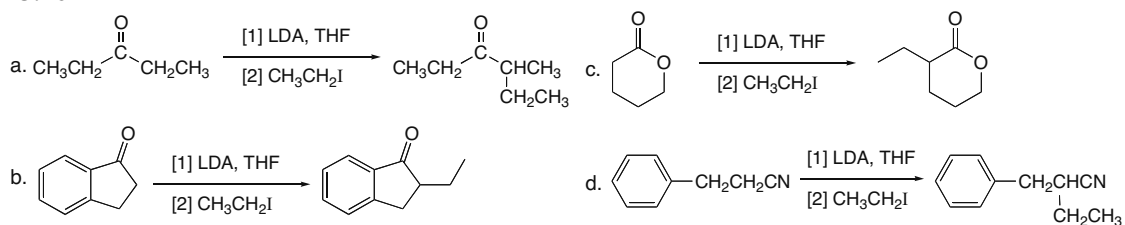
23.14



23.15 Bromination takes place on the α carbon to the carbonyl, followed by an S_N2 reaction with the nitrogen nucleophile.

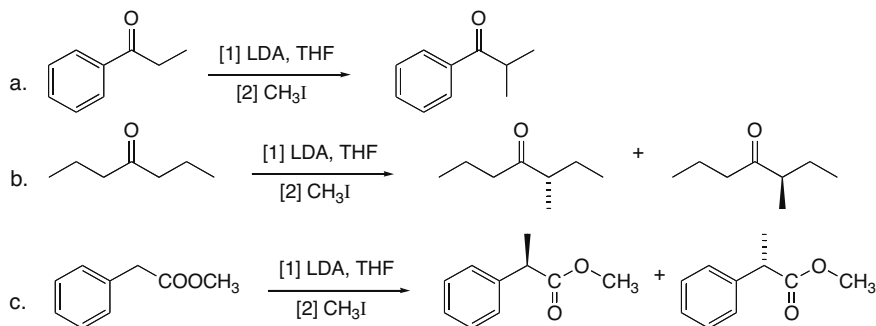


23.16

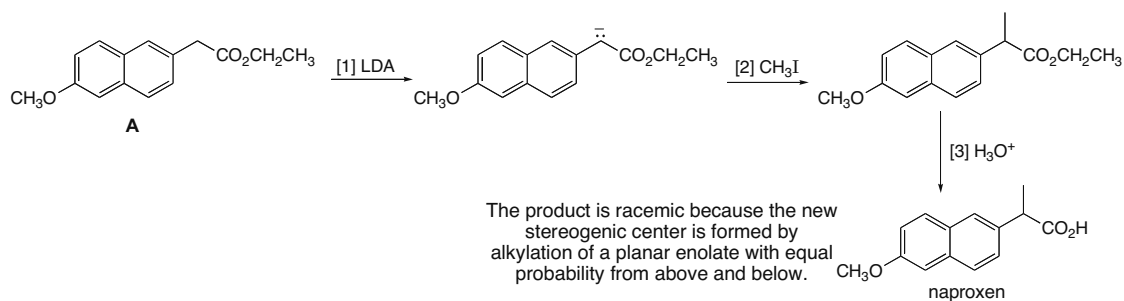


Substitution Reactions of Carbonyl Compounds at the α Carbon 23-9

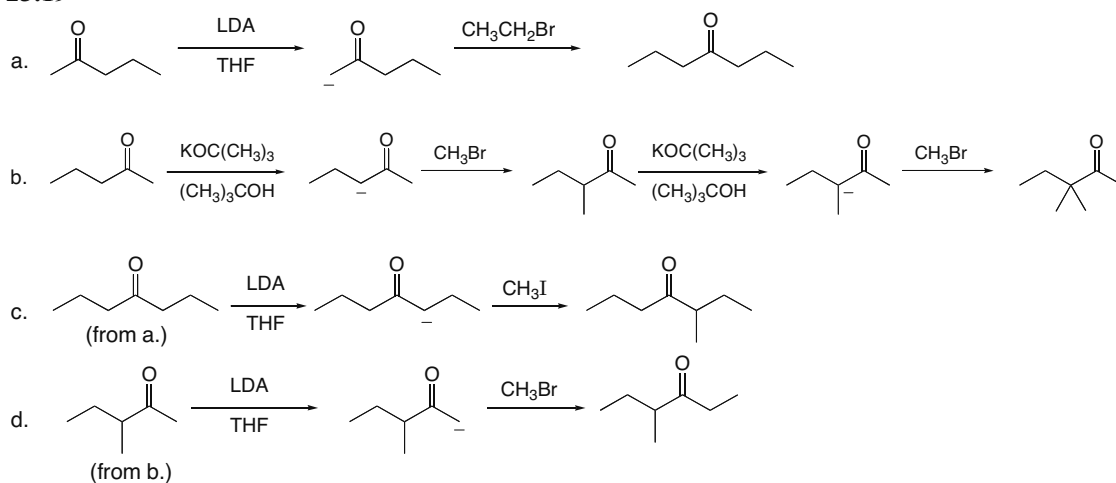
23.17



23.18 Three steps are needed: [1] formation of an enolate; [2] alkylation; [3] hydrolysis of the ester.

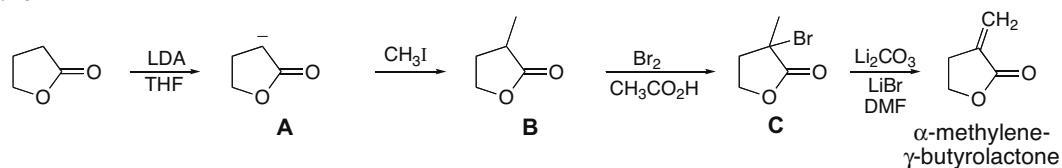


23.19

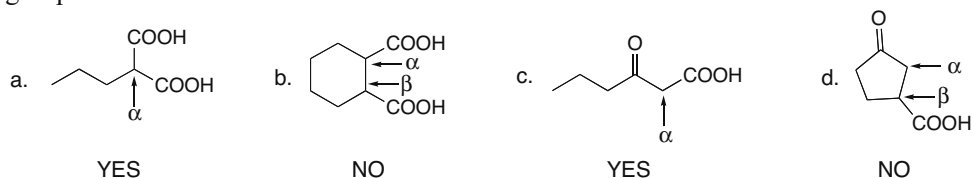


Chapter 23–10

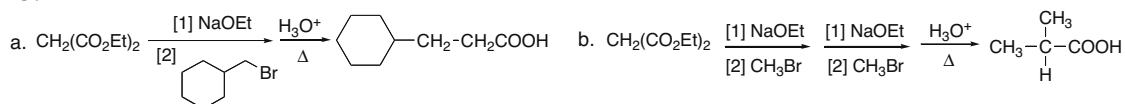
23.20



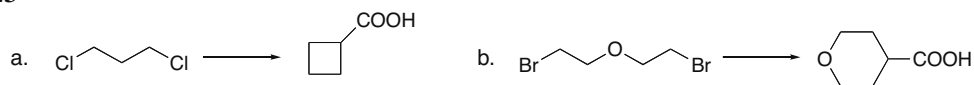
23.21 Decarboxylation occurs only when a carboxy group is bonded to the α C of another carbonyl group.



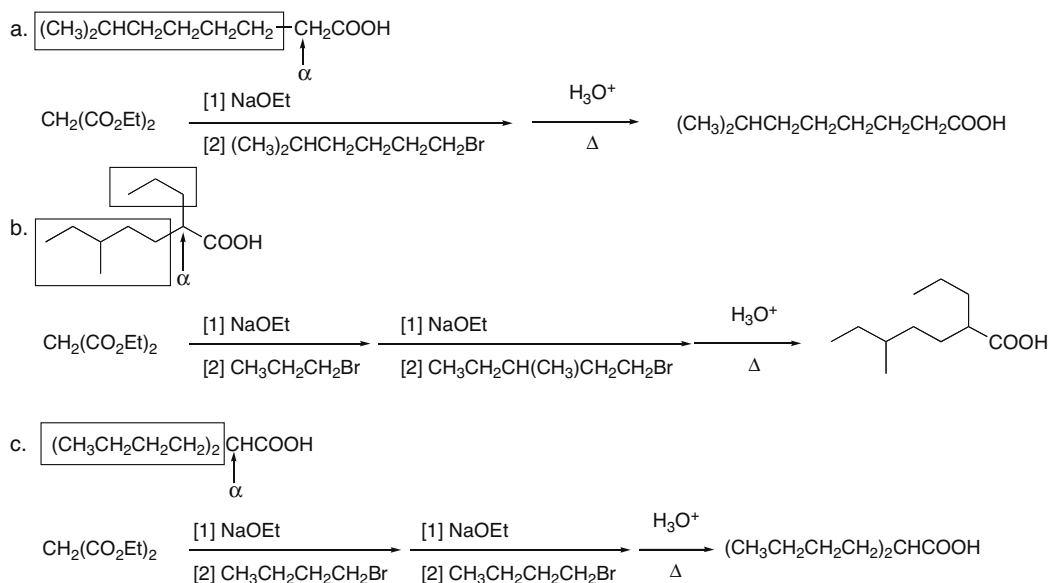
23.22



23.23

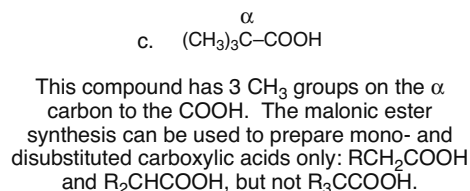
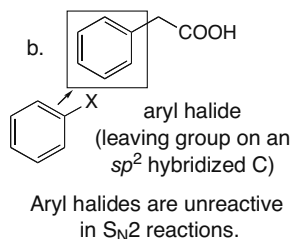
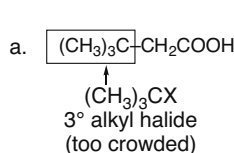
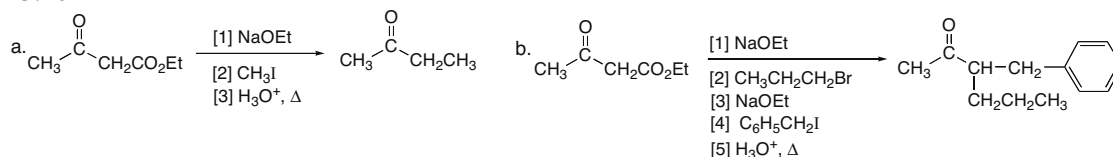


23.24 Locate the α C to the COOH group, and identify all of the alkyl groups bonded to it. These groups are from alkyl halides, and the remainder of the molecule is from diethyl malonate.

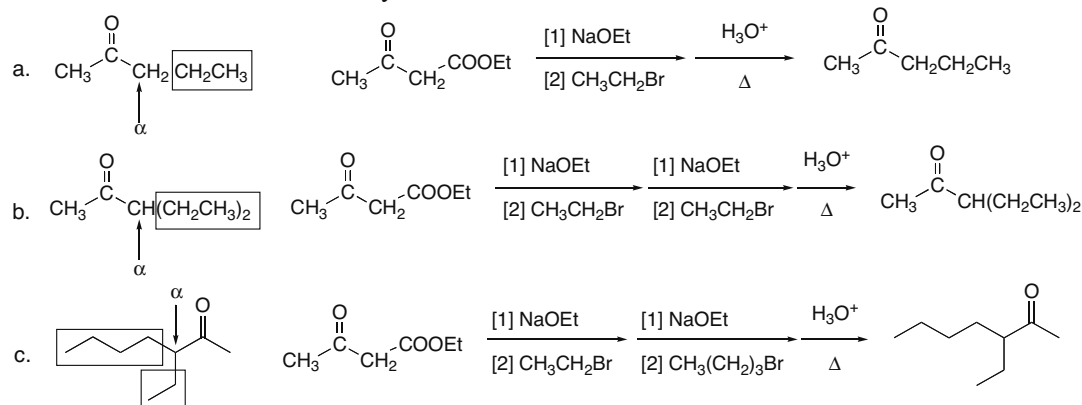
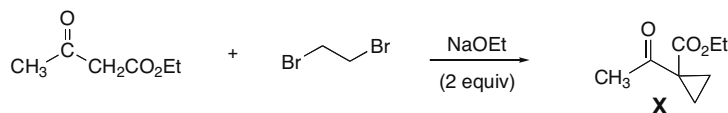


Substitution Reactions of Carbonyl Compounds at the α Carbon 23-11

23.25 The reaction works best when the alkyl halide is 1° or CH_3X , since this is an $\text{S}_\text{N}2$ reaction.

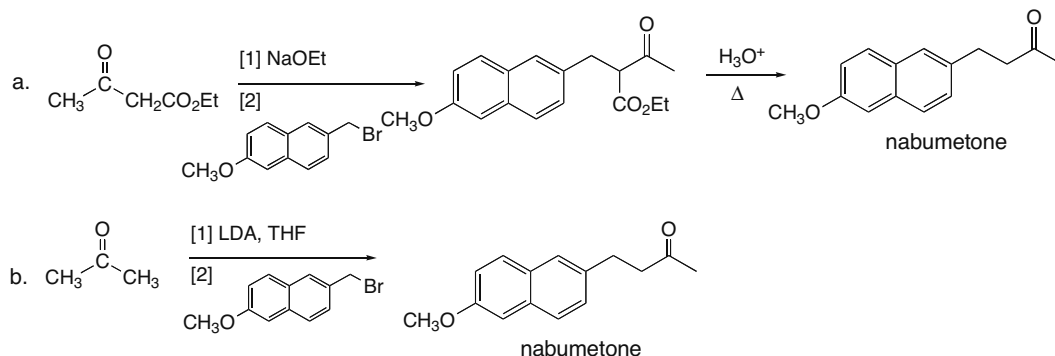
**23.26**

23.27 Locate the α C. All alkyl groups on the α C come from alkyl halides, and the remainder of the molecule comes from ethyl acetoacetate.

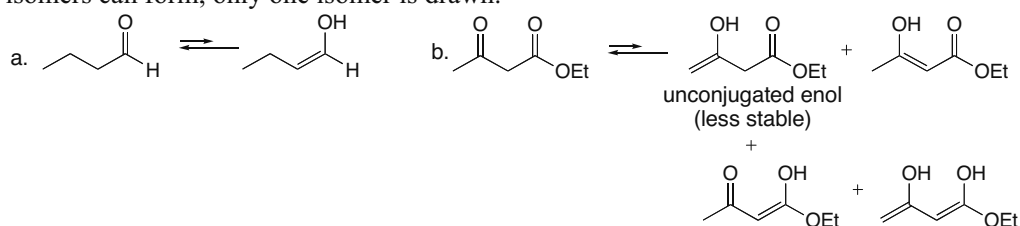
**23.28**

Chapter 23–12

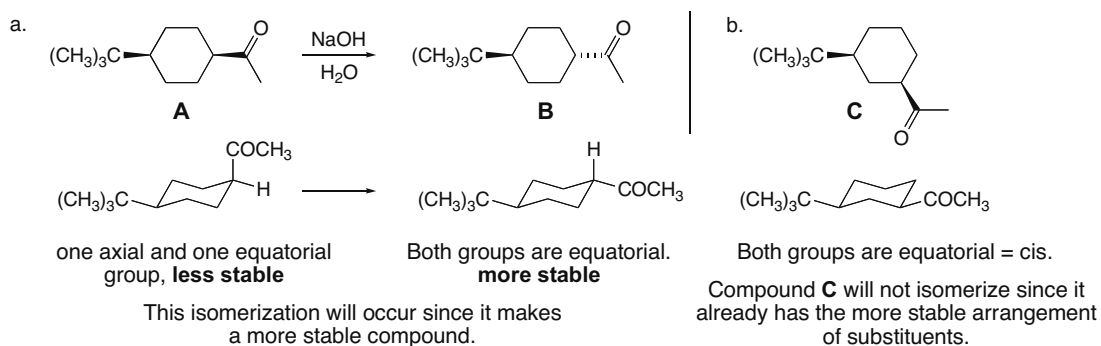
23.29



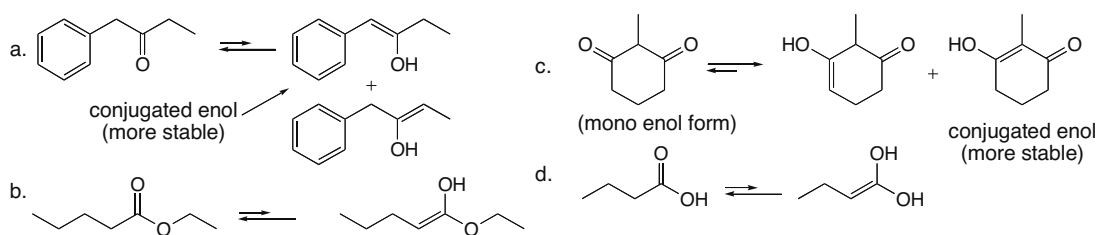
23.30 Use the directions from Answer 23.1 to draw the enol tautomer(s). In cases where *E* and *Z* isomers can form, only one isomer is drawn.



23.31

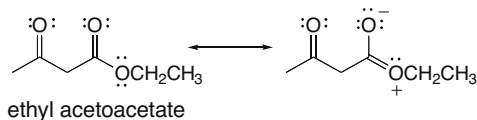


23.32 Use the directions from Answer 23.1 to draw the enol tautomer(s). In cases where *E* and *Z* isomers can form, only one isomer is drawn.



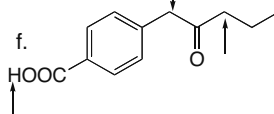
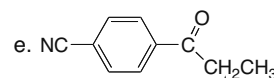
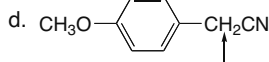
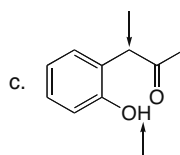
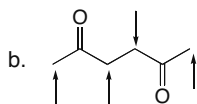
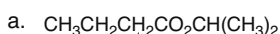
Substitution Reactions of Carbonyl Compounds at the α Carbon 23-13

23.33

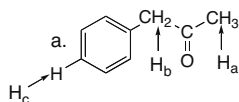


The ester C=O is resonance stabilized, and is therefore less available for tautomerization. Since the carbonyl form of the ester group is stabilized by electron delocalization, less enol is present at equilibrium.

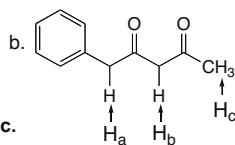
23.34



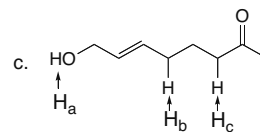
23.35



H_c is bonded to an sp^2 hybridized C = **least acidic**.
 H_a is bonded to an α C = **intermediate acidity**.
 H_b is bonded to an α C, and is adjacent to a benzene ring = **most acidic**.

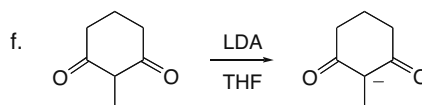
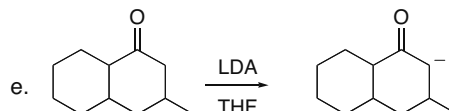
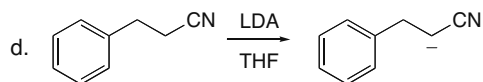
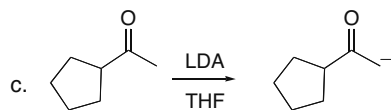
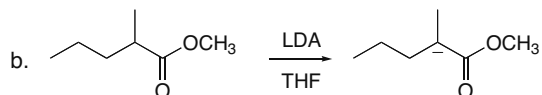
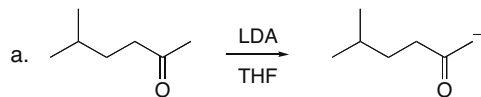


H_c is bonded to an α C = **least acidic**.
 H_a is bonded to an α C, and is adjacent to a benzene ring = **intermediate acidity**.
 H_b is bonded to an α C between two C=O groups = **most acidic**.



H_b is bonded to an sp^3 hybridized C = **least acidic**.
 H_c is bonded to an α C = **intermediate acidity**.
 H_a is bonded to O = **most acidic**.

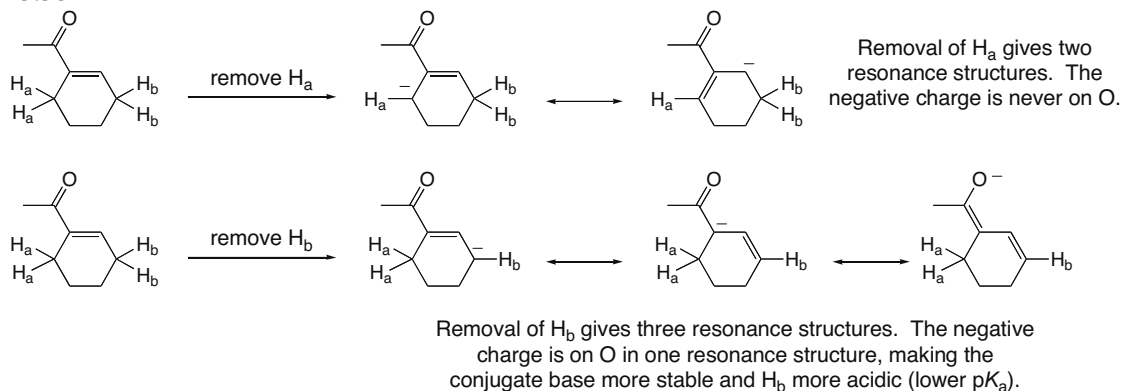
23.36



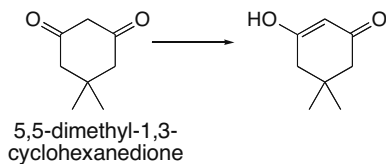
23.37 Enol tautomers have OH groups that give a broad OH absorption at $3600\text{--}3200\text{ cm}^{-1}$, which could be detected readily in the IR.

Chapter 23–14

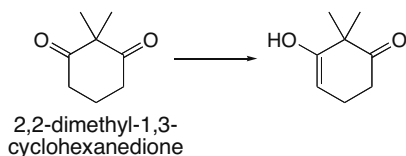
23.38



23.39

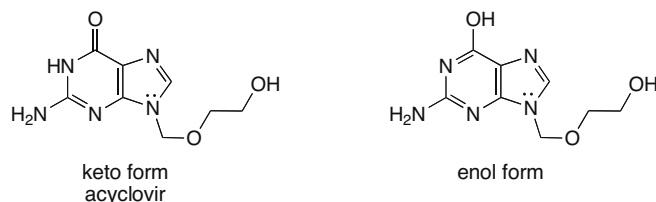


5,5-Dimethyl-1,3-cyclohexanedione exists predominantly in its enol form because the $C=C$ of the enol is conjugated with the other $C=O$ of the dicarbonyl compound. Conjugation stabilizes this enol.



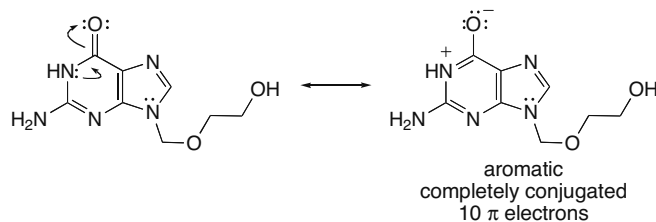
The enol of 2,2-dimethyl-1,3-cyclohexanedione is not conjugated with the other carbonyl group. In this way it resembles the enol of any other carbonyl compound, and thus it is present in low concentration.

23.40 a.



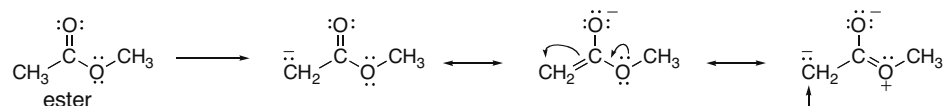
In the enol form, the bicyclic ring system has four π bonds (eight π electrons) and a lone pair on N, for a total of 10 π electrons. This makes it aromatic by Hückel's rule.

b. The keto form of acyclovir can also be drawn in a resonance form that gives it 10 π electrons, making it aromatic as well.

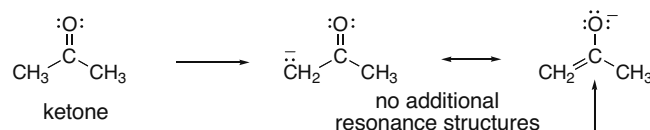


Substitution Reactions of Carbonyl Compounds at the α Carbon 23-15

23.41

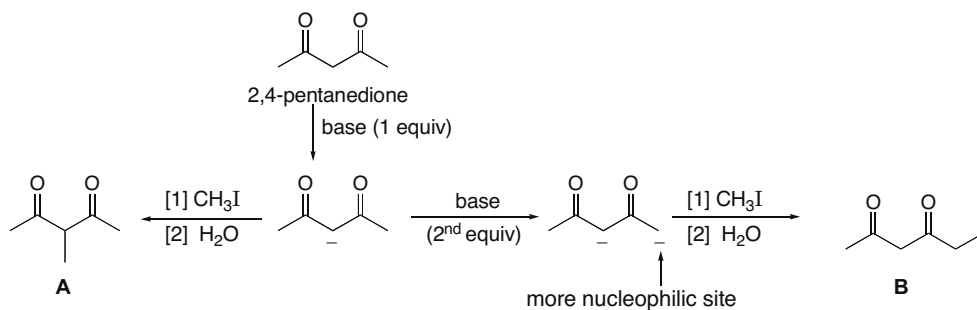


The O atom of the ester OR group donates electron density by a resonance effect. The resulting resonance structure keeps a negative charge on the less electronegative C end of the enolate. This destabilizes the resonance hybrid of the conjugate base, and makes the α H's of the ester less acidic.



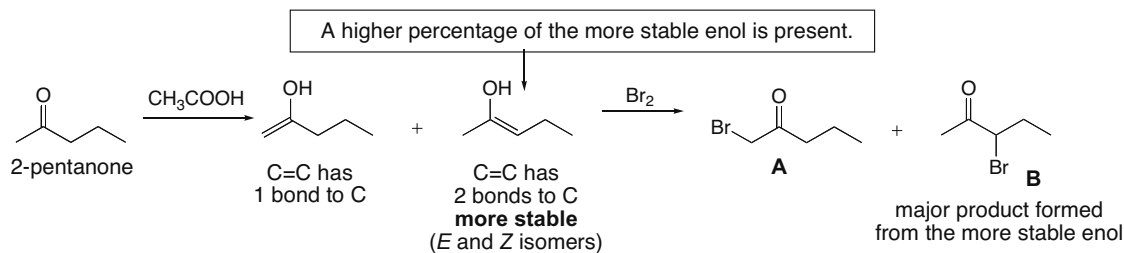
This structure, which places a negative charge on the O atom, is the major contributor to the hybrid, stabilizing it, and making the α H's of the ketone more acidic.

23.42



One equivalent of base removes the most acidic proton between the two C=O's, to form **A** on alkylation with CH_3I .

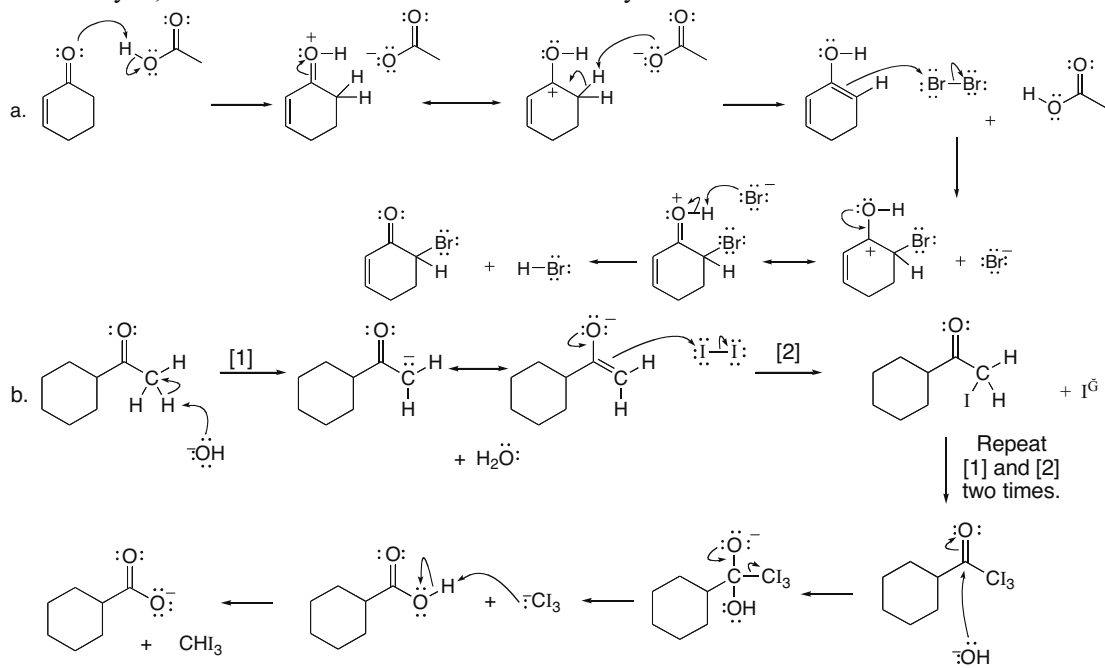
With a second equivalent of base a dianion is formed. Since the second enolate is less resonance stabilized, it is more nucleophilic and reacts first in an alkylation with CH_3I , forming **B** after protonation with H_2O .

23.43 The mechanism of acid-catalyzed halogenation consists of two parts: **tautomerization** of the carbonyl compound to the enol form and **reaction of the enol with halogen**.

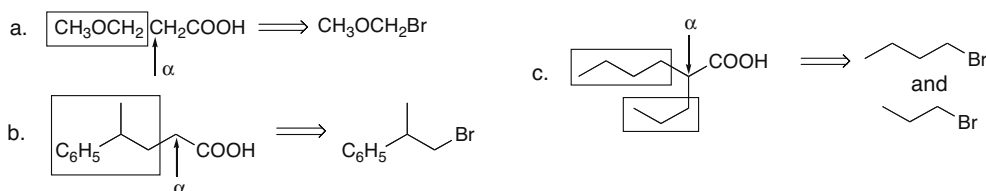
Chapter 23–16

23.44 • The mechanism of acid-catalyzed halogenation [Part (a)] consists of two parts: **tautomerization** of the carbonyl compound to the enol form and **reaction of the enol with halogen**.

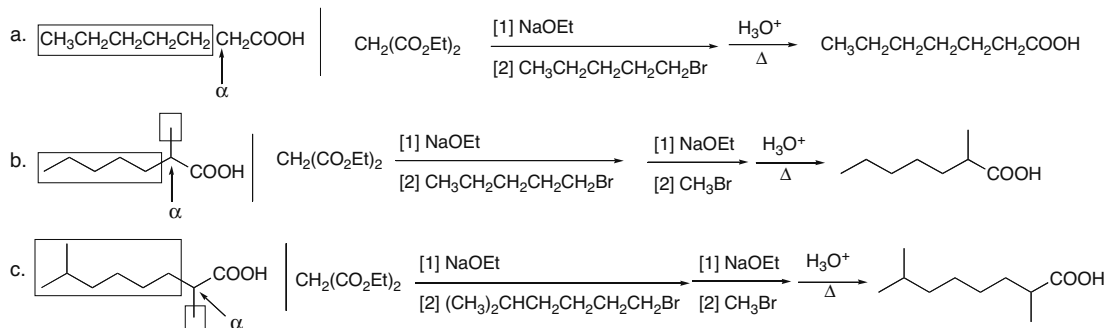
- In the haloform reaction [Part (b)], the three H's of the CH₃ group are successively replaced by X, to form an intermediate that is oxidatively cleaved with base.



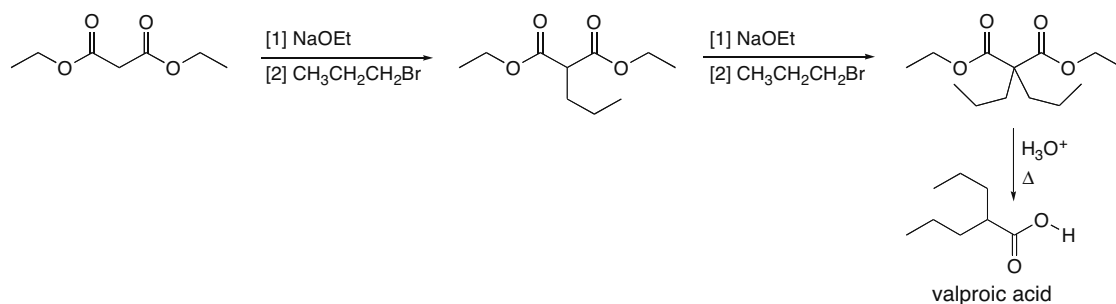
23.45 Use the directions from Answer 23.24.



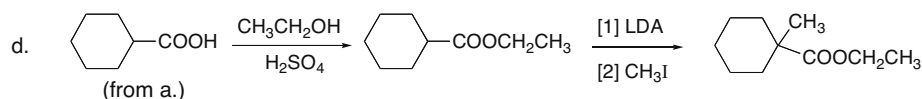
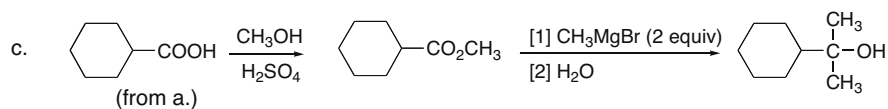
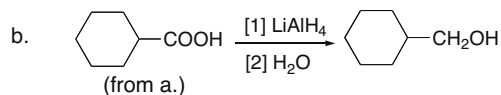
23.46



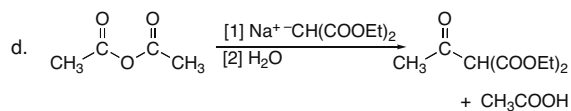
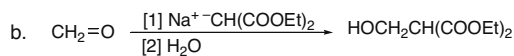
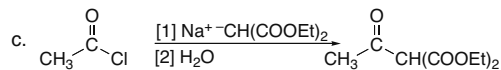
23.47



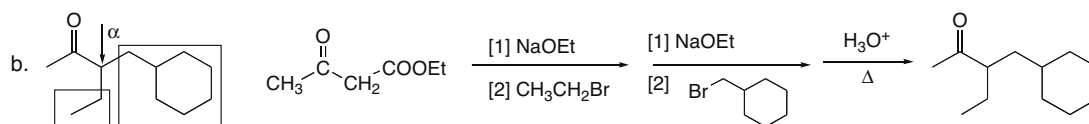
a. $\text{CH}_2(\text{CO}_2\text{Et})_2 \xrightarrow[\text{[3] NaOEt}]{\text{[1] NaOEt}}$ $\xrightarrow[\Delta]{\text{H}_3\text{O}^+}$



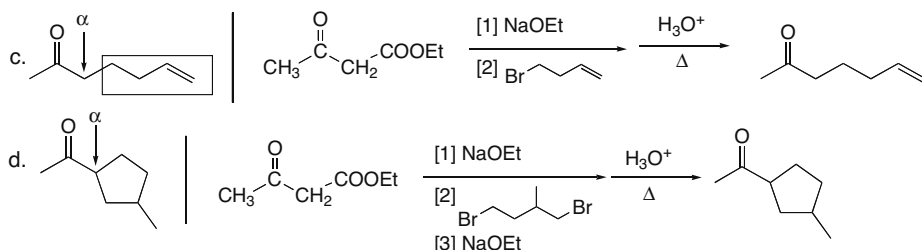
a.



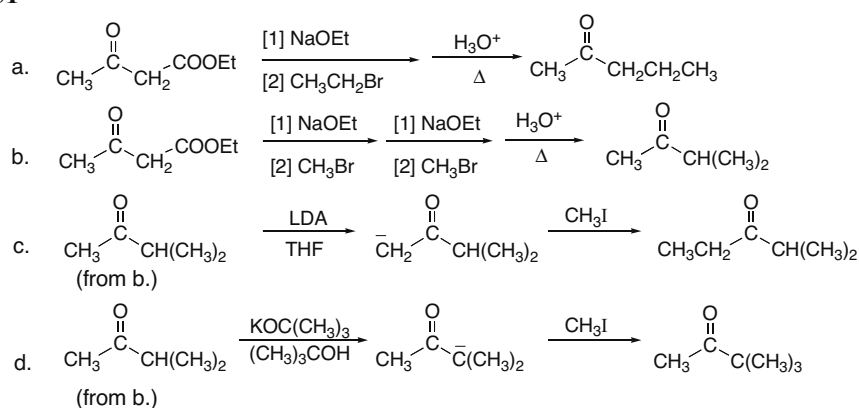
a.



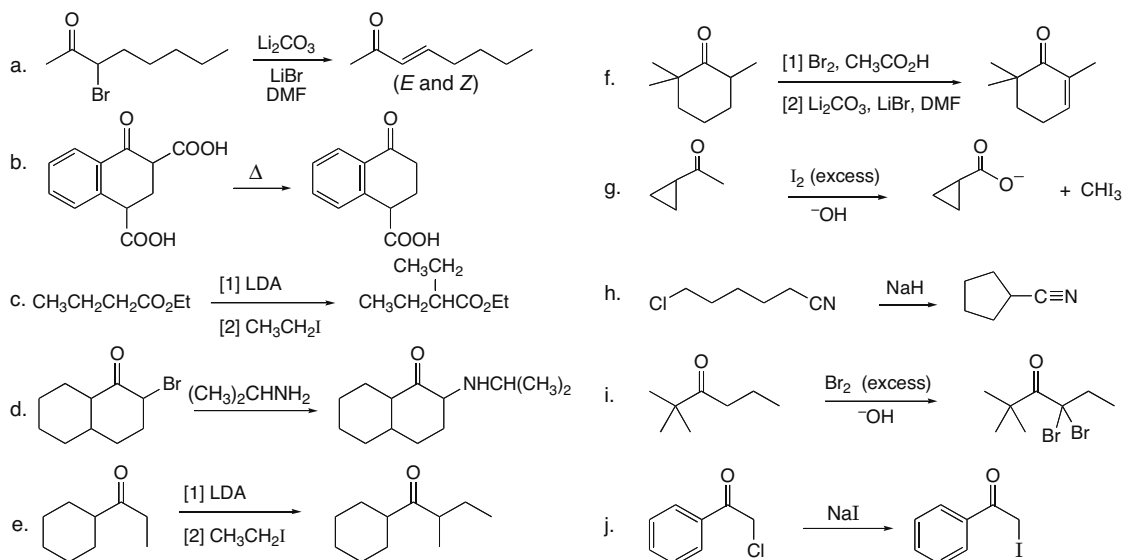
Chapter 23–18



23.51

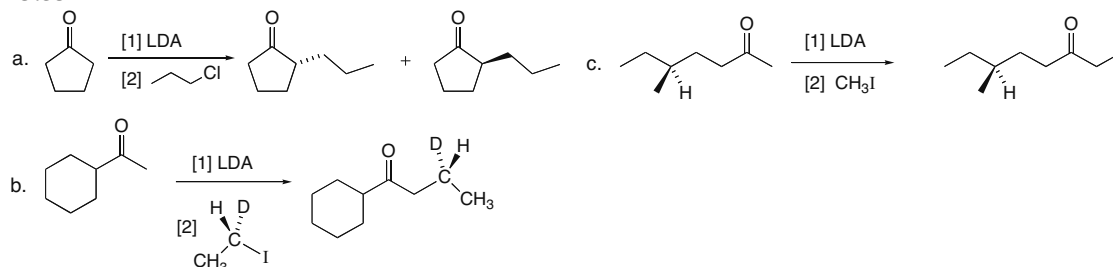


23.52

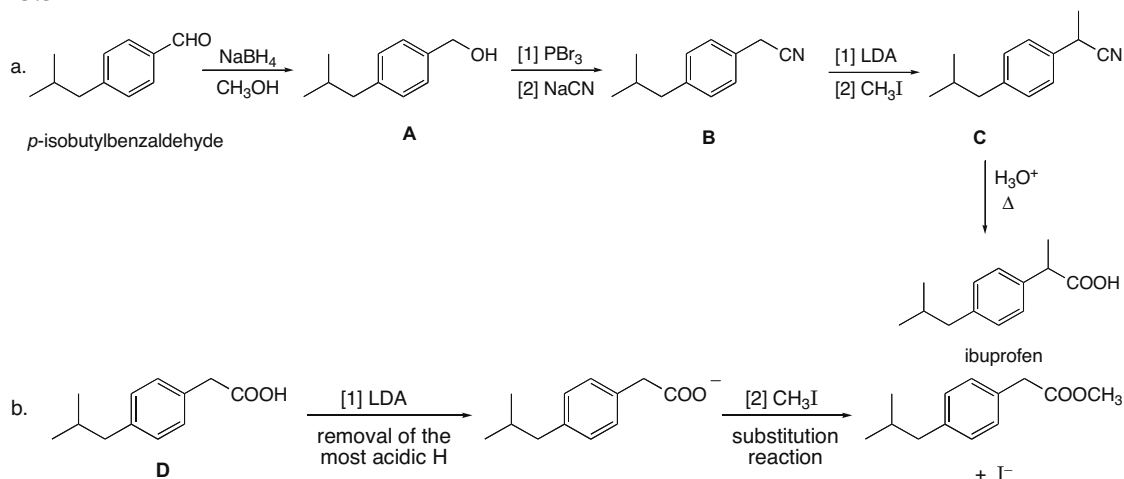


Substitution Reactions of Carbonyl Compounds at the α Carbon 23-19

23.53

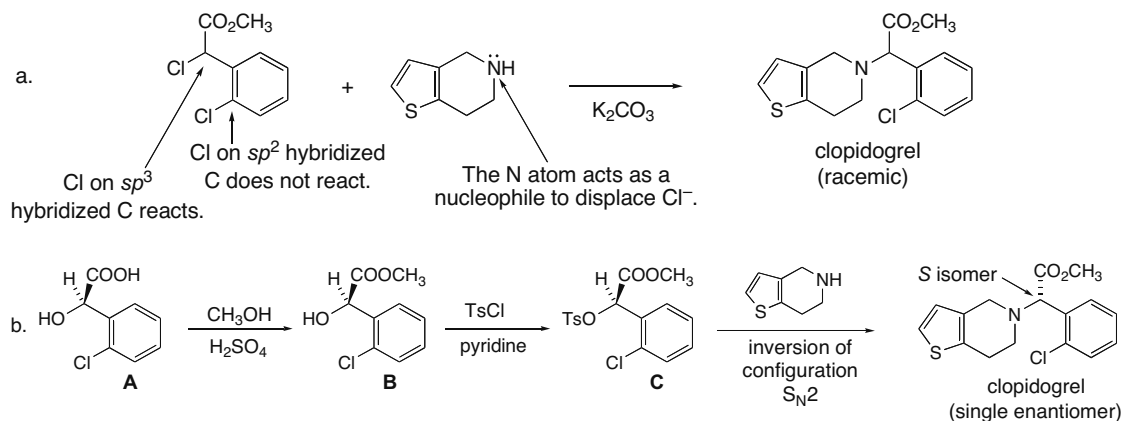


23.54



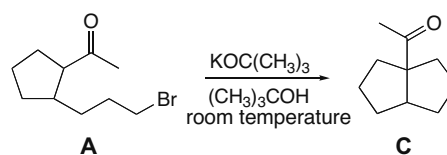
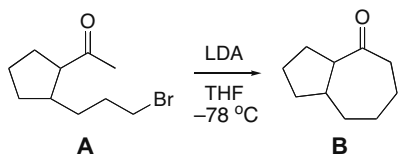
Removal of the most acidic proton with LDA forms a carboxylate anion that reacts as a nucleophile with CH_3I to form an ester as substitution product.

23.55

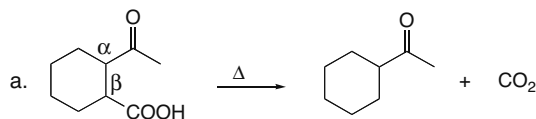


Chapter 23–20

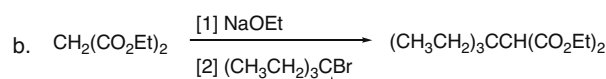
23.56



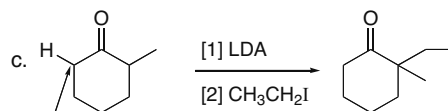
23.57



In order for decarboxylation to occur readily, the COOH group must be bonded to the α C of another carbonyl group. In this case, it is bonded to the β carbon.

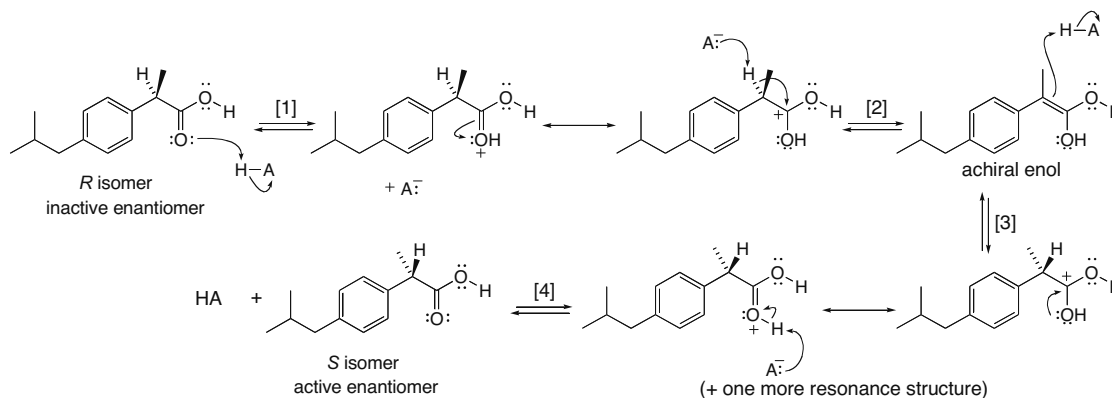


The 3° alkyl halide is too crowded to react with the strong nucleophile by an $\text{S}_{\text{N}}2$ mechanism.

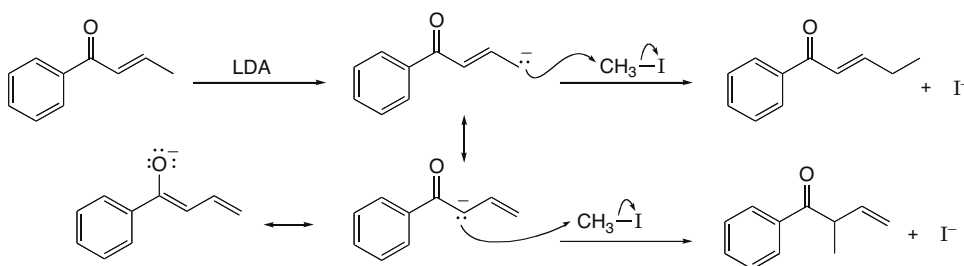


LDA removes a H from the less substituted C, forming the kinetic enolate. This product is from the thermodynamic enolate, which gives substitution on the more substituted α C.

23.58 Protonation in Step [3] can occur from below (to re-form the *R* isomer) or from above to form the *S* isomer as shown.

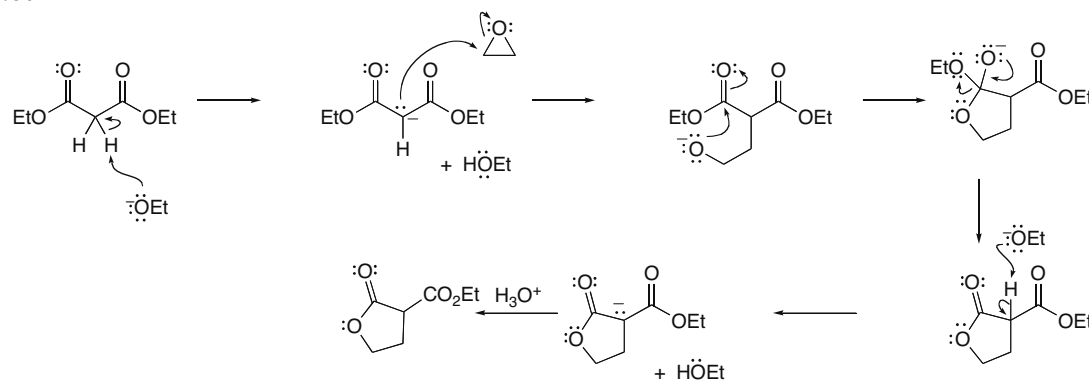


23.59

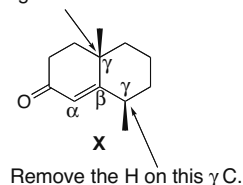


Substitution Reactions of Carbonyl Compounds at the α Carbon 23–21

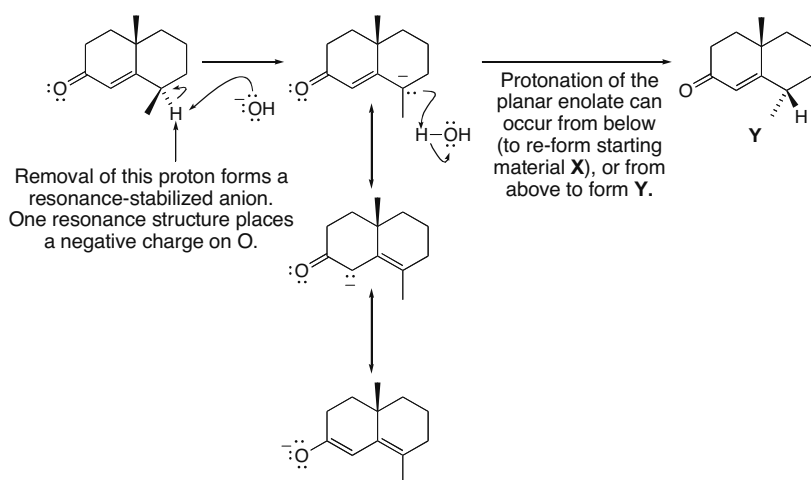
23.60

23.61 Protons on the γ carbon of an α,β -unsaturated carbonyl compound are acidic because of resonance.

There is no H on this C, so a planar enolate cannot form and this stereogenic center cannot change.



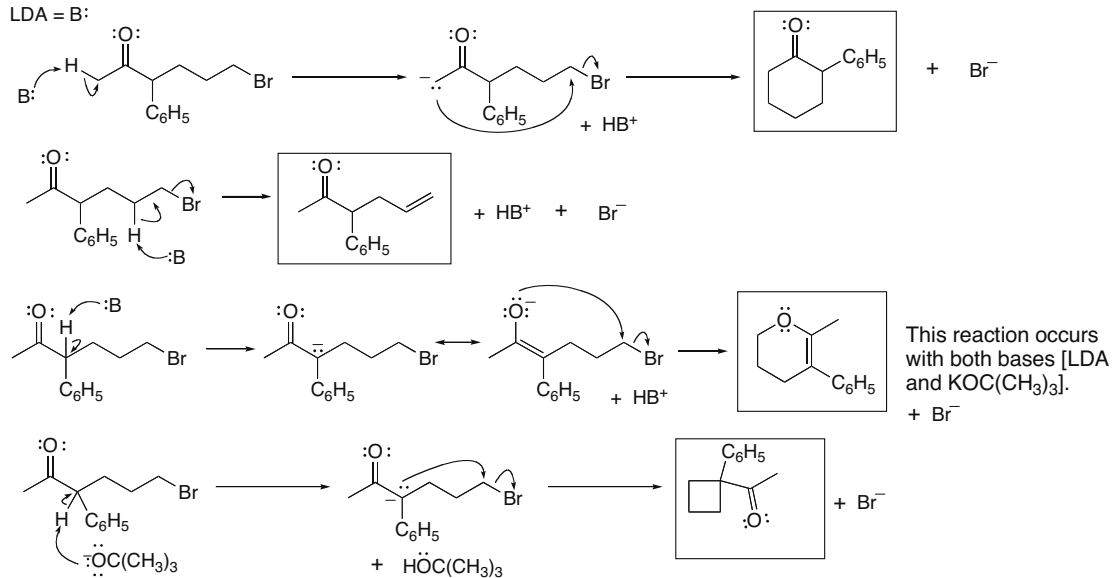
Remove the H on this γ C.



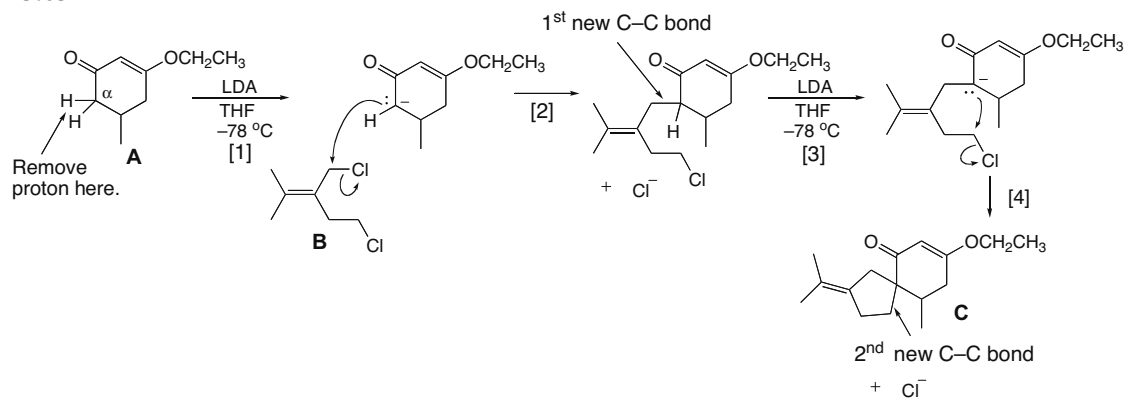
Chapter 23-22

23.62

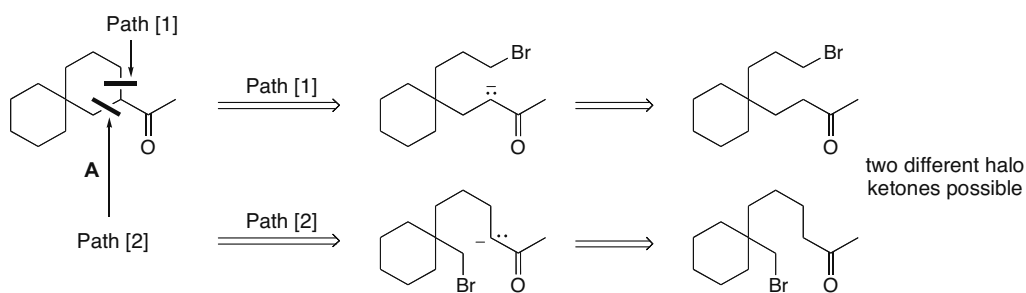
LDA = B:



23.63

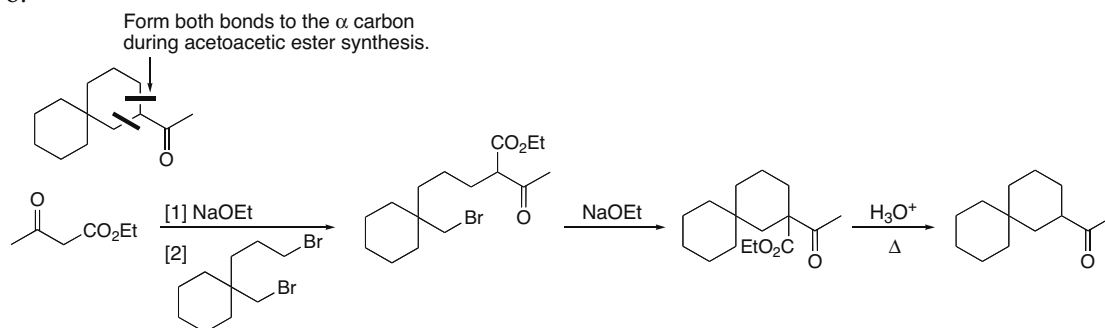


23.64 a. Since there are two C's bonded to the α carbon, there are two possible intramolecular alkylation reactions.

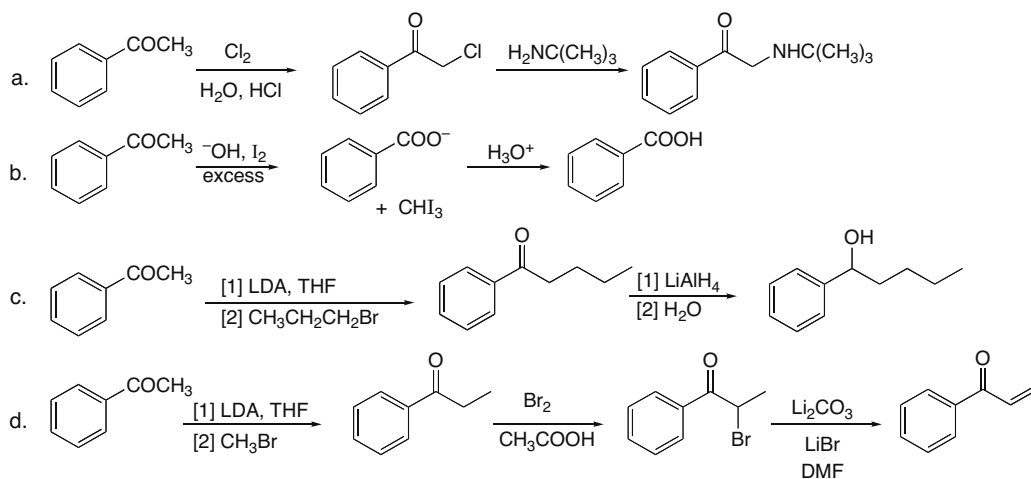


Substitution Reactions of Carbonyl Compounds at the α Carbon 23-23

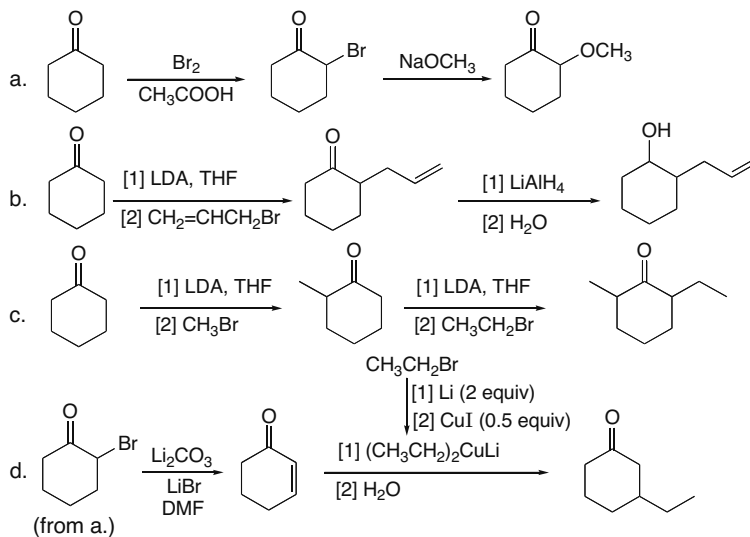
b.



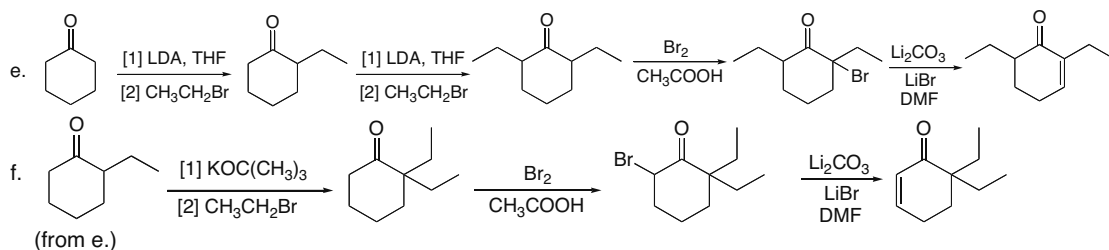
23.65



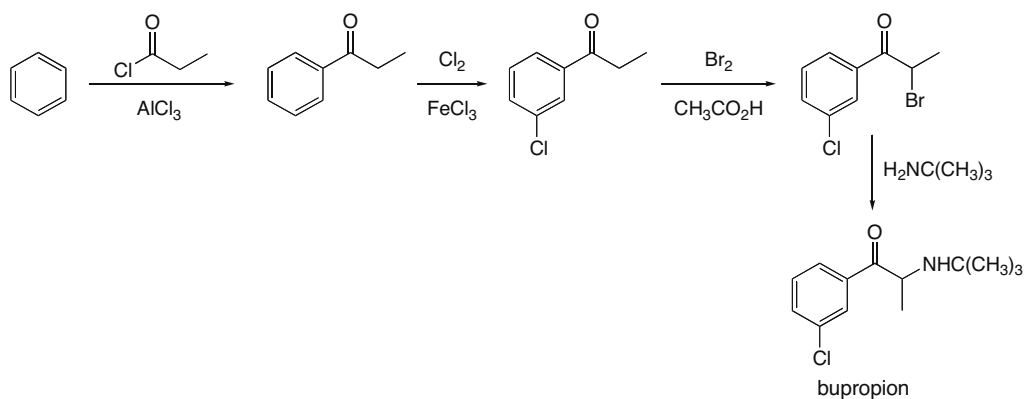
23.66



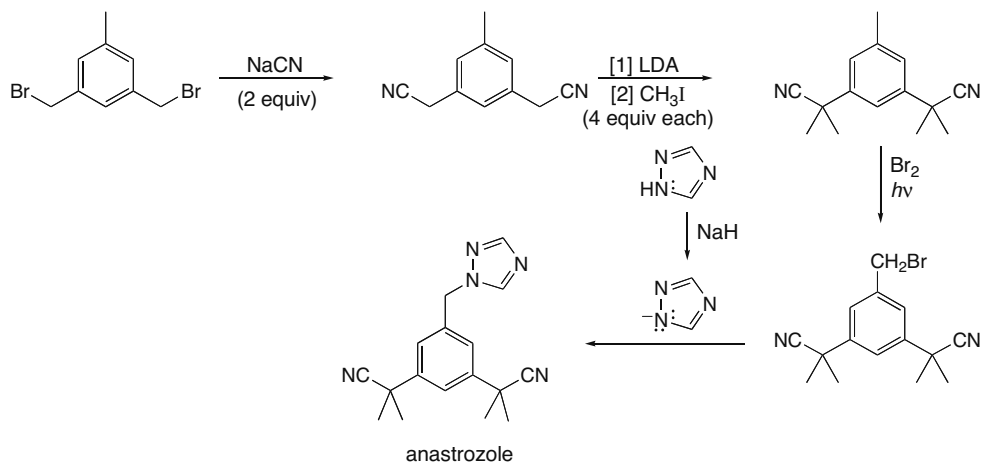
Chapter 23–24



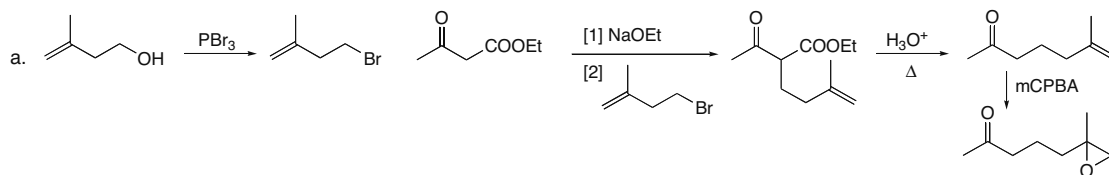
23.67

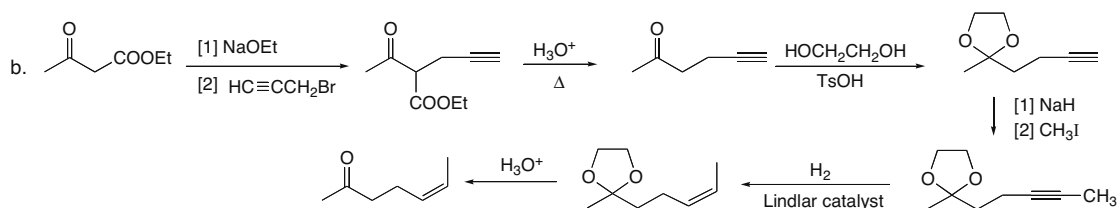


23.68

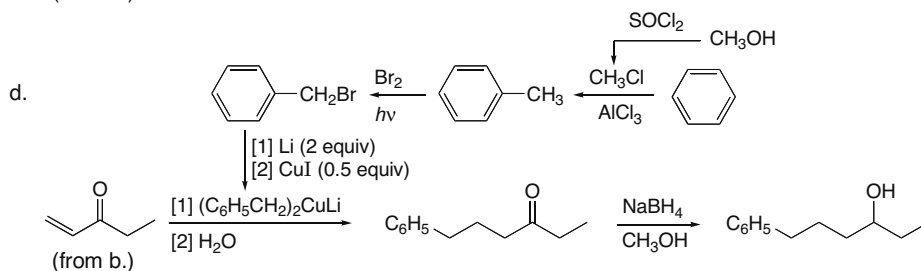
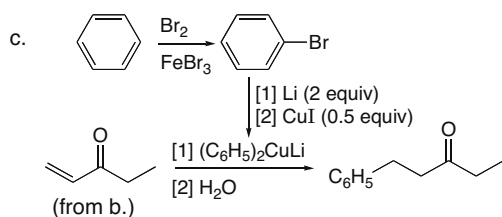
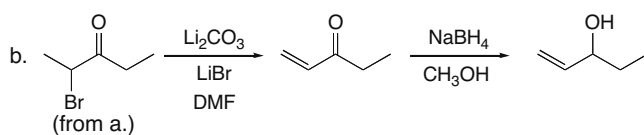
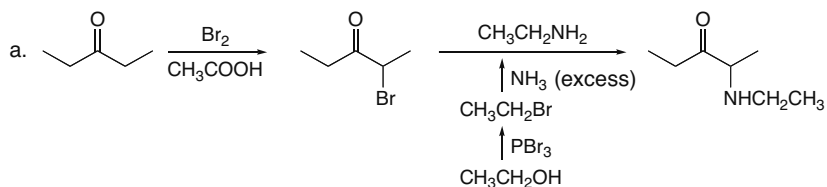


23.69



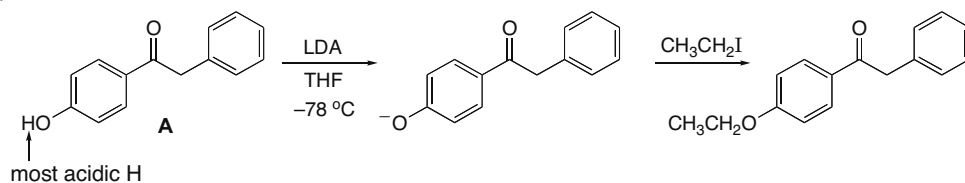
Substitution Reactions of Carbonyl Compounds at the α Carbon 23–25

23.70

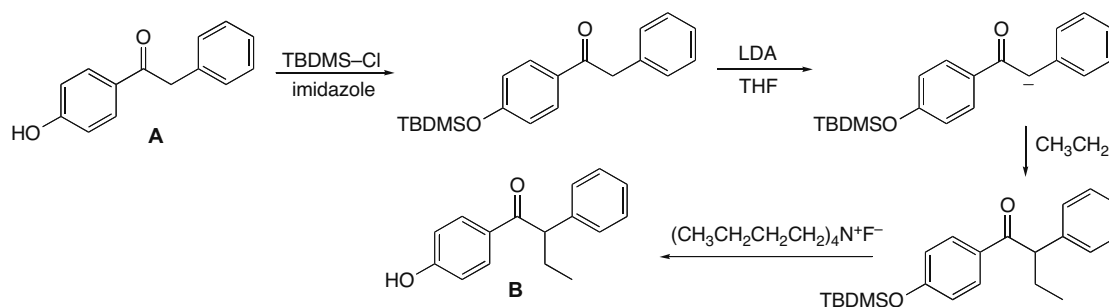


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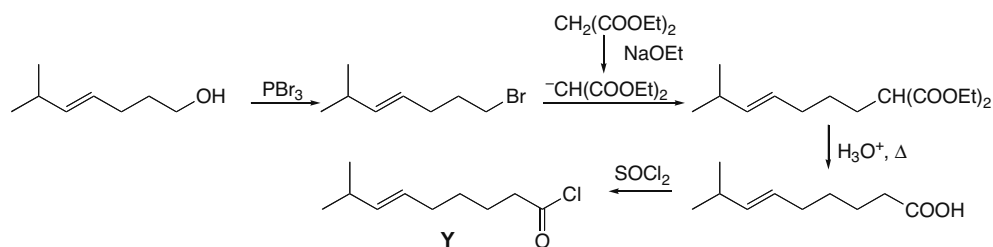
23.71



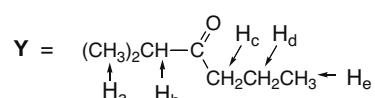
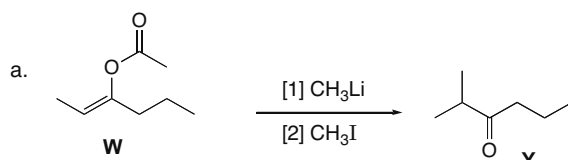
To synthesize the desired product, a protecting group is needed:



23.72



23.73



$\text{C}_7\text{H}_{14}\text{O} \rightarrow$ one degree of unsaturation

IR peak at $1713\text{ cm}^{-1} \rightarrow \text{C}=\text{O}$

^1H NMR signals at (ppm)

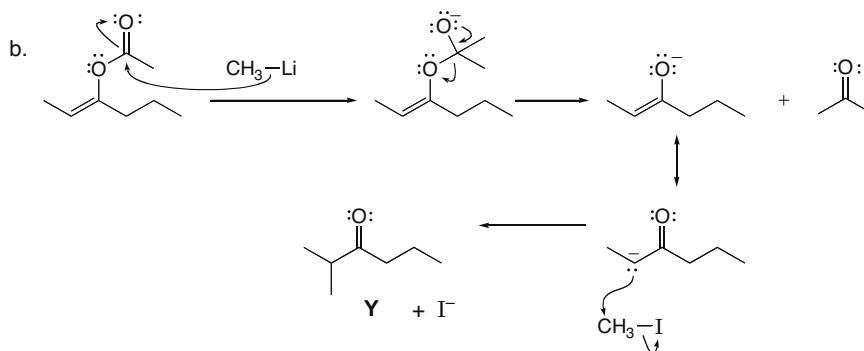
H_e : triplet at 0.8 (3 H)

H_a : doublet at 0.9 (6 H)

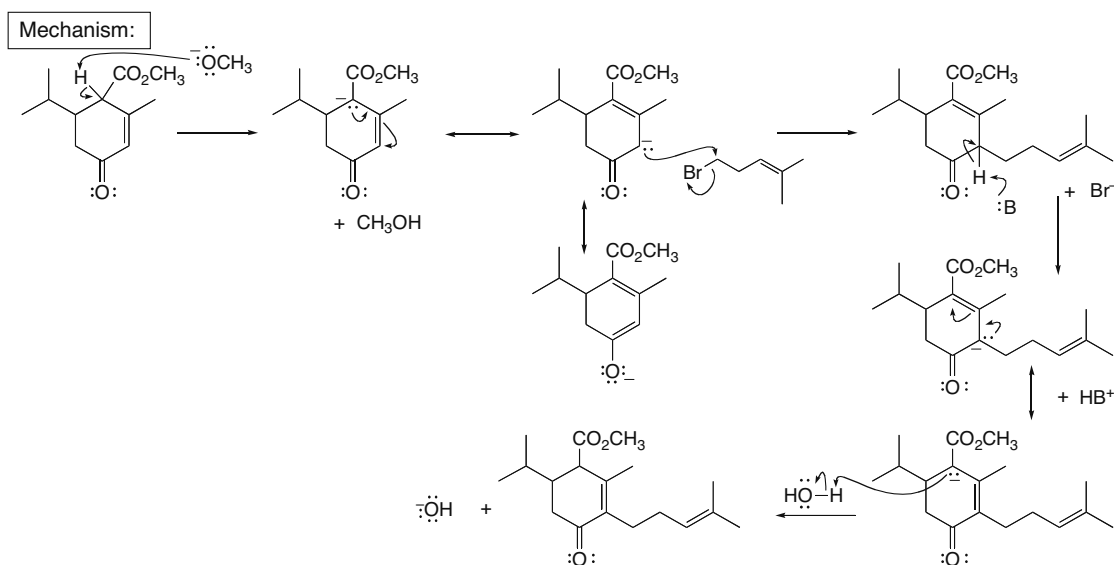
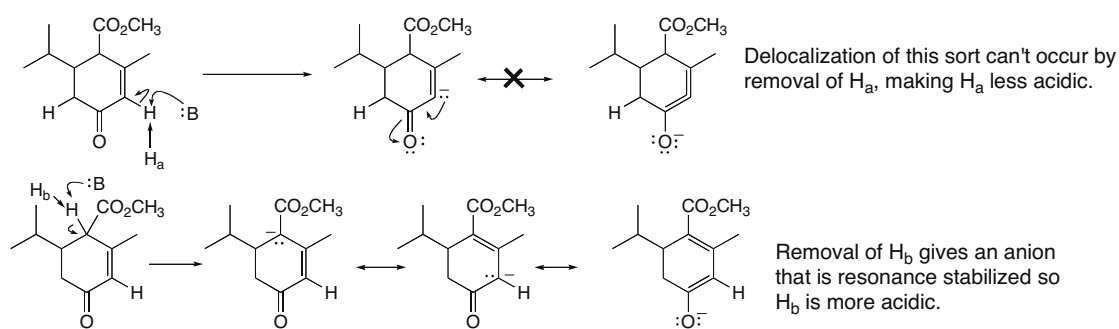
H_d : sextet at 1.4 (2 H)

H_c : triplet at 1.9 (2 H)

H_b : septet at 2.1 (1 H)

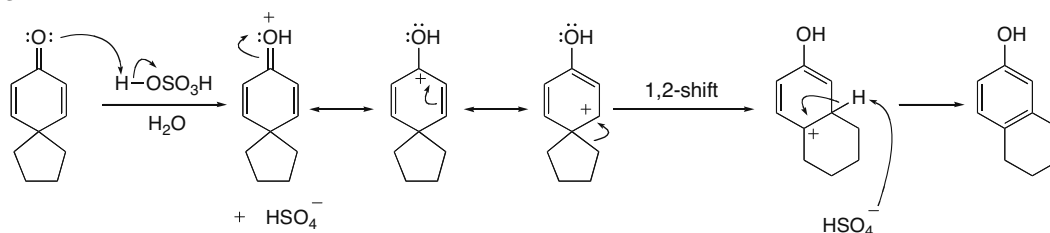
Substitution Reactions of Carbonyl Compounds at the α Carbon 23–27

23.74 Removal of H_a with base does not generate an anion that can delocalize onto the carbonyl O atom, whereas removal of H_b generates an enolate that is delocalized on O.

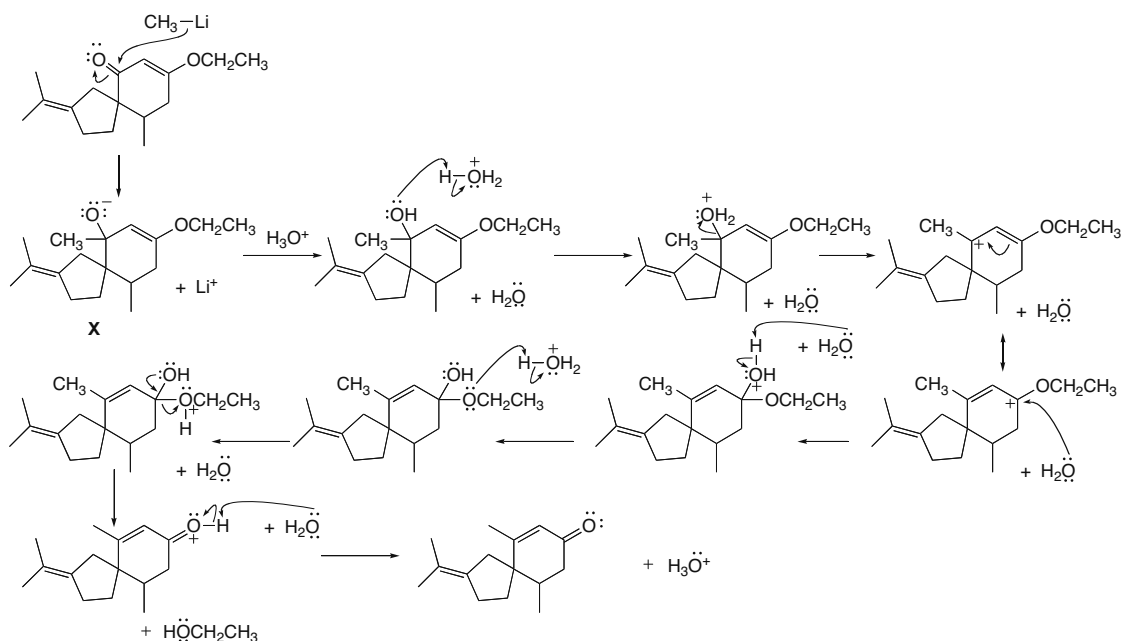


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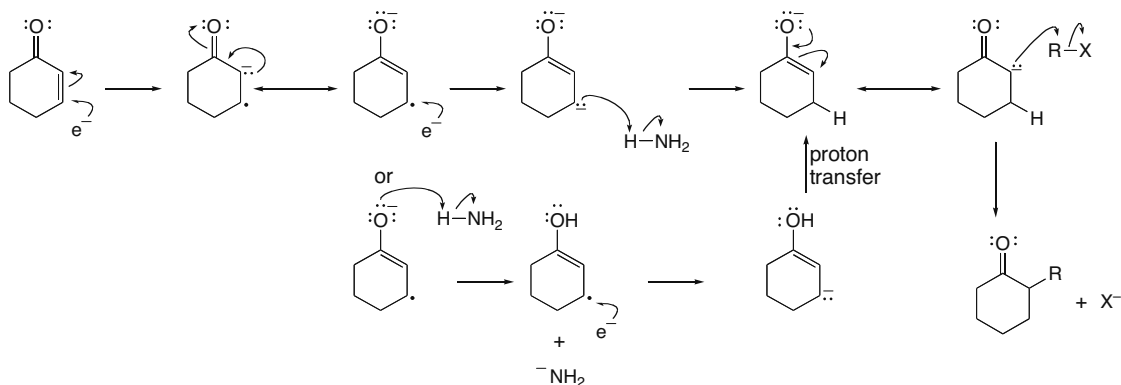
23.75



23.76

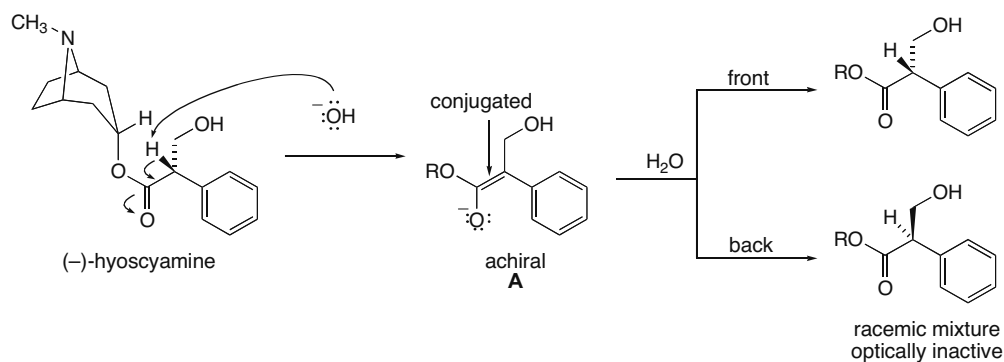


23.77

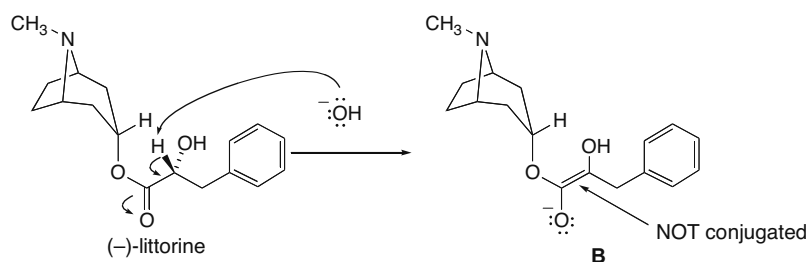


Substitution Reactions of Carbonyl Compounds at the α Carbon 23–29

- 23.78 a. In the presence of base an achiral enolate that can be protonated from both sides is formed.



- b. The enolate **A** formed from (-)-hyoscyamine is conjugated with the benzene ring, making it easier to form. The enolate **B** formed from (-)-littorine is not conjugated, so it is less readily formed.



Carbonyl Condensation Reactions 24-1

Chapter 24 Carbonyl Condensation Reactions

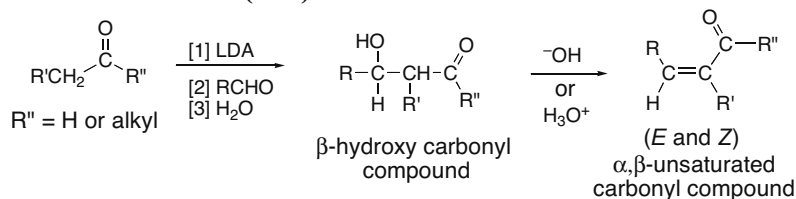
Chapter Review

The four major carbonyl condensation reactions

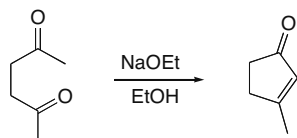
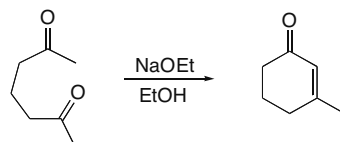
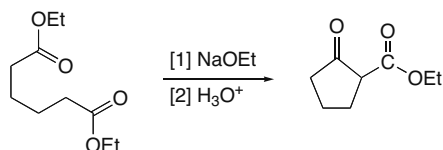
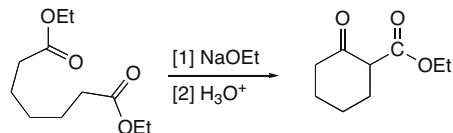
Reaction type	Reaction
[1] Aldol reaction (24.1)	$2 \text{ RCH}_2\text{C}(=\text{O})\text{H} \xrightleftharpoons[\text{H}_2\text{O}]{^-\text{OH}} \text{RCH}_2\text{C}(\text{OH})(\text{H})\text{CH}(\text{R})\text{CHO} \xrightarrow[\text{H}_3\text{O}^+]{^-\text{OH}} \text{RCH}_2\text{C}(\text{H})=\text{CH}(\text{R})\text{CHO}$ aldehyde (or ketone) β-hydroxy carbonyl compound α,β-unsaturated carbonyl compound (E and Z)
[2] Claisen reaction (24.5)	$2 \text{ RCH}_2\text{C}(=\text{O})\text{OR}' \xrightarrow[\text{[2] H}_3\text{O}^+]{\text{[1] NaOR}' } \text{RCH}_2\text{C}(=\text{O})\text{CH}(\text{R})\text{C}(=\text{O})\text{OR}'$ ester β-keto ester
[3] Michael reaction (24.8)	$\text{R}-\text{C}(=\text{O})\text{CH}=\text{CH}_2 + \text{CH}_3\text{C}(=\text{O})\text{CH}_3 \xrightarrow[\text{^-\text{OH}}]{^-\text{OR}' \text{ or } \text{H}_2\text{O}} \text{R}-\text{C}(=\text{O})\text{CH}_2\text{CH}_2\text{C}(=\text{O})\text{CH}_3$ α,β-unsaturated carbonyl compound carbonyl compound 1,5-dicarbonyl compound
[4] Robinson annulation (24.9)	$\text{CH}_3\text{C}(=\text{O})\text{CH}=\text{CH}_2 + \text{cyclohexanone} \xrightarrow[\text{H}_2\text{O}]{^-\text{OH}} \text{2-cyclohexenone}$ α,β-unsaturated carbonyl compound carbonyl compound 2-cyclohexenone

Useful variations

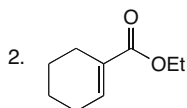
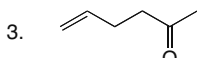
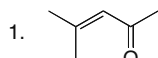
[1] Directed aldol reaction (24.3)



Chapter 24-2

[2] Intramolecular aldol reaction (24.4)**[a] With 1,4-dicarbonyl compounds:****[b] With 1,5-dicarbonyl compounds:****[3] Dieckmann reaction (24.7)****[a] With 1,6-diesters:****[b] With 1,7-diesters:****Practice Test on Chapter Review**

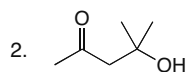
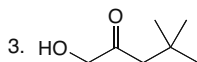
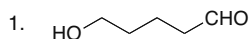
1. a. Which compounds are possible Michael acceptors?



4. Both compounds [1] and [2] are Michael acceptors.

5. Compounds [1], [2], and [3] are all Michael acceptors.

b. Which of the following compounds can be formed by an aldol reaction?

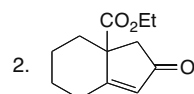
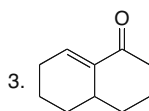
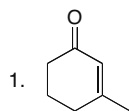


4. Both [1] and [2] can be formed by aldol reaction.

5. Compounds [1], [2], and [3] can all be formed by aldol reaction.

Carbonyl Condensation Reactions 24–3

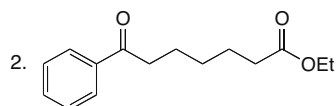
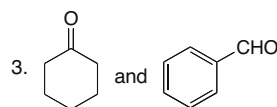
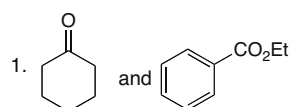
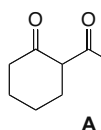
c. Which compounds can be formed in a Robinson annulation?



4. Compounds [1] and [2] can be formed by Robinson annulation.

5. Compounds [1], [2], and [3] can be formed by Robinson annulation.

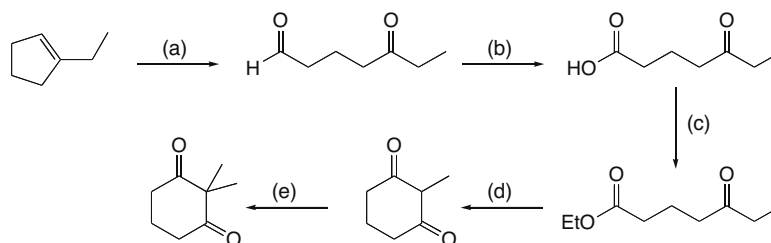
d. What compounds can be used to form **A** by a condensation reaction?



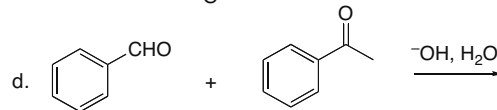
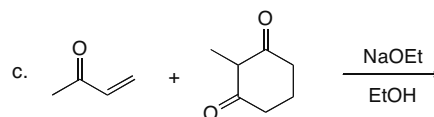
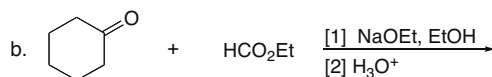
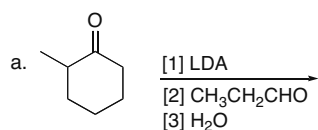
4. Compounds [1] and [2] can be used to form **A**.

5. Compounds [1], [2], and [3] can be used to form **A**.

2. Give the reagents required for each step.

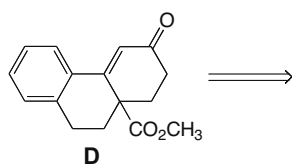


3. Draw the organic products formed in the following reactions.

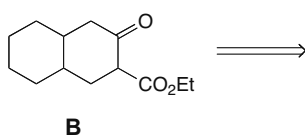


Chapter 24-4

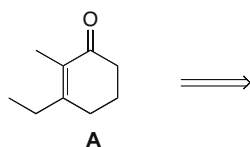
4. a. What organic starting materials are needed to synthesize **D** by a Robinson annulation reaction?



b. What organic starting materials are needed to synthesize β -keto ester **B** by a Dieckmann reaction?



c. What starting materials are needed to synthesize **A** by an aldol reaction?



Answers to Practice Test

1.a. 4

b. 2

c. 1

d. 4

2.a. [1] O_3 ; [2] $(\text{CH}_3)_2\text{S}$

b. CrO_3 , H_2SO_4 , H_2O

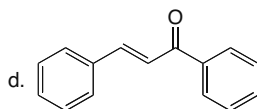
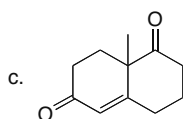
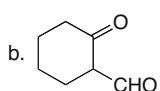
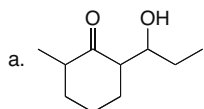
c. $\text{CH}_3\text{CH}_2\text{OH}$, H_2SO_4

d. [1] NaOEt , EtOH ;

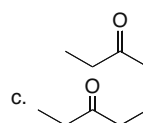
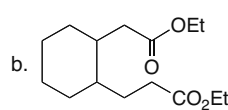
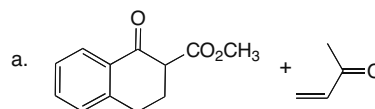
[2] H_3O^+

e. [1] LDA ; [2] CH_3I

3.



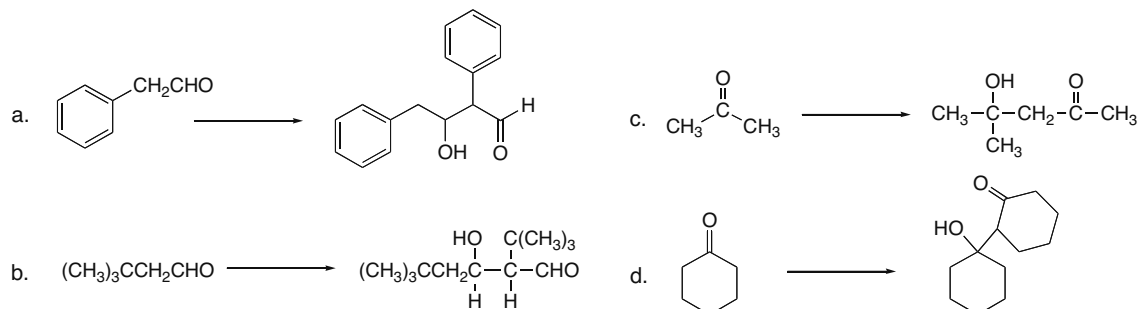
4.



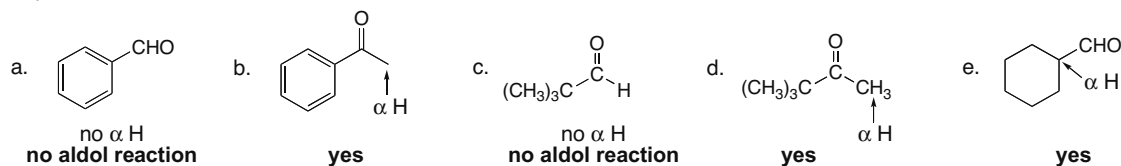
Carbonyl Condensation Reactions 24-5

Chapter 24: Answers to Problems

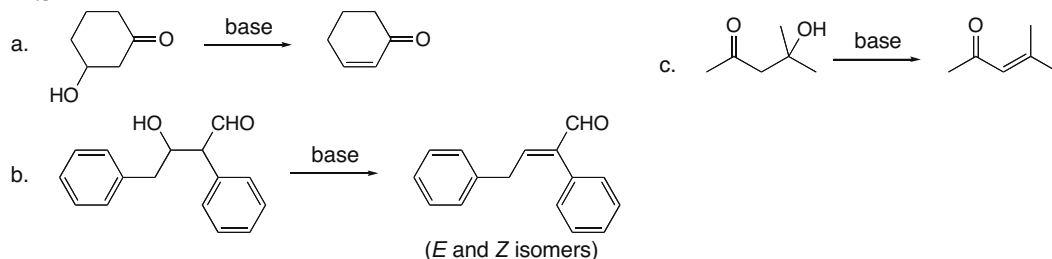
24.1



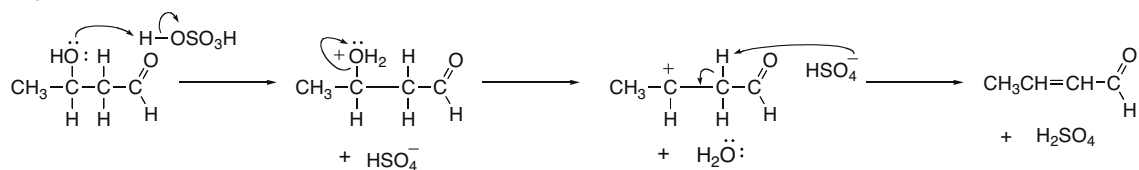
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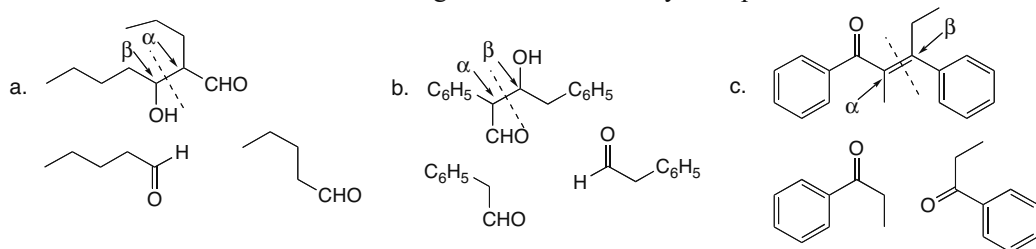
24.3



24.4

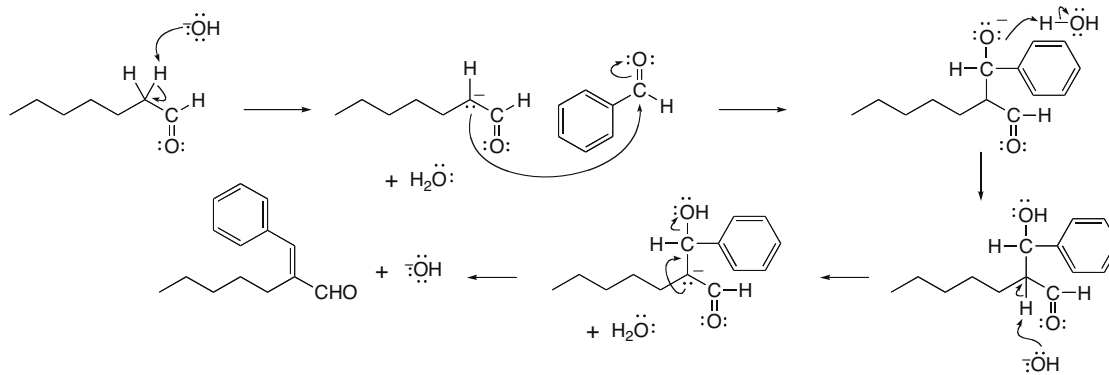


24.5 Locate the α and β C's to the carbonyl group, and break the molecule into two halves at this bond. The α C and all of the atoms bonded to it belong to one carbonyl component. The β C and all of the atoms bonded to it belong to the other carbonyl component.

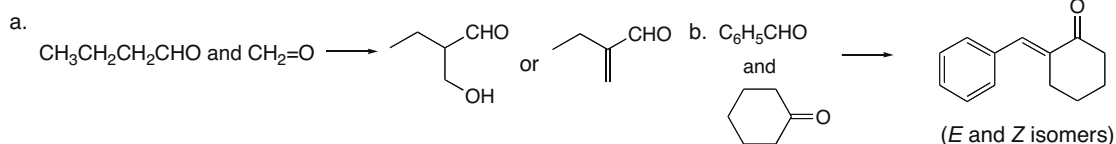


Chapter 24–6

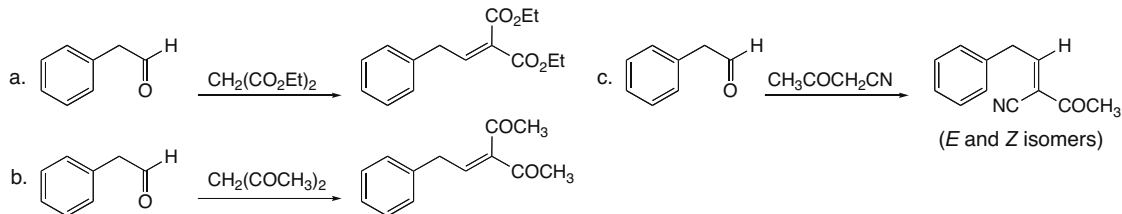
24.6



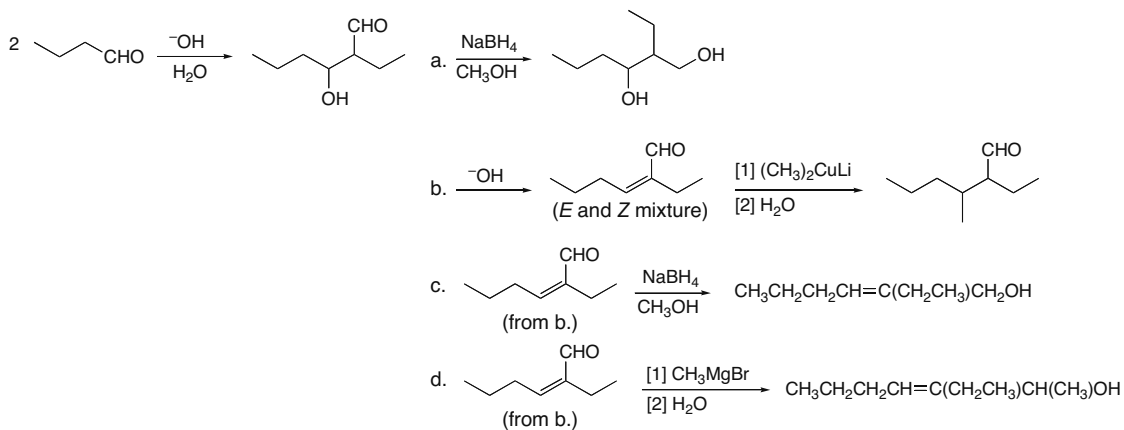
24.7



24.8

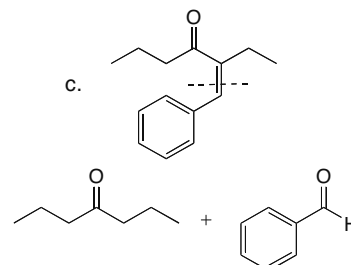
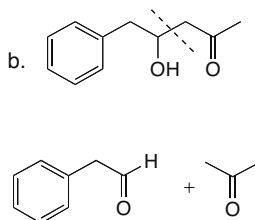
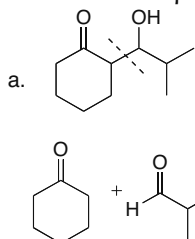


24.9

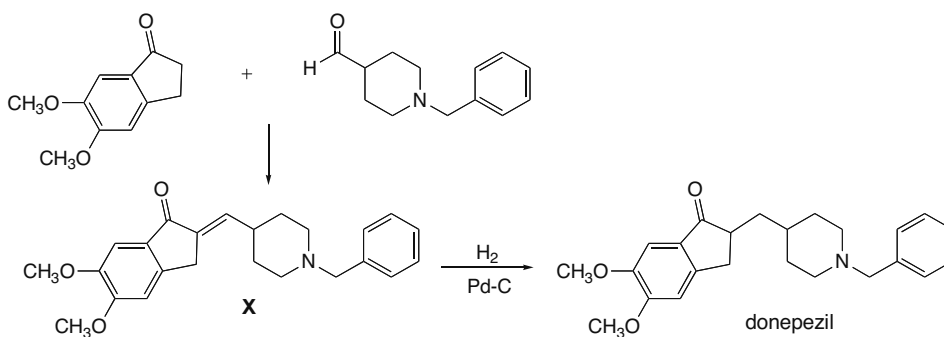


Carbonyl Condensation Reactions 24-7

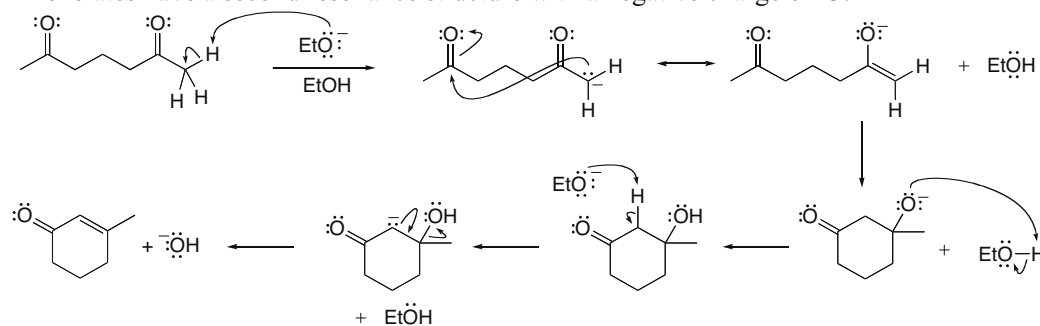
24.10 Find the α and β C's to the carbonyl group and break the bond between them.



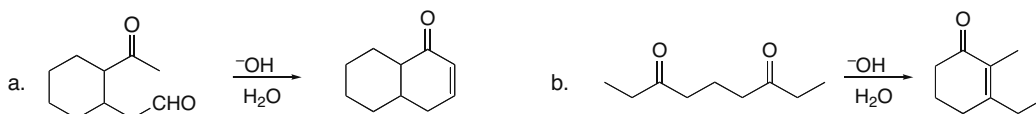
24.11



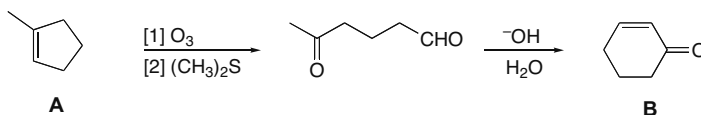
24.12 All enolates have a second resonance structure with a negative charge on O.



24.13

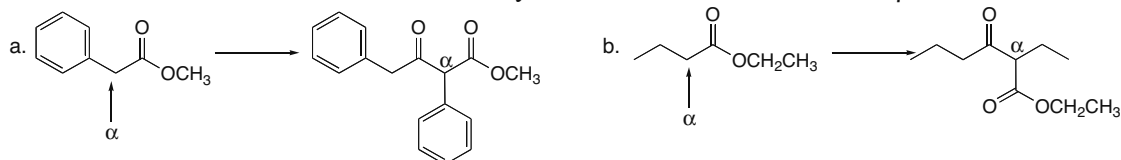


24.14

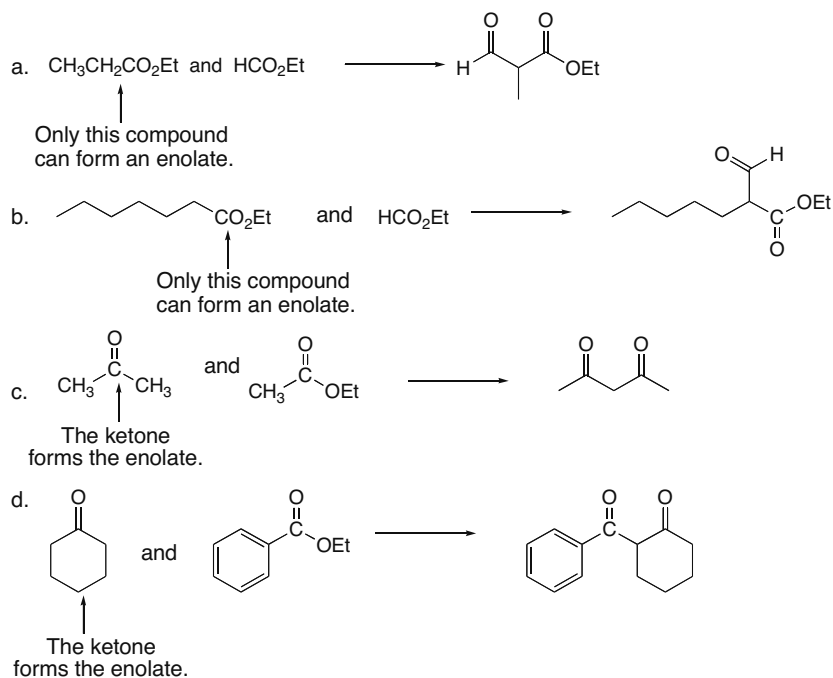


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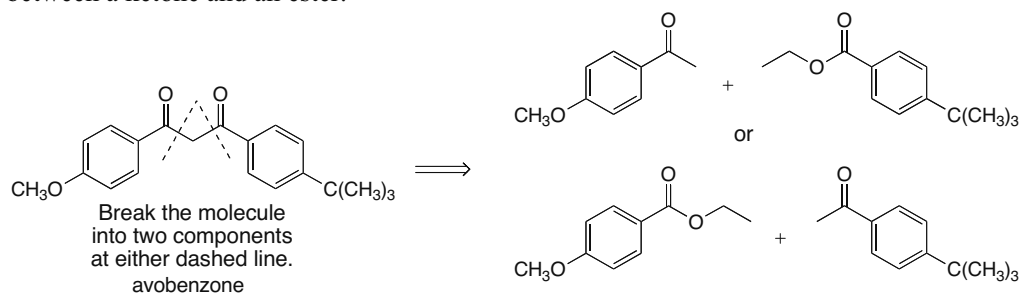
24.15 Join the α C of one ester to the carbonyl C of the other ester to form the β -keto ester.



24.16 In a crossed Claisen reaction between an ester and a ketone, the enolate is formed from the ketone, and the product is a β -dicarbonyl compound.

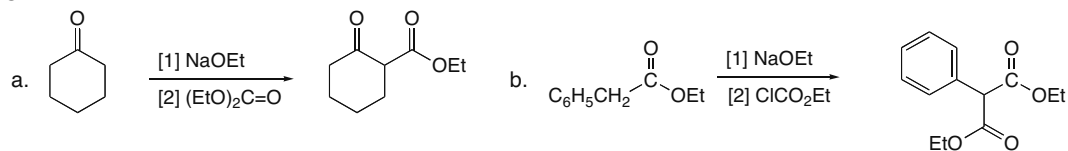


24.17 A β -dicarbonyl compound like avobenzone is prepared by a crossed Claisen reaction between a ketone and an ester.

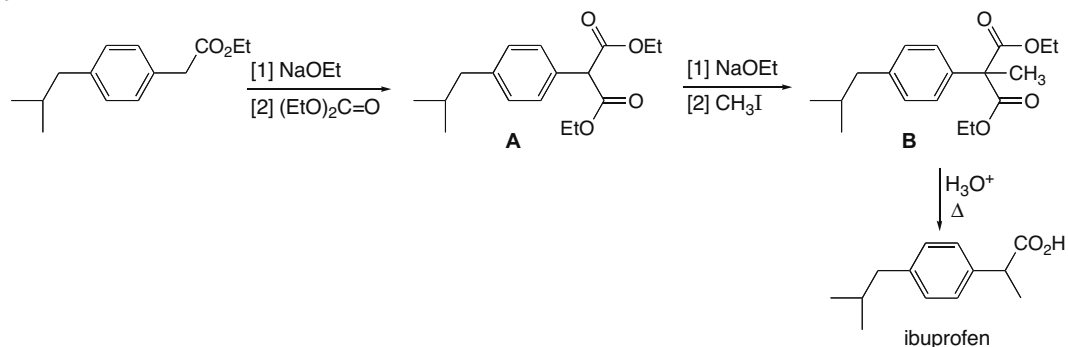


Carbonyl Condensation Reactions 24–9

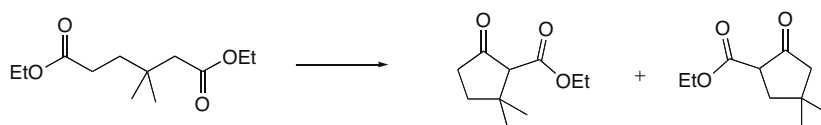
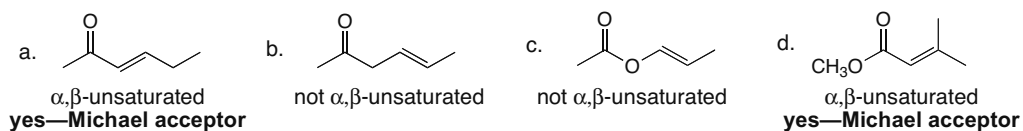
24.18



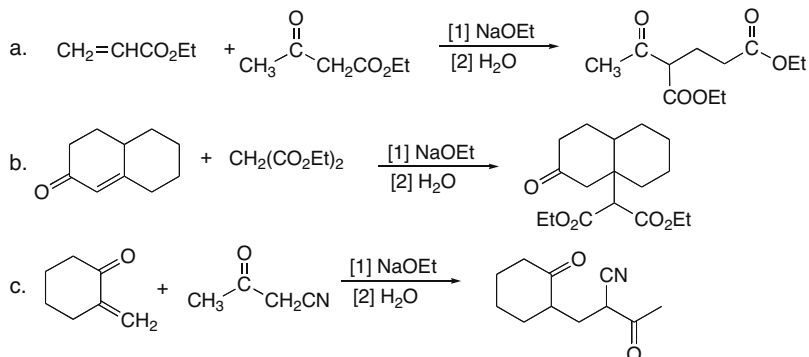
24.19



24.20

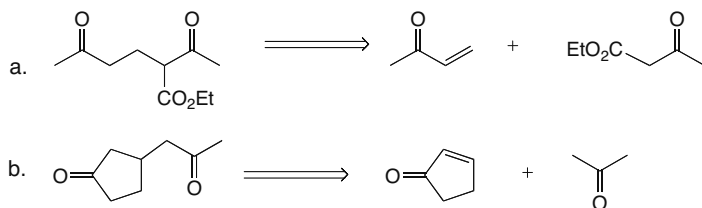
24.21 A Michael acceptor is an α,β -unsaturated carbonyl compound.

24.22

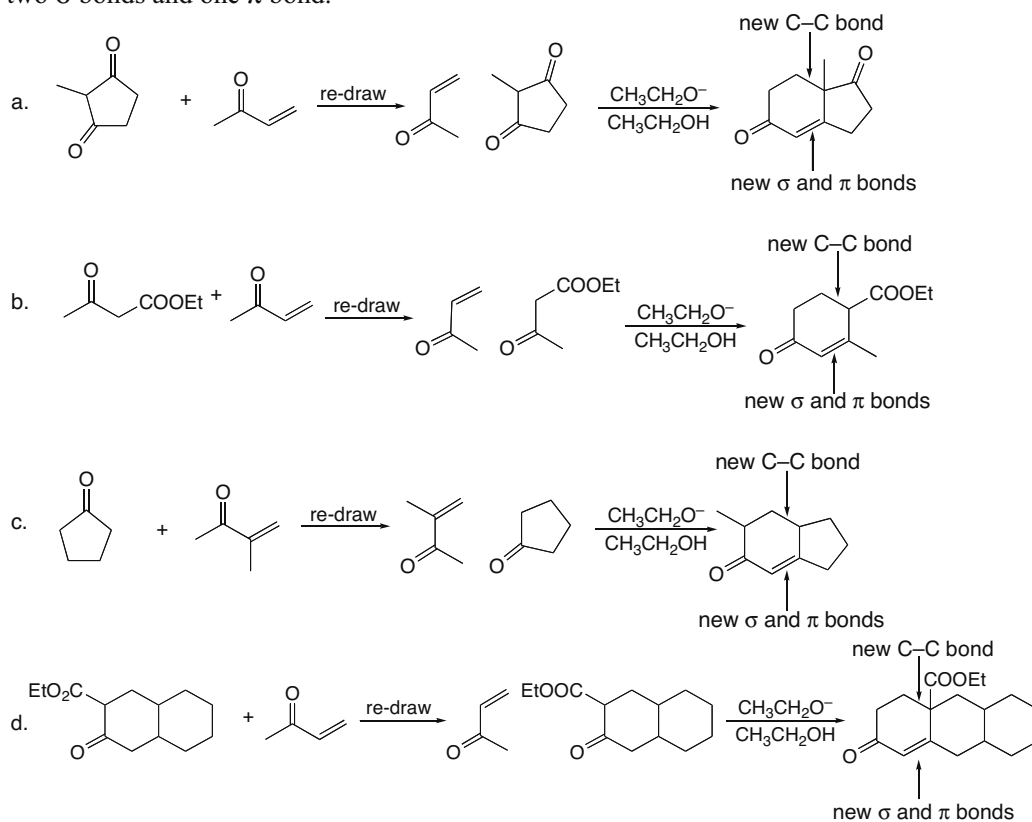


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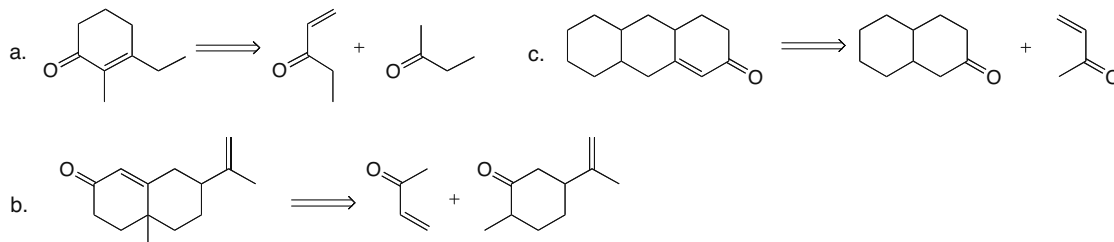
24.23



24.24 The Robinson annulation forms a six-membered ring and three new carbon–carbon bonds: two σ bonds and one π bond.

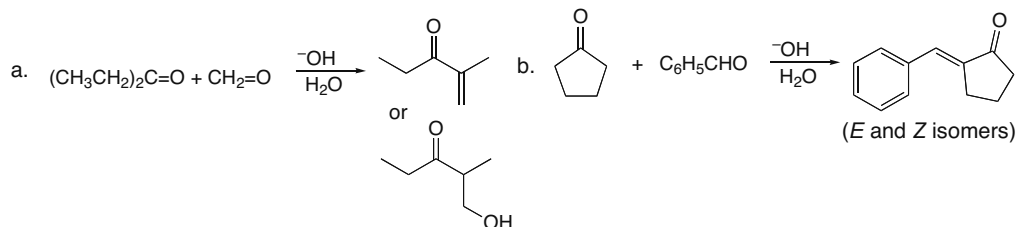


24.25

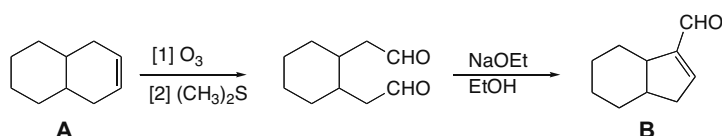


Carbonyl Condensation Reactions 24-11

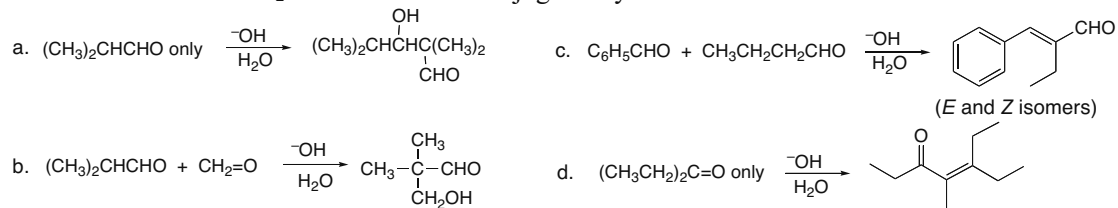
24.26



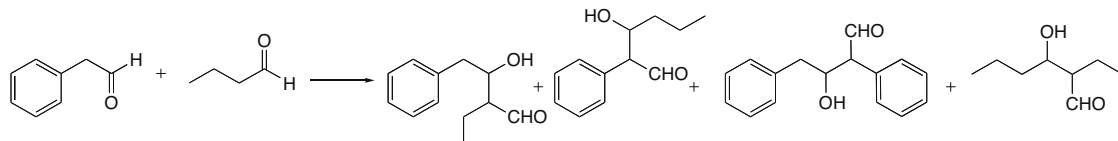
24.27



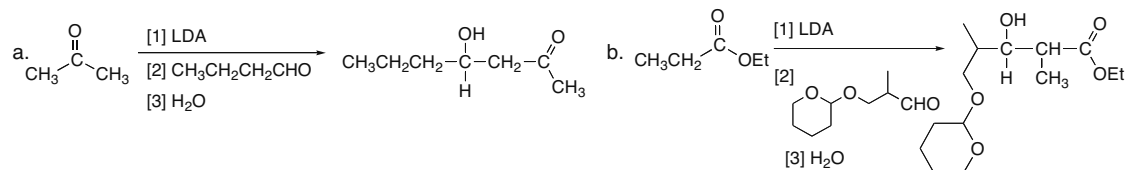
24.28 The product of an aldol reaction is a β -hydroxy carbonyl compound or an α,β -unsaturated carbonyl compound. The α,β -unsaturated carbonyl compound is drawn as product unless elimination of H_2O cannot form a conjugated system.



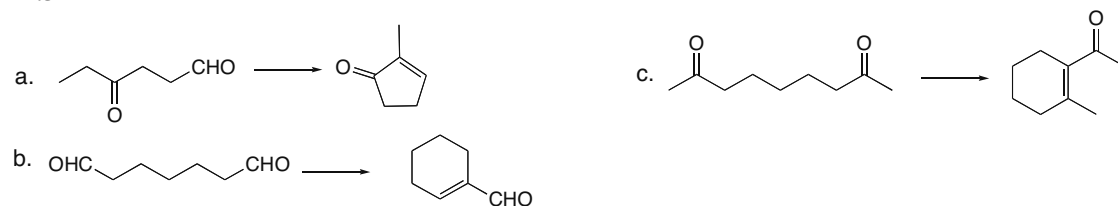
24.29



24.30

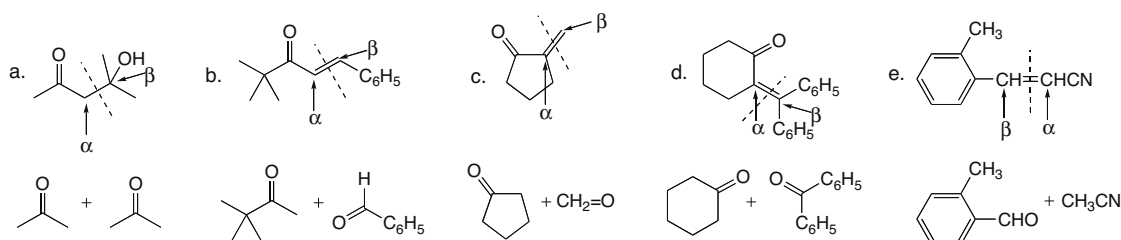
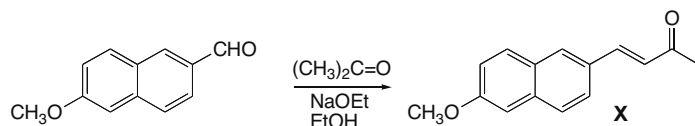


24.31

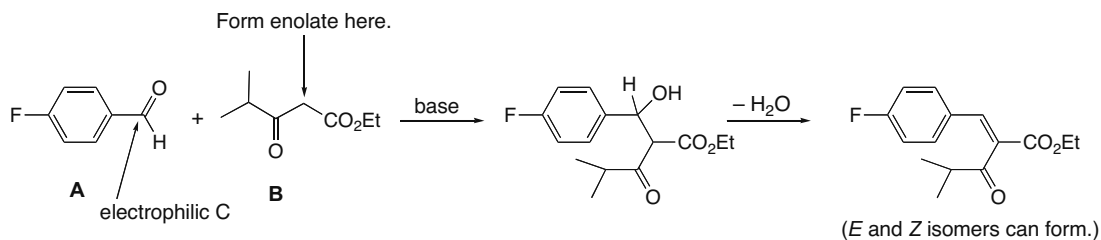
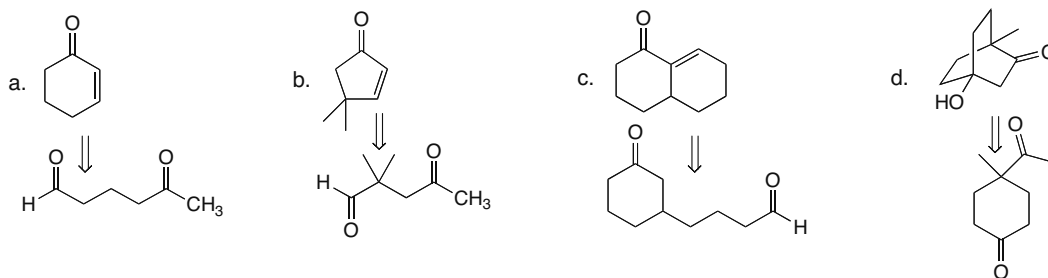


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24.32 Locate the α and β C's to the carbonyl group, and break the molecule into two halves at this bond. The α C and all of the atoms bonded to it belong to one carbonyl component. The β C and all the atoms bonded to it belong to the other carbonyl component.

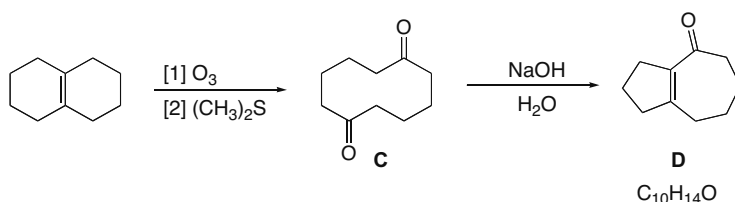
**24.33**

24.34 Base removes the most acidic proton between the two C=O's in **B**. This enolate reacts with the aldehyde in **A** to form a product that loses H_2O .

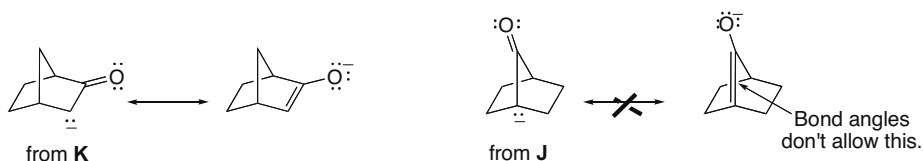
**24.35**

Carbonyl Condensation Reactions 24–13

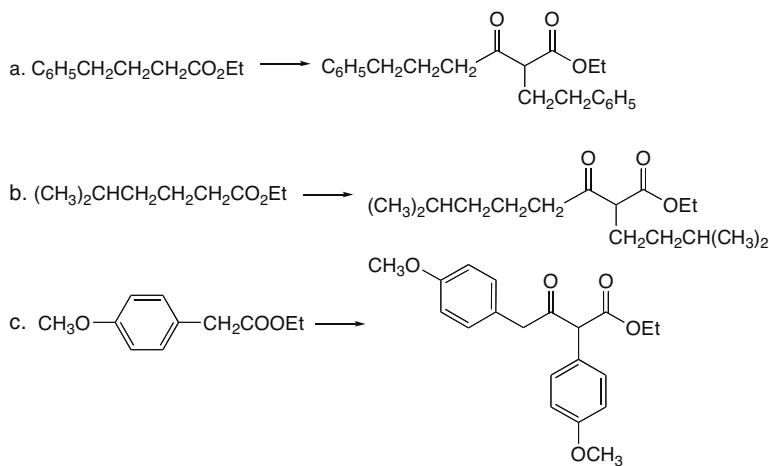
24.36 Ozonolysis cleaves the C=C, and base catalyzes an intramolecular aldol reaction.



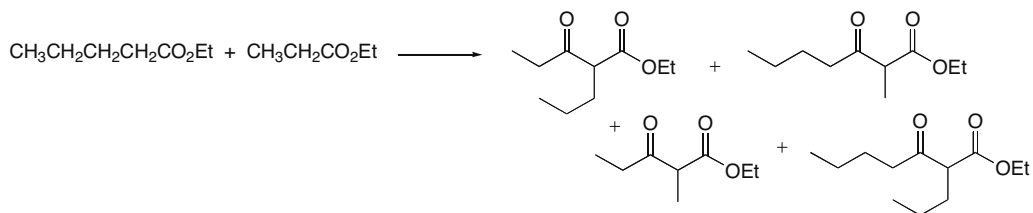
24.37 Aldol reactions proceed via resonance-stabilized enolates. **K** can form an enolate that allows for delocalization of the negative charge on O. Delocalization is not possible in **J**, because a double bond would be placed at a bridgehead carbon, which is geometrically impossible.



24.38

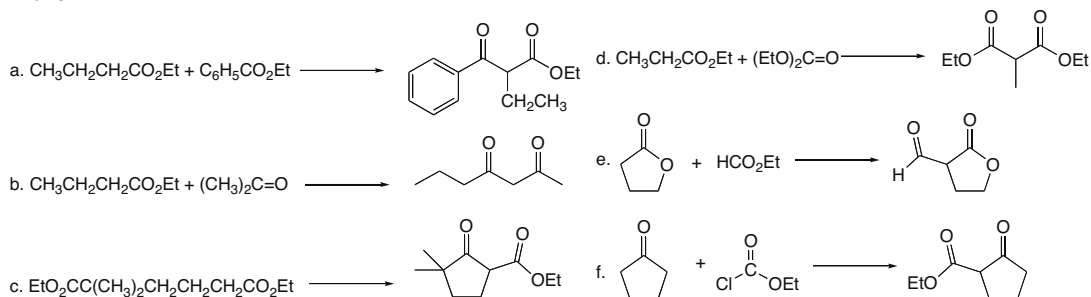


24.39

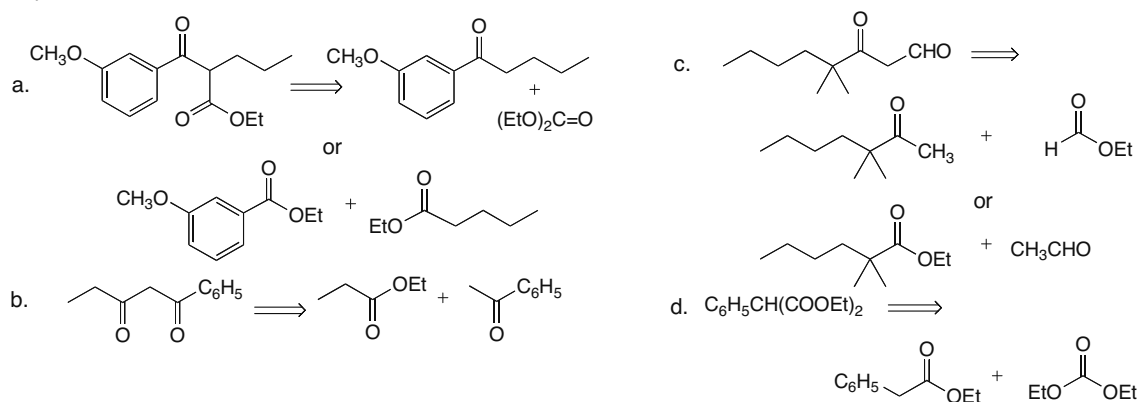


Chapter 24–14

24.40

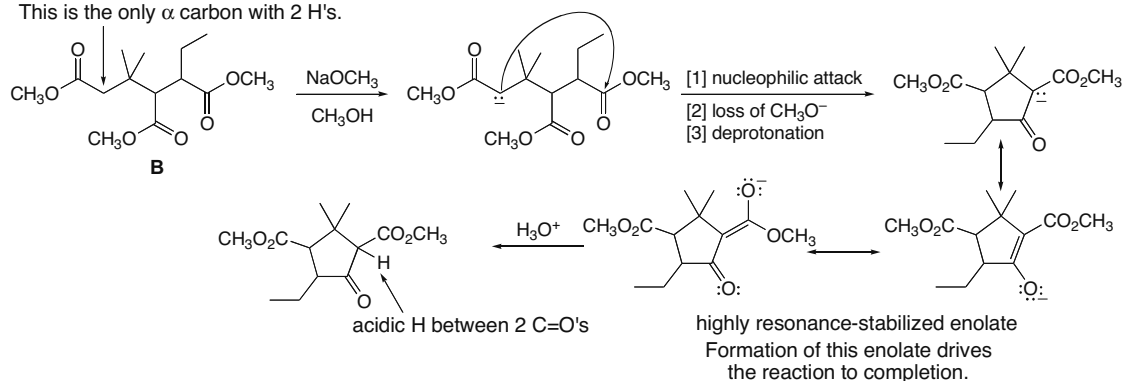


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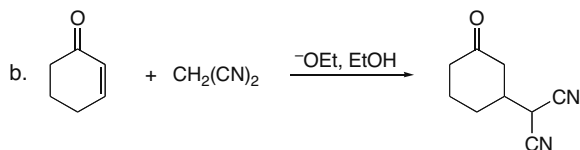
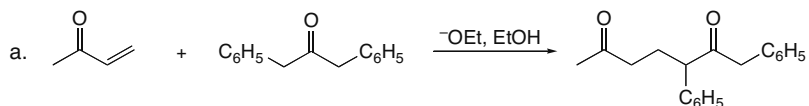
24.42 Only esters with two H's or three H's on the α carbon form enolates that undergo Claisen reaction to form resonance-stabilized enolates of the product β -keto ester. Thus, the enolate forms on the CH_2 α to one ester carbonyl, and cyclization yields a five-membered ring.

This is the only α carbon with 2 H's.

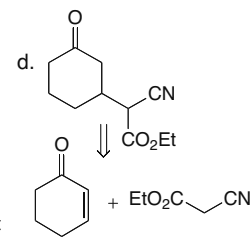
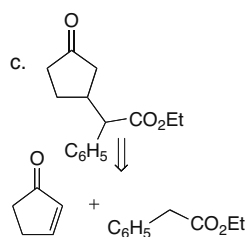
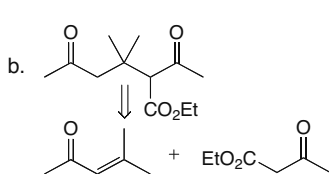
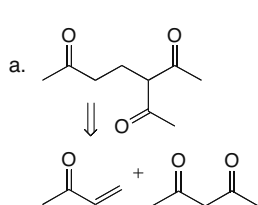


Carbonyl Condensation Reactions 24–15

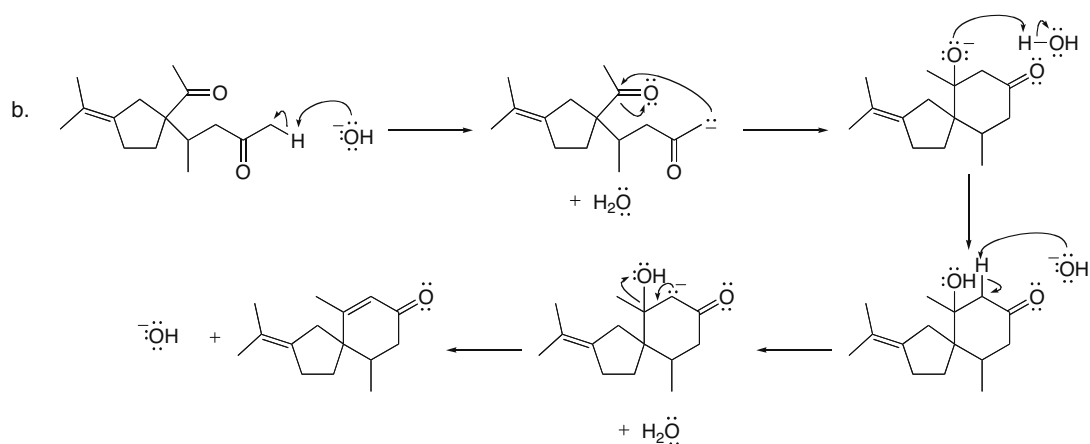
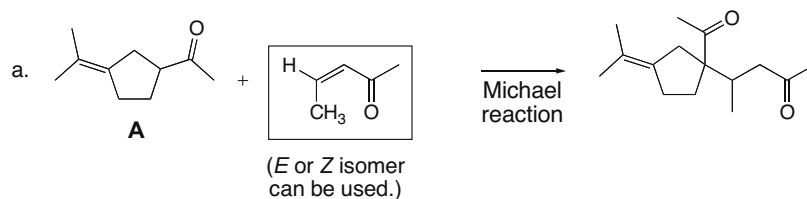
24.43



24.44

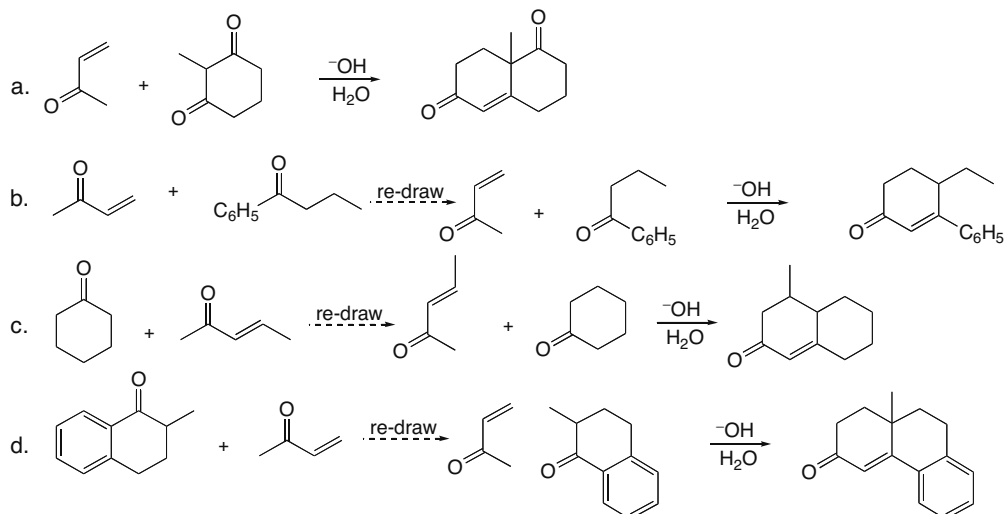


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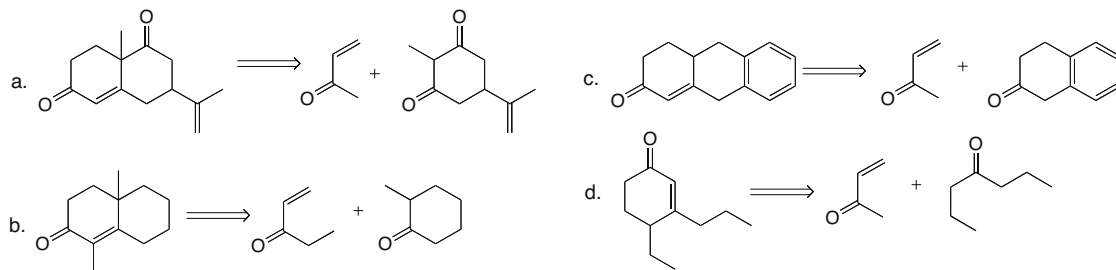


Chapter 24–16

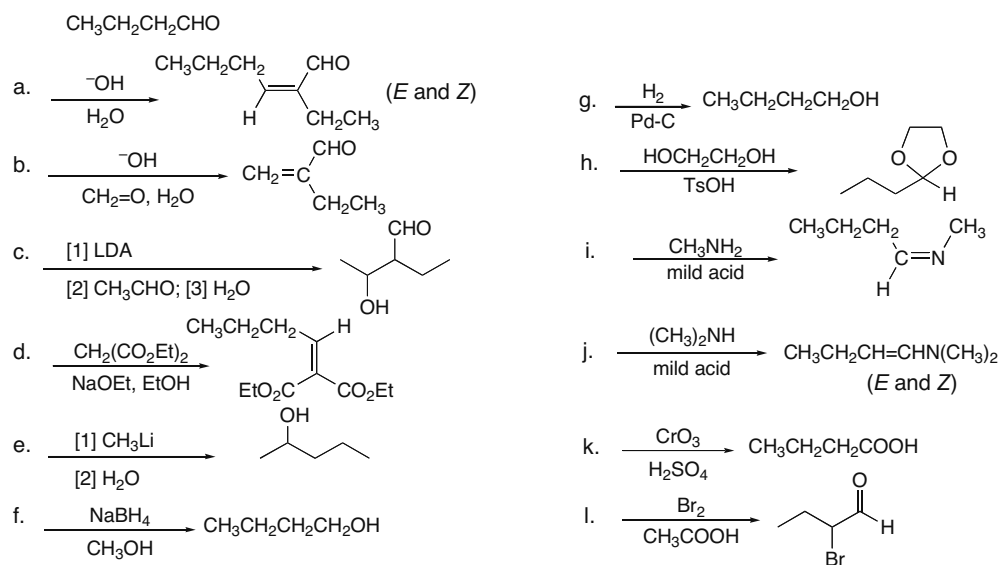
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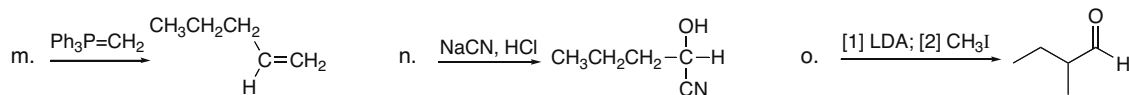
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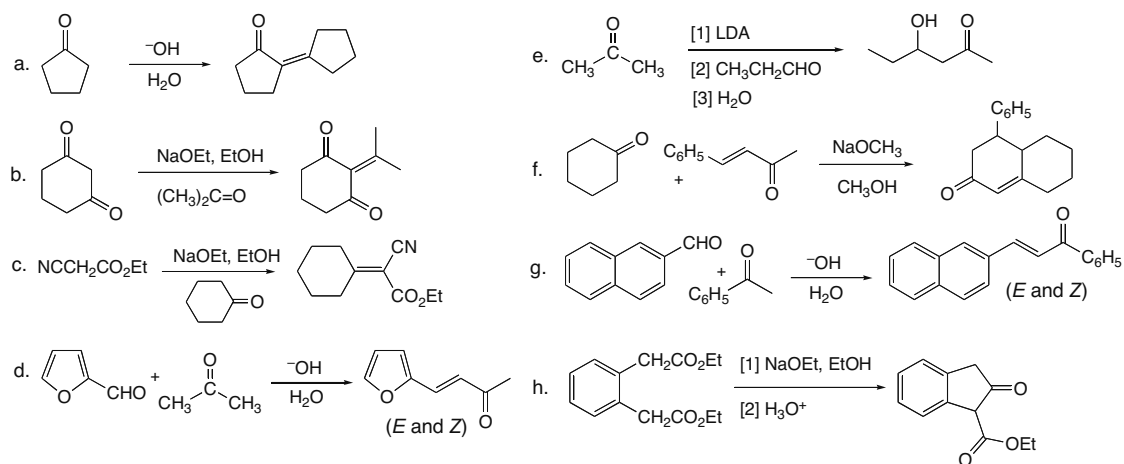
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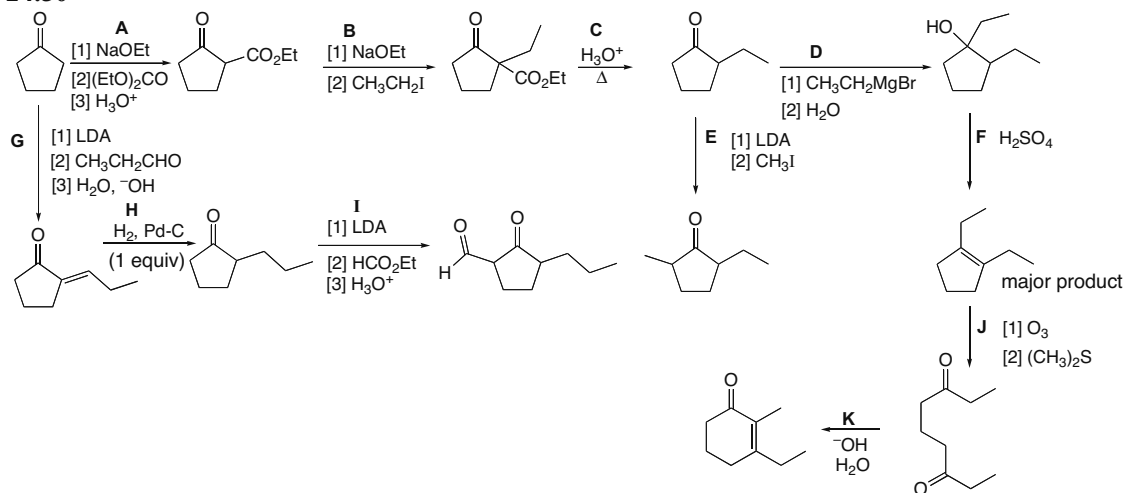
Carbonyl Condensation Reactions 24–17



24.49

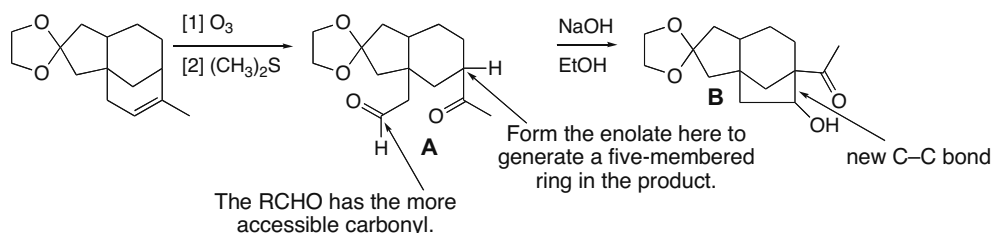


24.50

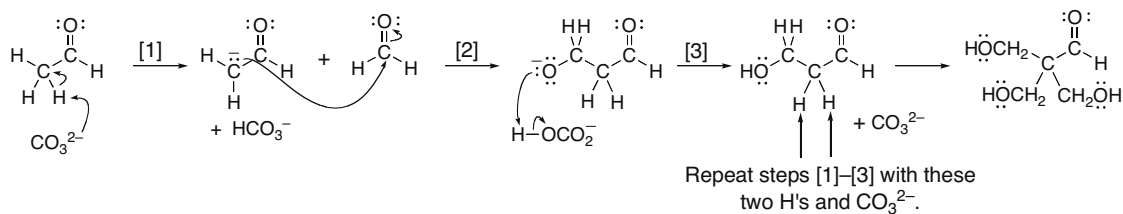


Chapter 24–18

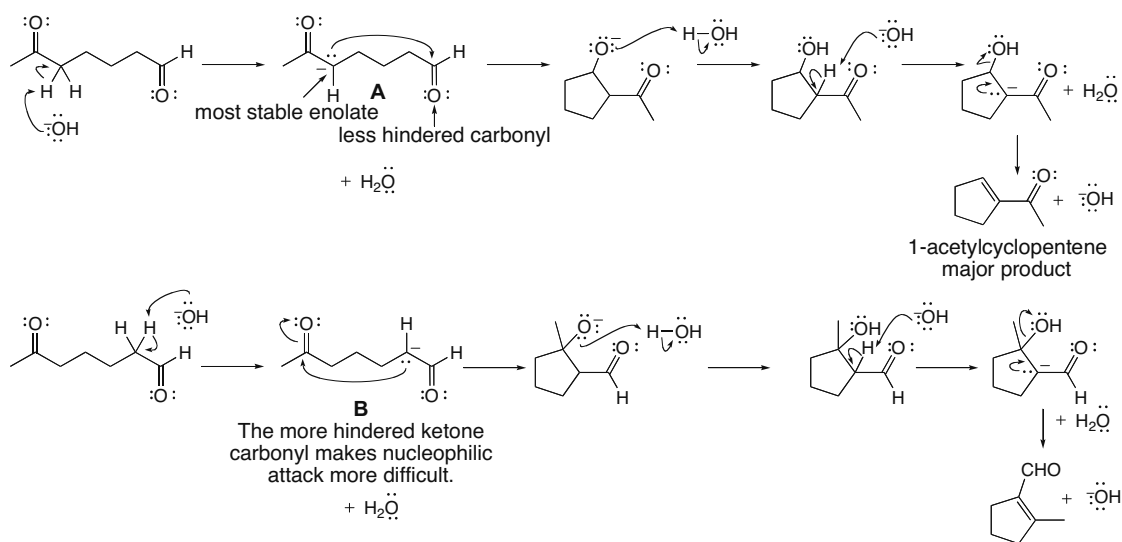
24.51



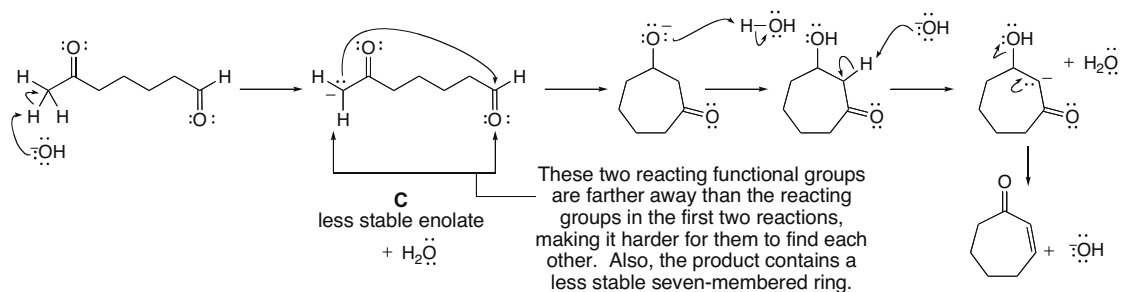
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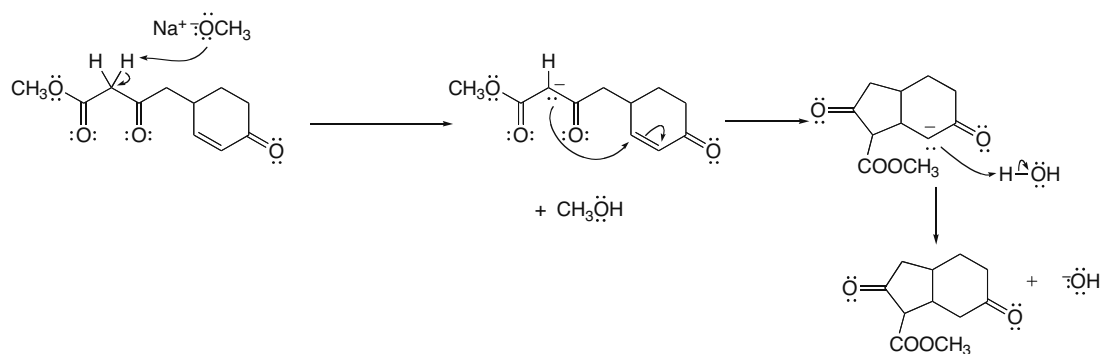
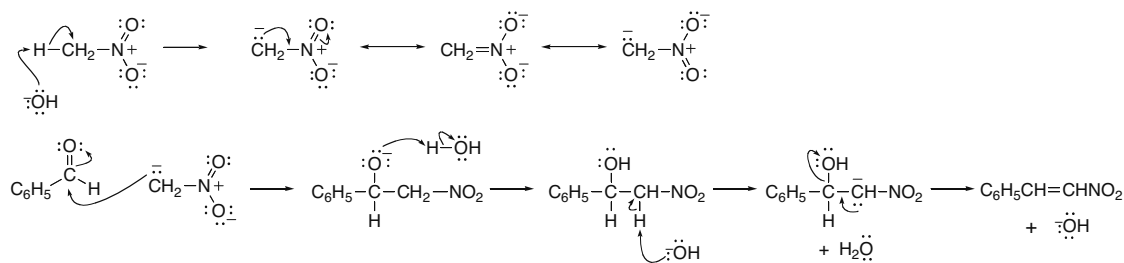
24.53 Enolate **A** is more substituted (and more stable) than either of the other two possible enolates and attacks an aldehyde carbonyl group, which is sterically less hindered than a ketone carbonyl. The resulting ring size (five-membered) is also quite stable. That is why 1-acetylcyclopentene is the major product.



Carbonyl Condensation Reactions 24–19

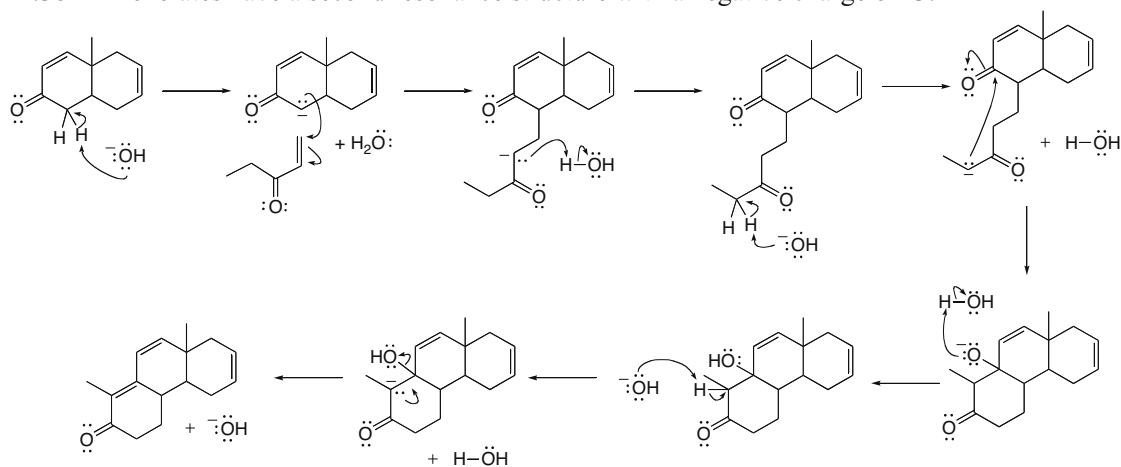


24.54

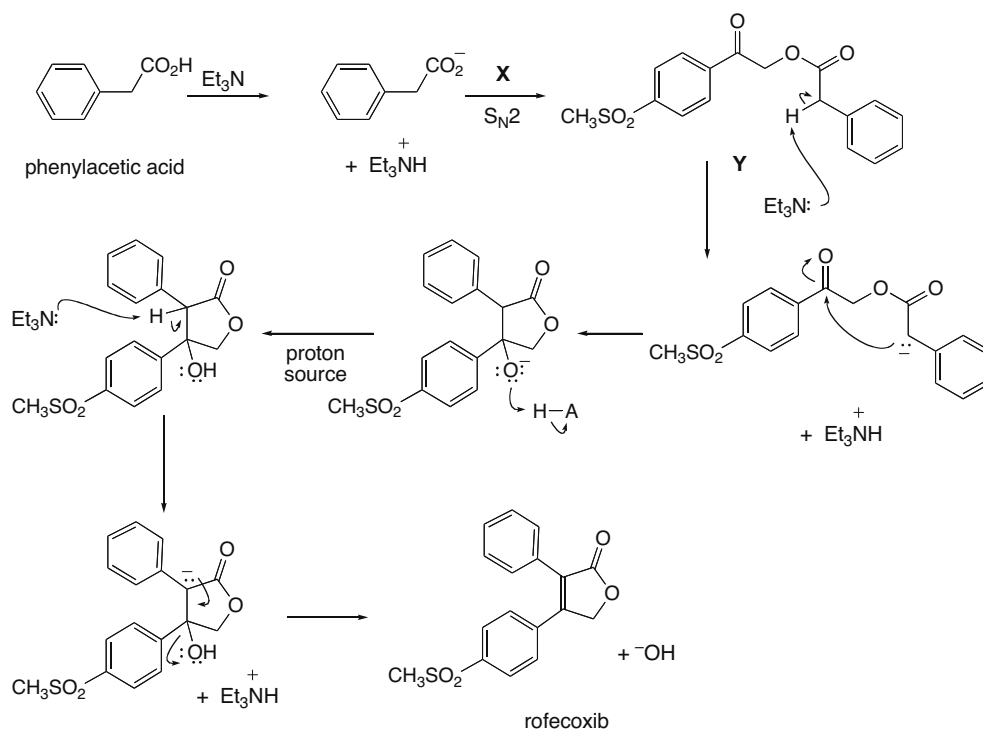
24.55 Removal of a proton from CH_3NO_2 forms an anion for which three resonance structures can be drawn.

Chapter 24–20

24.56 All enolates have a second resonance structure with a negative charge on O.

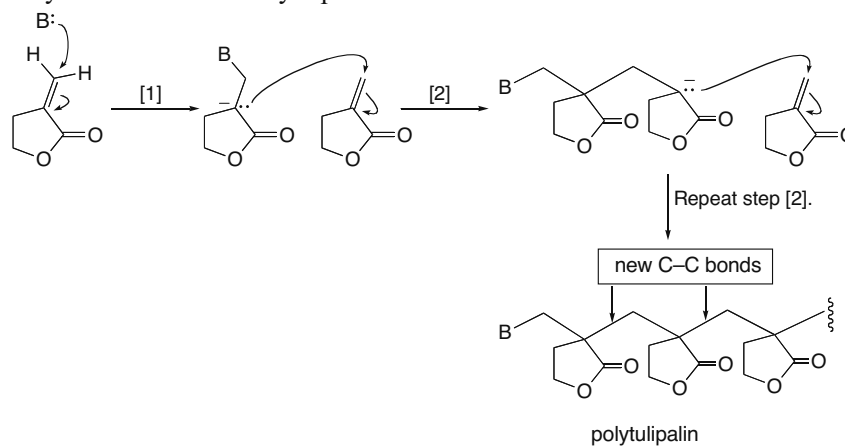


24.57 Et_3N reacts with phenylacetic acid to form a carboxylate anion that acts as a nucleophile to displace Br, forming **Y**. Then an intramolecular crossed-Claisen reaction yields rofecoxib.

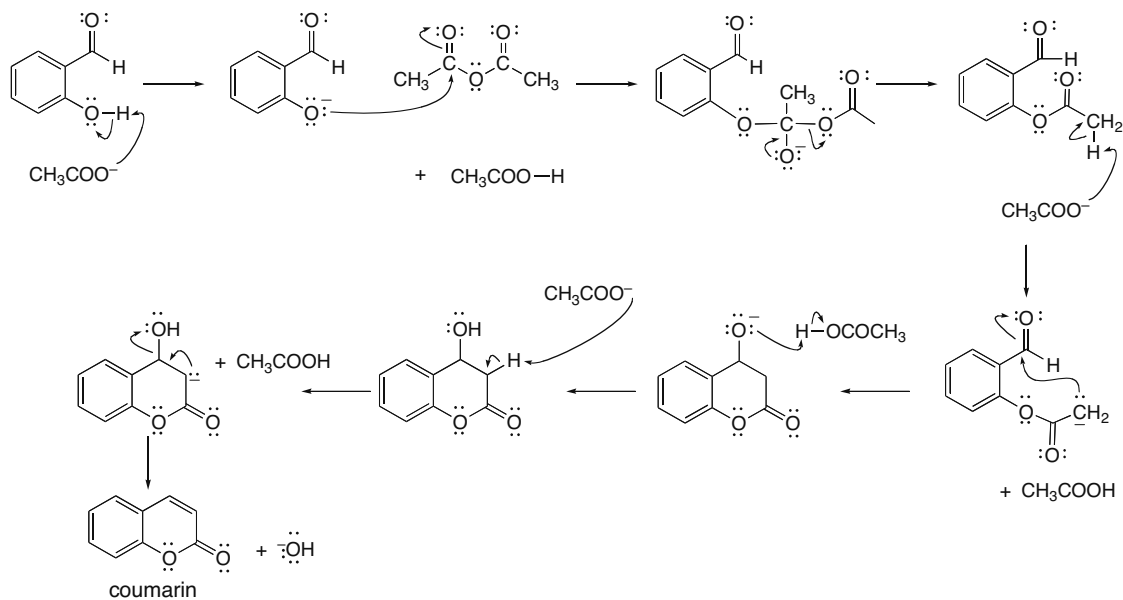


Carbonyl Condensation Reactions 24–21

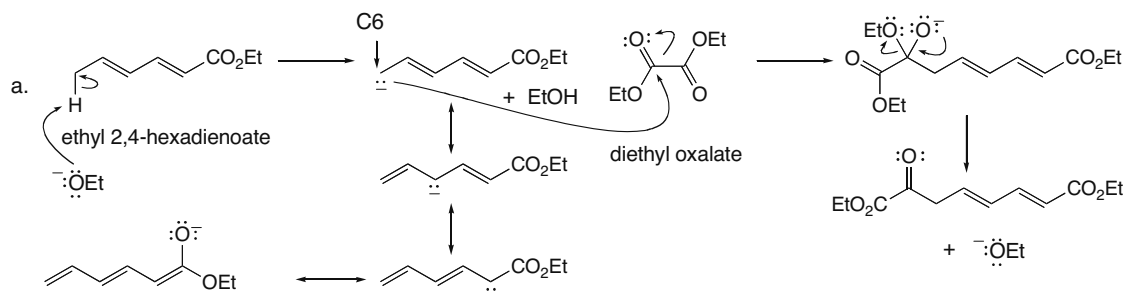
24.58 Polymerization occurs by repeated Michael reactions.



24.59



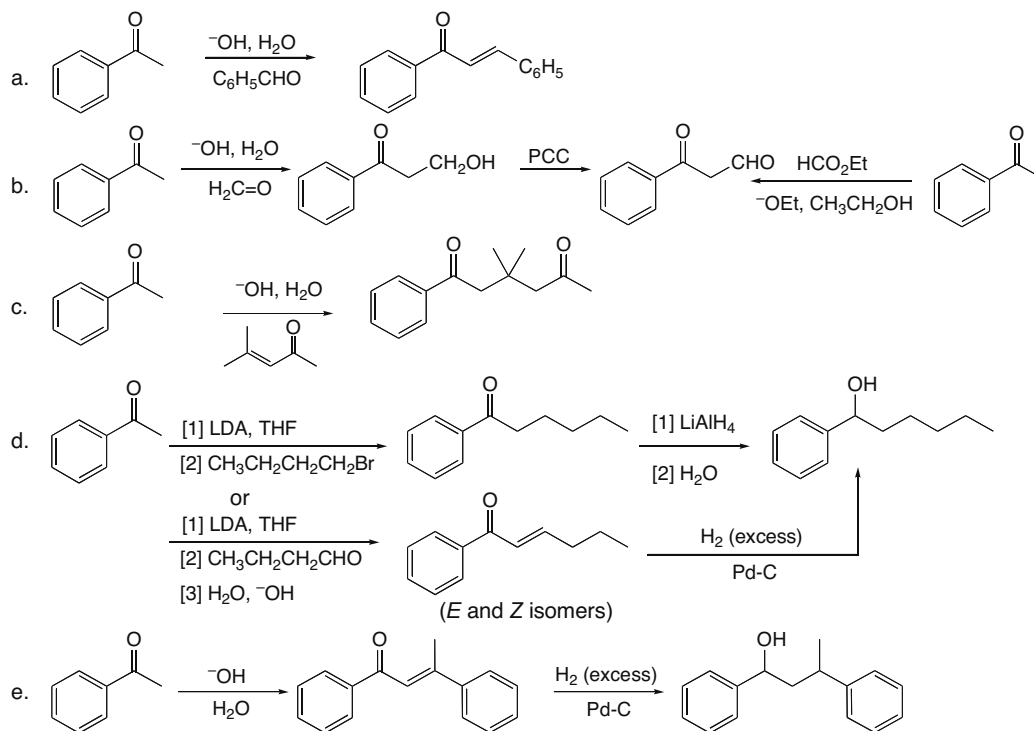
24.60



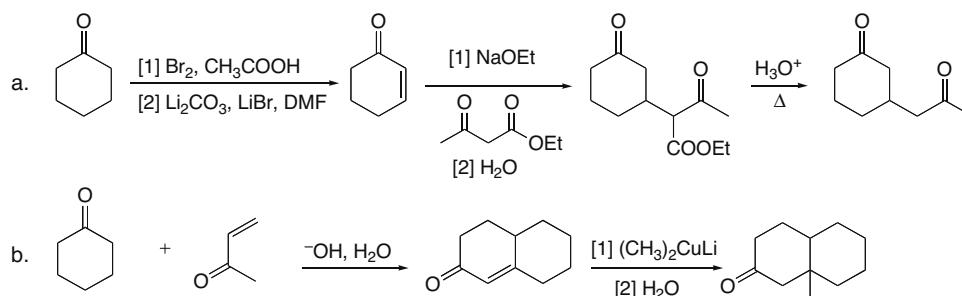
Chapter 24–22

- b. The protons on C6 are more acidic than other sp^3 hybridized C–H bonds because a highly resonance-stabilized carbanion is formed when a proton is removed. One resonance structure places a negative charge on the carbonyl O atom. This makes the protons on C6 similar in acidity to the α H's to a carbonyl.
- c. This is a crossed Claisen because it involves the enolate of a conjugated ester reacting with the carbonyl group of a second ester.

24.61

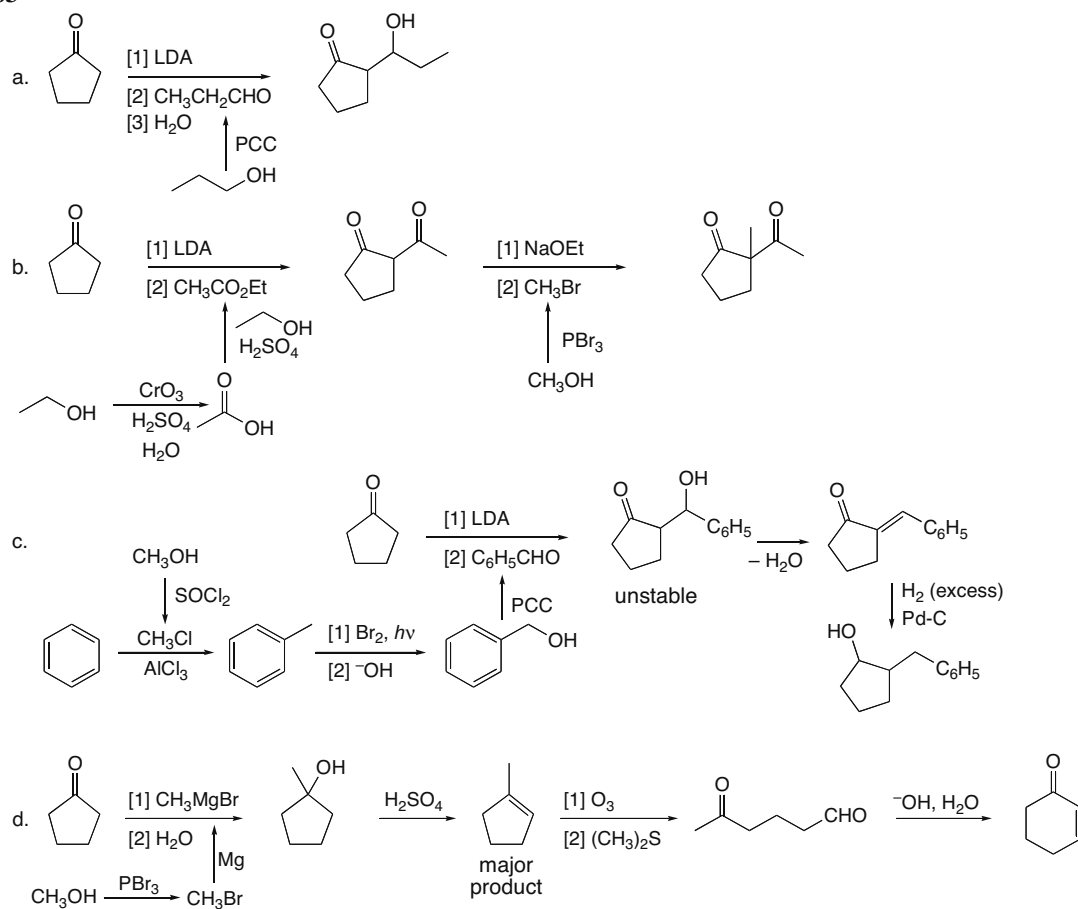


24.62

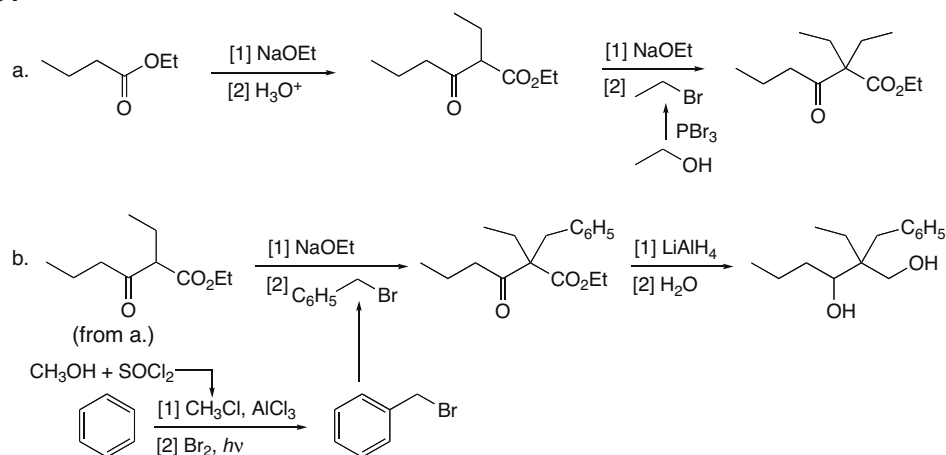


Carbonyl Condensation Reactions 24–23

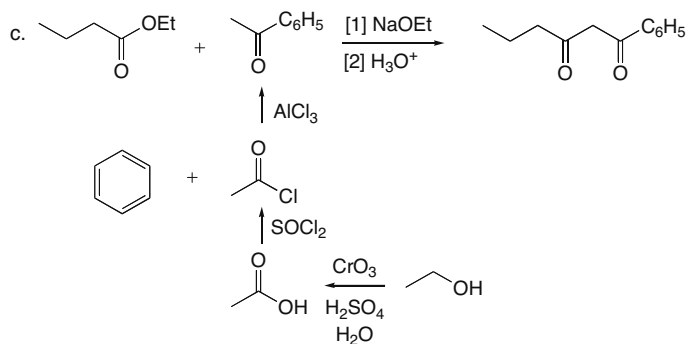
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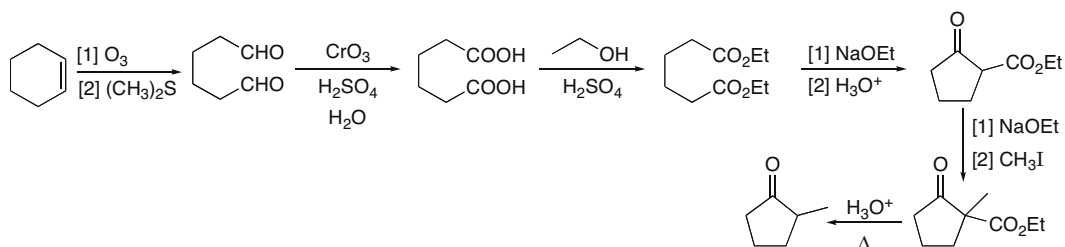
24.64



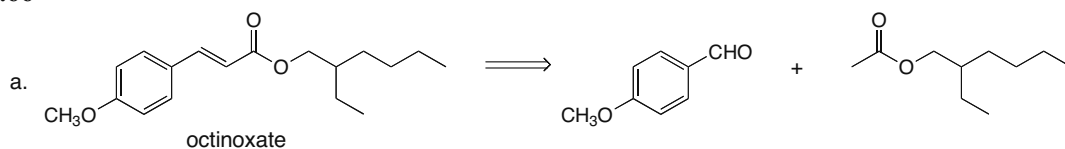
Chapter 24–24



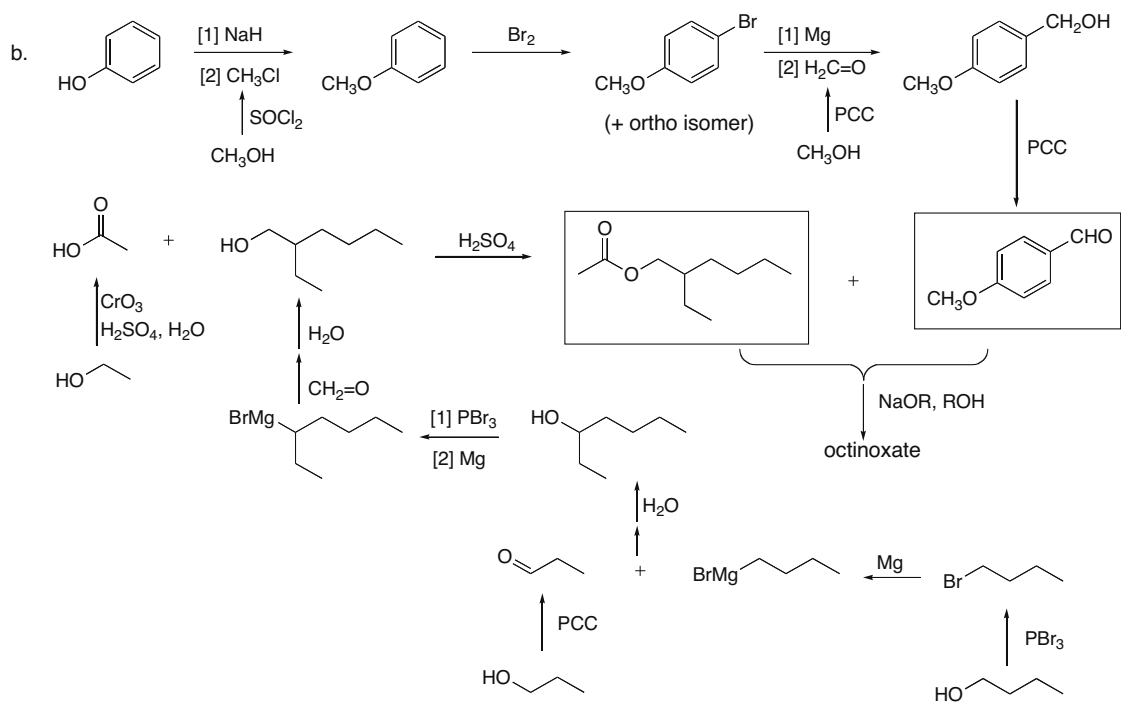
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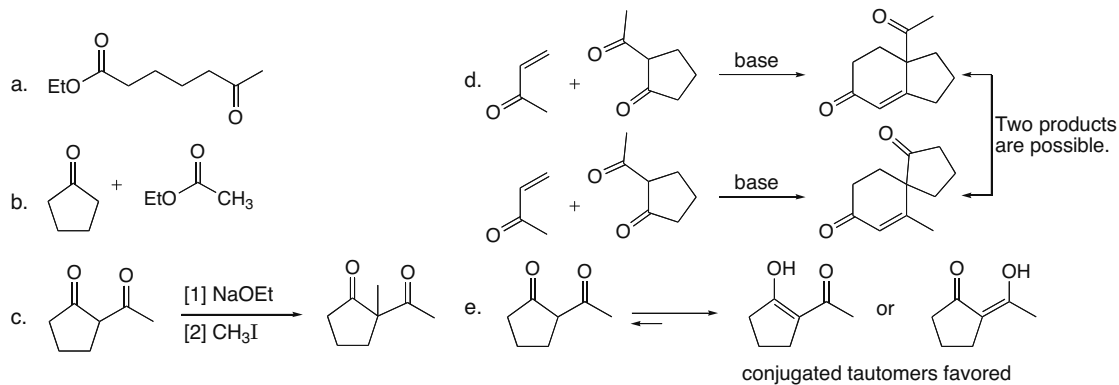
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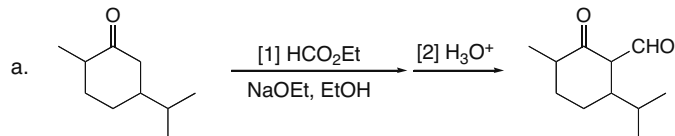
Carbonyl Condensation Reactions 24–25



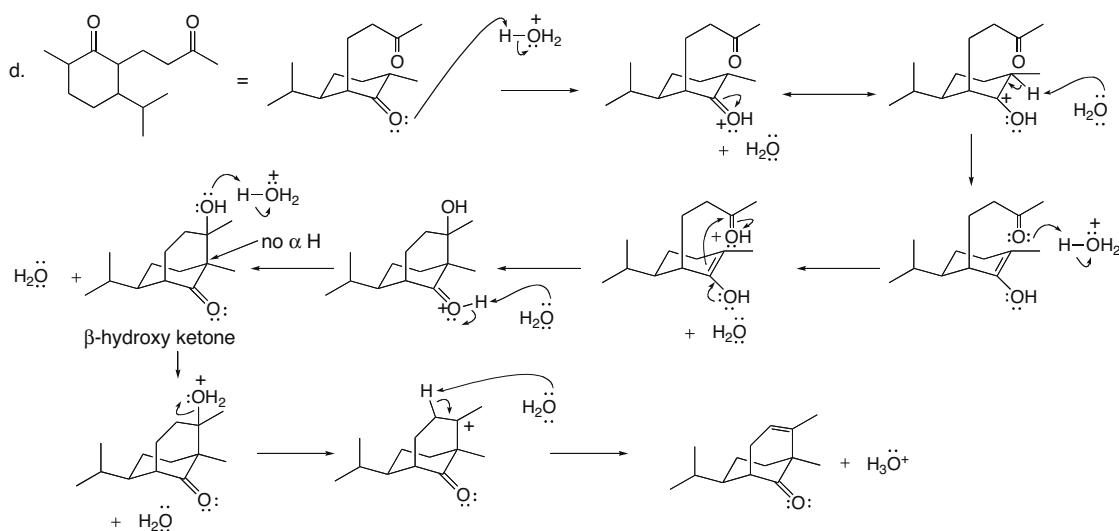
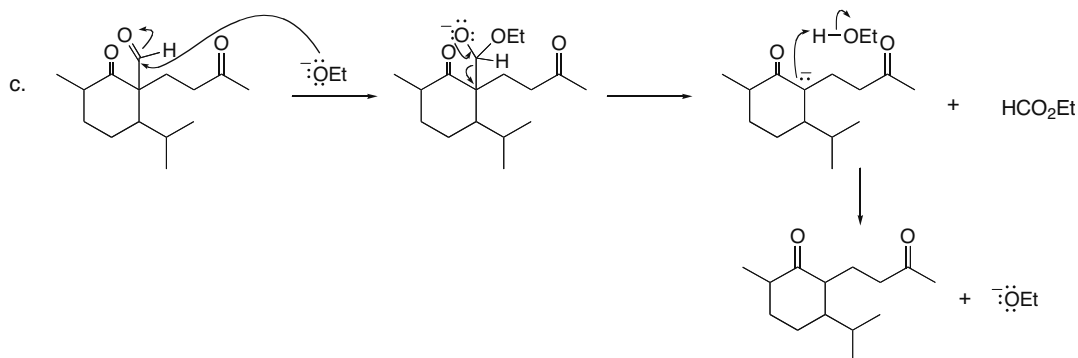
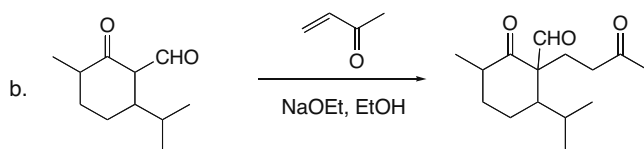
24.67



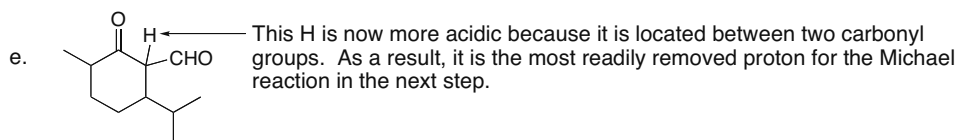
24.68



Chapter 24–26

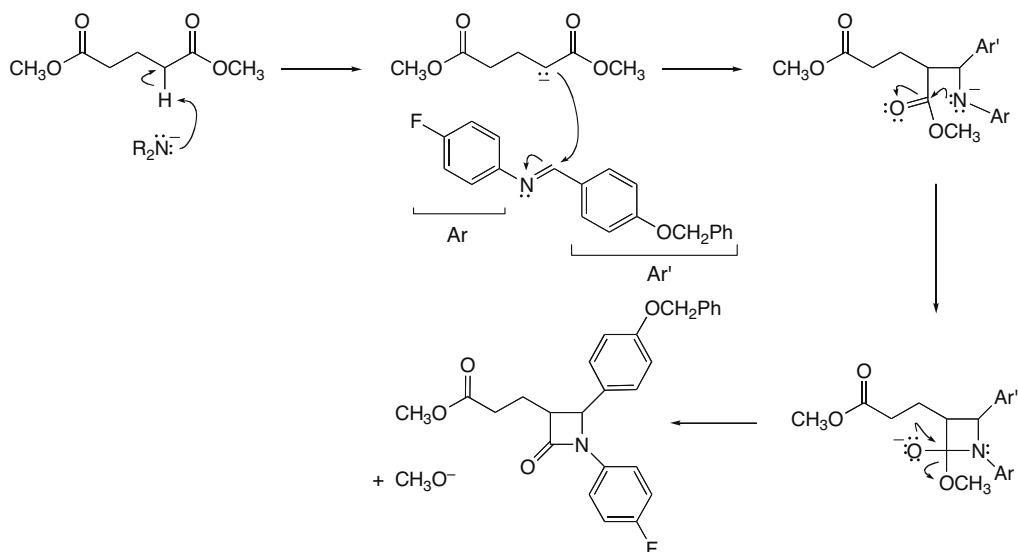


This reaction is an acid-catalyzed aldol that proceeds by way of enols not enolates. The β -hydroxy ketone initially formed cannot dehydrate to form an α,β -unsaturated carbonyl because there is no H on the α carbon. Thus, dehydration occurs, but the resulting $\text{C}=\text{C}$ is not conjugated with the $\text{C}=\text{O}$.

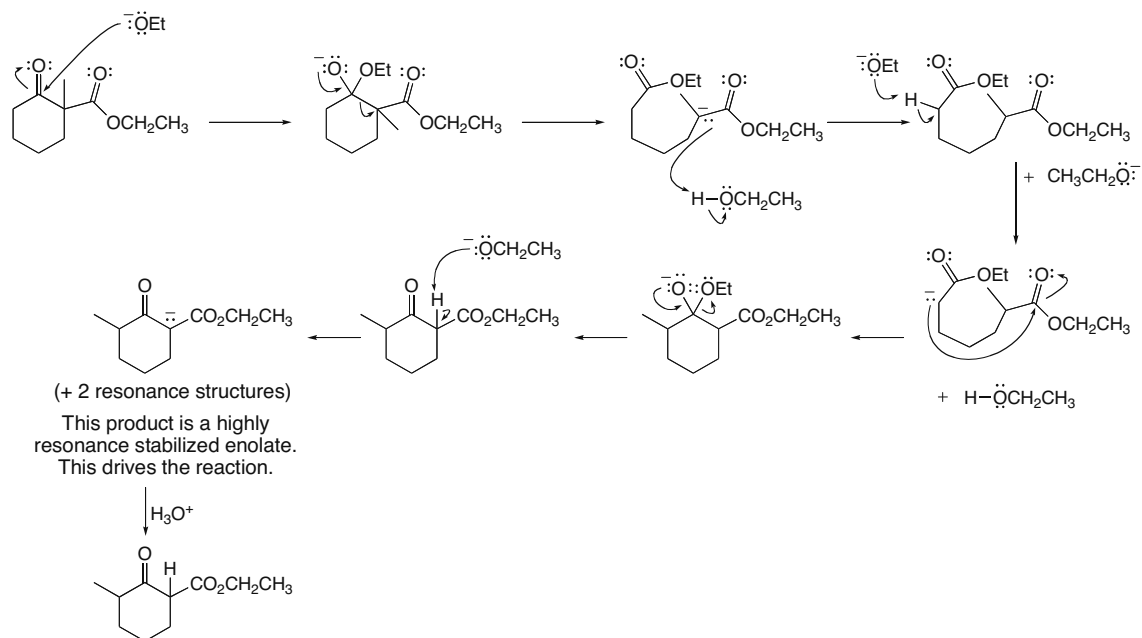


Carbonyl Condensation Reactions 24–27

24.69

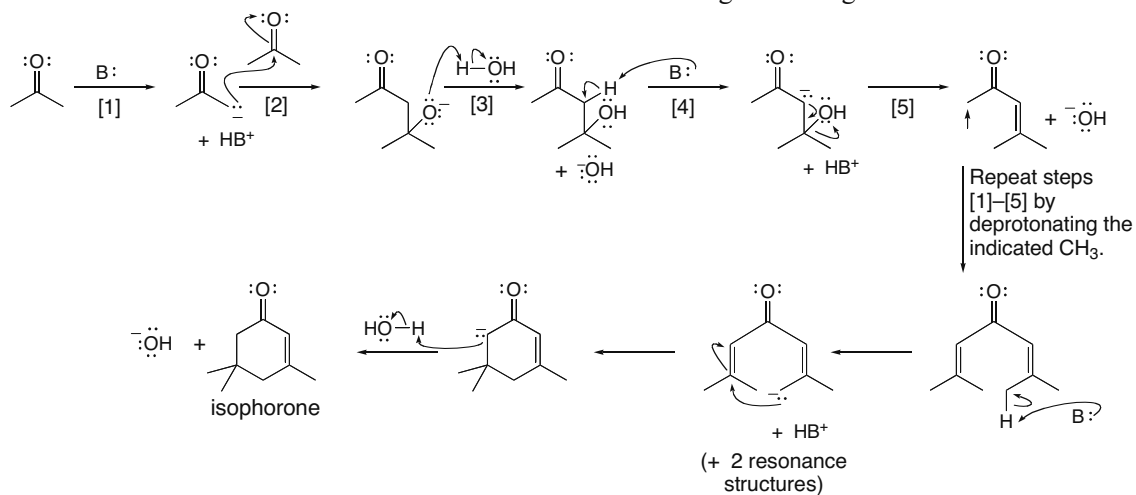


24.70 Rearrangement generates a highly resonance-stabilized enolate between two carbonyl groups.

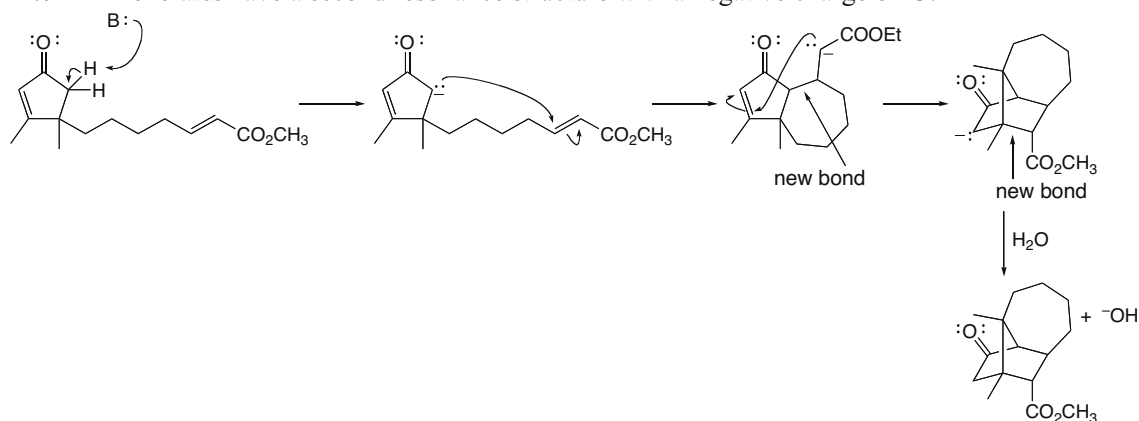


Chapter 24–28

24.71 All enolates have a second resonance structure with a negative charge on O.

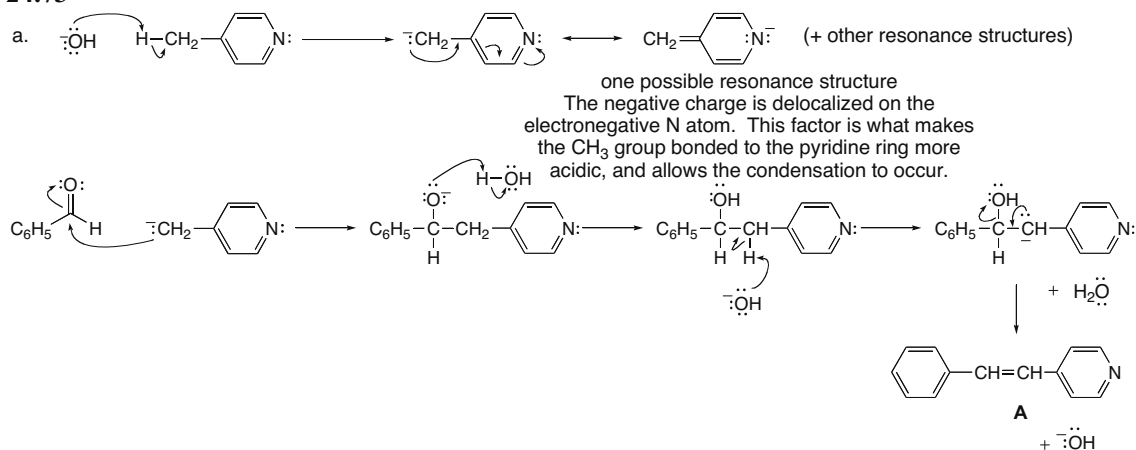


24.72 All enolates have a second resonance structure with a negative charge on O.

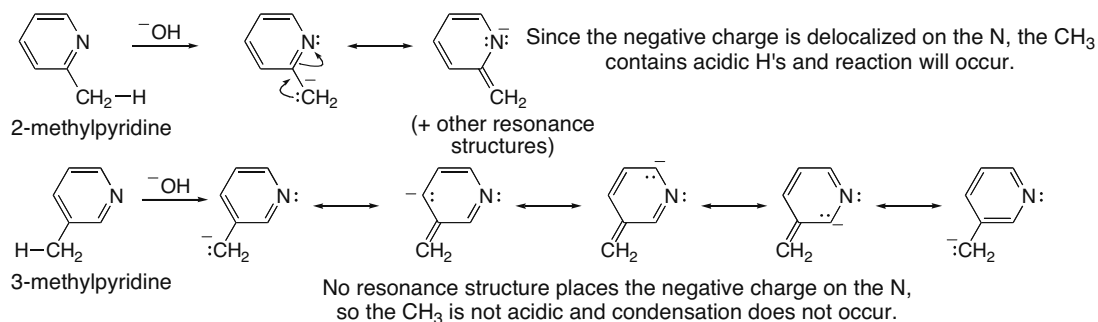


Carbonyl Condensation Reactions 24–29

24.73

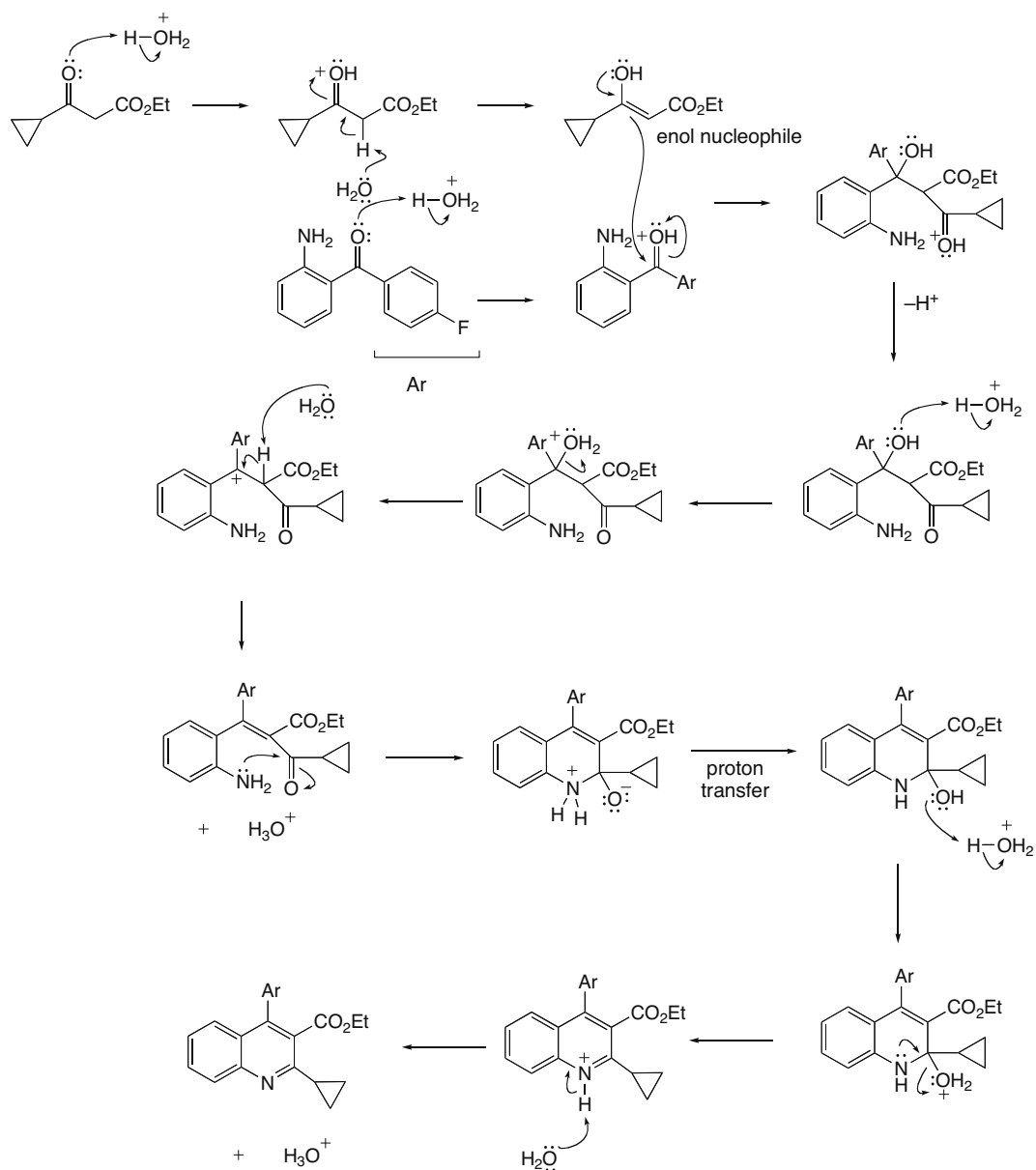


- b. The condensation reaction can occur only if the CH_3 group bonded to the pyridine ring has acidic hydrogens that can be removed with OH^- .



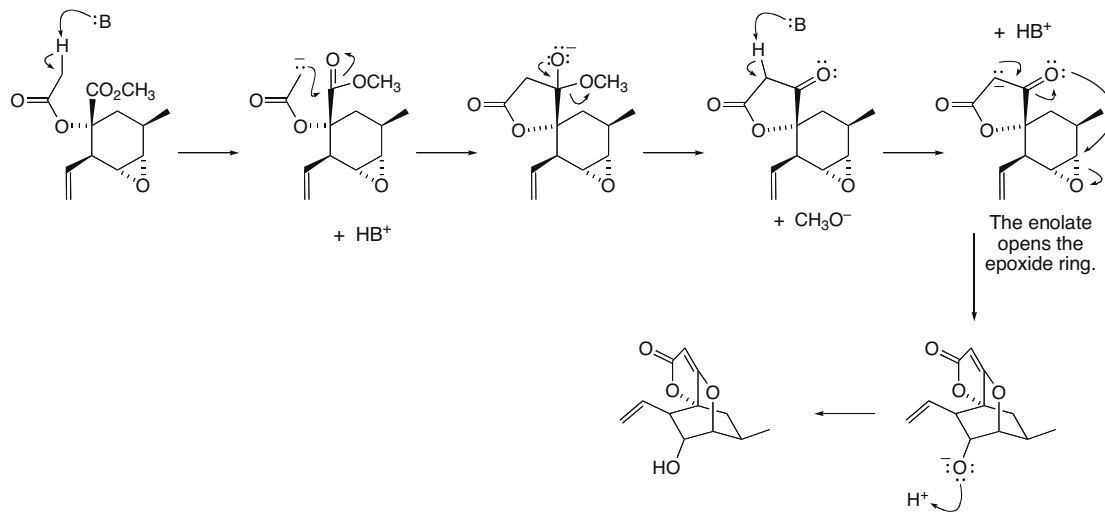
Chapter 24–30

24.74 Since the reaction takes place in acid, enols are involved. After the initial condensation reaction, the NH_2 and $\text{C}=\text{O}$ groups form an imine by an intramolecular reaction.



Carbonyl Condensation Reactions 24–31

24.75



Chapter 25 Amines

Chapter Review

General facts

- Amines are organic nitrogen compounds having the general structure RNH_2 , R_2NH , or R_3N , with a lone pair of electrons on N (25.1).
- Amines are named using the suffix *-amine* (25.3).
- All amines have polar C–N bonds. Primary (1°) and 2° amines have polar N–H bonds and are capable of intermolecular hydrogen bonding (25.4).
- The lone pair on N makes amines strong organic bases and nucleophiles (25.8).

Summary of spectroscopic absorptions (25.5)

Mass spectra Molecular ion Amines with an odd number of N atoms give an odd molecular ion.

IR absorptions N–H 3300–3500 cm^{-1} (two peaks for RNH_2 , one peak for R_2NH)

^1H NMR absorptions NH 0.5–5 ppm (no splitting with adjacent protons)
 CH–N 2.3–3.0 ppm (deshielded $\text{C}_{\text{sp}^3}\text{--H}$)

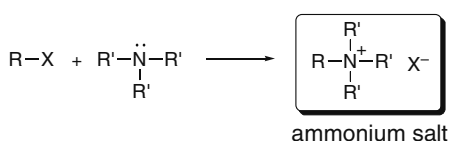
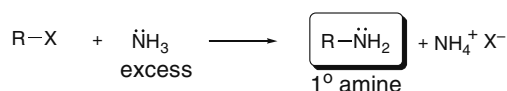
^{13}C NMR absorption C–N 30–50 ppm

Comparing the basicity of amines and other compounds (25.10)

- Alkylamines (RNH_2 , R_2NH , and R_3N) are more basic than NH_3 because of the electron-donating R groups (25.10A).
- Alkylamines (RNH_2) are more basic than arylamines ($\text{C}_6\text{H}_5\text{NH}_2$), which have a delocalized lone pair from the N atom (25.10B).
- Arylamines with electron-donor groups are more basic than arylamines with electron-withdrawing groups (25.10B).
- Alkylamines (RNH_2) are more basic than amides (RCONH_2), which have a delocalized lone pair from the N atom (25.10C).
- Aromatic heterocycles with a localized electron pair on N are more basic than those with a delocalized lone pair from the N atom (25.10D).
- Alkylamines with a lone pair in an sp^3 hybrid orbital are more basic than those with a lone pair in an sp^2 hybrid orbital (25.10E).

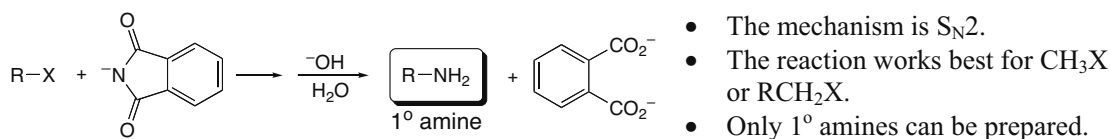
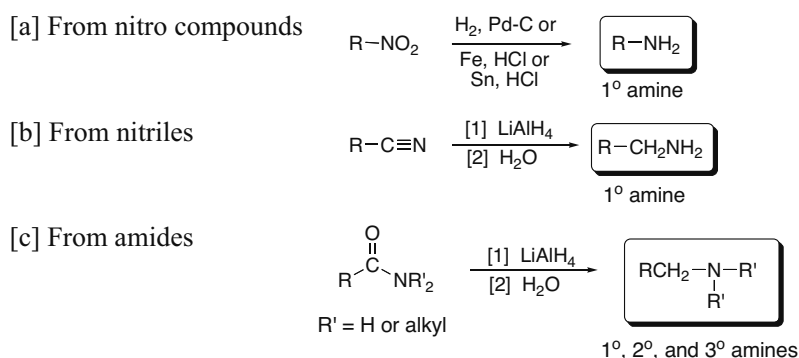
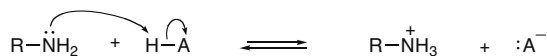
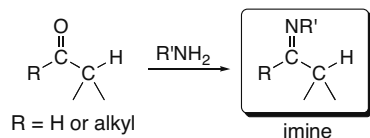
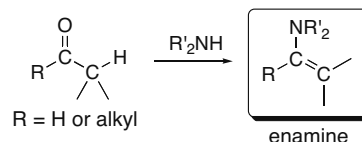
Preparation of amines (25.7)

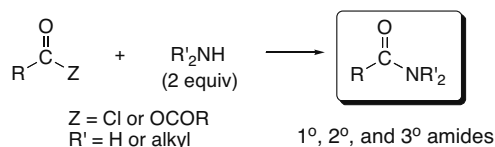
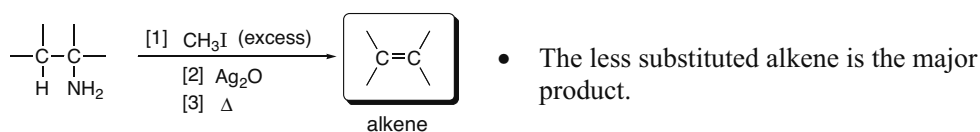
[1] Direct nucleophilic substitution with NH_3 and amines (25.7A)



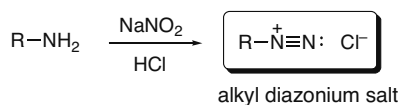
- The mechanism is $\text{S}_{\text{N}}2$.
- The reaction works best for CH_3X or RCH_2X .
- The reaction works best to prepare 1° amines and ammonium salts.

Chapter 25-2

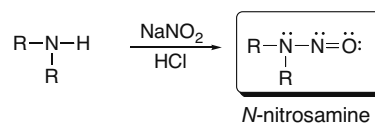
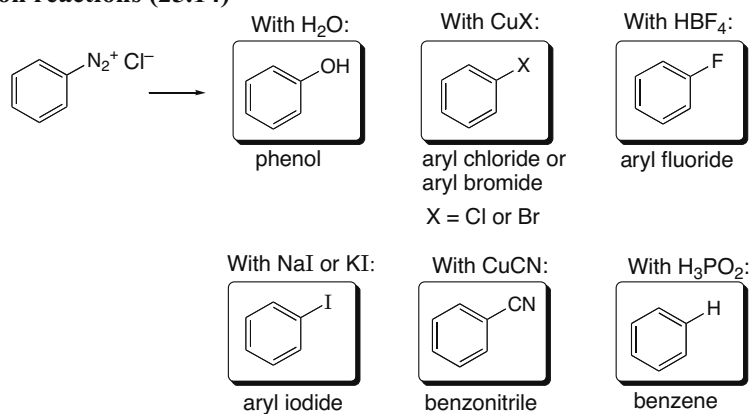
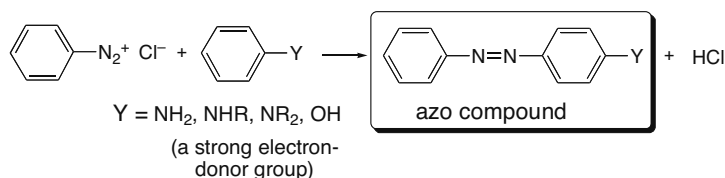
[2] Gabriel synthesis (25.7A)**[3] Reduction methods (25.7B)****[4] Reductive amination (25.7C)****Reactions of amines****[1] Reaction as a base (25.9)****[2] Nucleophilic addition to aldehydes and ketones (25.11)**With 1° amines:With 2° amines:

[3] Nucleophilic substitution with acid chlorides and anhydrides (25.11)**[4] Hofmann elimination (25.12)****[5] Reaction with nitrous acid (25.13)**

With 1° amines:



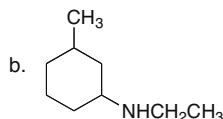
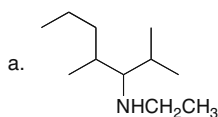
With 2° amines:

**Reactions of diazonium salts****[1] Substitution reactions (25.14)****[2] Coupling to form azo compounds (25.15)**

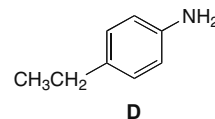
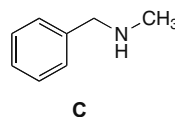
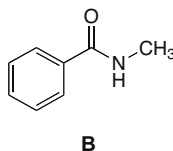
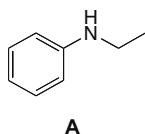
Chapter 25-4

Practice Test on Chapter Review

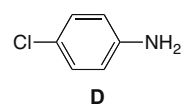
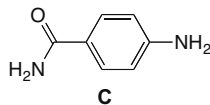
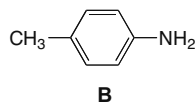
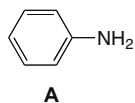
1. Give a systematic name for each of the following compounds.



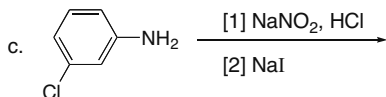
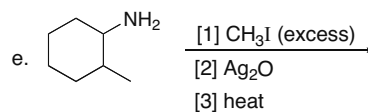
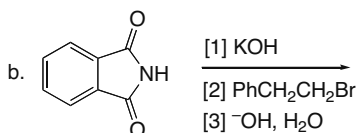
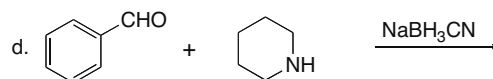
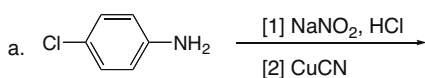
2. (a) Which compound is the weakest base? (b) Which compound is the strongest base?



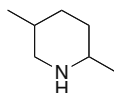
3. (a) Which compound is the weakest base? (b) Which compound is the strongest base?



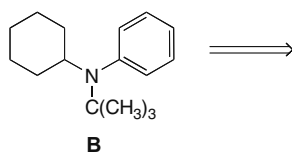
4. Draw the organic products formed in each of the following reactions.



5. Draw the products formed when the given amine is treated with [1] CH_3I (excess); [2] Ag_2O ; [3] Δ , and indicate the major product. You need not consider any stereoisomers formed in the reaction.



6. What organic starting materials are needed to synthesize **B** by reductive amination?



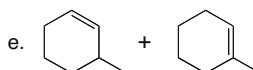
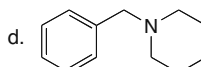
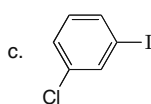
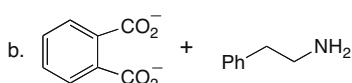
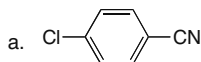
Answers to Practice Test

- 1.a. *N*-ethyl-2,4-dimethyl-3-heptanamine
 b. *N*-ethyl-3-methylcyclohexanamine

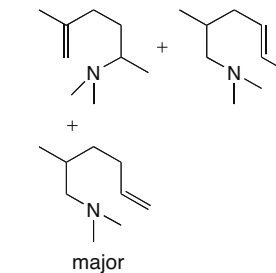
- 2.a. **B**
 b. **C**

- 3.a. **C**
 b. **B**

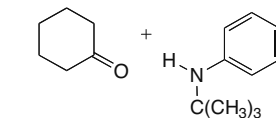
4.



5.

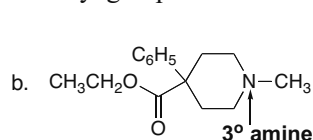
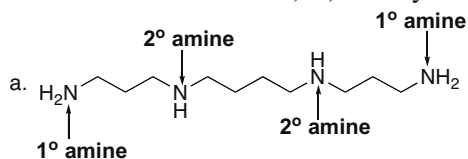


6.

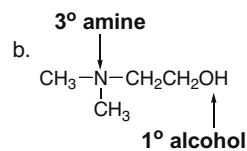
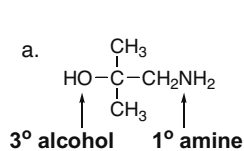


Answers to Problems

25.1 Amines are classified as 1°, 2°, or 3° by the number of alkyl groups bonded to the *nitrogen* atom.

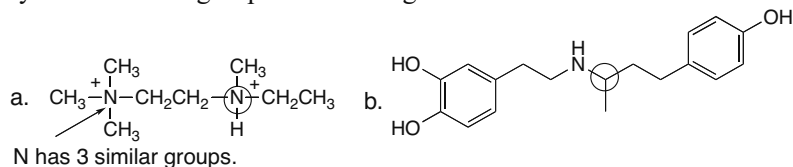
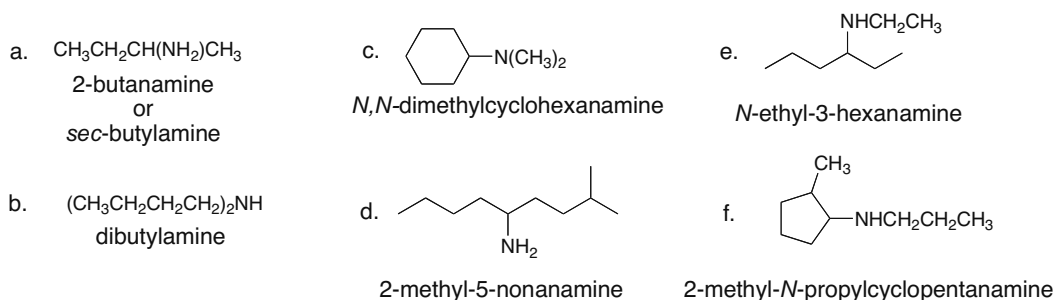


25.2

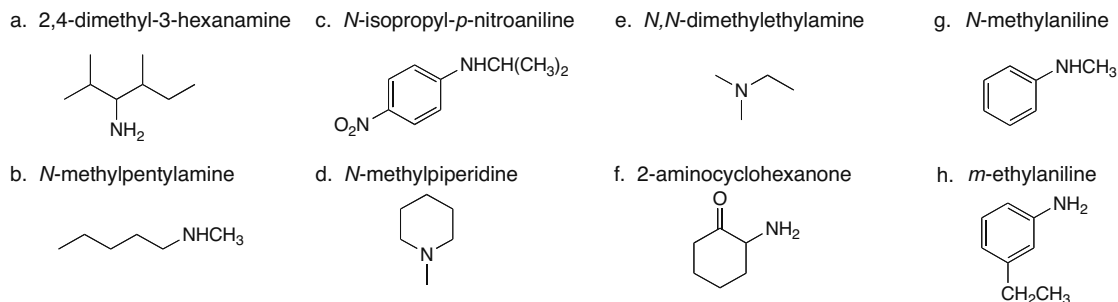


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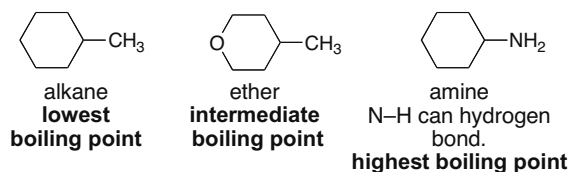
25.3 The N atom of a quaternary ammonium salt is a stereogenic center when the N is surrounded by four different groups. All stereogenic centers are circled.

**25.4**

25.5 An NH_2 group named as a substituent is called an **amino group**.



25.6 Primary (1°) and 2° amines have higher bp's than similar compounds (like ethers) incapable of hydrogen bonding, but lower bp's than alcohols that have stronger intermolecular hydrogen bonds. Tertiary amines (3°) have lower boiling points than 1° and 2° amines of comparable molecular weight because they have no N–H bonds.

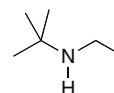


- 25.7 The NH signal occurs between 0.5 and 5.0 ppm.** The protons on the carbon bonded to the amine nitrogen are deshielded and typically absorb at 2.3–3.0 ppm. The NH protons are not split.

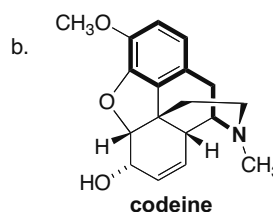
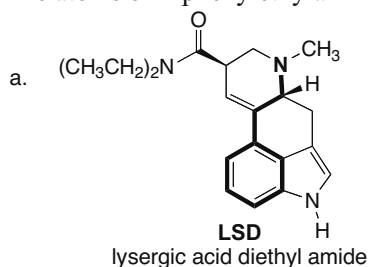
molecular formula $C_6H_{15}N$

^1H NMR absorptions (ppm):

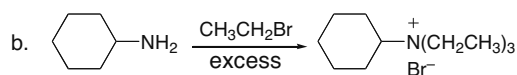
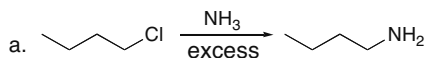
- 0.9 (singlet, 1 H) $\longrightarrow$ NH
 1.10 (triplet, 3 H) $\longrightarrow$ CH_3 adjacent to CH_2
 1.15 (singlet, 9 H) $\longrightarrow$ $(CH_3)_3C$
 2.6 (quartet, 2 H) $\longrightarrow$ CH_2 adjacent to CH_3



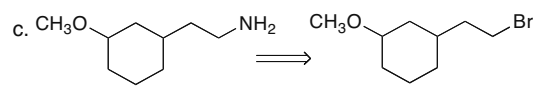
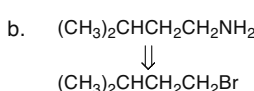
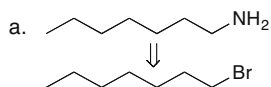
- 25.8** The atoms of 2-phenylethylamine are in bold.



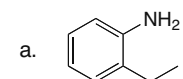
- 25.9** S_N2 reaction of an alkyl halide with NH_3 or an amine forms an amine or an ammonium salt.



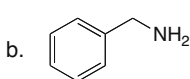
- 25.10** The Gabriel synthesis converts an alkyl halide into a 1° amine by a two-step process: nucleophilic substitution followed by hydrolysis.



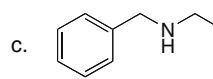
- 25.11** The Gabriel synthesis prepares 1° amines from alkyl halides. Since the reaction proceeds by an S_N2 mechanism, the halide must be CH_3 or 1° , and X can't be bonded to an sp^2 hybridized C.



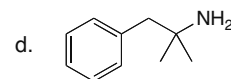
aromatic
An S_N2 does not occur
on an aryl halide.
cannot be made by
Gabriel synthesis



can be made by Gabriel
synthesis

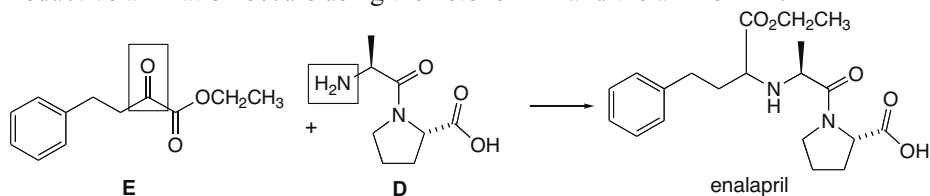
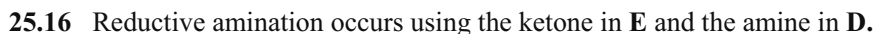
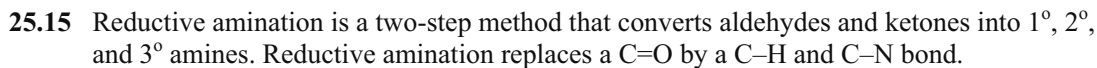
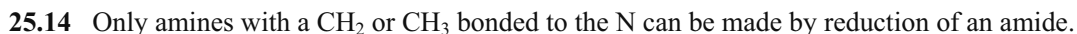
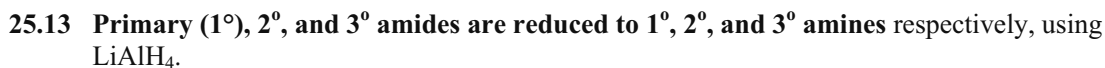


2° amine
cannot be made by
Gabriel synthesis

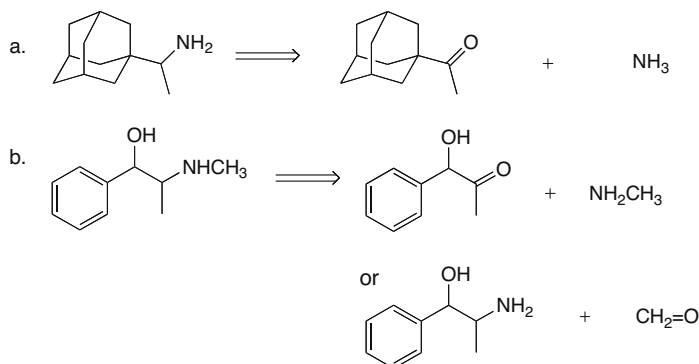


N on 3° C
An S_N2 does not
occur on a 3° RX.
cannot be made by
Gabriel synthesis

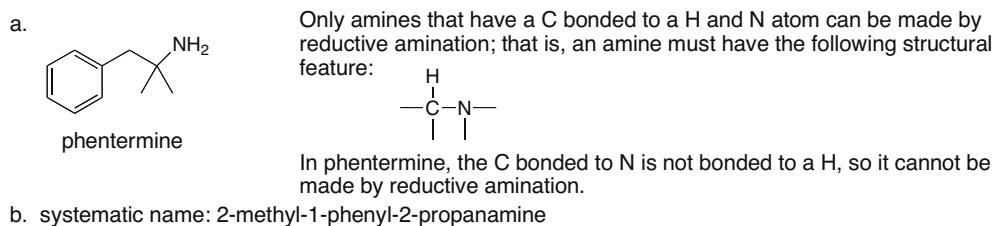
25.12 Nitriles are reduced to 1° amines with LiAlH_4 . Nitro groups are reduced to 1° amines using a variety of reducing agents. Primary (1°), 2°, and 3° amides are reduced to 1°, 2°, and 3° amines respectively, using LiAlH_4 .



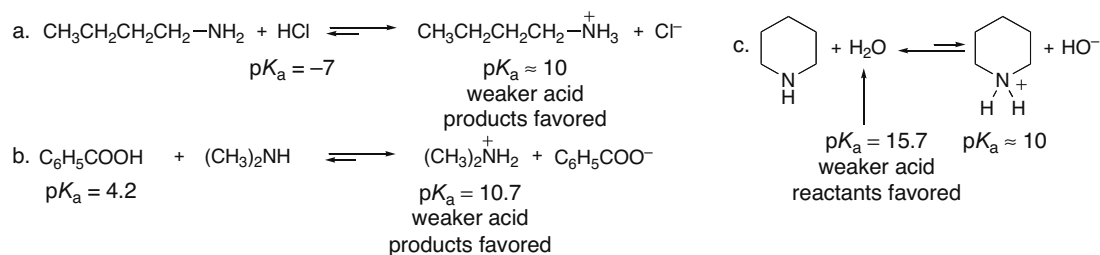
25.17



25.18

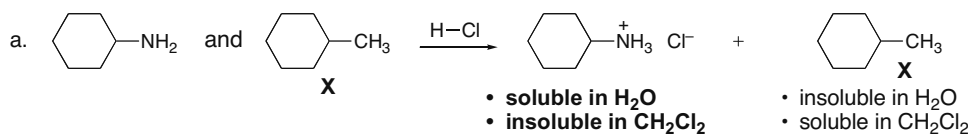


25.19 The pK_a of many protonated amines is 10–11, so the pK_a of the starting acid must be **less than 10** for equilibrium to favor the products. Amines are thus readily protonated by strong inorganic acids (e.g., HCl and H_2SO_4) and by carboxylic acids.

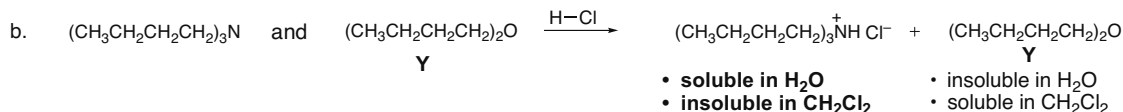


25.20 An amine can be separated from other organic compounds by converting it to a water-soluble ammonium salt by an acid–base reaction. In each case, the extraction procedure would employ the following steps:

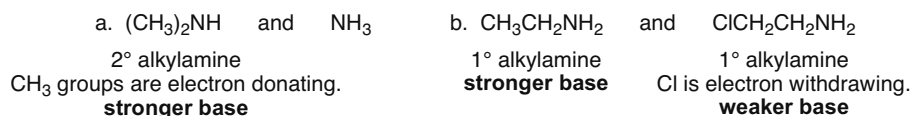
- Dissolve the amine and either **X** or **Y** in CH_2Cl_2 .
- Add a solution of 10% HCl. The amine will be protonated and dissolve in the aqueous layer, while **X** or **Y** will remain in the organic layer as a neutral compound.
- Separate the layers.



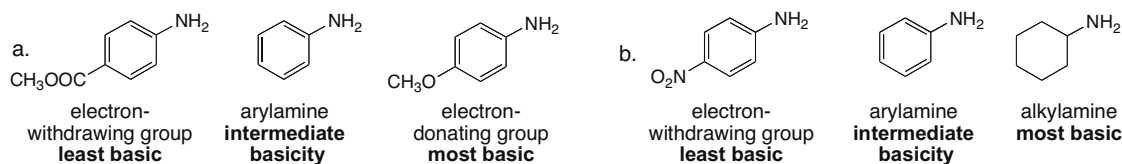
Chapter 25–10



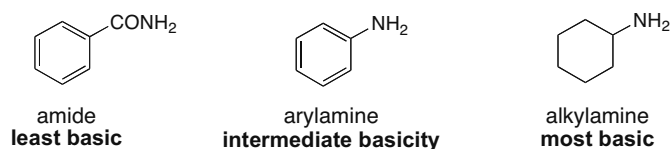
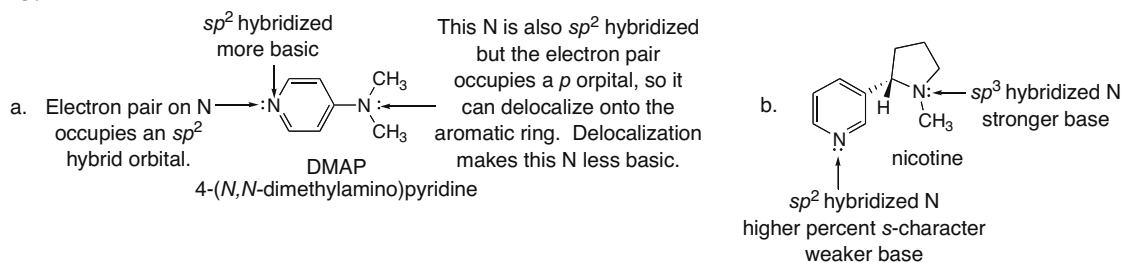
25.21 Primary (1°), 2° , and 3° alkylamines are more basic than NH_3 because of the electron-donating inductive effect of the R groups.



25.22 Arylamines are less basic than alkylamines because the electron pair on N is delocalized. Electron-donor groups add electron density to the benzene ring making the arylamine more basic than aniline. Electron-withdrawing groups remove electron density from the benzene ring, making the arylamine less basic than aniline.

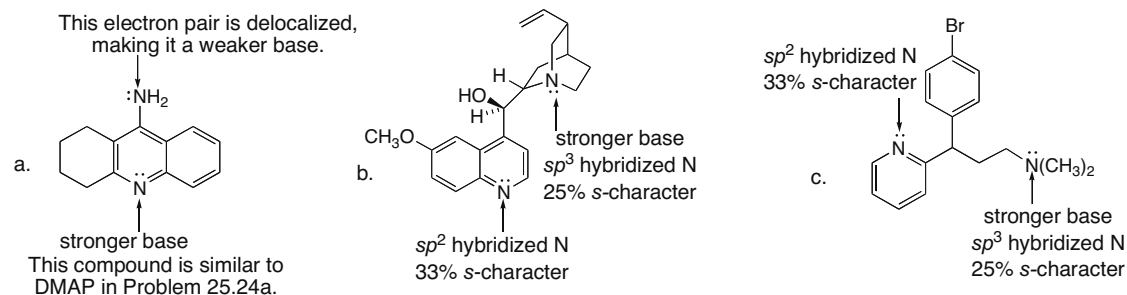


25.23 Amides are much less basic than amines because the electron pair on N is highly delocalized.

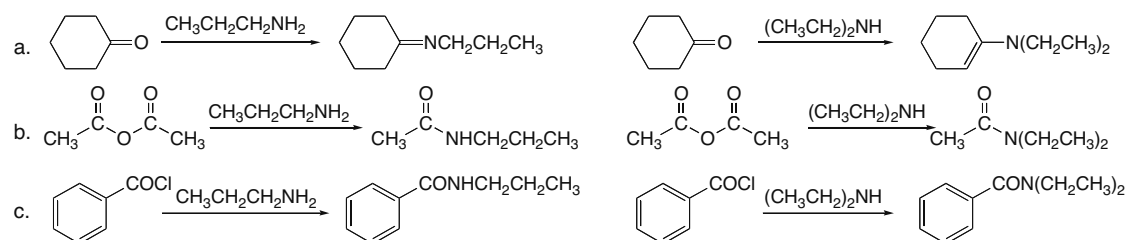
**25.24**

Amines 25-11

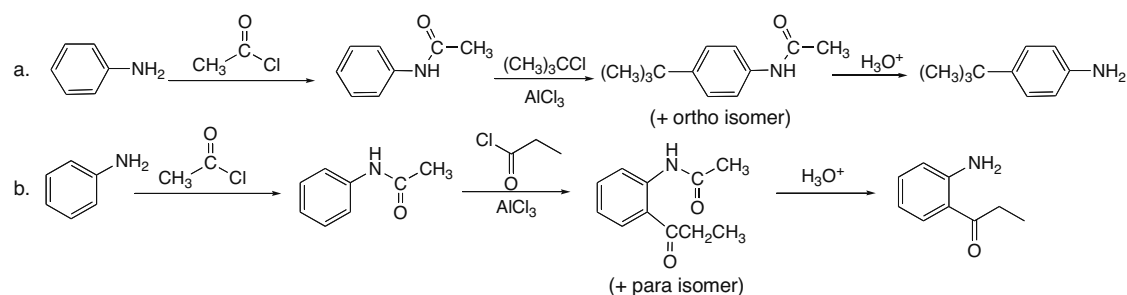
25.25



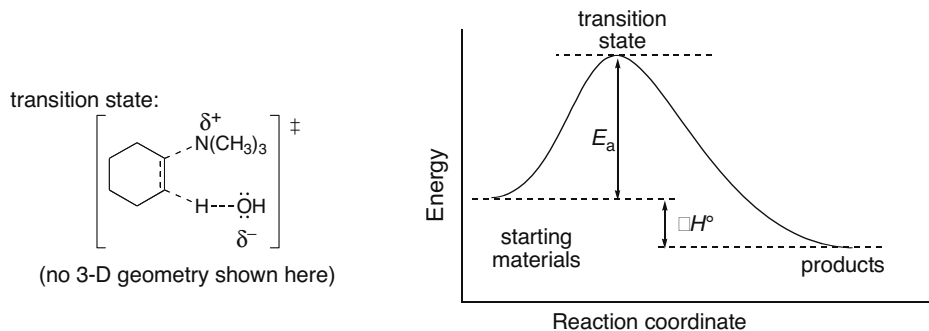
25.26 Amines attack carbonyl groups to form products of nucleophilic addition or substitution.



- 25.27 [1] Convert the amine (aniline) into an amide (acetanilide).
 [2] Carry out the Friedel-Crafts reaction.
 [3] Hydrolyze the amide to generate the free amino group.

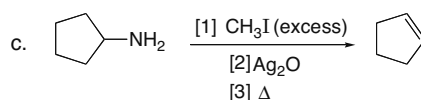
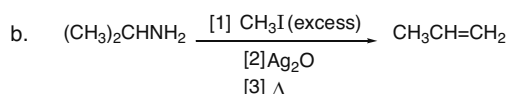
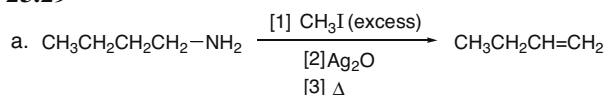


25.28

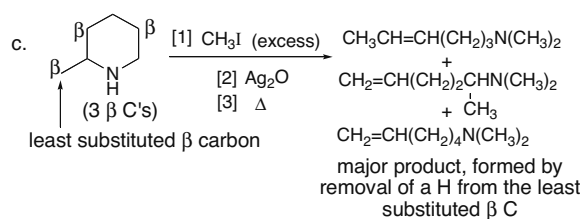
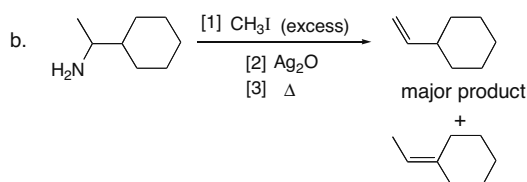
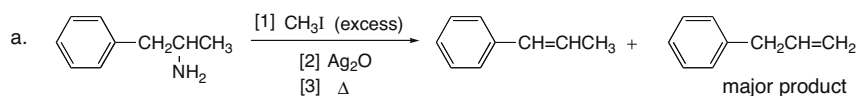


Chapter 25–12

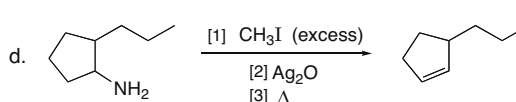
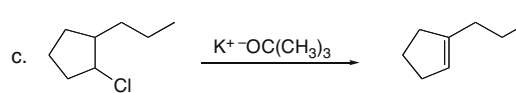
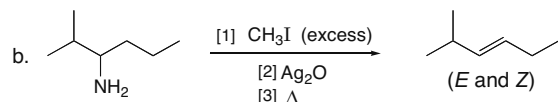
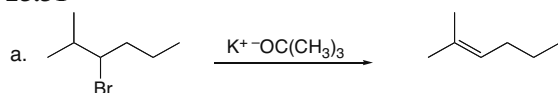
25.29



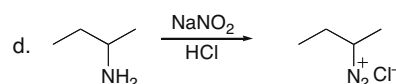
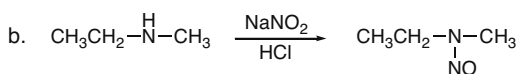
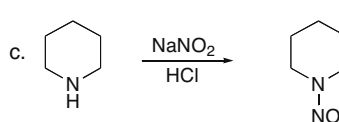
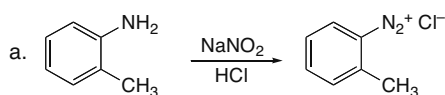
25.30 In a Hofmann elimination, the base removes a proton from the less substituted, more accessible β carbon atom, because of the bulky leaving group on the nearby α carbon.



25.31

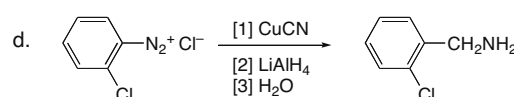
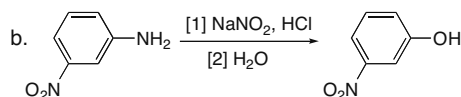
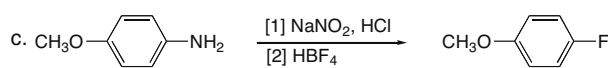
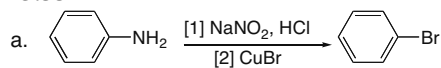


25.32

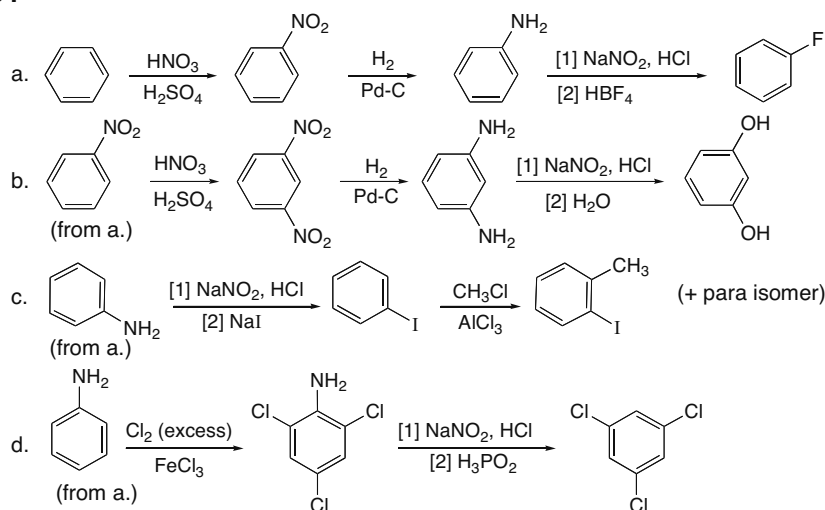


Amines 25-13

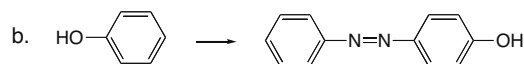
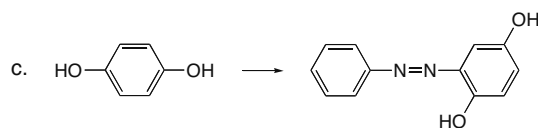
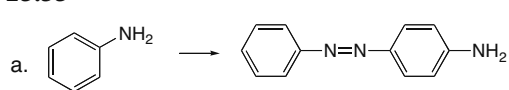
25.33



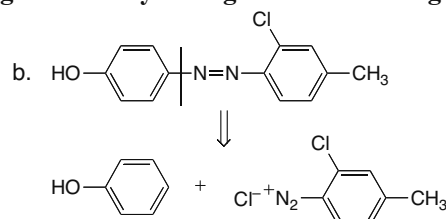
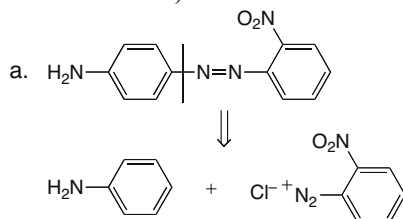
25.34



25.35

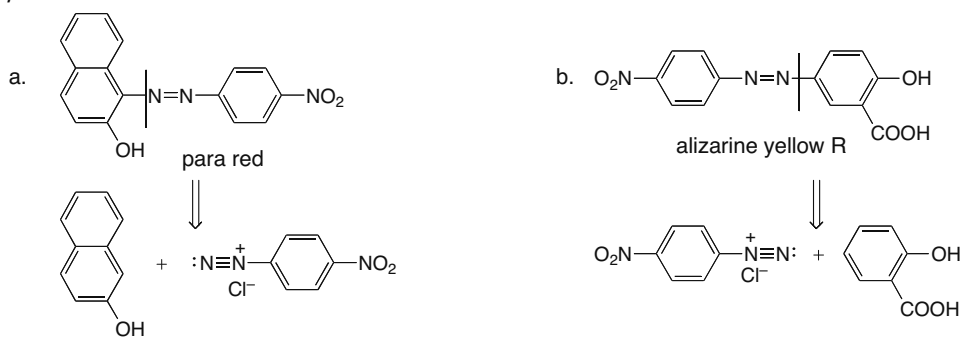


25.36 To determine what starting materials are needed to synthesize a particular azo compound, always divide the molecule into two components: **one has a benzene ring with a diazonium ion, and one has a benzene ring with a very strong electron-donor group.**

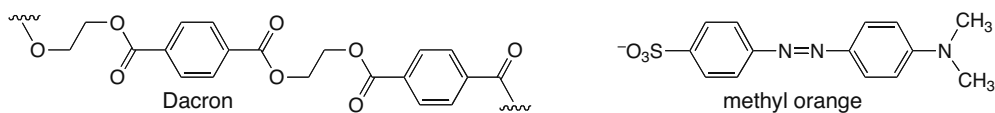


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25.37

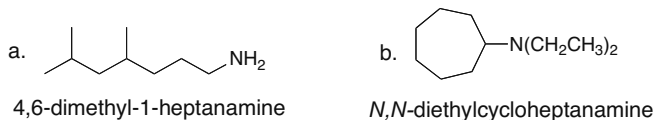


25.38

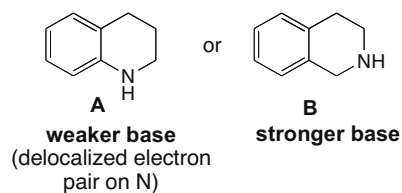


To bind to fabric, methyl orange (an anion) needs to interact with positively charged sites. Since Dacron is a neutral compound with no cationic sites on the chain, it does not bind methyl orange well.

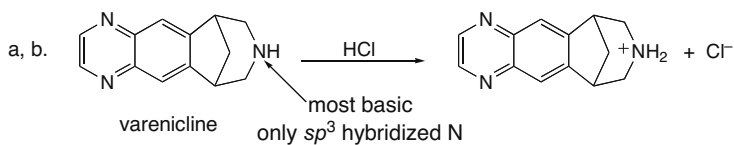
25.39



25.40

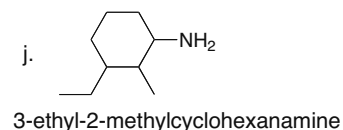
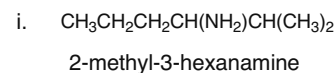
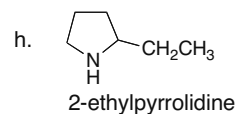
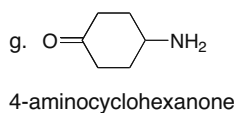
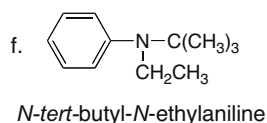
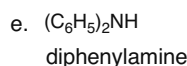
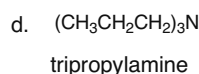
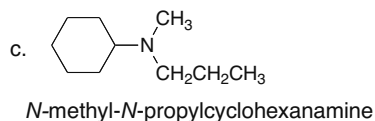
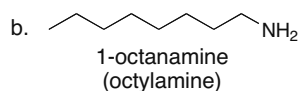
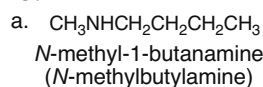


25.41

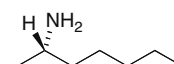
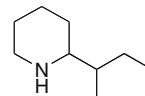
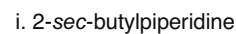
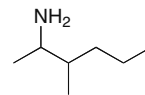
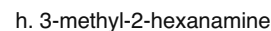
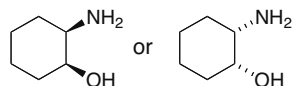
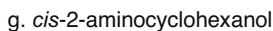
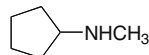
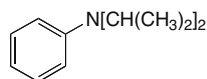
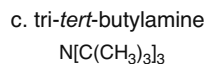
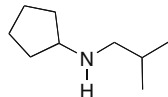
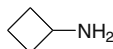


Amines 25–15

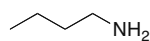
25.42



25.43



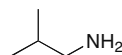
25.44



1-butanamine



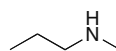
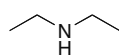
2-butanamine



2-methyl-1-propanamine



2-methyl-2-propanamine

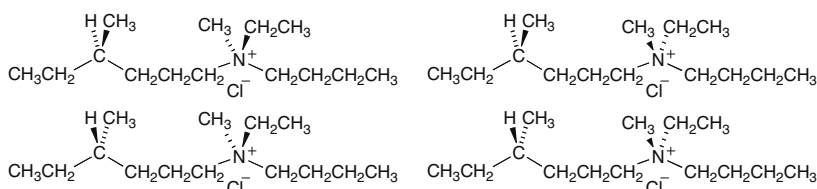
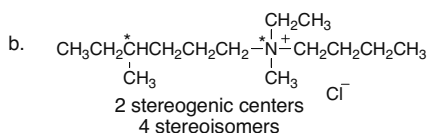
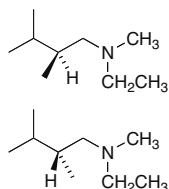
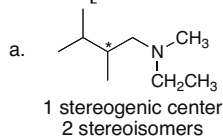
*N*-methyl-1-propanamine

diethylamine

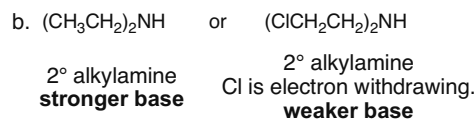
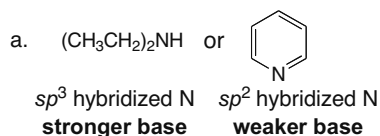
*N*-methyl-2-propanamine*N,N*-dimethylethanamine

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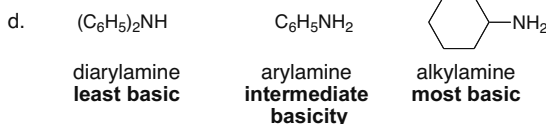
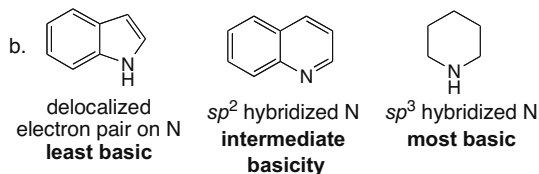
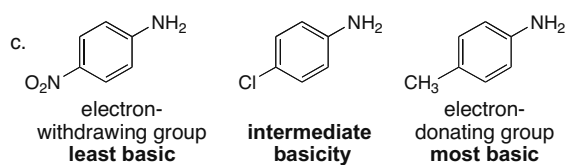
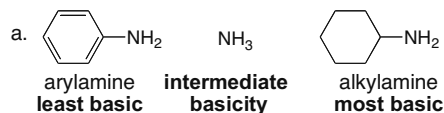
25.45 [* denotes a stereogenic center.]



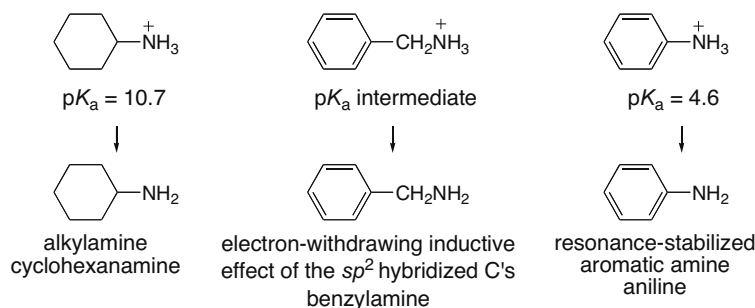
25.46



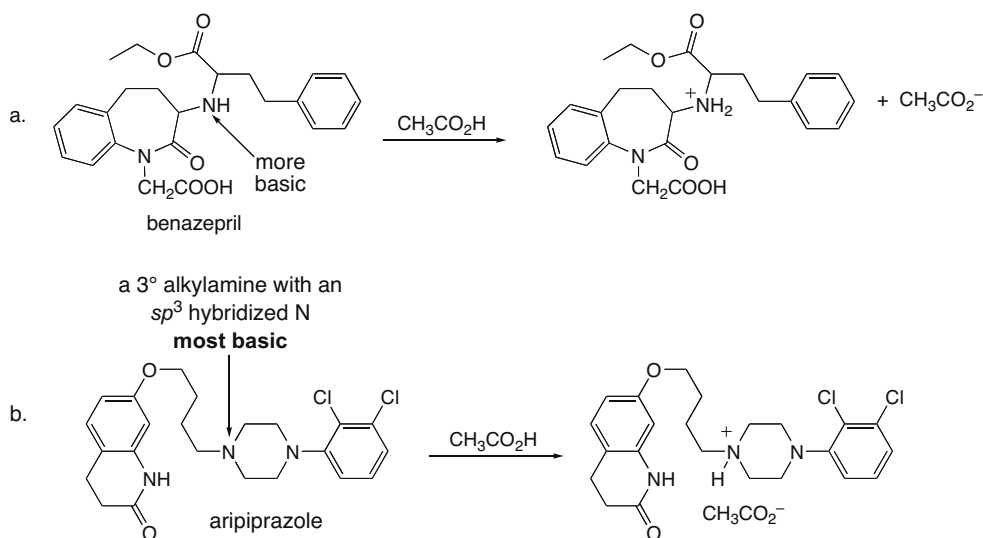
25.47



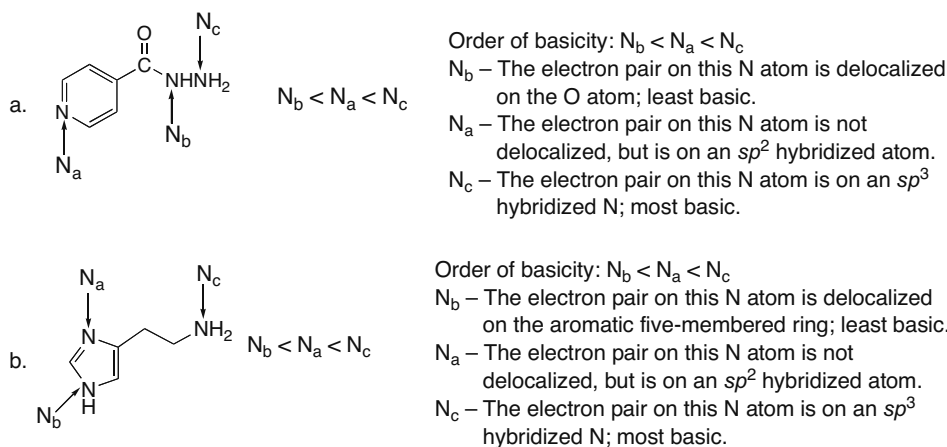
25.48 The electron-withdrawing inductive effect of the phenyl group stabilizes benzylamine, making its conjugate acid more acidic than the conjugate acid of cyclohexylamine. The conjugate acid of aniline is more acidic than the conjugate acid of benzylamine, since loss of a proton generates a resonance-stabilized amine, $\text{C}_6\text{H}_5\text{NH}_2$.



25.49 The most basic N atom is protonated on treatment with acid.

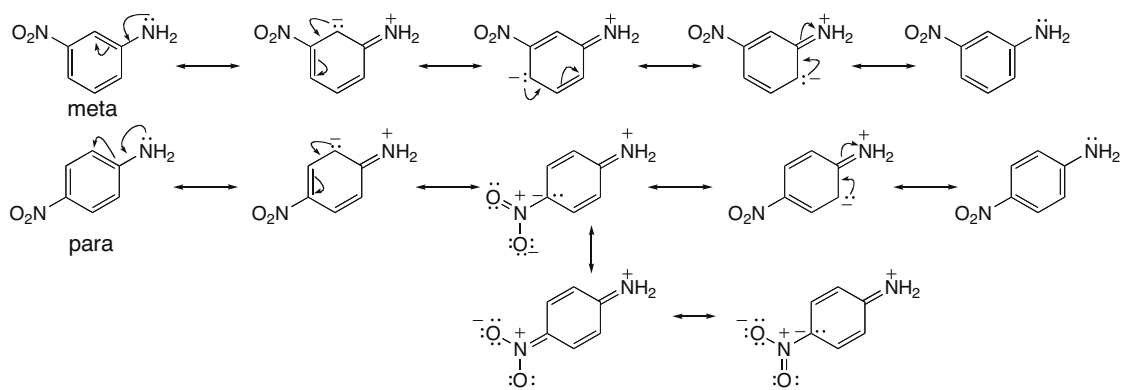


25.50

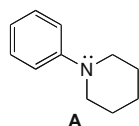


25.51 The para isomer is the weaker base because the electron pair on its NH_2 group can be delocalized onto the NO_2 group. In the meta isomer, no resonance structure places the electron pair on the NO_2 group, and fewer resonance structures can be drawn:

Chapter 25–18

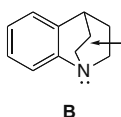


25.52



pK_a of the conjugate acid = 5.2
stronger conjugate acid
weaker base

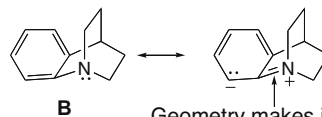
The electron pair of this arylamine is delocalized on the benzene ring, decreasing its basicity.



pK_a of the conjugate acid = 7.29
weaker conjugate acid
stronger base

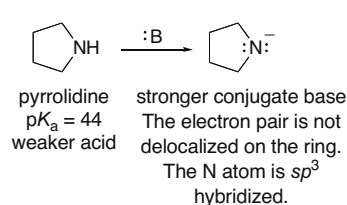
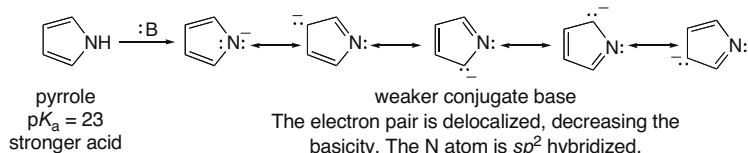
This two-carbon bridge makes it difficult for the lone pair on N to delocalize on the aromatic ring.

Resonance structures that place a double bond between the N atom and the benzene ring are destabilized. Since the electron pair is more localized on N, compound **B** is more basic.

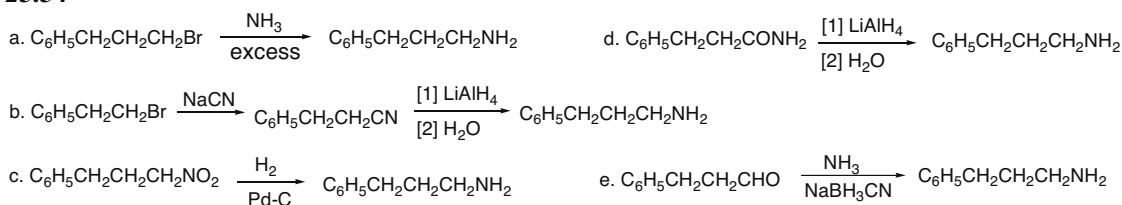


Geometry makes it difficult to have a double bond here.

25.53

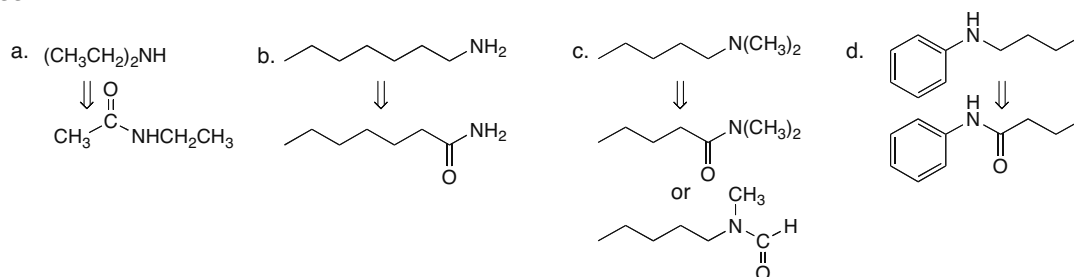


25.54

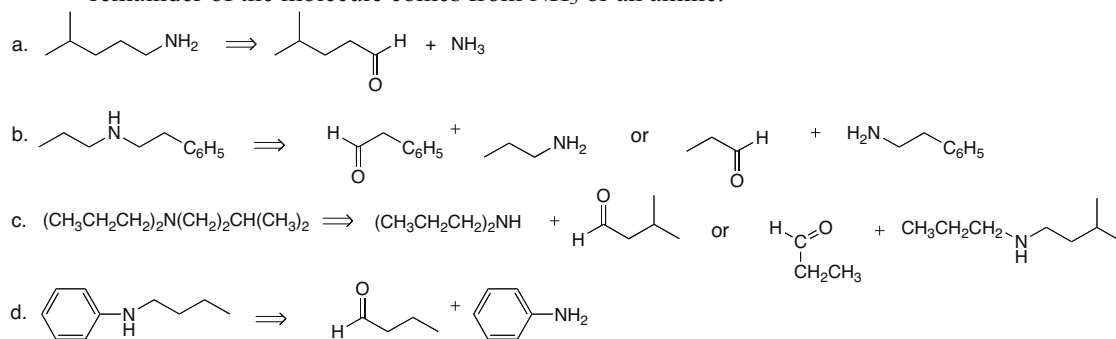


Amines 25-19

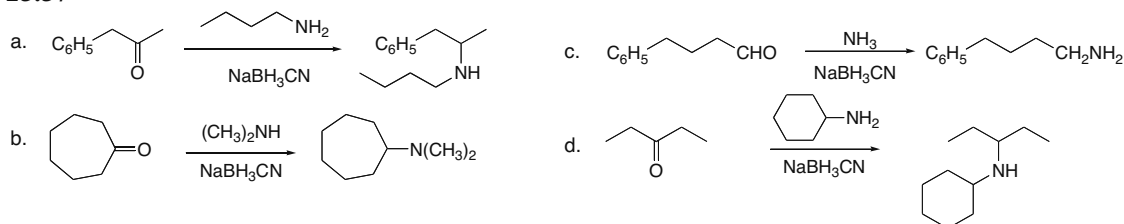
25.55



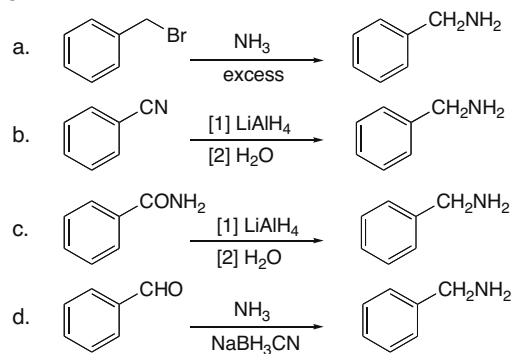
25.56 In reductive amination, one alkyl group on N comes from the carbonyl compound. The remainder of the molecule comes from NH_3 or an amine.



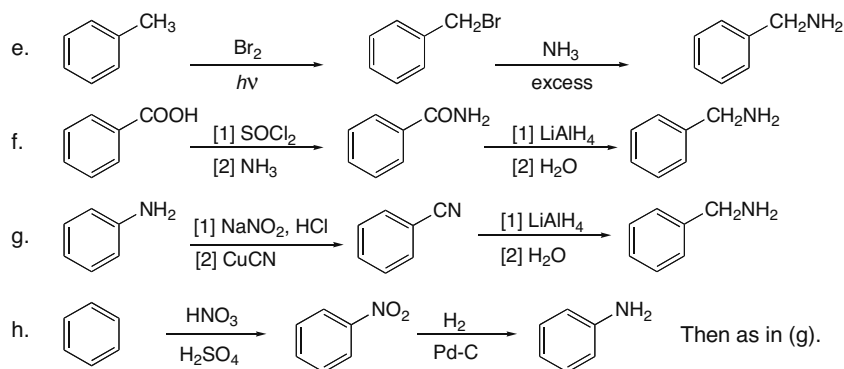
25.57



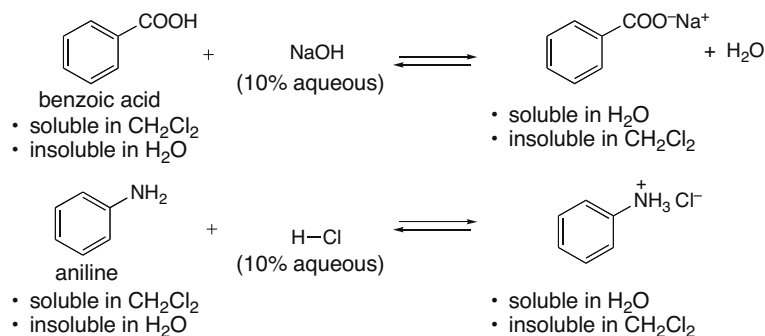
25.58



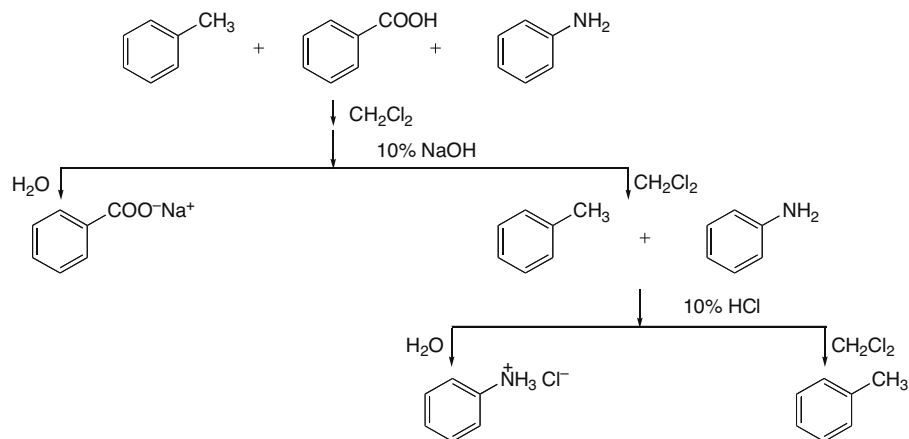
Chapter 25-20



25.59 Use the directions from Answer 25.20. Separation can be achieved because benzoic acid reacts with aqueous base and aniline reacts with aqueous acid according to the following equations:

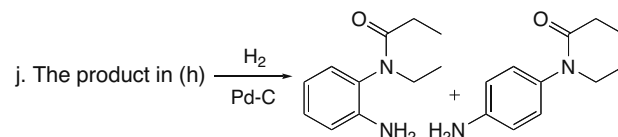
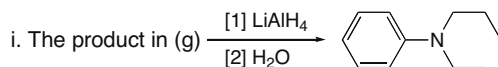
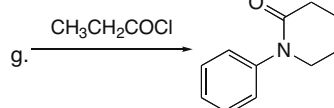
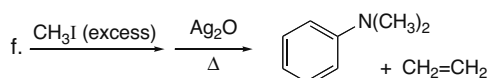
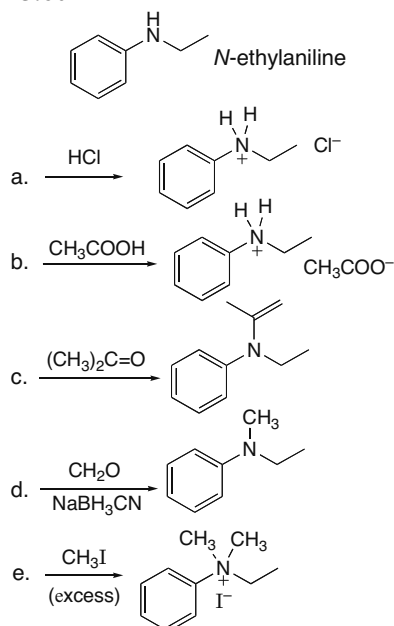


Toluene ($\text{C}_6\text{H}_5\text{CH}_3$), on the other hand, is not protonated or deprotonated in aqueous solution, so it is always soluble in CH_2Cl_2 and insoluble in H_2O . The following flow chart illustrates the process.

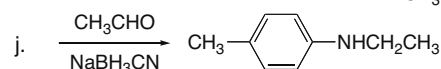
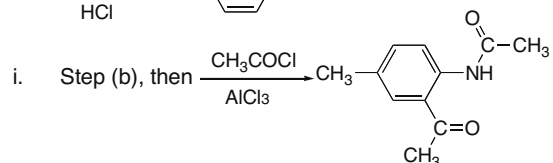
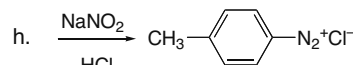
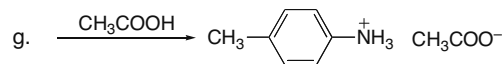
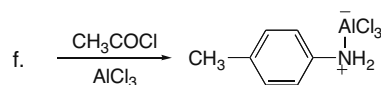
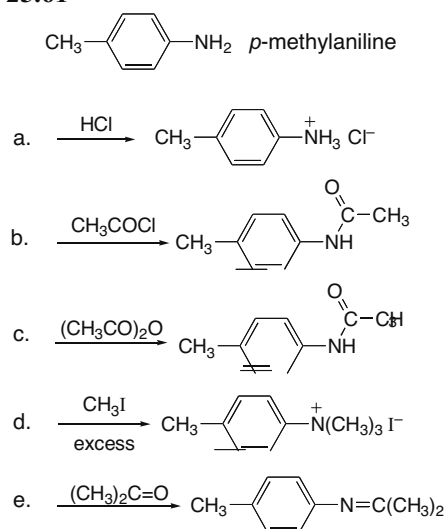


Amines 25–21

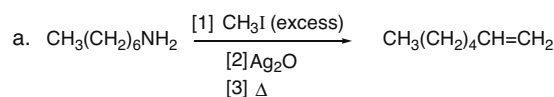
25.60



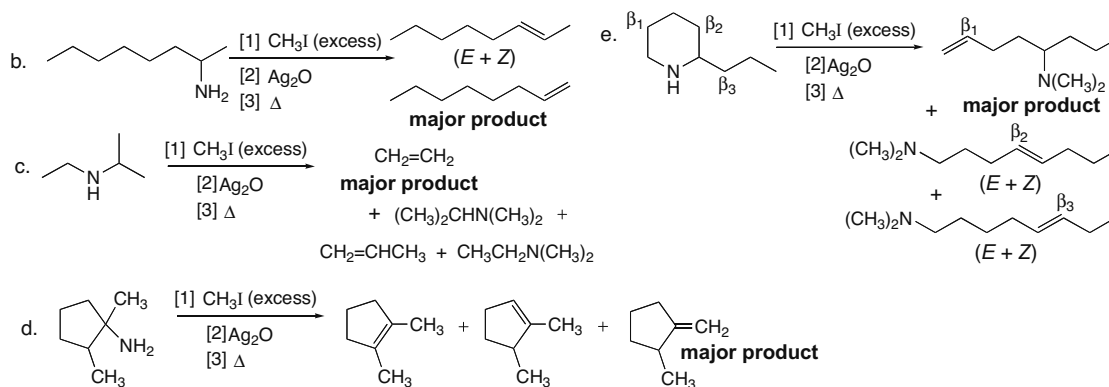
25.61



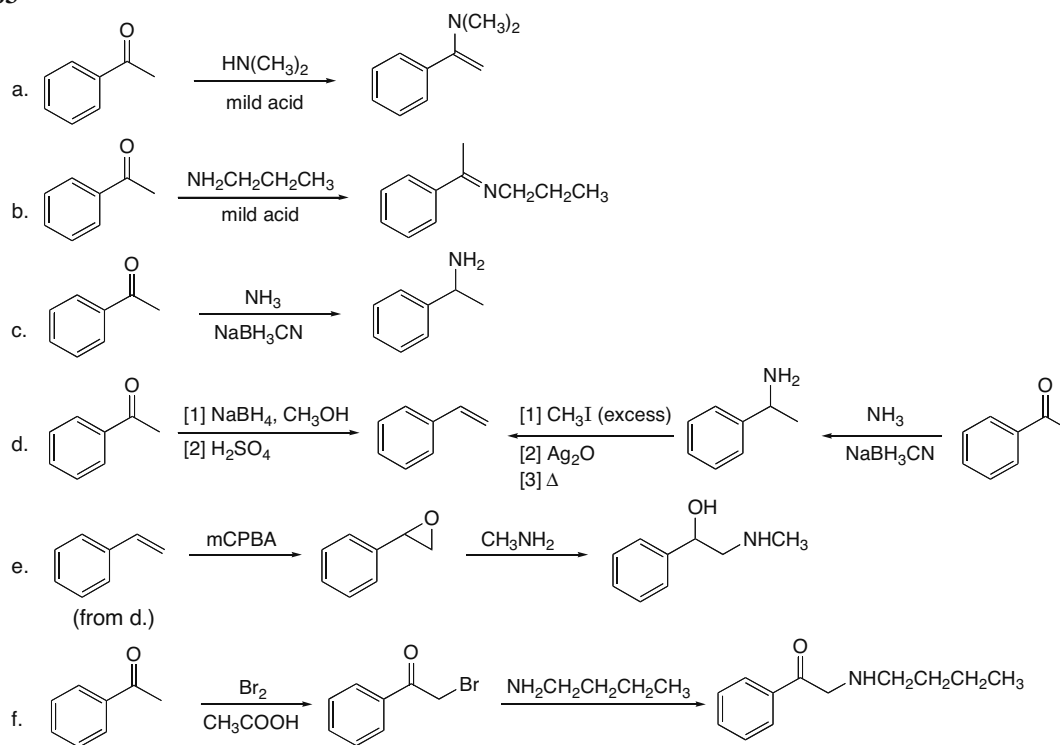
25.62



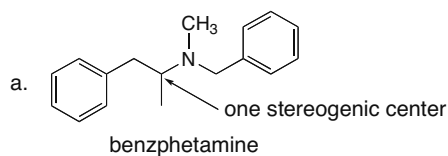
Chapter 25-22



25.63

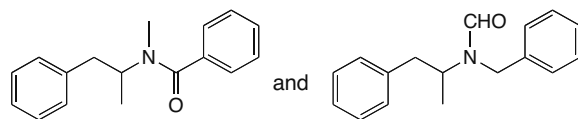


25.64

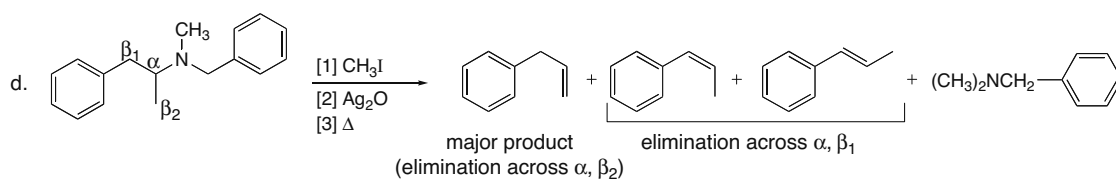
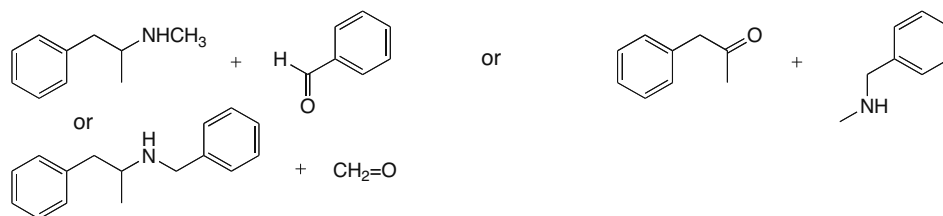


Amines 25–23

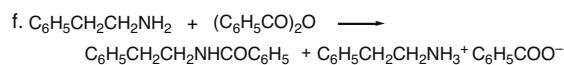
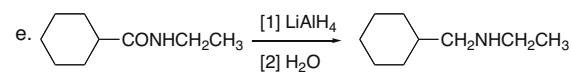
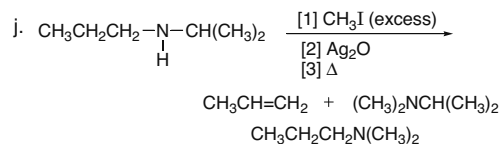
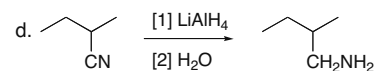
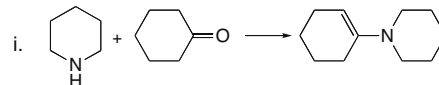
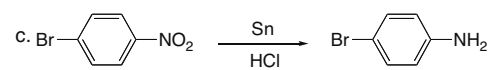
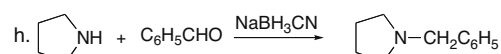
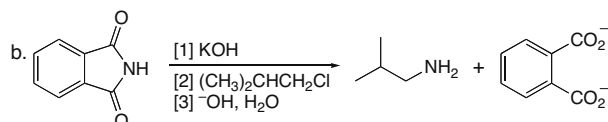
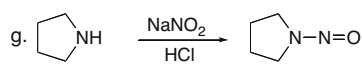
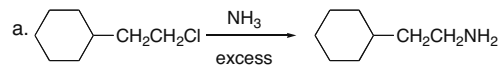
b. Amides that can be reduced to benzphetamine:



c. Amines + carbonyl compounds that form benzphetamine by reductive amination:

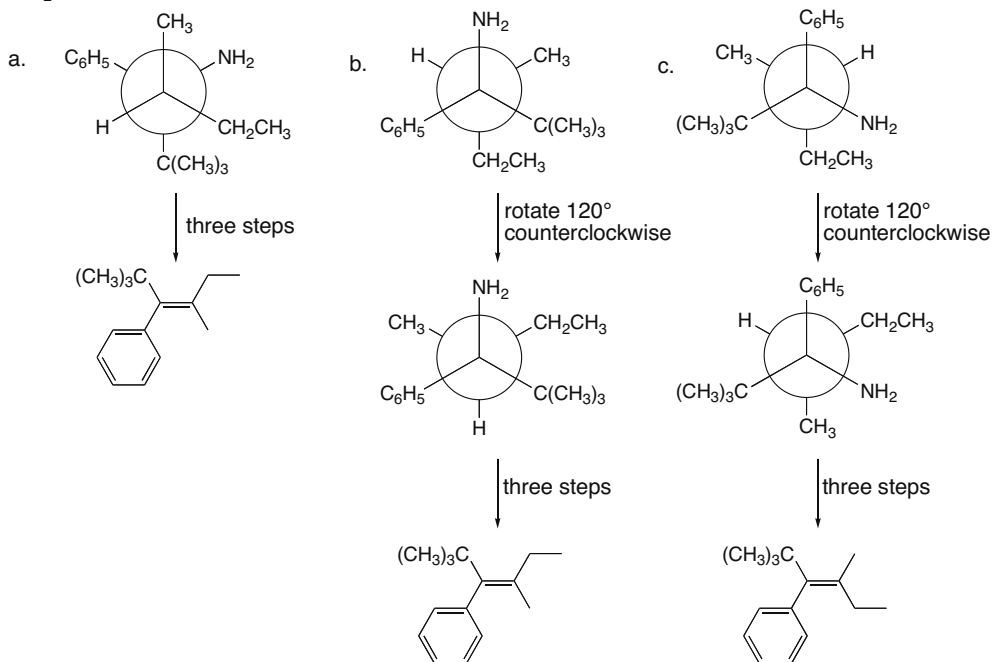
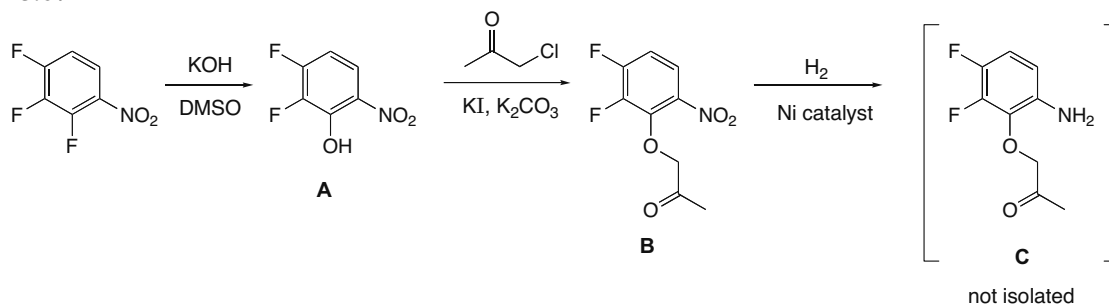


25.65



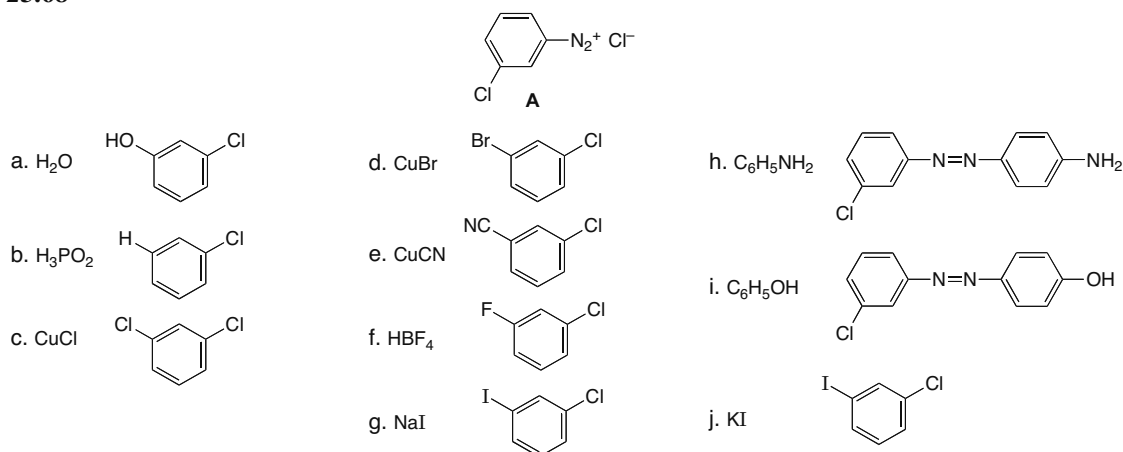
Chapter 25–24

25.66 NH_2 and H must be anti for the Hofmann elimination. Rotate around the C–C bond so the NH_2 and H are anti.

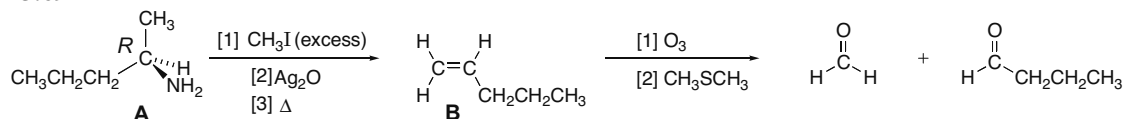
**25.67**

Amines 25–25

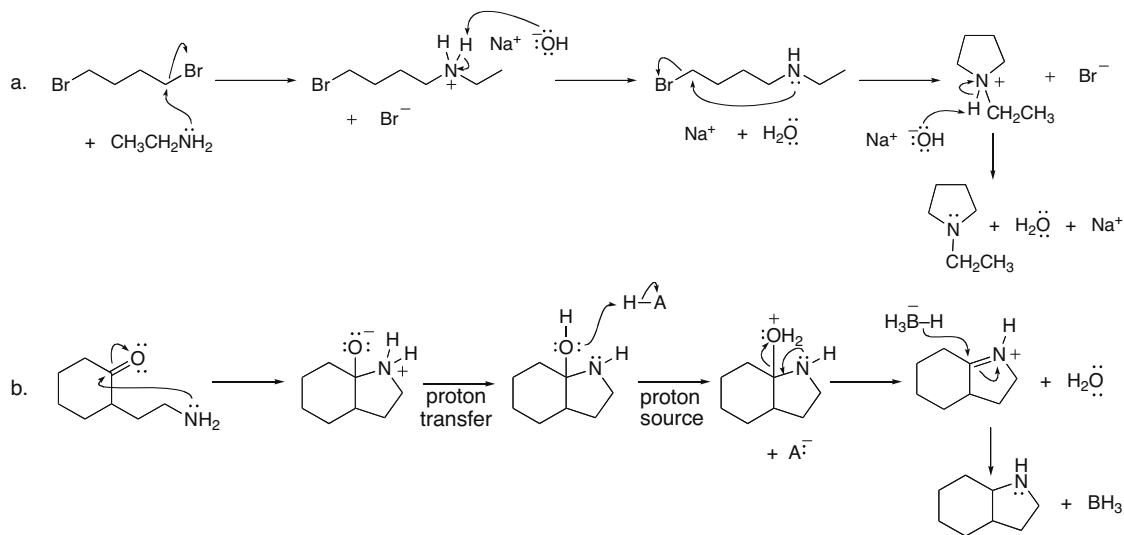
25.68



25.69

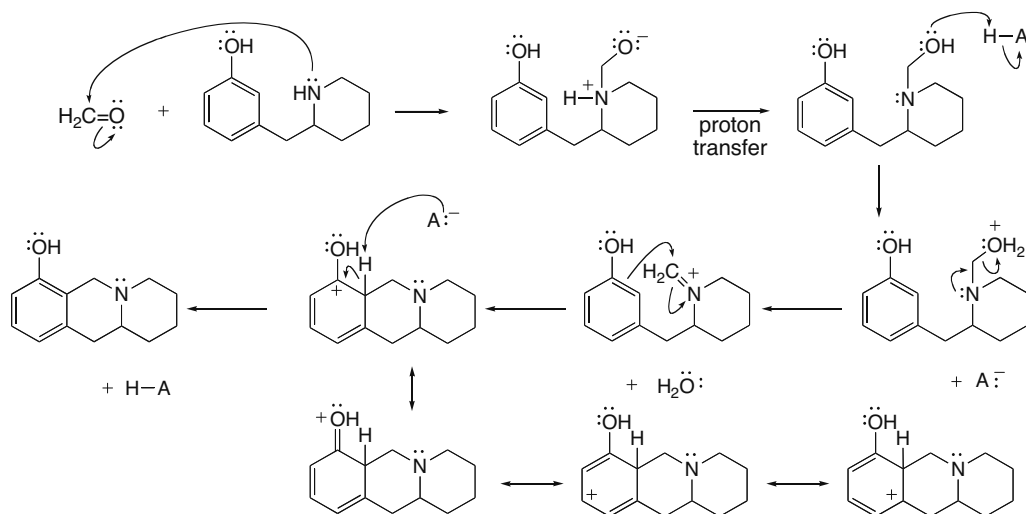


25.70

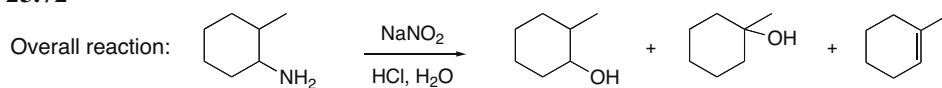


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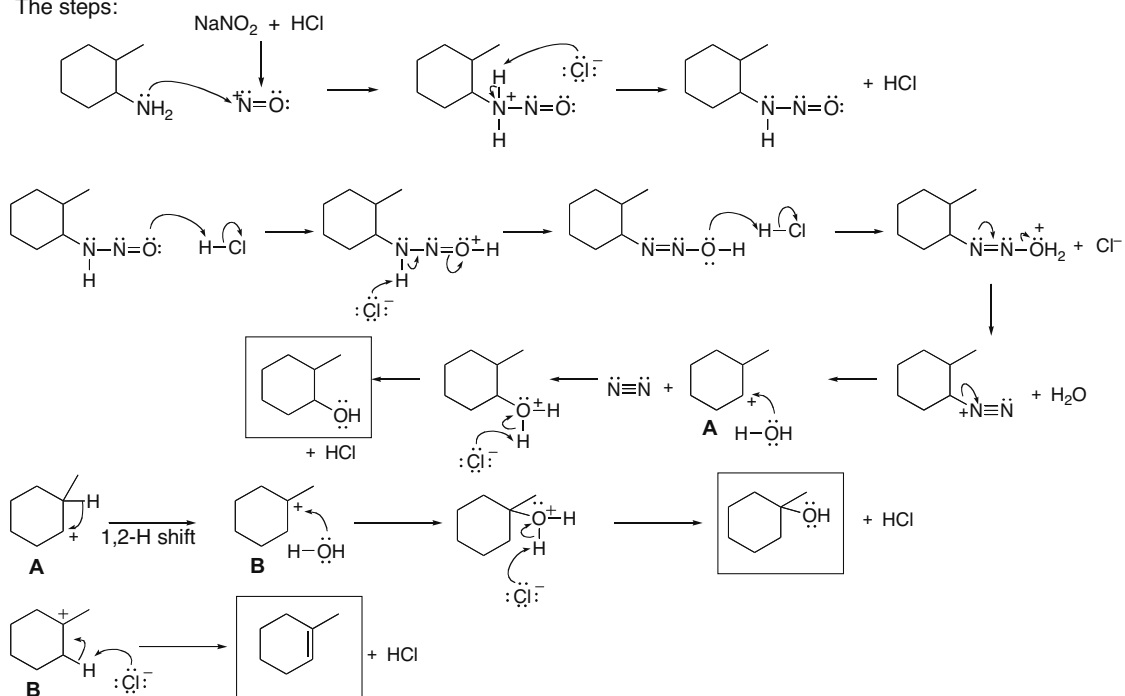
25.71



25.72

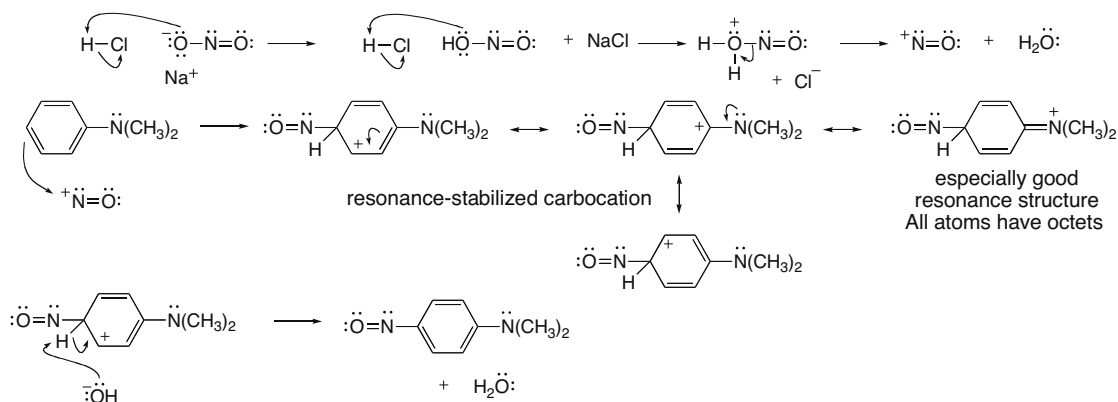
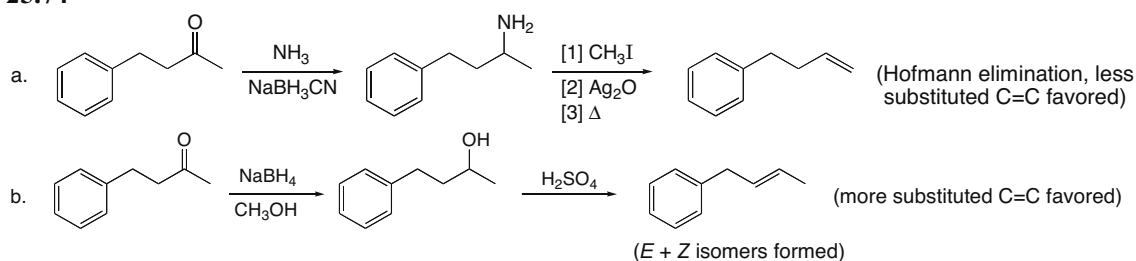
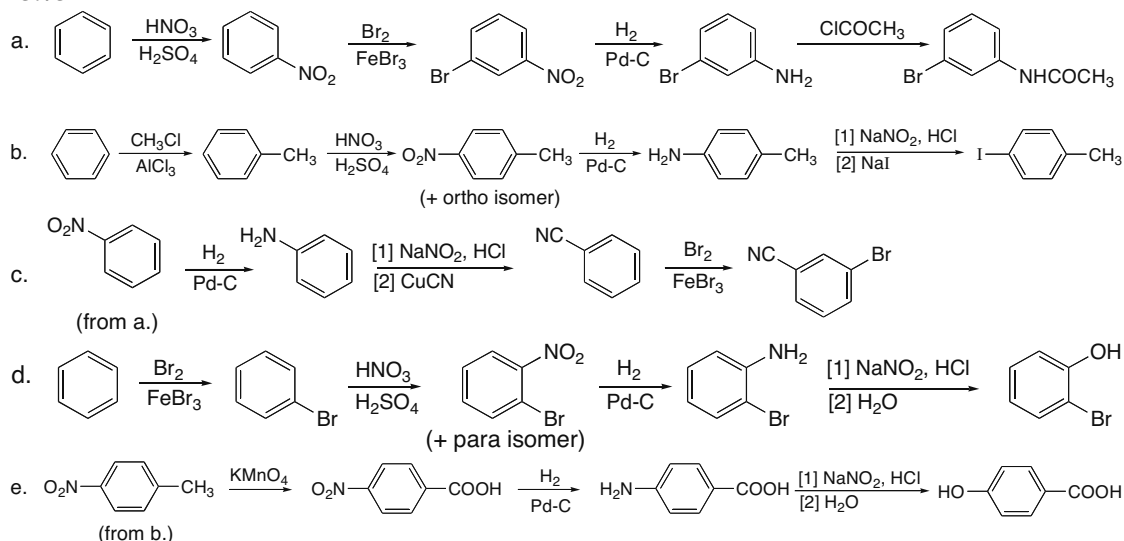


The steps:

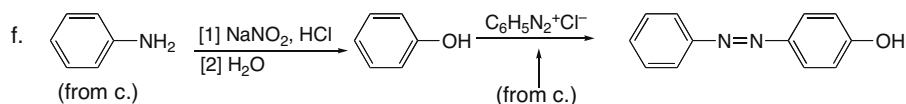


Amines 25–27

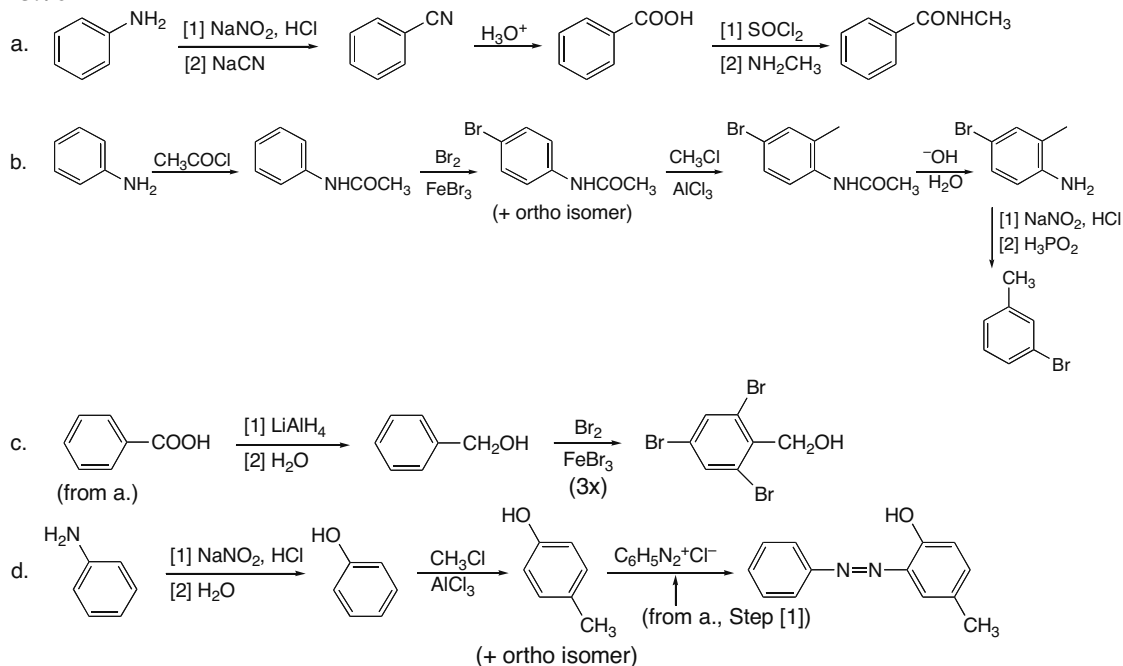
25.73 A nitrosonium ion (NO^+) is a weak electrophile so electrophilic aromatic substitution occurs only with a strong electron-donor group that stabilizes the intermediate carbocation.

**25.74****25.75**

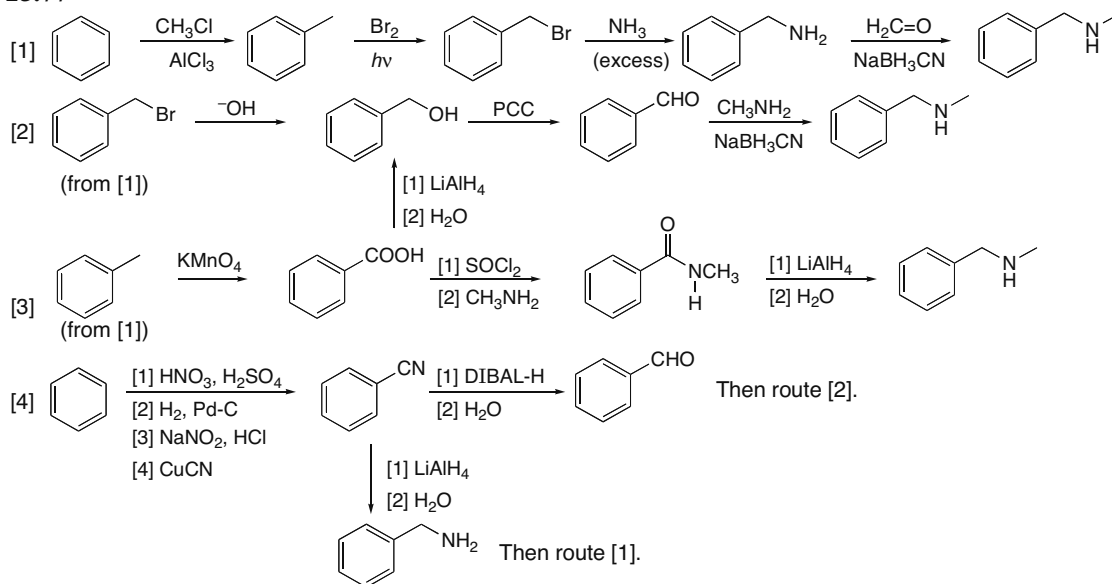
Chapter 25–28



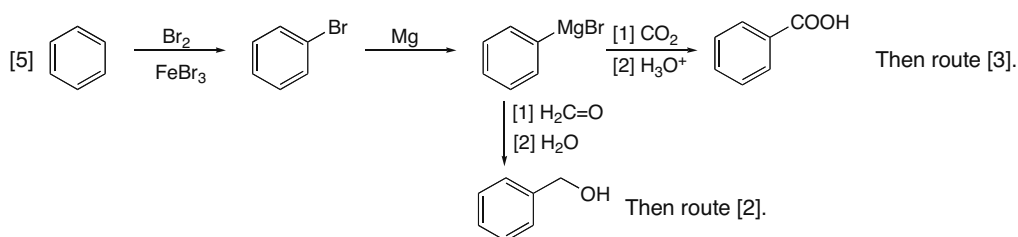
25.76



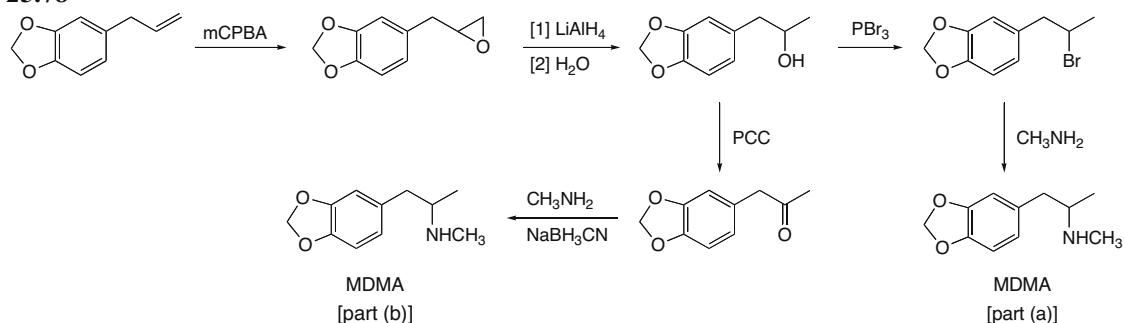
25.77



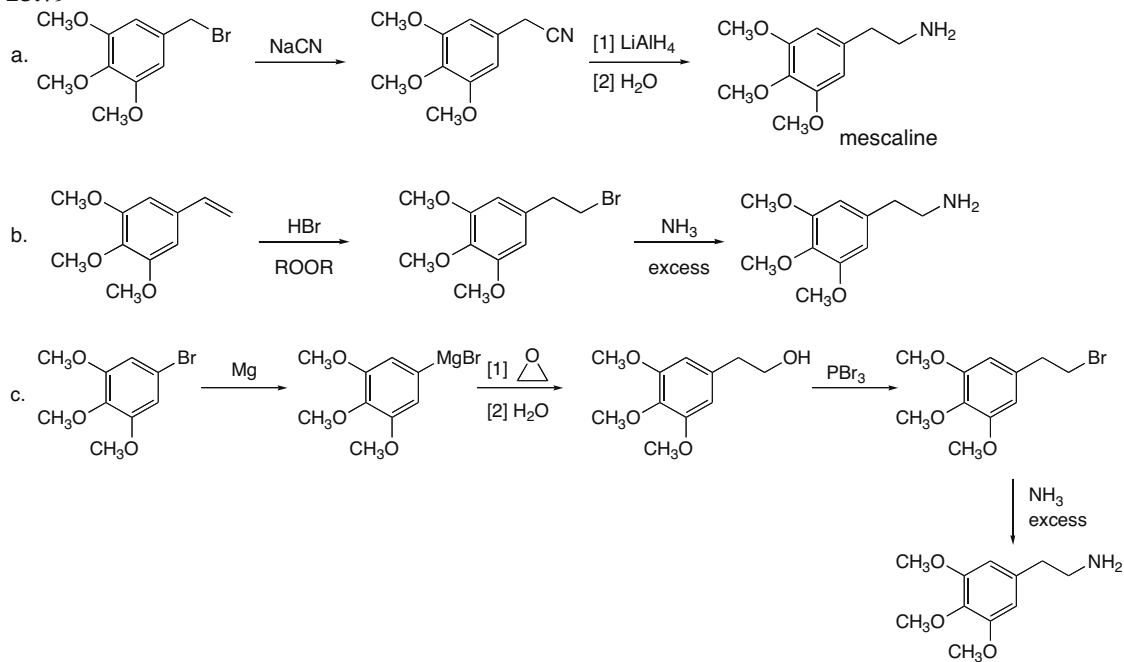
Amines 25–29



25.78

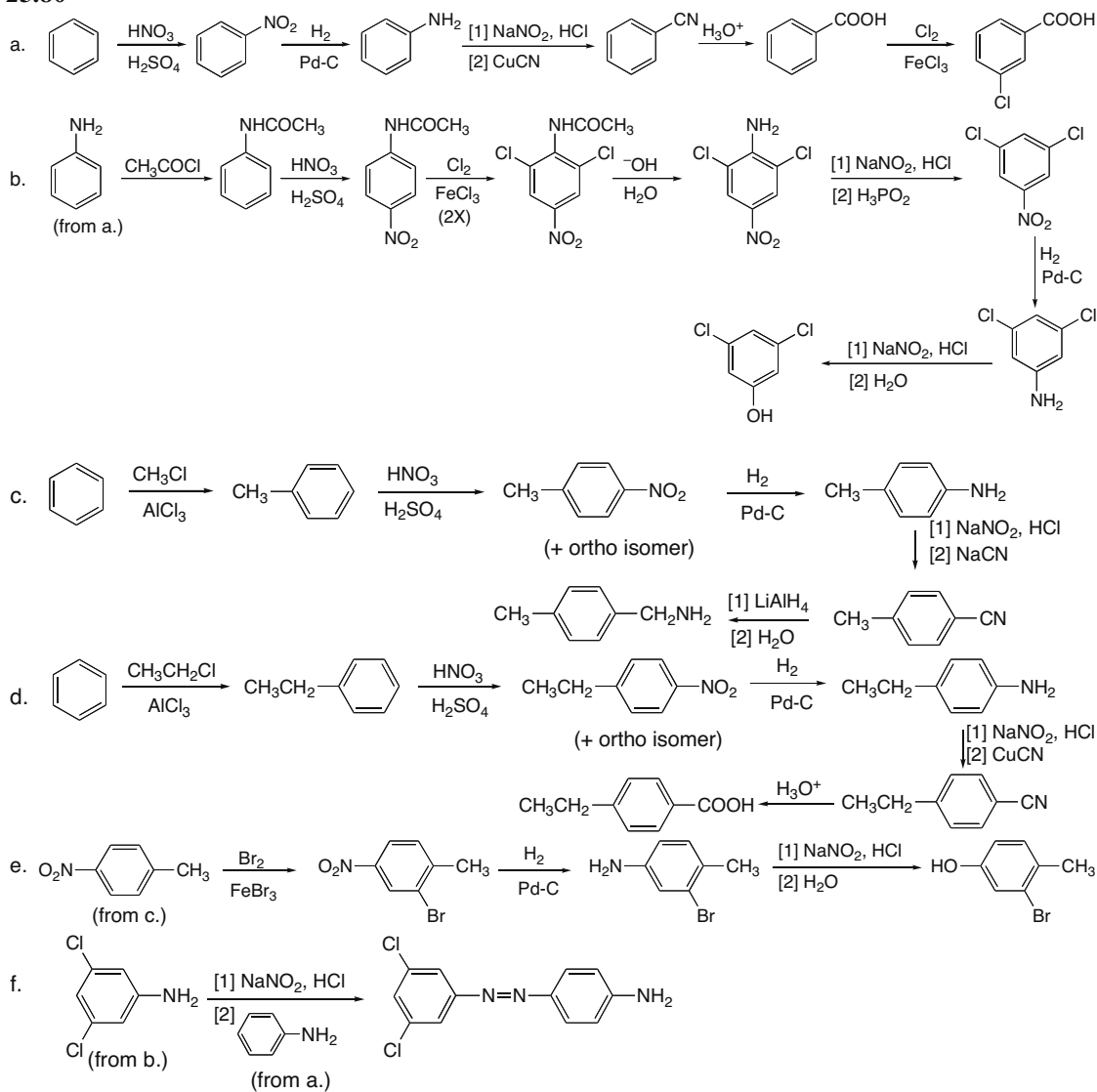


25.79

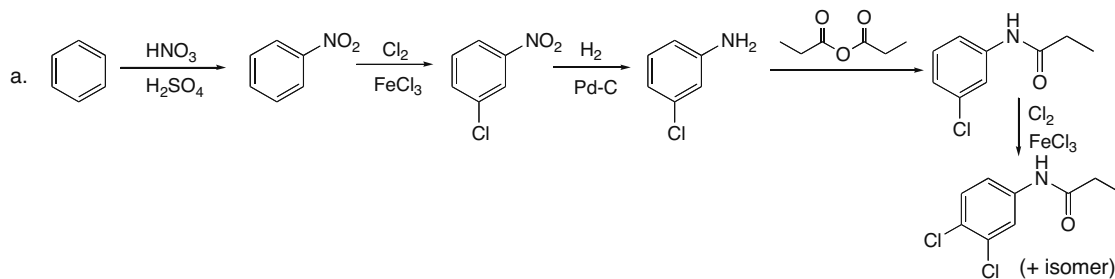


Chapter 25–30

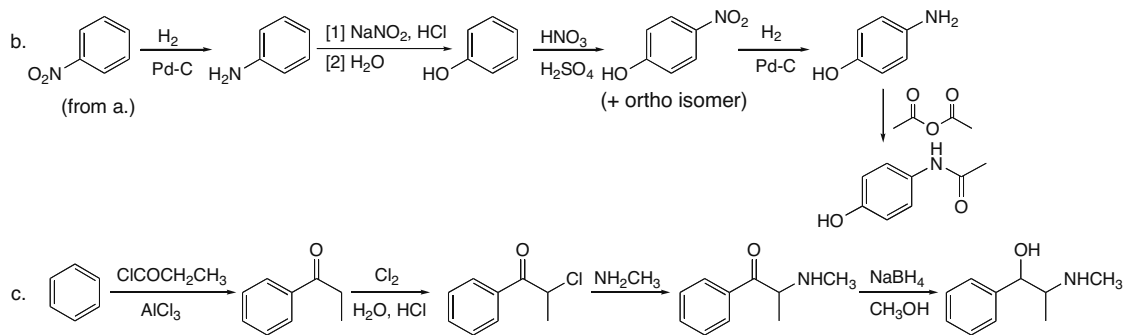
25.80



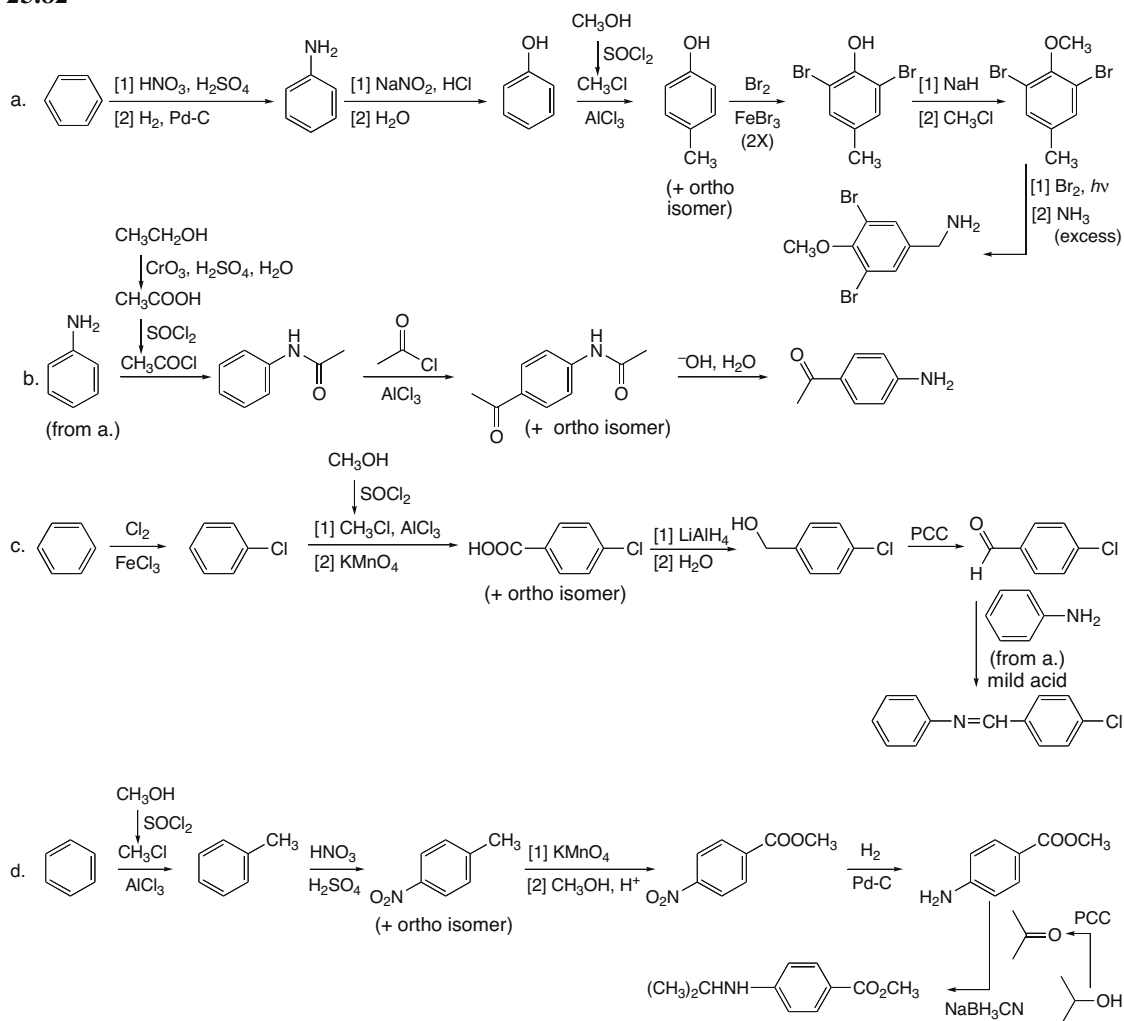
25.81



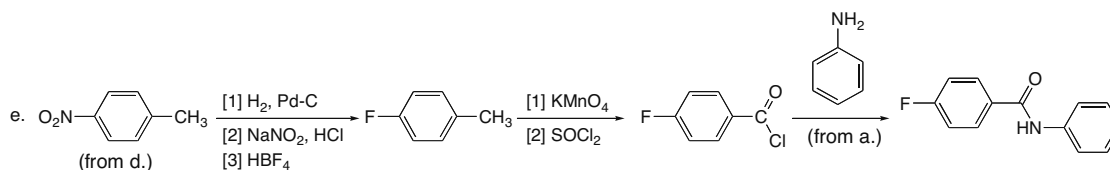
Amines 25–31



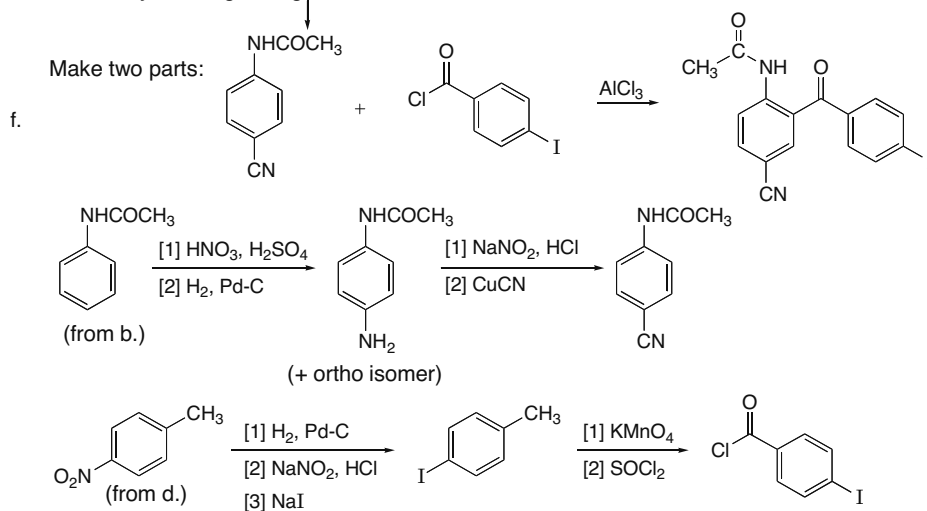
25.82



Chapter 25–32

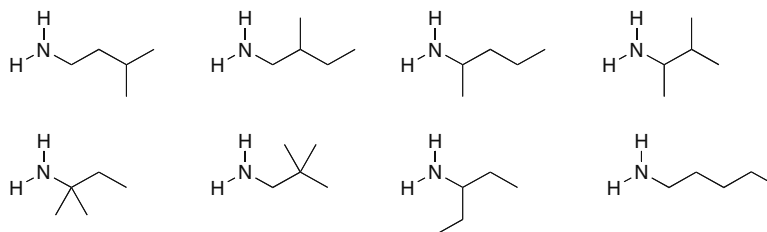


Probably a strong enough activator that the Friedel–Crafts reaction will still occur.

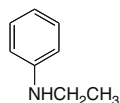


25.83

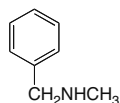
molecular weight = 87
 $C_5H_{13}N$
 two IR peaks = 1° amine



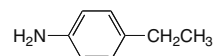
25.84



Compound **A**: $C_8H_{11}N$
 IR absorption at $3400\text{ cm}^{-1} \rightarrow 2^\circ$ amine
 ^1H NMR signals at (ppm):
 1.3 (triplet, 3 H) CH_3 adjacent to 2 H's
 3.1 (quartet, 2 H) CH_2 adjacent to 3 H's
 3.6 (singlet, 1 H) amine H
 6.8–7.2 (multiplet, 5 H) benzene ring

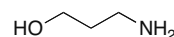
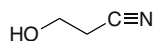


Compound **B**: $C_8H_{11}N$
 IR absorption at $3310\text{ cm}^{-1} \rightarrow 2^\circ$ amine
 ^1H NMR signals at (ppm):
 1.4 (singlet, 1 H) amine H
 2.4 (singlet, 3 H) CH_3
 3.8 (singlet, 2 H) CH_2
 7.2 (multiplet, 5 H) benzene ring



Compound **C**: $C_8H_{11}N$
 IR absorption at 3430 and $3350\text{ cm}^{-1} \rightarrow 1^\circ$ amine
 ^1H NMR signals at (ppm):
 1.3 (triplet, 3 H) CH_3 near CH_2
 2.5 (quartet, 2 H) CH_2 near CH_3
 3.6 (singlet, 2 H) amine H's
 6.7 (doublet, 2 H) para disubstituted
 7.0 (doublet, 2 H) benzene ring

25.85

Compound **D**:Molecular ion at $m/z = 71$: C_3H_5NO (possible formula)IR absorption at $3600\text{--}3200\text{ cm}^{-1} \rightarrow \text{OH}$ $2263\text{ cm}^{-1} \rightarrow \text{CN}$

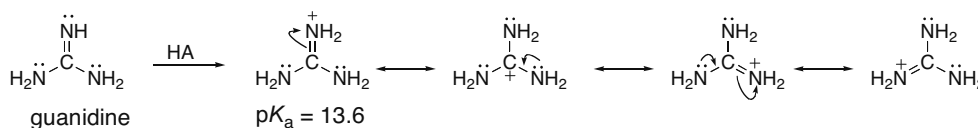
Use integration values and the molecular formula to determine the number of H's that give rise to each signal.

 ^1H NMR signals at (ppm):2.6 (triplet, 2 H) CH_2 adjacent to 2 H's

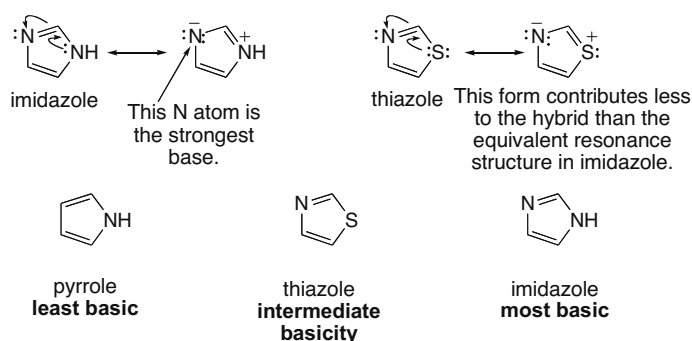
3.2 (singlet, 1 H) OH

3.9 (triplet, 2 H) CH_2 adjacent to 2 H'sCompound **E**:Molecular ion at $m/z = 75$: C_3H_9NO (possible formula)IR absorption at $3600\text{--}3200\text{ cm}^{-1} \rightarrow \text{OH}$ $3636\text{ cm}^{-1} \rightarrow \text{N-H of amine}$ ^1H NMR signals at (ppm):1.6 (quintet, 2 H) CH_2 split by 2 CH_2 's2.5 (singlet, 3 H) NH_2 and OH2.8 (triplet, 2 H) CH_2 split by CH_2 3.7 (triplet, 2 H) CH_2 split by CH_2

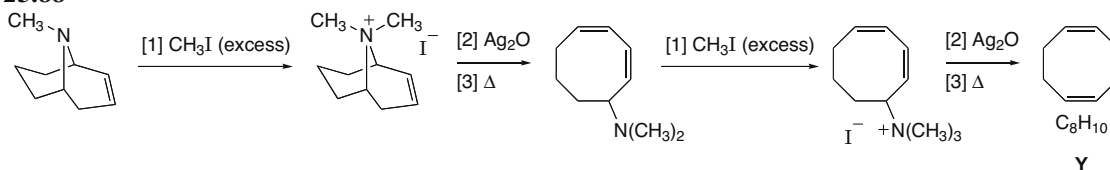
25.86 Guanidine is a strong base because its conjugate acid is stabilized by resonance. This resonance delocalization makes guanidine easily donate its electron pair; thus it's a strong base.



25.87 The compound with the most available electron pair or the compound with the highest electron density on an atom (N in this case) is the strongest base. Pyrrole is the weakest base because its lone pair is delocalized on the five-membered ring to make it aromatic. Both imidazole and thiazole contain sp^2 hybridized N atoms with electron pairs that are localized on N. Imidazole is a stronger base than thiazole, because its second N atom is more basic than thiazole's S atom, so it places more electron density on N by a resonance effect.



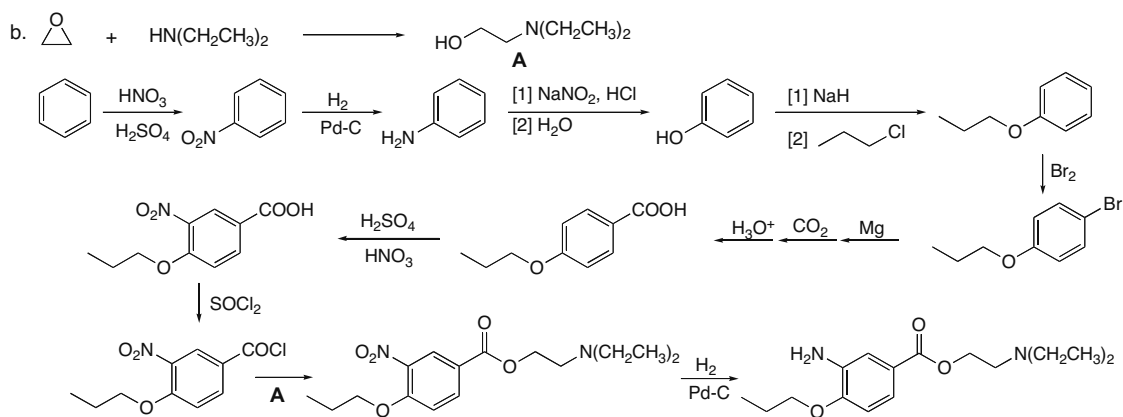
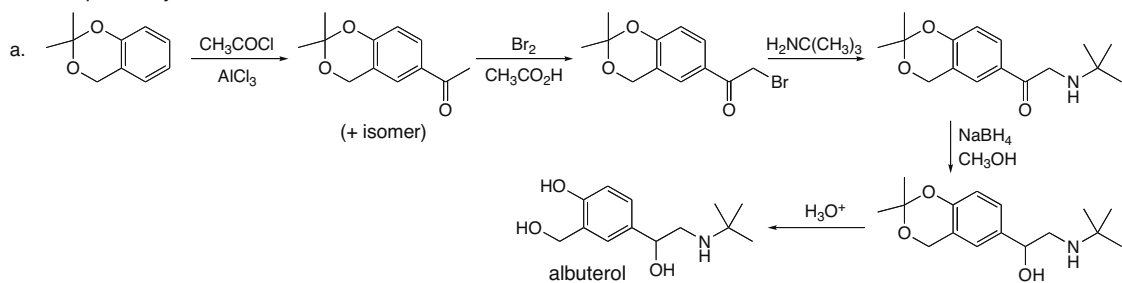
25.88



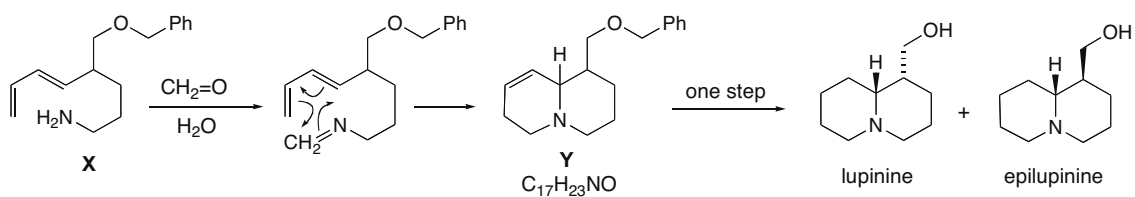
Chapter 25–34

25.89

One possibility:



25.90 $\text{CH}_2=\text{O}$ reacts with the amine to form an intermediate imine, which undergoes an intramolecular Diels–Alder reaction.



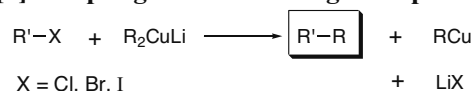
Carbon–Carbon Bond-Forming Reactions in Organic Synthesis 26–1

Chapter 26 Carbon–Carbon Bond-Forming Reactions in Organic Synthesis

Chapter Review

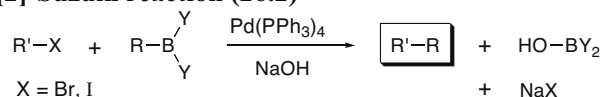
Coupling reactions

[1] Coupling reactions of organocuprate reagents (26.1)



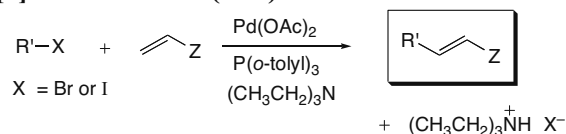
- R'X can be CH₃X, RCH₂X, 2° cyclic halides, vinyl halides, and aryl halides.
- X may be Cl, Br, or I.
- With vinyl halides, coupling is stereospecific.

[2] Suzuki reaction (26.2)



- R'X is most often a vinyl halide or aryl halide.
- With vinyl halides, coupling is stereospecific.

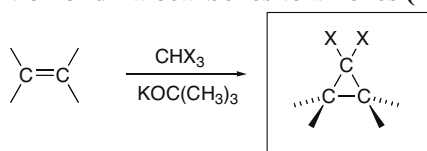
[3] Heck reaction (26.3)



- R'X is a vinyl halide or aryl halide.
- Z = H, Ph, COOR, or CN
- With vinyl halides, coupling is stereospecific.
- The reaction forms trans alkenes.

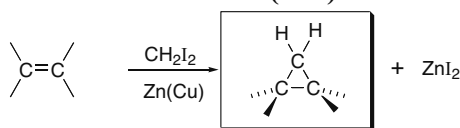
Cyclopropane synthesis

[1] Addition of dihalocarbenes to alkenes (26.4)



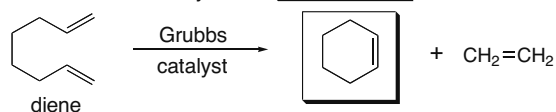
- The reaction occurs with syn addition.
- The position of substituents in the alkene is retained in the cyclopropane.

[2] Simmons–Smith reaction (26.5)



- The reaction occurs with syn addition.
- The position of substituents in the alkene is retained in the cyclopropane.

Metathesis (26.6)



- Metathesis works best when CH₂=CH₂, a gas that escapes from the reaction mixture, is formed as one product.

Chapter 26-2

Practice Test on Chapter Review

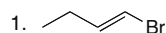
1. a. Which functional groups react with lithium dialkyl cuprates?

1. epoxides
2. vinyl halides
3. acid chlorides
4. Compounds [1] and [2] both react with R_2CuLi .
5. Compounds [1], [2], and [3] all react with R_2CuLi .

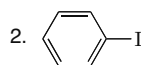
b. Which of the following statements is (are) true for the Suzuki reaction?

1. Arylboranes can serve as one reactant.
2. The reaction is stereospecific.
3. The reaction occurs between a vinyl or aryl halide and an alkene in the presence of a palladium catalyst.
4. Statements [1] and [2] are both true.
5. Statements [1], [2], and [3] are all true.

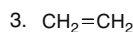
c. Which of the following compounds can react with $CH_2=CHCN$ in a Heck reaction?



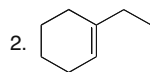
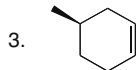
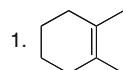
4. Both [1] and [2] can react.



5. Compounds [1], [2], and [3] can all react.



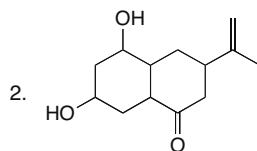
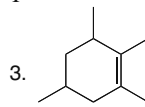
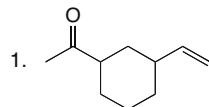
d. Which of the following compounds yields a pair of enantiomers on reaction with the Simmons-Smith reagent?



4. Compounds [1] and [2] both yield a pair of enantiomers.

5. Compounds [1], [2], and [3] all yield a pair of enantiomers.

e. Which of the following compounds can be made by a ring-closing metathesis reaction?

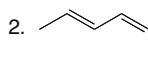
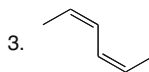
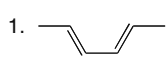


4. Compounds [1] and [2] can both be prepared.

5. Compounds [1], [2], and [3] can all be prepared.

Carbon–Carbon Bond-Forming Reactions in Organic Synthesis 26–3

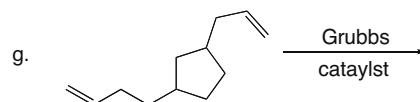
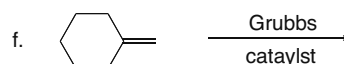
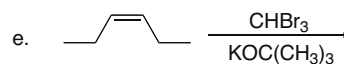
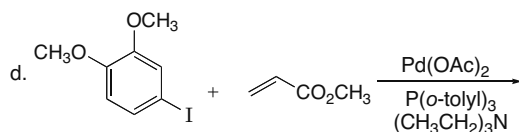
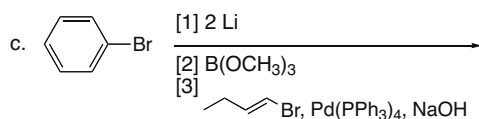
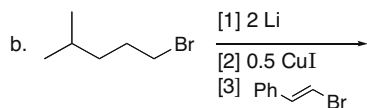
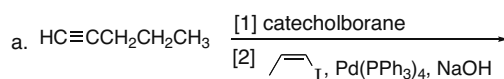
- f. Which of the following compounds can be prepared from $\text{CH}_3\text{--C}\equiv\text{C--H}$ by a Suzuki reaction? You may use other organic compounds or inorganic reagents.



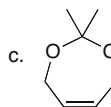
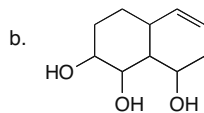
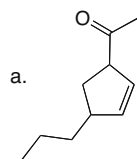
4. Compounds [1] and [2] can both be prepared.

5. Compounds [1], [2], and [3] can all be prepared.

2. Draw the product formed in each reaction. Indicate the stereochemistry around double bonds and stereogenic centers when necessary.



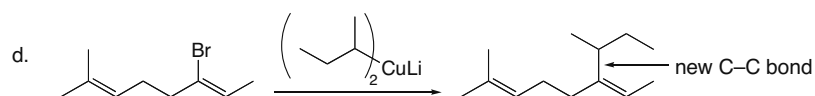
3. What starting material is needed to synthesize each compound by ring-closure metathesis?



Answers to Practice Test

- c. 

26.1 A new C–C bond is formed in each coupling reaction.



Chemical synthesis of C_{18} juvenile hormone:

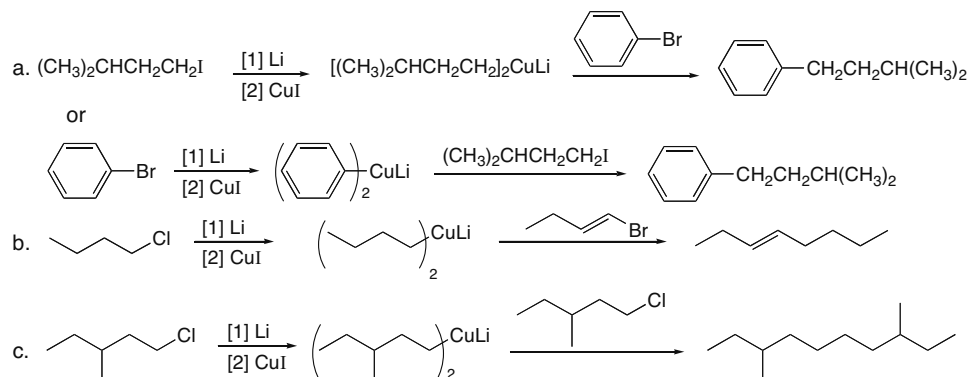
Starting material (a substituted allyl alcohol) reacts with **A = $(CH_3CH_2)_2CuLi$** to form an intermediate.

This intermediate undergoes **several steps** to form a di-allyl intermediate (containing an iodide and a hydroxyl group).

This intermediate reacts with **B = $(CH_3)_2CuLi$** to form a branched intermediate (containing a hydroxyl group).

This intermediate undergoes **several steps** to form the final product, **C_{18} juvenile hormone**, which is a complex branched molecule with a lactone ring and a methyl ester group.

26.3



a. + $\xrightarrow[\text{NaOH}]{\text{Pd(PPh}_3)_4}$

b. + $\xrightarrow[\text{NaOH}]{\text{Pd(PPh}_3)_4}$

c. $\xrightarrow[\text{[2] B(OCH}_3)_3]{\text{[1] Li}}$ + LiOCH_3

d. + $\longrightarrow$

Chemical reaction scheme showing the synthesis of compound **1**. The reaction involves the coupling of 4-methylphenylboronic acid (**B**) and 2-bromo-3-phenylisobenzofuran-1-one (**A**) to form 1-(4-methylphenyl)-2-phenylisobenzofuran-3-one (**1**).

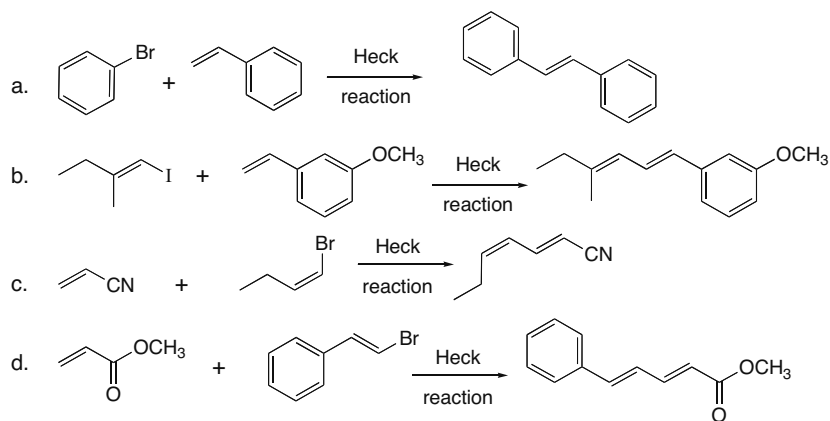
a. $\text{CH}_3\text{CH}_2\text{CH}_2\text{-C}\equiv\text{C-H} \xrightarrow{\text{H-B} \begin{array}{c} \diagup \text{O} \diagdown \\ \diagdown \text{O} \diagup \end{array} \text{C}_6\text{H}_5} \text{H} \begin{array}{c} \diagup \text{O} \diagdown \\ \diagdown \text{O} \diagup \end{array} \text{C}_6\text{H}_5 \text{CH}_2\text{CH}_2\text{CH}_3 \xrightarrow[\text{NaOH}]{\text{Pd(PPh}_3)_4, \text{I-CH}_2\text{CH}_2\text{CH}_2\text{CH}_3} \text{CH}_3\text{CH}_2\text{CH}_2\text{CH=CHCH}_2\text{CH}_2\text{CH}_3$

b. $\text{C}_6\text{H}_5\text{-I} \xrightarrow{\text{Li}} \text{C}_6\text{H}_5\text{-Li} \xrightarrow{\text{B(OCH}_3)_3} \text{C}_6\text{H}_5\text{-B(OCH}_3)_2 + \text{C}_6\text{H}_5\text{-I} \xrightarrow[\text{NaOH}]{\text{Pd(PPh}_3)_4} \text{C}_6\text{H}_5\text{-C}_6\text{H}_5$

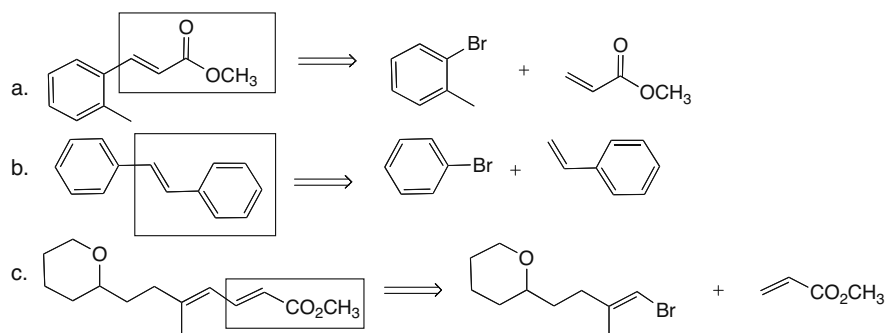
c. $\text{CH}_3\text{O-C}_6\text{H}_5 \xrightarrow{\text{Br}_2} \text{CH}_3\text{O-C}_6\text{H}_4\text{-Br} \xrightarrow[\text{CH}_3\text{O-C}_6\text{H}_5]{\text{Li}} \text{CH}_3\text{O-C}_6\text{H}_4\text{-Li} \xrightarrow[\text{CH}_3\text{O-C}_6\text{H}_5]{\text{B(OCH}_3)_3} \text{CH}_3\text{O-C}_6\text{H}_4\text{-B(OCH}_3)_2 \xrightarrow[\text{NaOH}]{\text{Pd(PPh}_3)_4, \text{CH}_3\text{CH}_2\text{CH}_2\text{CH}_2\text{Br}} \text{CH}_3\text{O-C}_6\text{H}_4\text{-CH=CH-CH}_2\text{CH}_2\text{CH}_3$
(+ ortho isomer)

Chapter 26–6

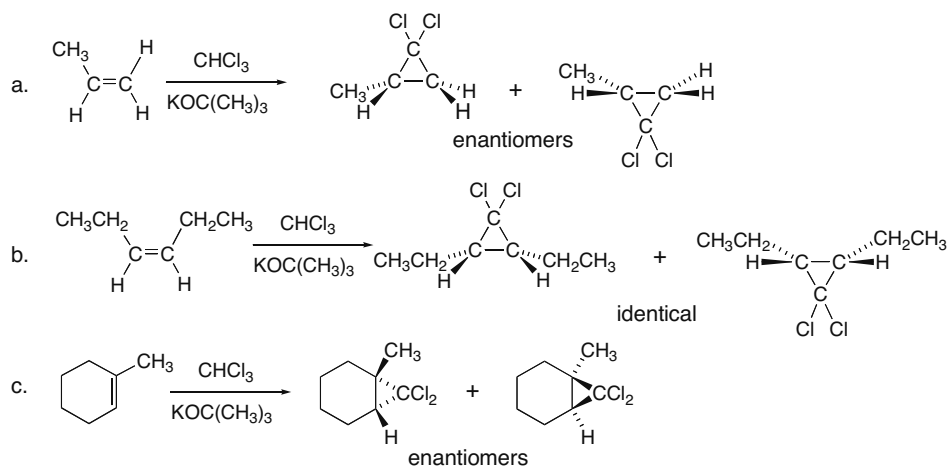
26.7



26.8 Locate the double bond with the aryl, COOR, or CN substituent, and break the molecule into two components at the end of the C=C not bonded to one of these substituents.

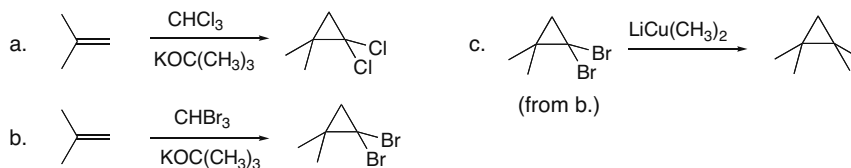


26.9 Add the carbene carbon from either side of the alkene.

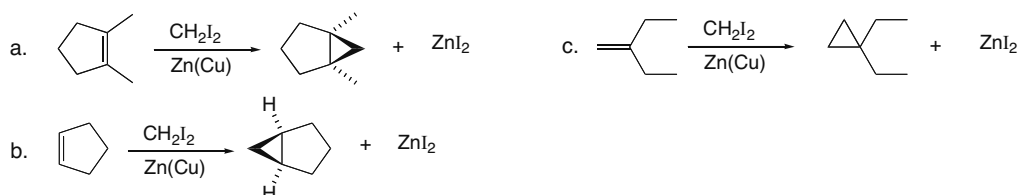


Carbon–Carbon Bond-Forming Reactions in Organic Synthesis 26–7

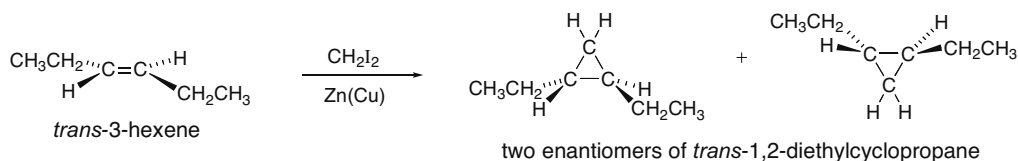
26.10



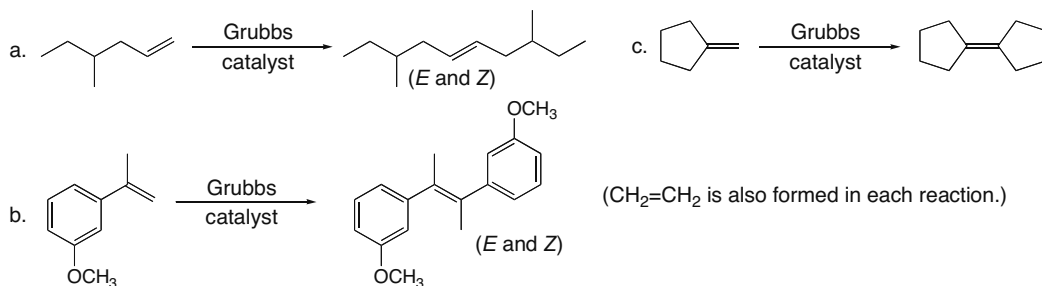
26.11



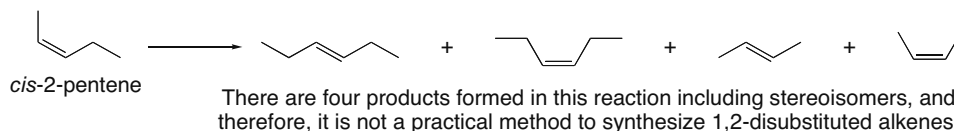
26.12 The relative position of substituents in the reactant is retained in the product.



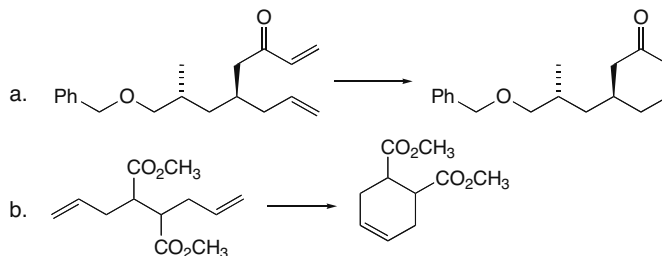
26.13



26.14

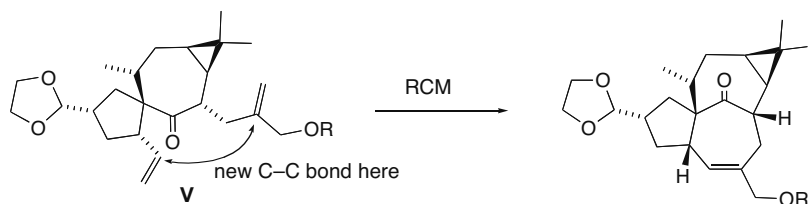


26.15

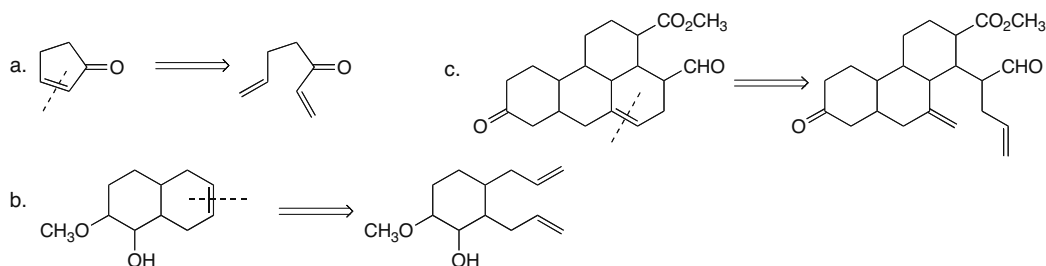


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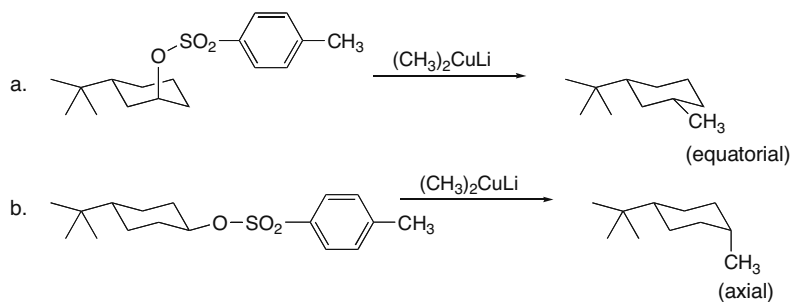
26.16



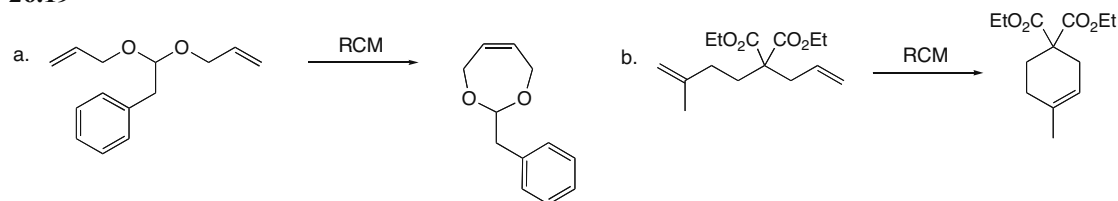
26.17 Cleave the C=C bond in the product, and then bond each carbon of the original alkene to a CH₂ group using a double bond.



26.18 Inversion of configuration occurs with the substitution of the methyl group for the tosylate.

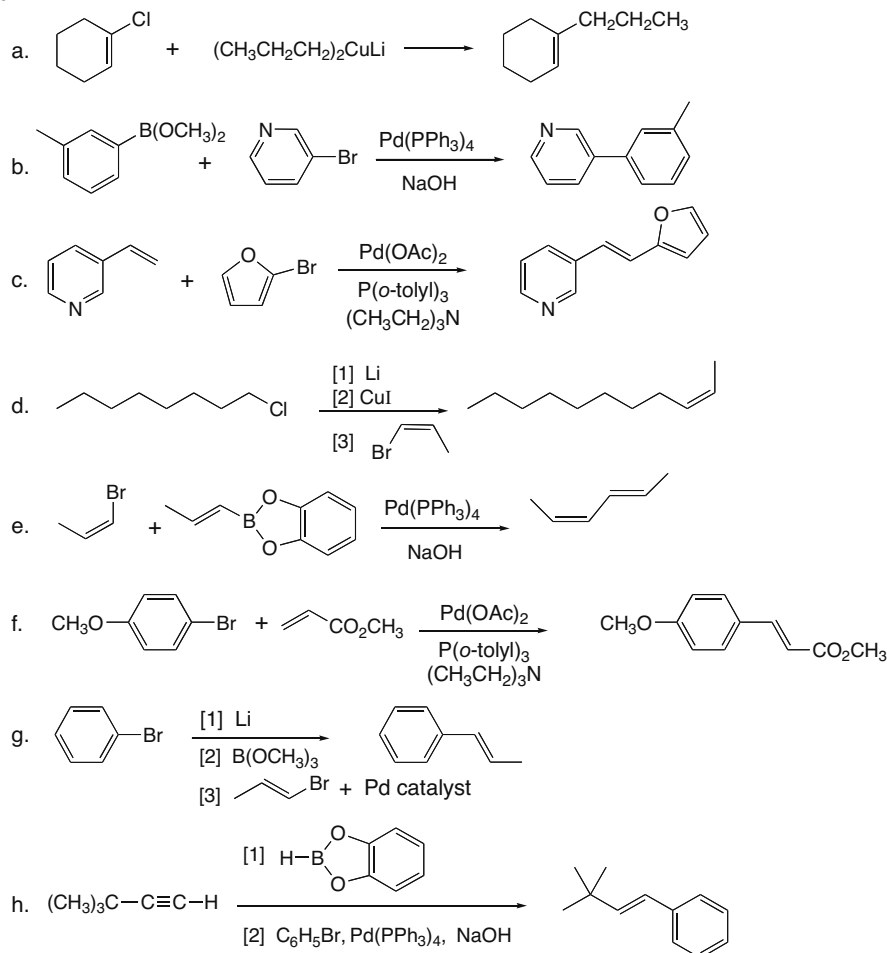


26.19

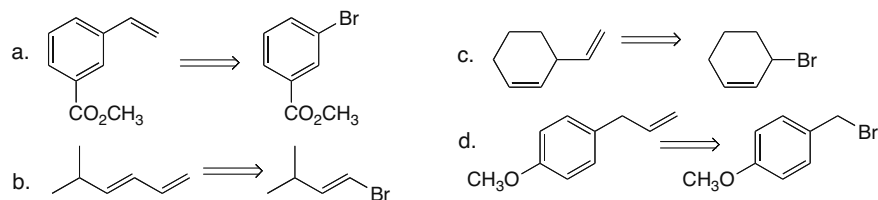


Carbon–Carbon Bond-Forming Reactions in Organic Synthesis 26–9

26.20



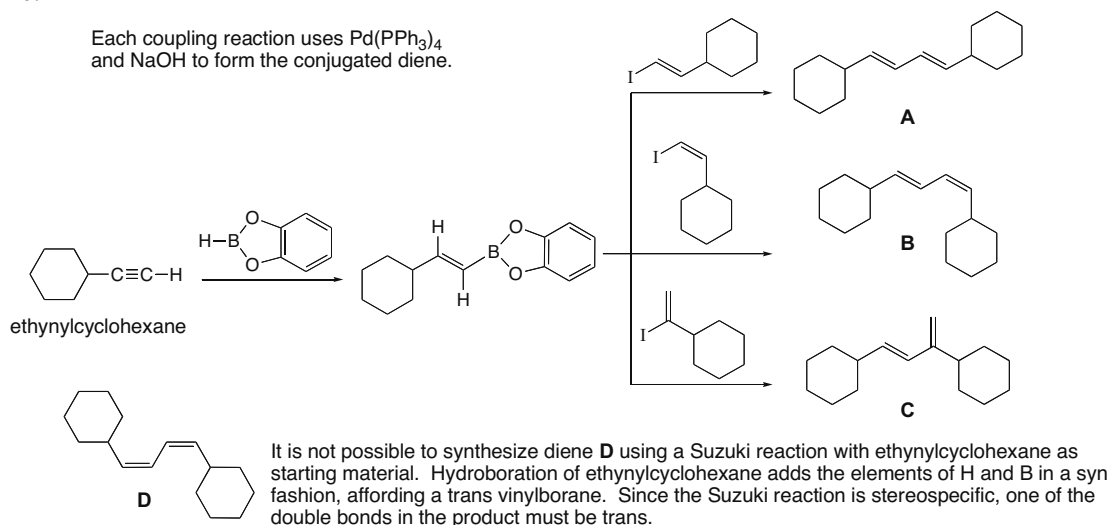
26.21



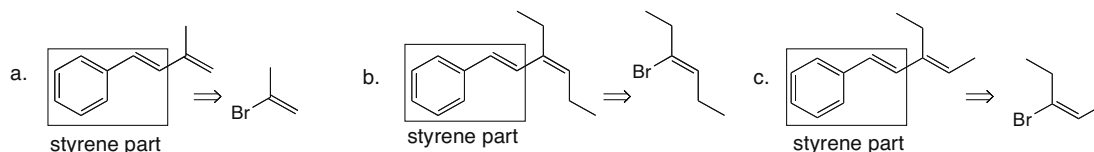
Chapter 26–10

26.22

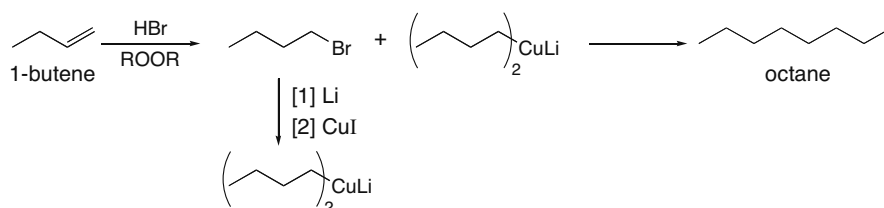
Each coupling reaction uses $\text{Pd}(\text{PPh}_3)_4$ and NaOH to form the conjugated diene.



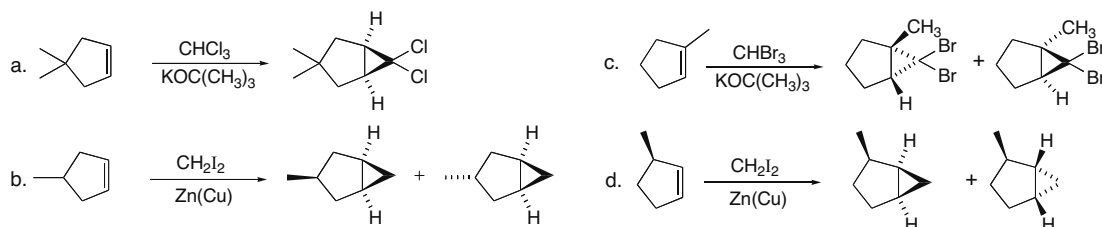
26.23 Locate the styrene part of the molecule, and break the molecule into two components. The second component in each reaction is styrene, $\text{C}_6\text{H}_5\text{CH}=\text{CH}_2$.



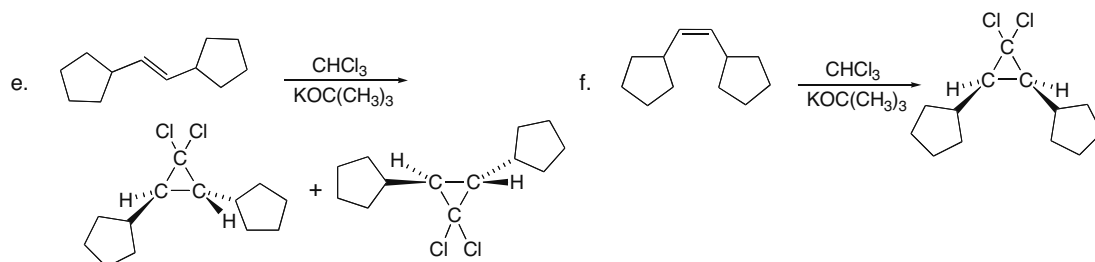
26.24



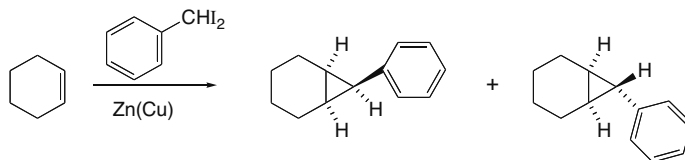
26.25 Add the carbene carbon from either side of the alkene.



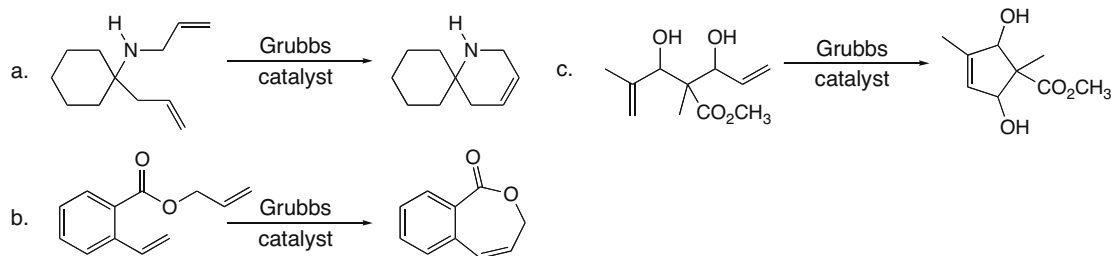
Carbon–Carbon Bond-Forming Reactions in Organic Synthesis 26–11



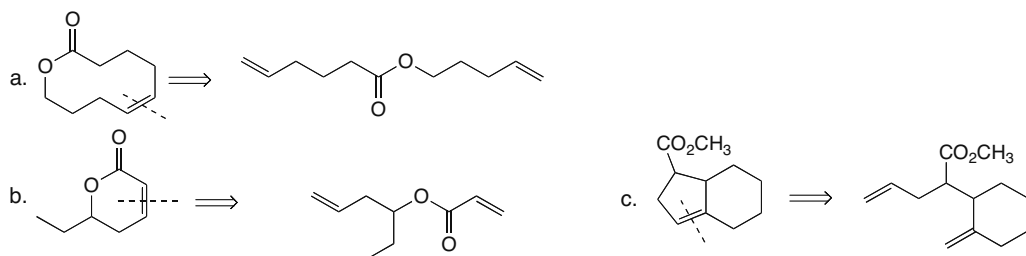
26.26 Since the new three-membered ring has a stereogenic center on the C bonded to the phenyl group, the phenyl group can be oriented in two different ways to afford two stereoisomers. These products are diastereomers of each other.



26.27 High dilution conditions favor intramolecular metathesis.

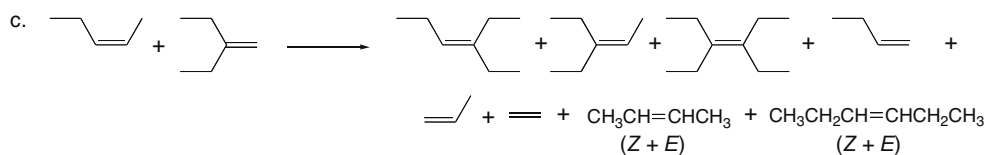
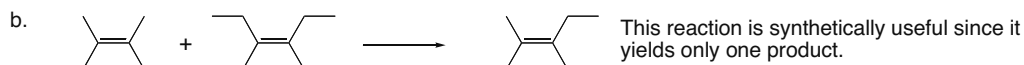
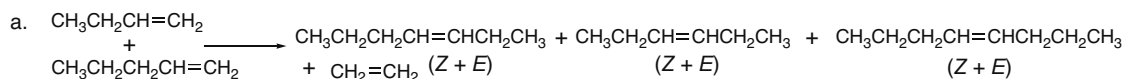


26.28 Retrosynthetically break the double bond in the cyclic compound and add a new $=\text{CH}_2$ at each end to find the starting material.

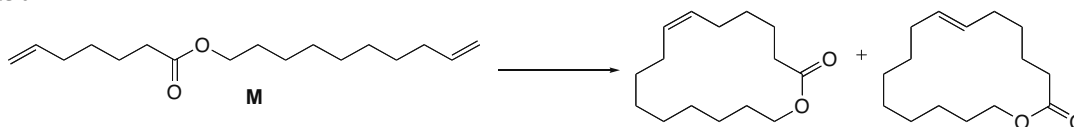
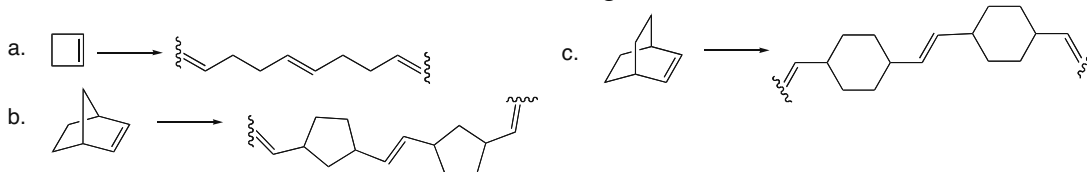


26.29 Alkene metathesis with two different alkenes is synthetically useful only when both alkenes are symmetrically substituted; that is, the two groups on each end of the double bond are identical to the two groups on the other end of the double bond.

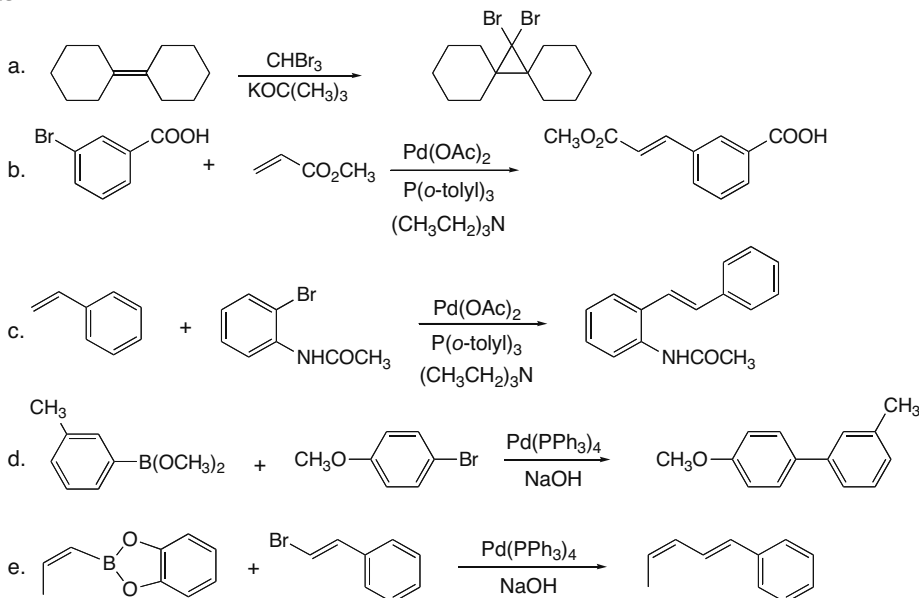
Chapter 26–12



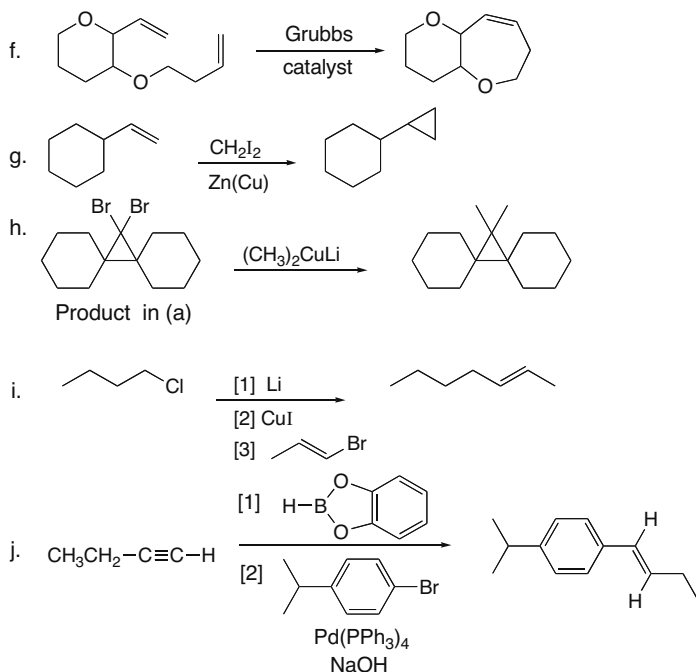
26.30

26.31 All double bonds can have either the *E* or *Z* configuration.

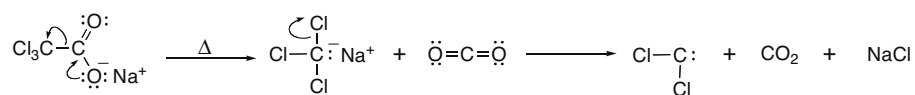
26.32



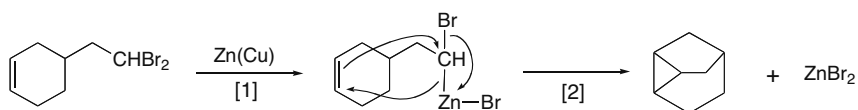
Carbon–Carbon Bond-Forming Reactions in Organic Synthesis 26–13



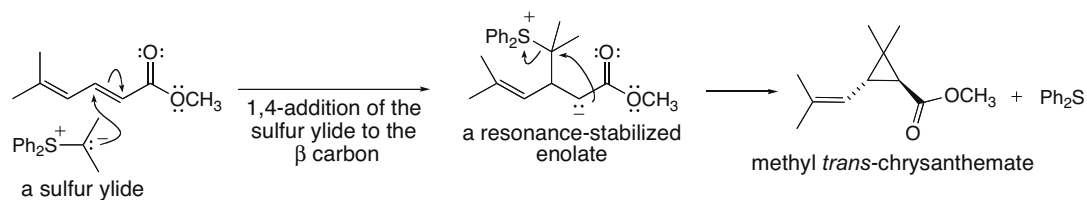
26.33



26.34 This reaction follows the Simmons–Smith reaction mechanism illustrated in Mechanism 26.5.

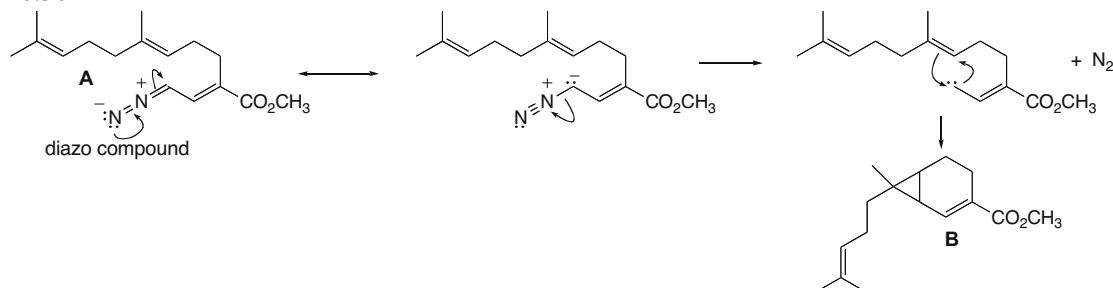


26.35

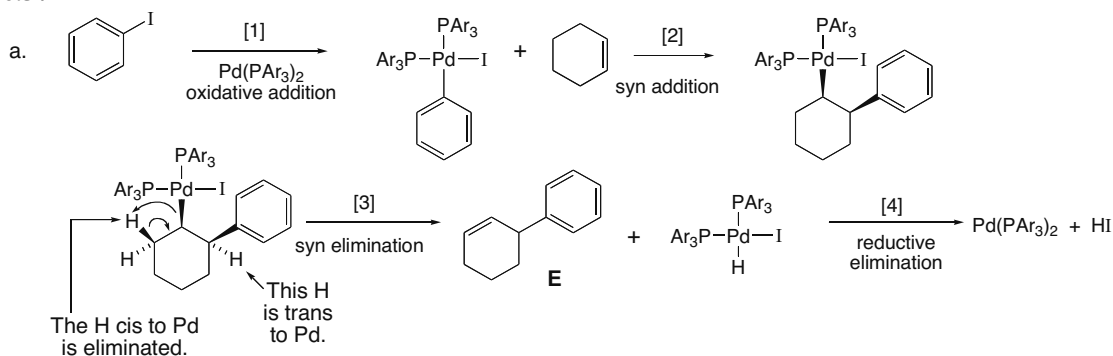


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26.36

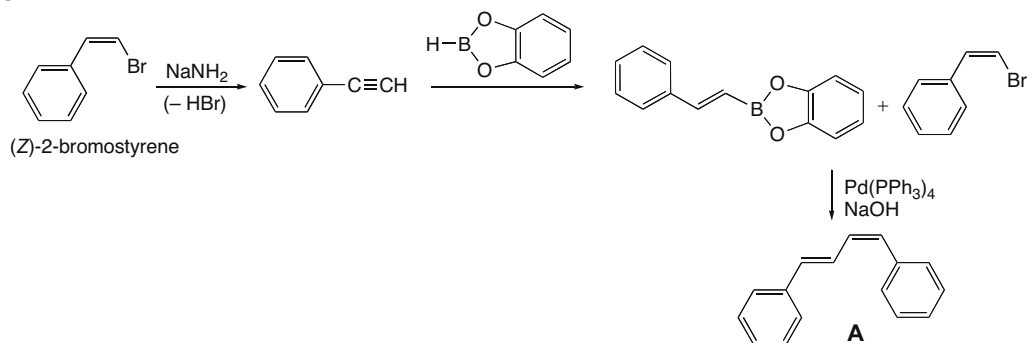


26.37

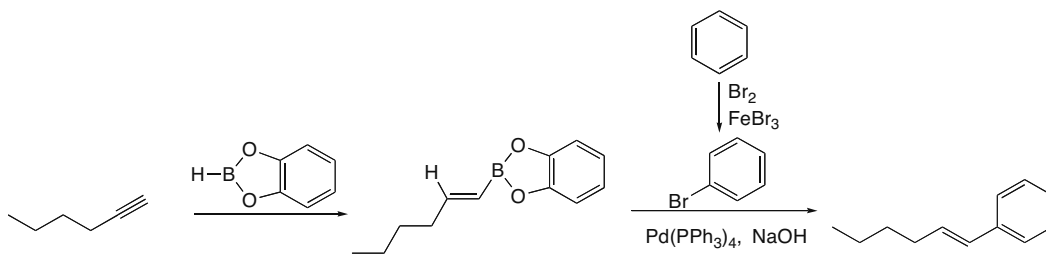


- b. This suggests that the stereochemistry in Step [3] must occur with syn elimination of H and Pd to form **E**. Product **F** cannot form because the only H on the C bonded to the benzene ring is trans to the Pd species, so it cannot be removed if elimination occurs in a syn fashion.

26.38

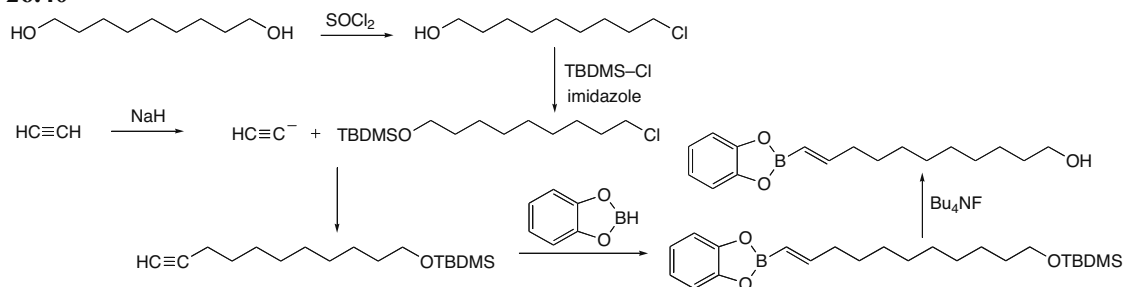


26.39

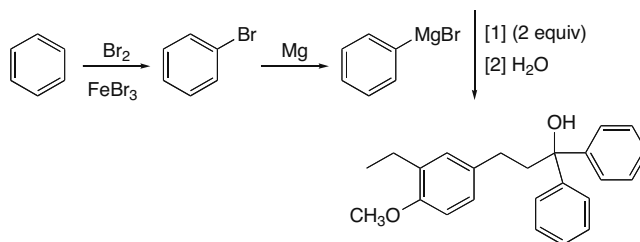
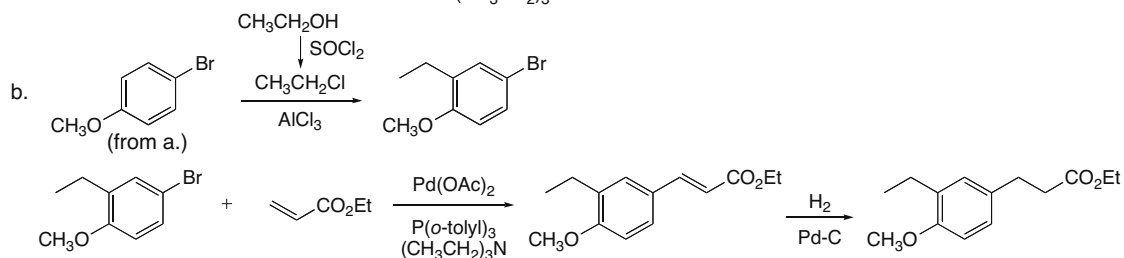
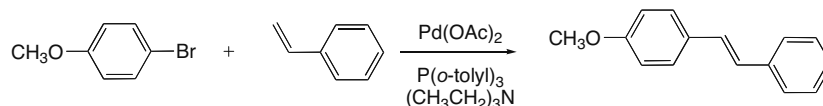
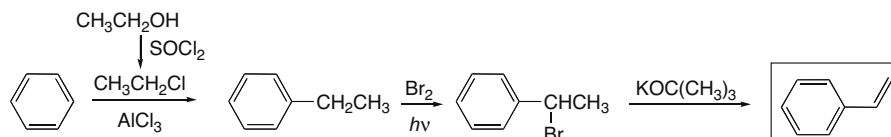
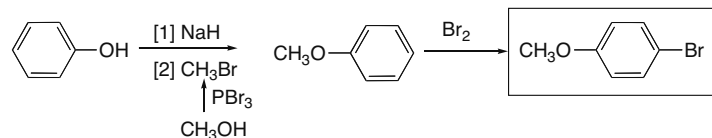
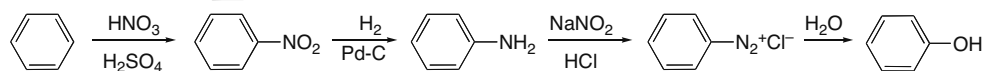
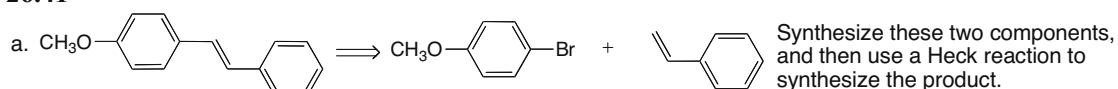


Carbon–Carbon Bond-Forming Reactions in Organic Synthesis 26–15

26.40

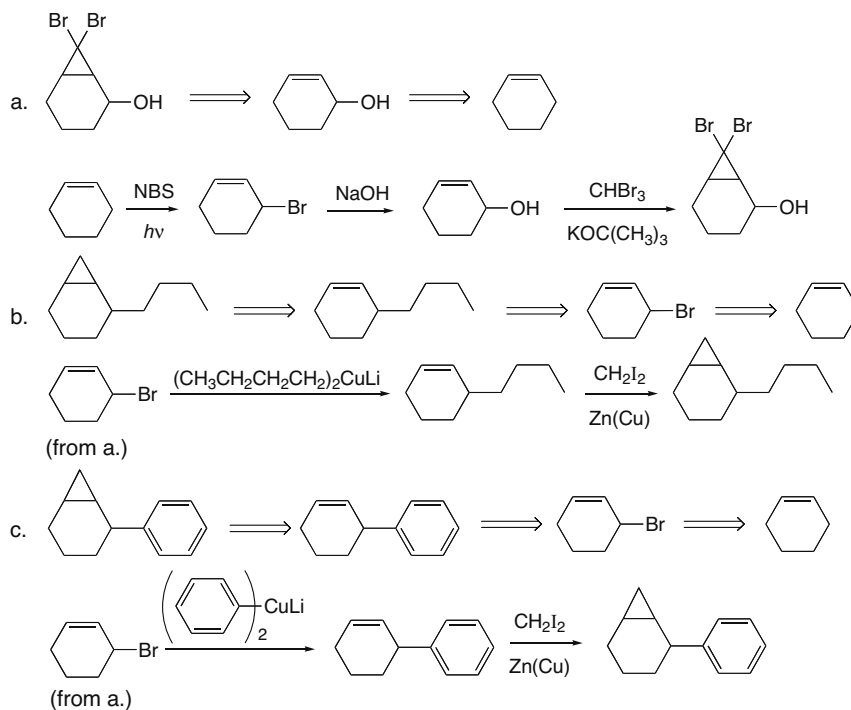


26.41

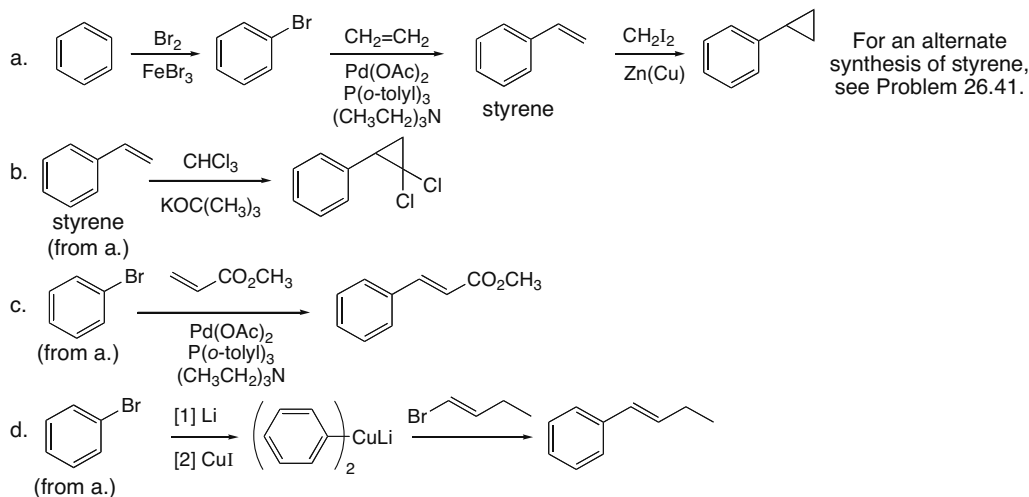


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26.42

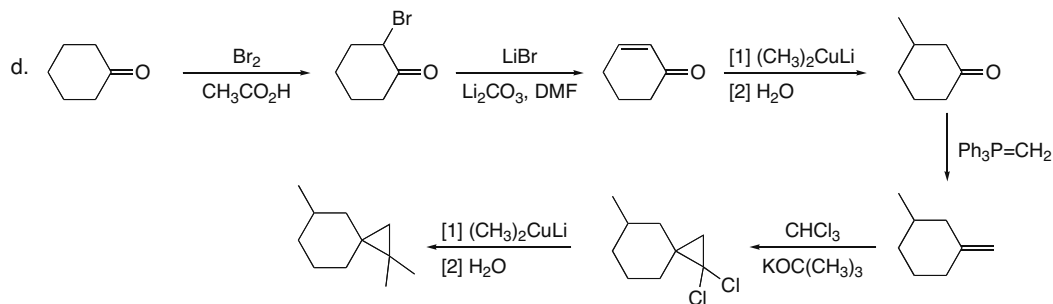
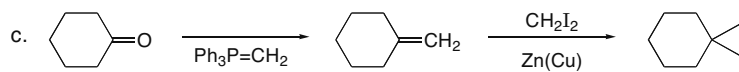
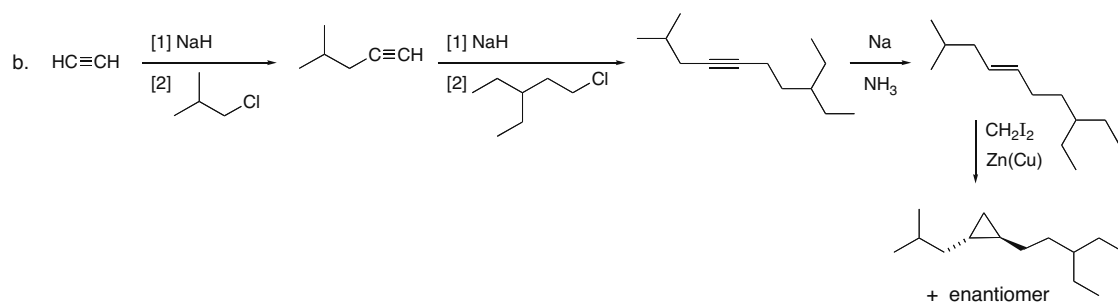
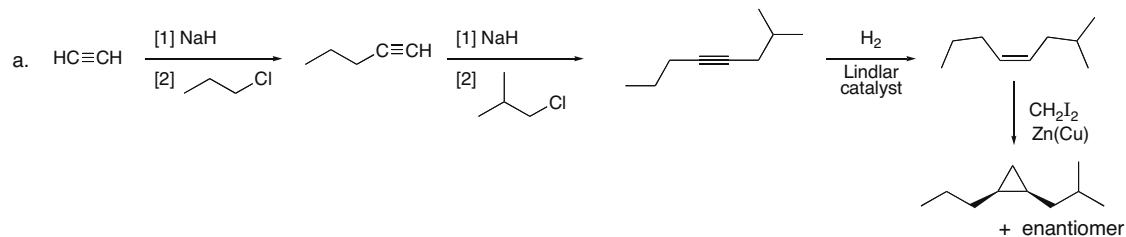


26.43



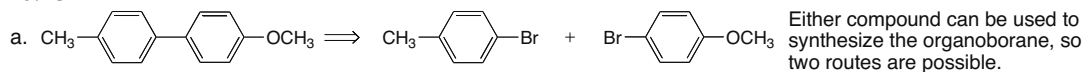
Carbon–Carbon Bond-Forming Reactions in Organic Synthesis 26–17

26.44

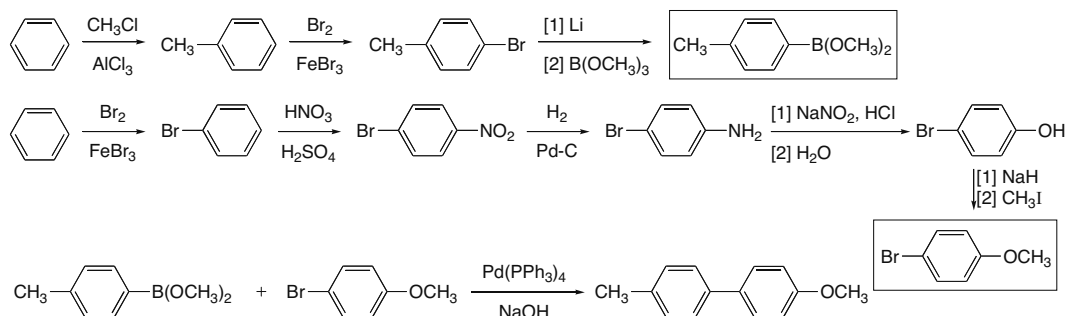


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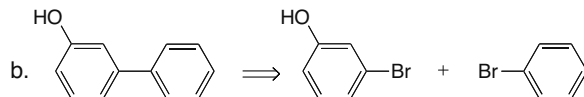
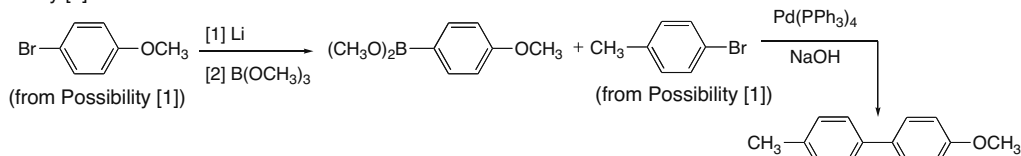
26.45



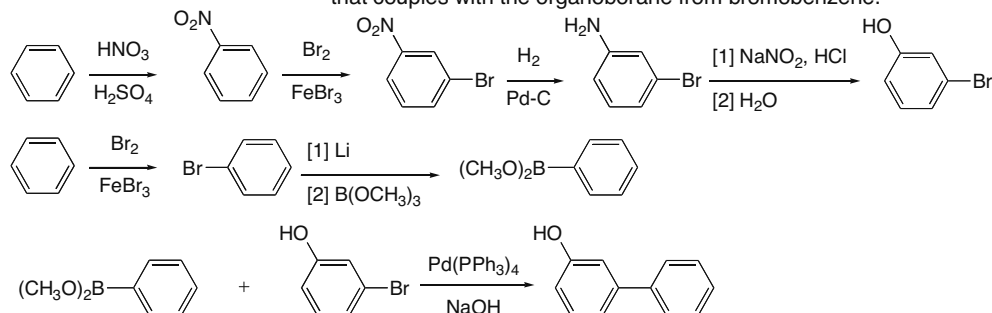
Possibility [1]:



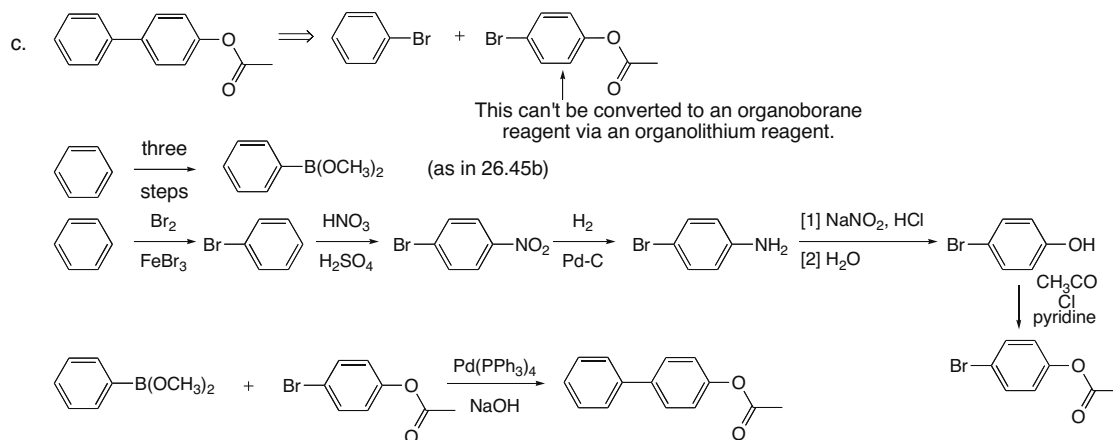
Possibility [2]:



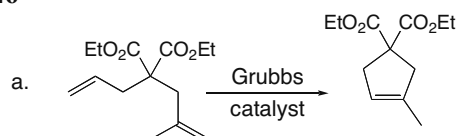
The acidic OH makes it impossible to prepare an organolithium reagent from this aryl halide, so this compound must be used as the aryl halide that couples with the organoborane from bromobenzene.



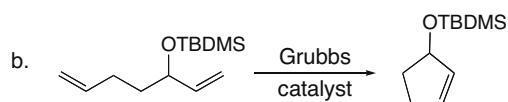
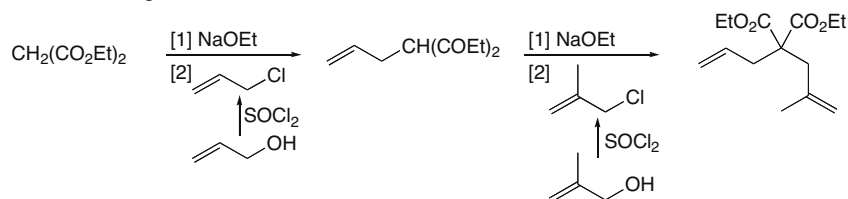
Carbon–Carbon Bond-Forming Reactions in Organic Synthesis 26–19



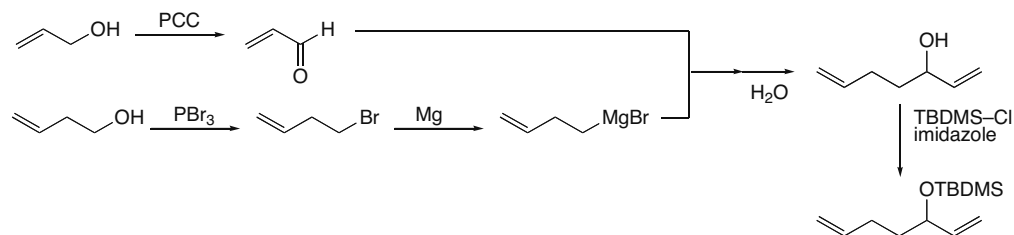
26.46



Synthesis of starting material:

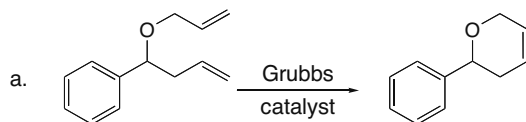


Synthesis of starting material:

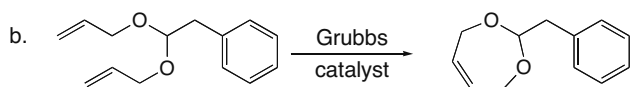
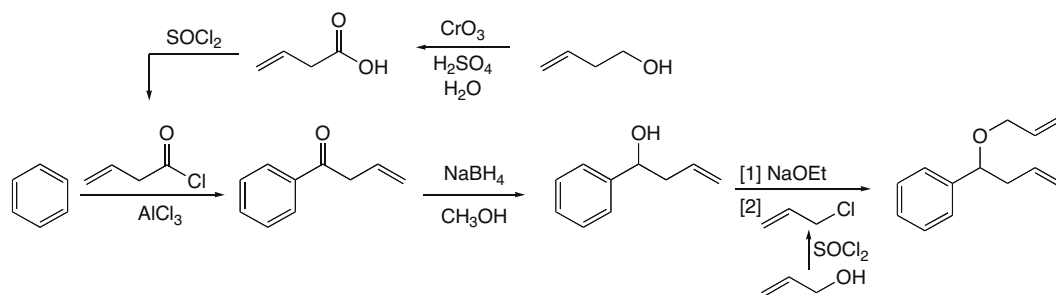


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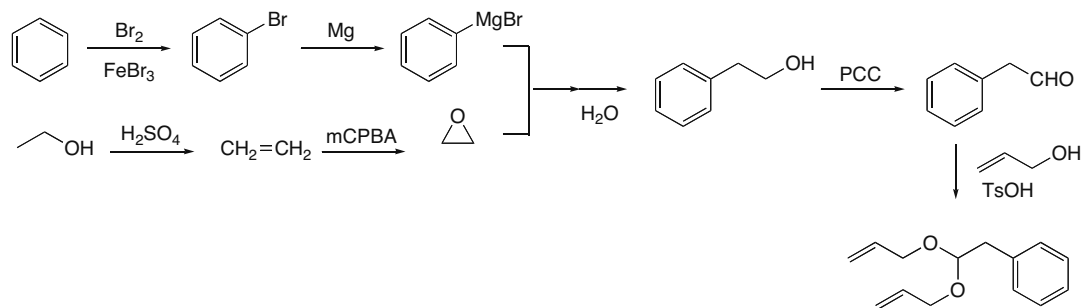
26.47



Synthesis of starting material:

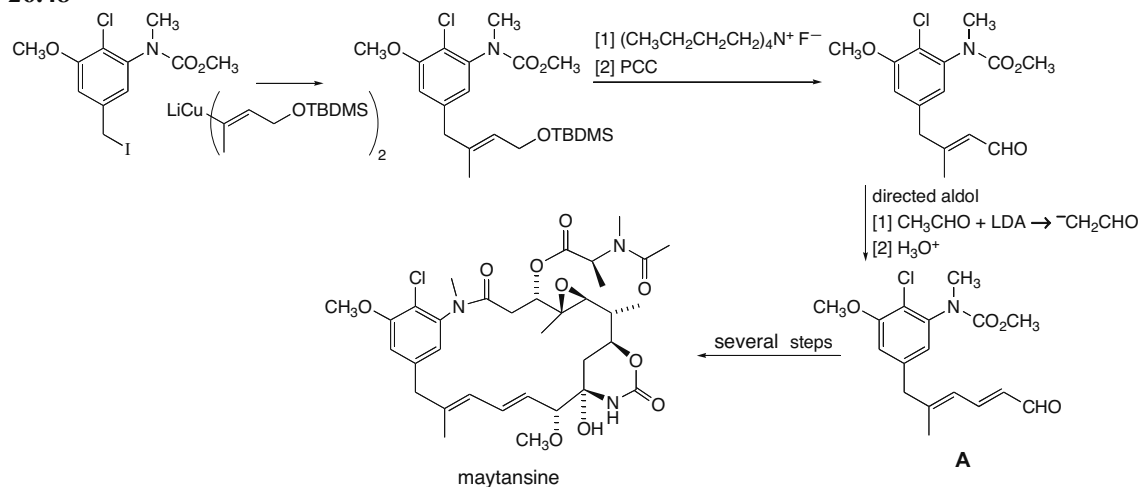


Synthesis of starting material:

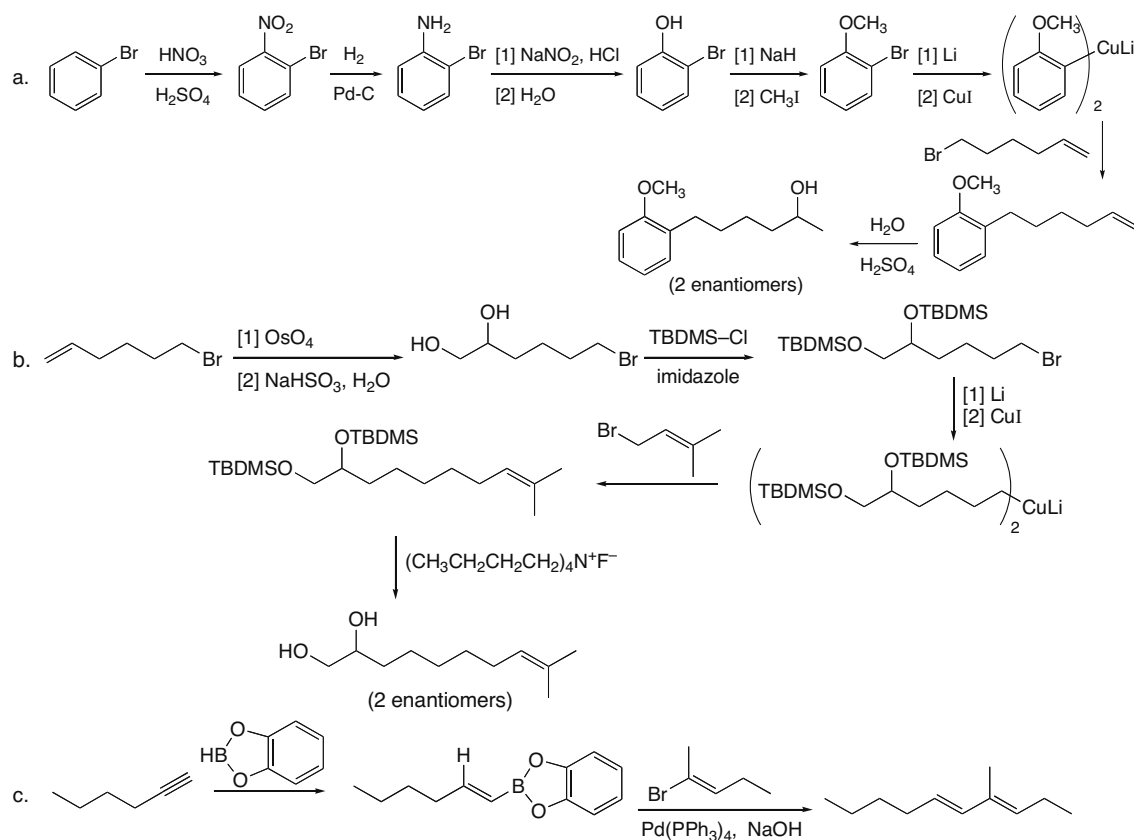


Carbon–Carbon Bond-Forming Reactions in Organic Synthesis 26–21

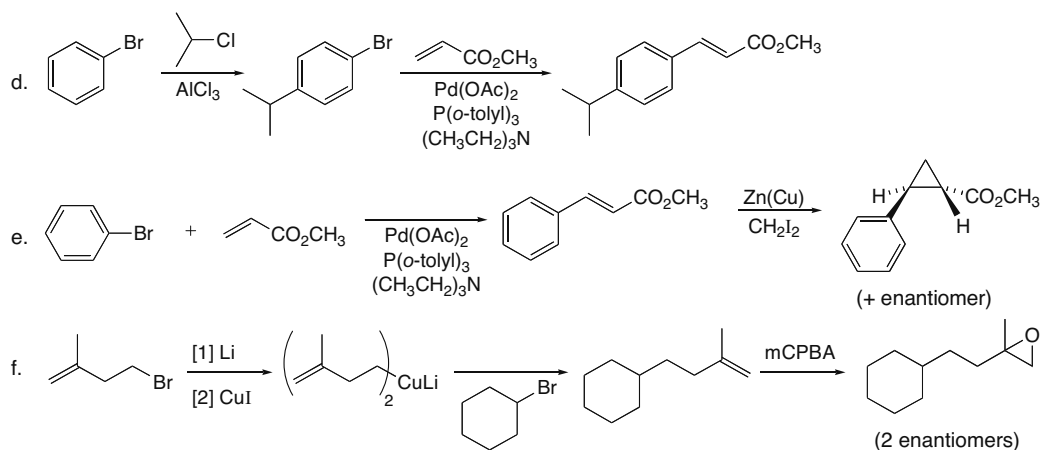
26.48



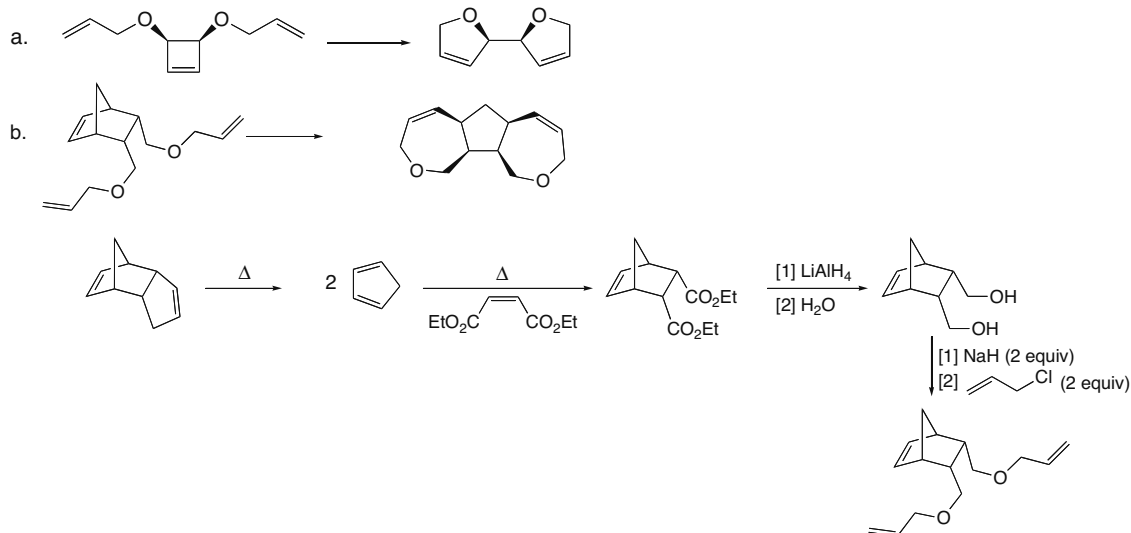
26.49



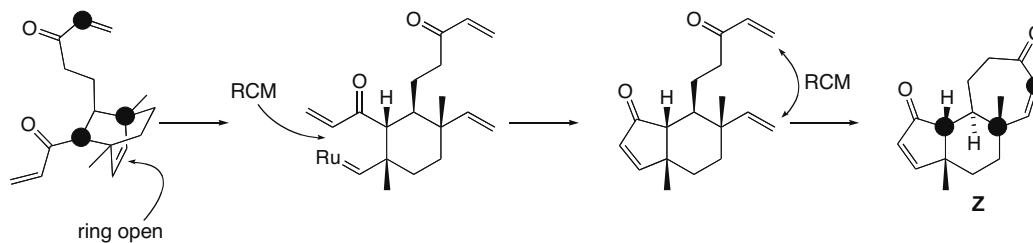
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26.50

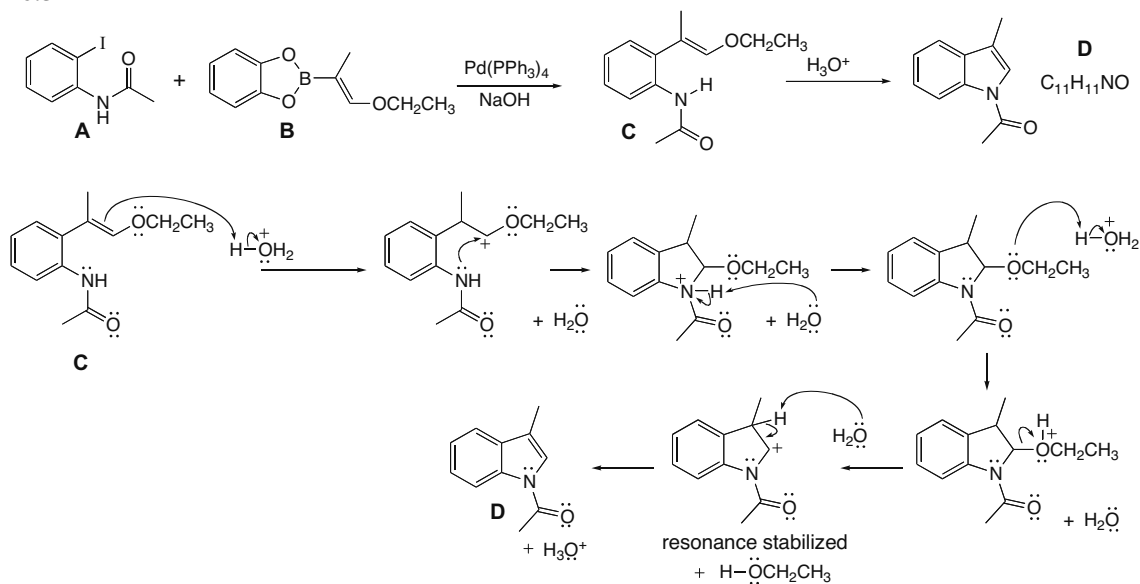


26.51 There is more than one way to form **Z** by metathesis reactions. One possibility involves ring opening of the bicyclic alkene followed by successive ring closures to generate the five- and seven-membered rings.

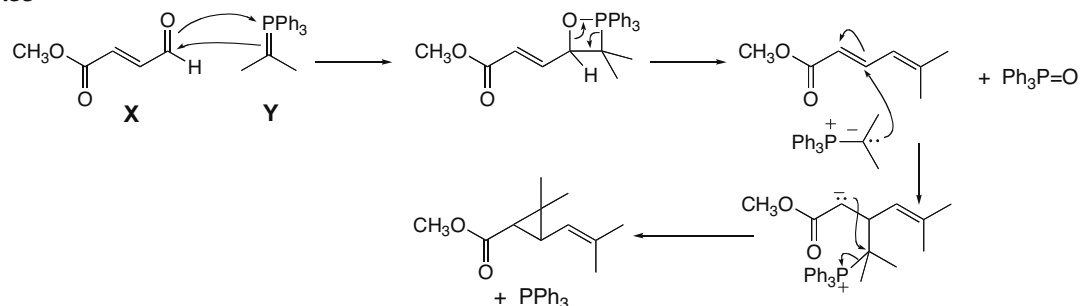


Carbon–Carbon Bond-Forming Reactions in Organic Synthesis 26–23

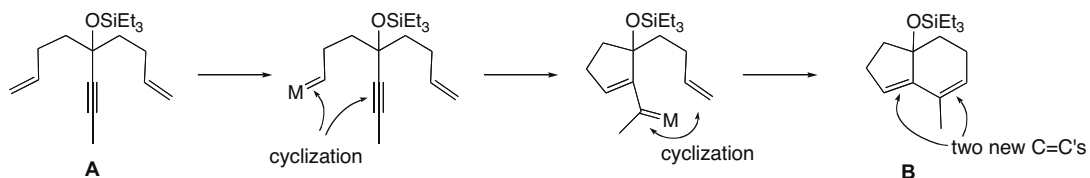
26.52



26.53

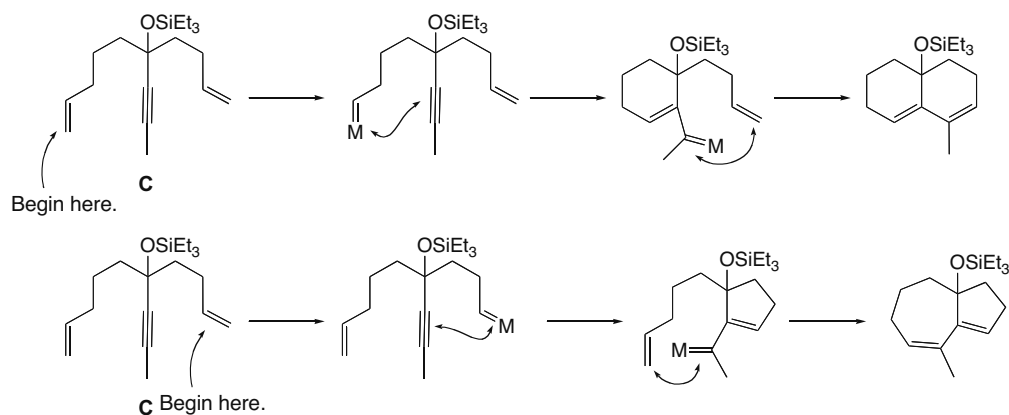


26.54 a. Reaction of a terminal alkene with the catalyst forms a metal–carbene that undergoes an intramolecular reaction with the triple bond, generating a new metal–carbene. A second intramolecular reaction forms the bicyclic product.



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- b. Two products are possible because the cascade of reactions can begin at two different double bonds.



Chapter 27 Pericyclic Reactions

Chapter Review

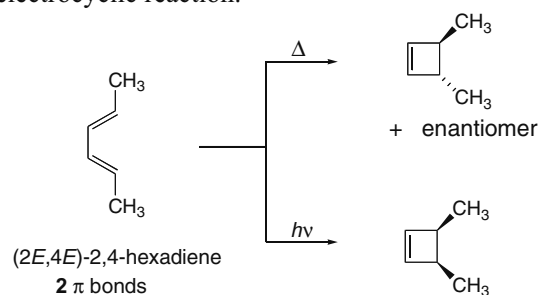
Electrocyclic reactions (27.3)

Woodward–Hoffmann rules for electrocyclic reactions

Number of π bonds	Thermal reaction	Photochemical reaction
Even	Conrotatory	Disrotatory
Odd	Disrotatory	Conrotatory

Examples

The stereochemistry of a thermal electrocyclic reaction is opposite to that of a photochemical electrocyclic reaction.



- A thermal electrocyclic reaction with an even number of π bonds occurs in a conrotatory fashion.

- A photochemical electrocyclic reaction with an even number of π bonds occurs in a disrotatory fashion.

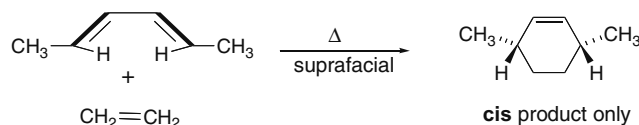
Cycloaddition reactions (27.4)

Woodward–Hoffmann rules for cycloaddition reactions

Number of π bonds	Thermal reaction	Photochemical reaction
Even	Antarafacial	Suprafacial
Odd	Suprafacial	Antarafacial

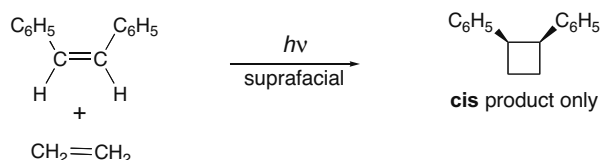
Examples

- [1] A thermal $[4 + 2]$ cycloaddition takes place in a suprafacial fashion with an odd number of π bonds. An antarafacial photochemical $[4 + 2]$ cycloaddition to form a six-membered ring cannot occur, because of the geometrical constraints of forming a six-membered ring.



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- [2] A photochemical [2 + 2] cycloaddition takes place in a suprafacial fashion with an even number of π bonds. An antarafacial thermal [2 + 2] cycloaddition to form a four-membered ring cannot occur, because of the geometrical constraints of forming a four-membered ring.



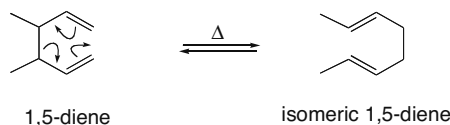
Sigmatropic rearrangements (27.5)

Woodward–Hoffmann rules for sigmatropic rearrangements

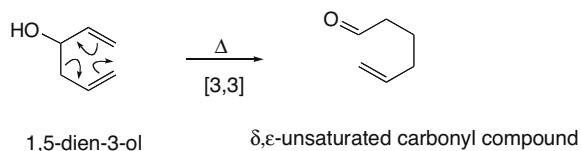
Number of electron pairs	Thermal reaction	Photochemical reaction
Even	Antarafacial	Suprafacial
Odd	Suprafacial	Antarafacial

Examples

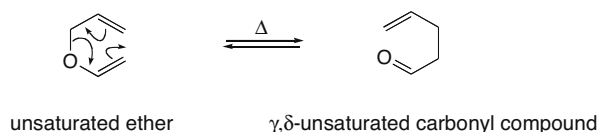
- [1] A **Cope rearrangement** is a thermal [3,3] sigmatropic rearrangement that converts a 1,5-diene into an isomeric 1,5-diene.



- [2] An **oxy-Cope rearrangement** is a thermal [3,3] sigmatropic rearrangement that converts a 1,5-dien-3-ol into a δ, ϵ -unsaturated carbonyl compound, after tautomerization of an intermediate enol.

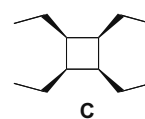
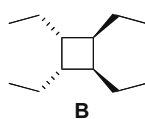
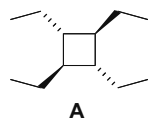


- [3] A **Claisen rearrangement** is a thermal [3,3] sigmatropic rearrangement that converts an unsaturated ether into a γ, δ -unsaturated carbonyl compound.



Practice Test on Chapter Review

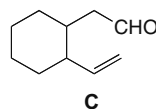
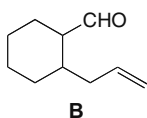
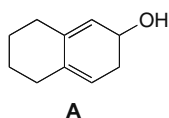
1. a. Which of the following pericyclic reactions is symmetry allowed and readily occurs?
1. a photochemical conrotatory electrocyclic ring closure of a conjugated triene
 2. a disrotatory thermal electrocyclic ring opening of a substituted cyclohexadiene
 3. a thermal $[2 + 2]$ cycloaddition
 4. Reactions [1] and [2] will both occur.
 5. Reactions [1], [2], and [3] will all occur.
- b. Which of the following reactions requires suprafacial stereochemistry to be symmetry allowed?
1. a photochemical $[1,5]$ sigmatropic rearrangement
 2. a thermal $[8 + 2]$ cycloaddition
 3. a photochemical $[4 + 2]$ cycloaddition
 4. Reactions [1] and [2] are both suprafacial.
 5. Reactions [1], [2], and [3] are all suprafacial.
- c. What product(s) are formed from the photochemical $[2 + 2]$ cycloaddition of (3*E*)-3-hexene?



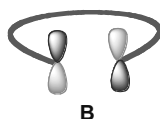
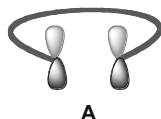
1. **A** only
 2. **B** only
 3. **C** only
 4. **A** and **B**
 5. **A, B, and C**
- d. What product(s) are formed from the photochemical electrocyclic ring opening of *cis*-3,4-dimethylcyclobutene?
1. (2*E*,4*E*)-2,4-hexadiene
 2. (2*E*,4*Z*)-2,4-hexadiene
 3. (3*Z*)-1,3,5-hexatriene
 4. Compounds [1] and [2] are both formed.
 5. Compounds [1], [2], and [3] are all formed.

Chapter 27-4

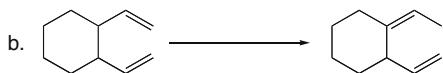
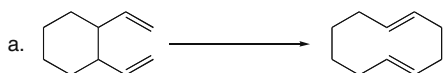
e. What product(s) are formed by the [3,3] sigmatropic rearrangement of 1,5-cyclodecadien-3-ol?



1. **A** only
 2. **B** only
 3. **C** only
 4. **A** and **B**
 5. **A**, **B**, and **C**
2. Consider the p orbitals of the terminal carbons of a conjugated polyene with like phases on the same side of the molecule (as in **A**) or opposite sides of the molecule (as in **B**), and answer each question.



- a. Which drawing is consistent with the ground state HOMO of a conjugated triene?
 - b. Which drawing is consistent with the excited state LUMO of a conjugated diene?
 - c. Which drawing is consistent with the ground state LUMO for a conjugated tetraene?
3. What type of sigmatropic rearrangement is depicted in each reaction?



Answers to Practice Test

1. a. 4
- b. 2
- c. 4
- d. 1
- e. 3

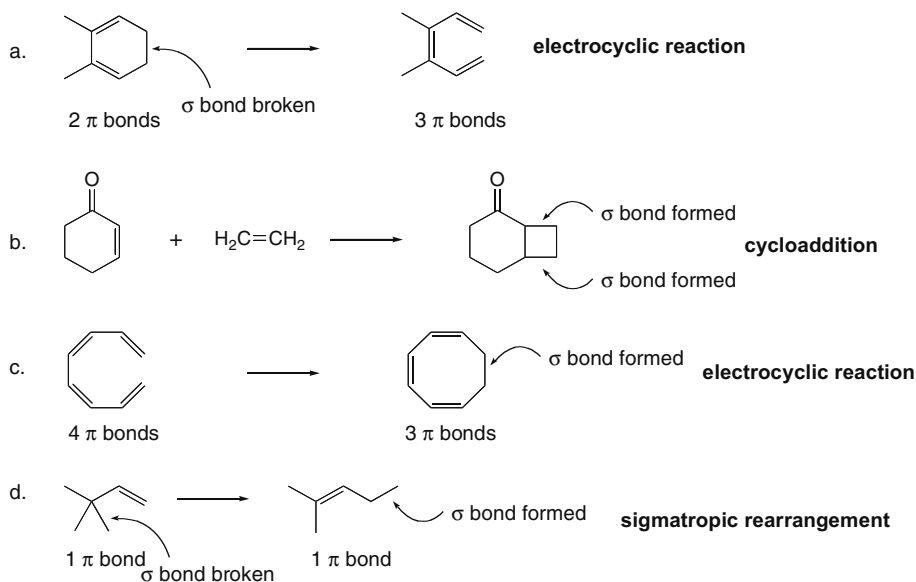
2. a. **A**
- b. **B**
- c. **A**

3. a. [3,3]
- b. [1,3]

Answers to Problems

27.1 Use the following definitions:

- An **electrocyclic ring closure** is an intramolecular reaction that forms a cyclic product containing one more σ bond and one fewer π bond than the reactant. An **electrocyclic ring opening** is a reaction in which a σ bond of a cyclic reactant is cleaved to form a conjugated product with one more π bond.
- A **cycloaddition** is a reaction between two compounds with π bonds that forms a cyclic product with two new σ bonds.
- A **sigmatropic rearrangement** is a reaction in which a σ bond is broken in the reactant, the π bonds rearrange, and a σ bond is formed in the product.



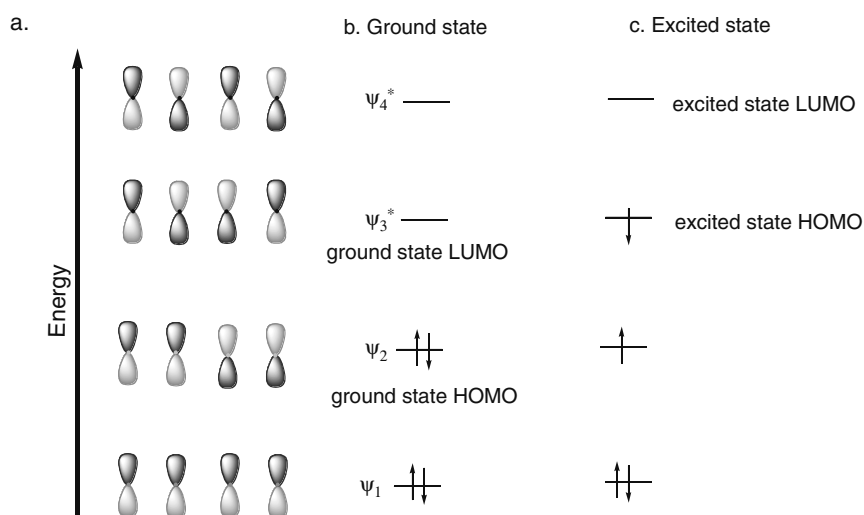
- 27.2 a. For a bonding molecular orbital, the number of bonding interactions is greater than the number of nodes.
 b. For an antibonding molecular orbital, the number of bonding interactions is less than the number of nodes.

For 1,3-butadiene:

	Bonding	Nodes	Type of MO
ψ_1	3	0	bonding MO
ψ_2	2	1	bonding MO
ψ_3^*	1	2	antibonding MO
ψ_4^*	0	3	antibonding MO

Chapter 27-6

27.3 The molecular orbitals of all conjugated dienes look similar.



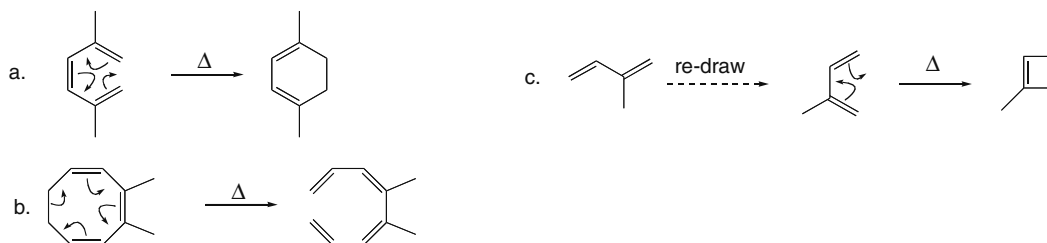
- 27.4
- There are 10 molecular orbitals from the 10 p orbitals of the five π bonds.
 - Five molecular orbitals are bonding and five molecular orbitals are antibonding.
 - The lowest energy molecular orbital (ψ_1) has zero nodes.



- The highest energy molecular orbital (ψ_{10}^*) has nine nodes.

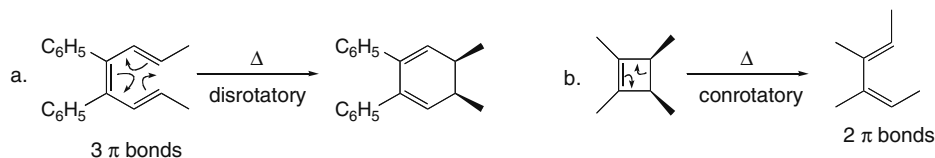


- 27.5 To draw the product of an electrocyclic reaction, use curved arrows and begin at a π bond. Move the π electrons to an adjacent carbon-carbon bond, and continue in a cyclic fashion.

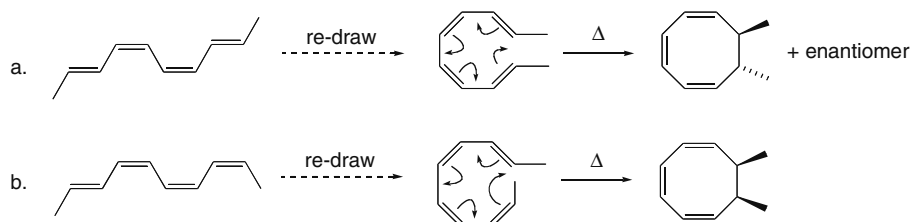


Pericyclic Reactions 27-7

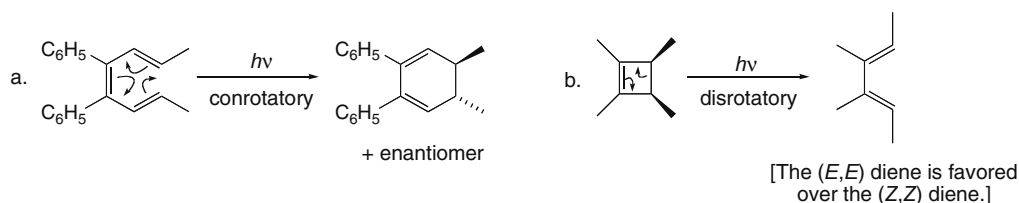
- 27.6** Thermal electrocyclic reactions occur in a *disrotatory* fashion for a conjugated polyene with an *odd* number of π bonds, and in a *conrotatory* fashion for a conjugated polyene with an *even* number of π bonds.



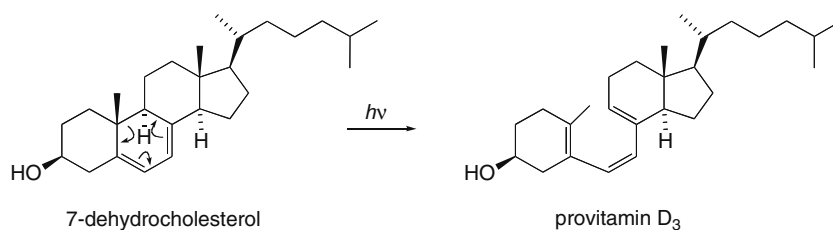
- 27.7** For an *even* number of π bonds, thermal electrocyclic reactions occur in a *conrotatory* fashion.



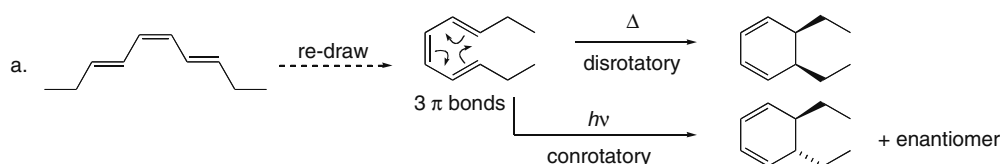
- 27.8** Photochemical electrocyclic reactions occur in a *conrotatory* fashion for a conjugated polyene with an *odd* number of π bonds, and in a *disrotatory* fashion for a conjugated polyene with an *even* number of π bonds.



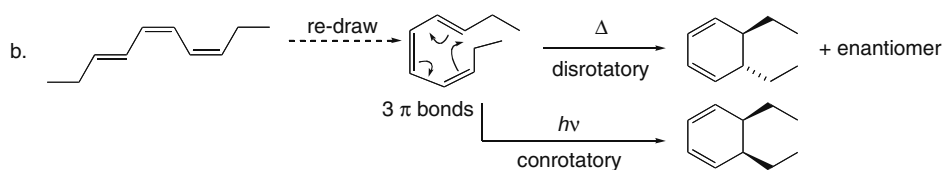
- 27.9** The photochemical electrocyclic reaction cleaves a six-membered ring to form a hexatriene.



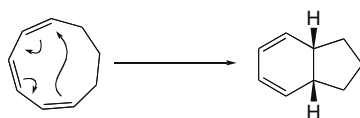
- 27.10** Use the rules for electrocyclic reactions found in Answers 27.6 and 27.8.



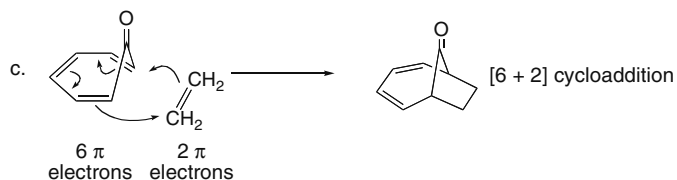
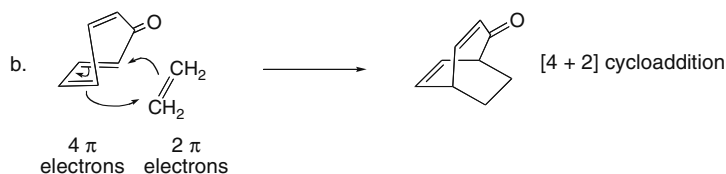
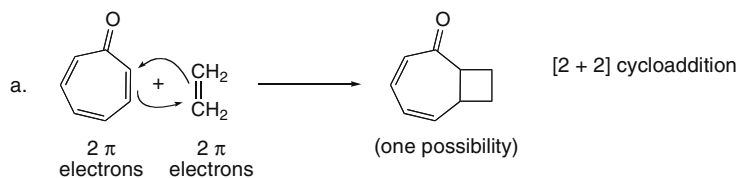
Chapter 27-8



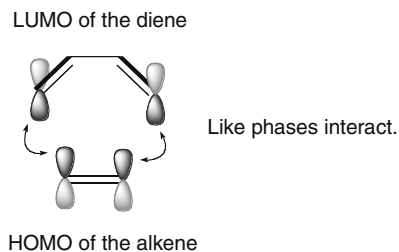
27.11 Use the rules for electrocyclic reactions found in Answer 27.6. A reaction with three π bonds and a disrotatory cyclization is thermal.



27.12 Count the number of π electrons in each reactant to classify the cycloaddition.

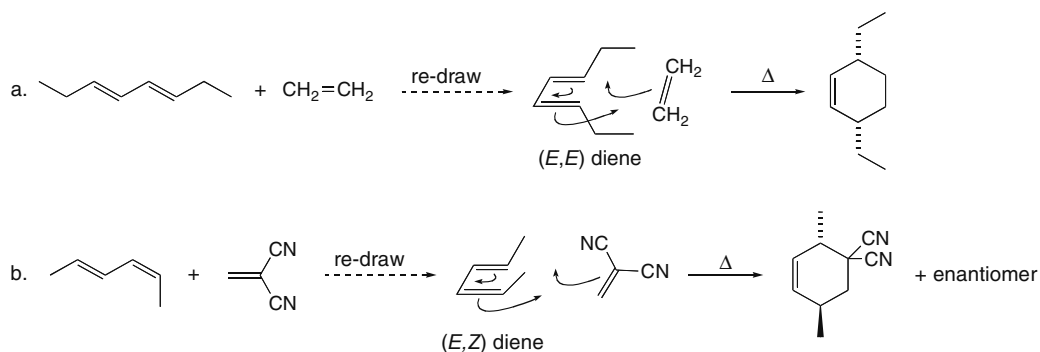


27.13 A thermal suprafacial addition is symmetry allowed in a $[4 + 2]$ cycloaddition because like phases interact.

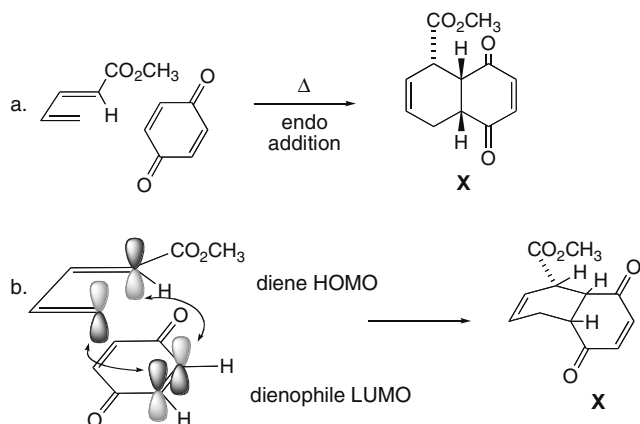


Pericyclic Reactions 27-9

27.14 A thermal $[4 + 2]$ cycloaddition is suprafacial.

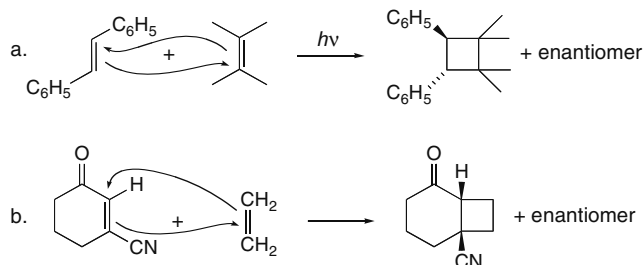


27.15



The dienophile is under the diene, by the rule of endo addition (Section 16.13). The H's at the ring fusion are cis to each other, but trans to the CO_2CH_3 group.

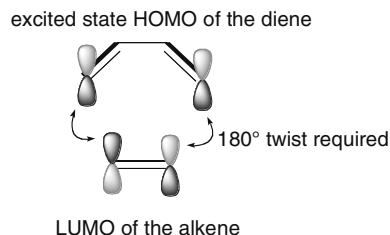
27.16 A photochemical $[2 + 2]$ cycloaddition is suprafacial.



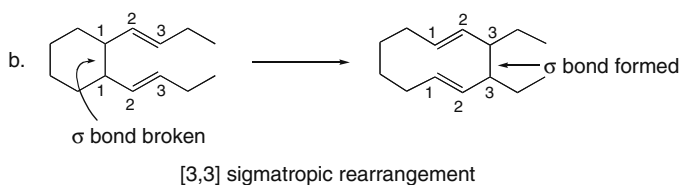
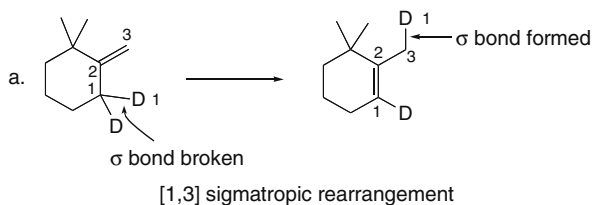
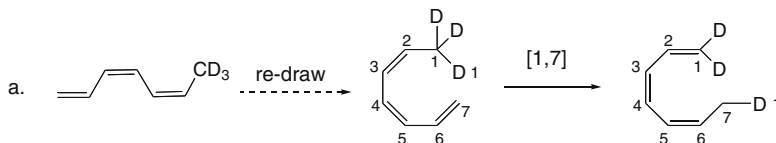
27.17 a. The photochemical $[6 + 4]$ cycloaddition involves five π bonds (the total number of π electrons divided by two) and is antarafacial.
b. A thermal $[8 + 2]$ cycloaddition involves five π bonds and is suprafacial.

Chapter 27–10

- 27.18** A photochemical $[4 + 2]$ cycloaddition like the Diels–Alder reaction must proceed by an antarafacial pathway. This would require either the 1,3-diene or the alkene component to twist 180° in order for the like phases of the p orbitals to overlap. Such a rotation is not possible in the formation of a six-membered ring.

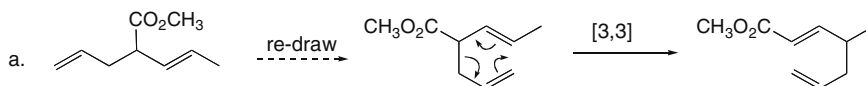


- 27.19** Locate the σ bonds broken and formed, and count the number of atoms that connects them.

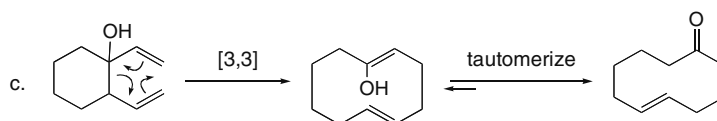
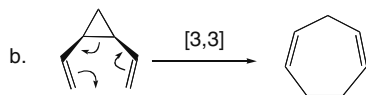
**27.20**

- b, c. The reaction involves four electron pairs (three π bonds and one σ bond), so it proceeds by an antarafacial pathway under thermal conditions, and by a suprafacial pathway under photochemical conditions.

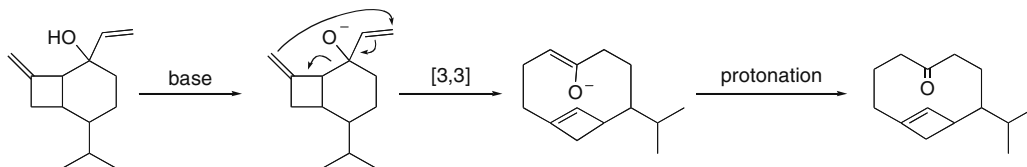
- 27.21** Draw the products of each reaction.



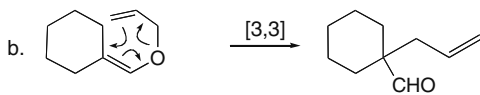
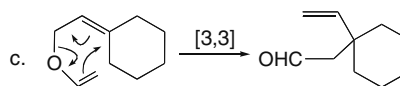
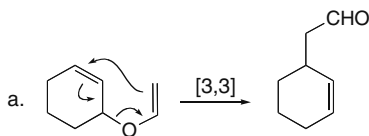
Pericyclic Reactions 27-11



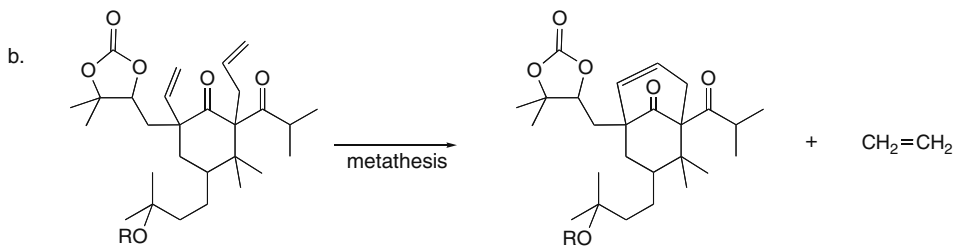
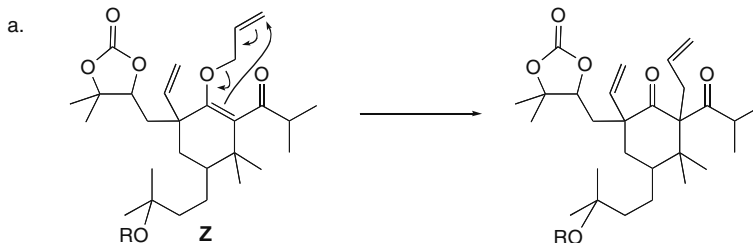
27.22 Draw the product after protonation.



27.23 Draw the product of Claisen rearrangement.



27.24

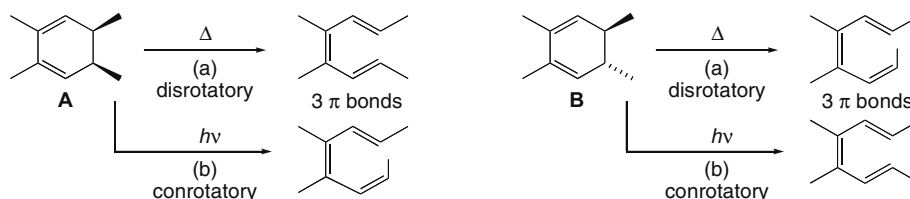


Chapter 27-12

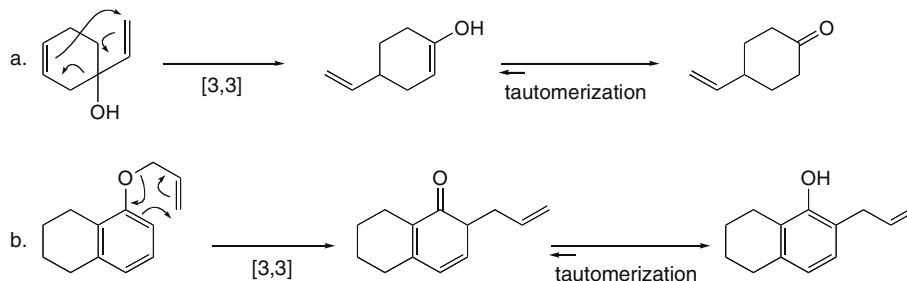
27.25 Predict the stereochemistry of each reaction using Table 27.4.

- A $[6 + 4]$ thermal cycloaddition involves five electron pairs, making the reaction suprafacial.
- A photochemical electrocyclic ring closure of 1,3,5,7,9-decapentaene involves five electron pairs, making the reaction conrotatory.
- A $[4 + 4]$ photochemical cycloaddition involves four electron pairs, making the reaction suprafacial.
- A thermal $[5,5]$ sigmatropic rearrangement involves five electron pairs, making the reaction suprafacial.

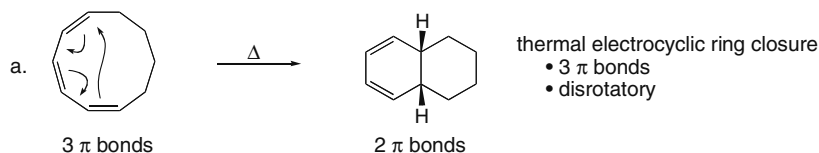
27.26 Use the rules found in Answers 27.6 and 27.8.



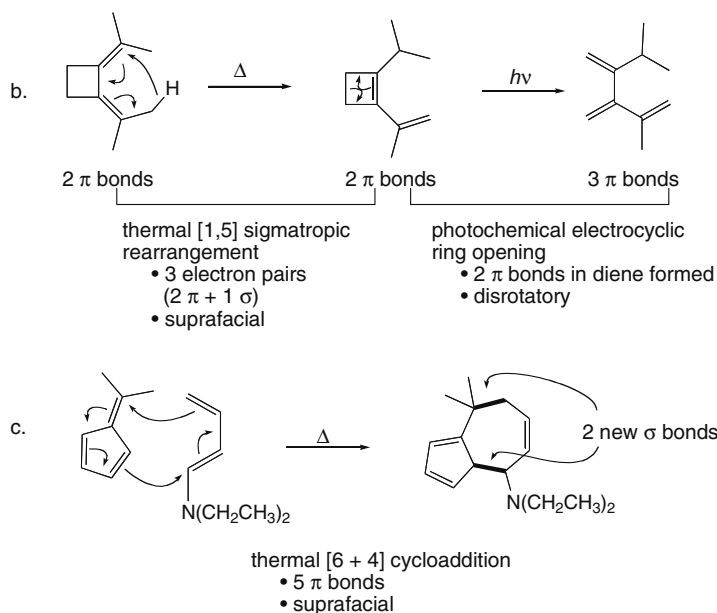
27.27 Draw the product of $[3,3]$ sigmatropic rearrangement of each compound.



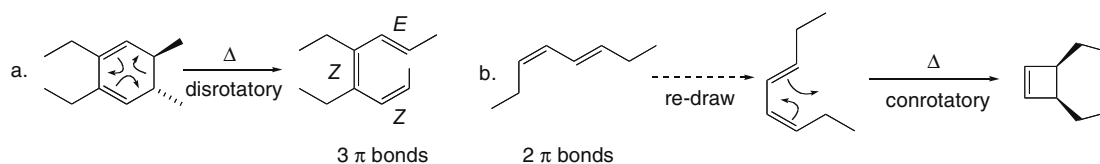
27.28 An electrocyclic reaction forms a product with one more or one fewer π bond than the starting material. A cycloaddition forms a ring with two new σ bonds. A sigmatropic rearrangement forms a product with the same number of π bonds, but the π bonds are rearranged. Use Table 27.4 to determine the stereochemistry.



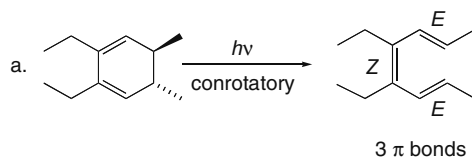
Pericyclic Reactions 27-13



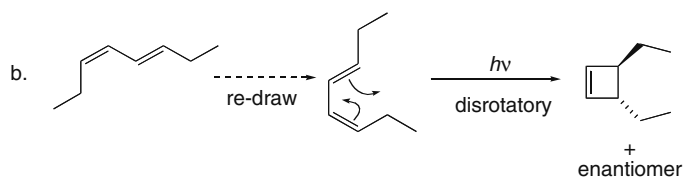
27.29 Use the rules for thermal electrocyclic reactions found in Answer 27.6.



27.30 Use the rules for photochemical electrocyclic reactions found in Answer 27.8.

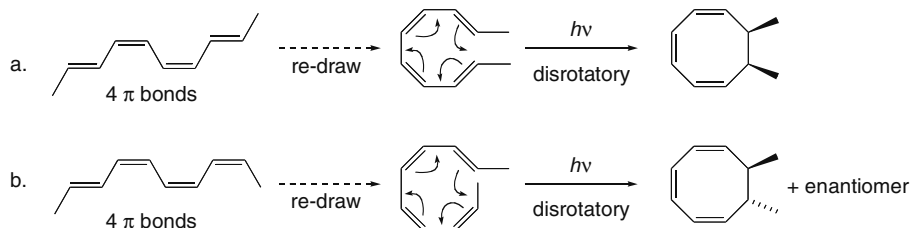


Although conrotatory ring opening could also form, at least in theory, an all-(*Z*) triene, steric hindrance during ring opening would cause the terminal CH_3 's to crash into one another, making this process unlikely.

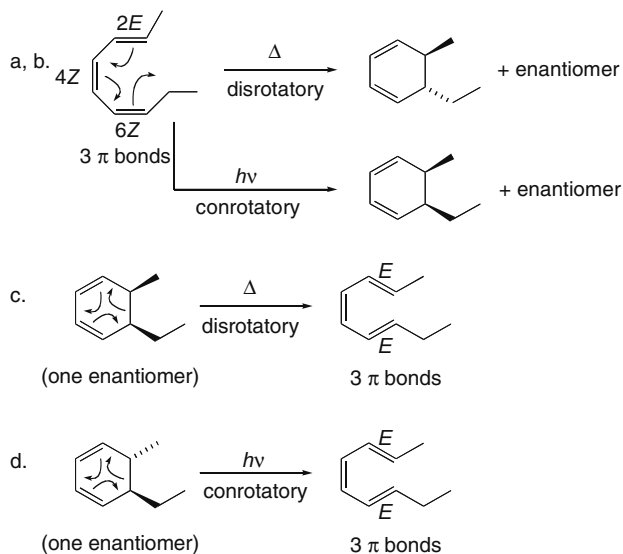


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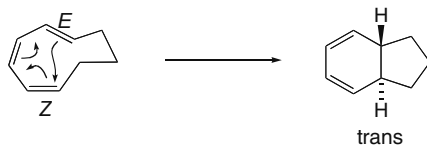
27.31 Use the rules found in Answer 27.8.



27.32 Use the rules found in Answers 27.6 and 27.8.

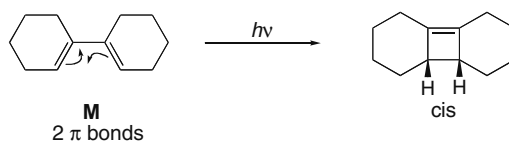


27.33 The trans product is indicative of a disrotatory ring closure from the cyclic triene with the given stereochemistry at the double bonds. A disrotatory ring closure with a polyene having three π bonds must occur under thermal conditions.

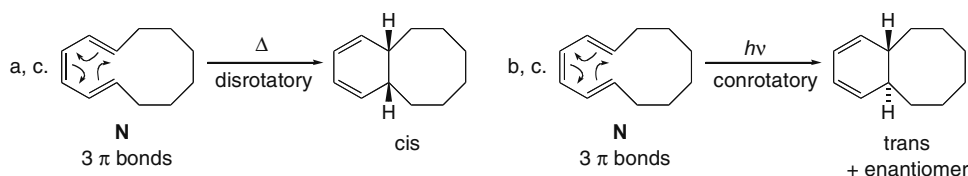


Pericyclic Reactions 27-15

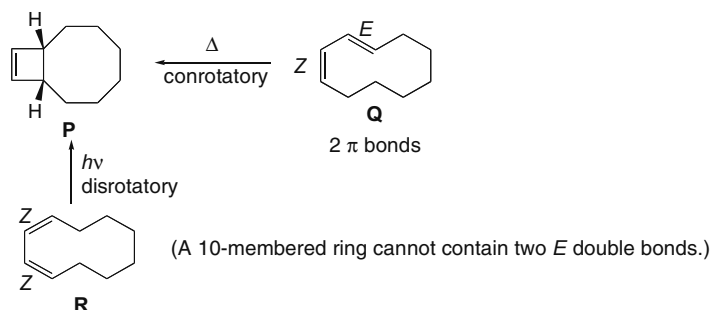
- 27.34** A disrotatory cyclization of a reactant with an even number of π bonds must occur under photochemical conditions.



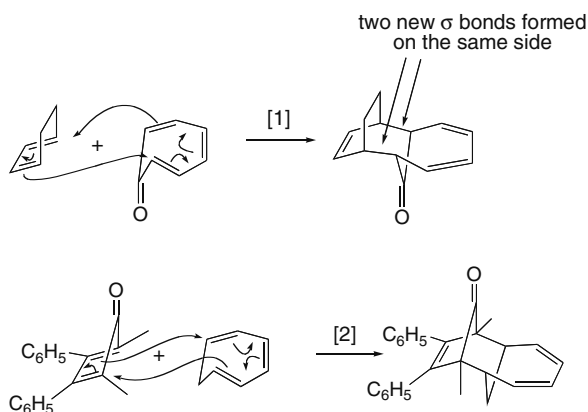
- 27.35** Use the rules found in Answers 27.6 and 27.8.



- 27.36** Use the rules found in Answers 27.6 and 27.8.

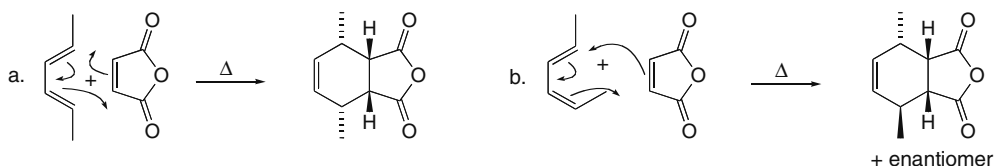


- 27.37** Since the reaction involves three π bonds in one reactant and two π bonds in the second reactant, the reaction is a $[6 + 4]$ cycloaddition. A suprafacial cycloaddition with five π bonds must proceed under thermal conditions.



Chapter 27-16

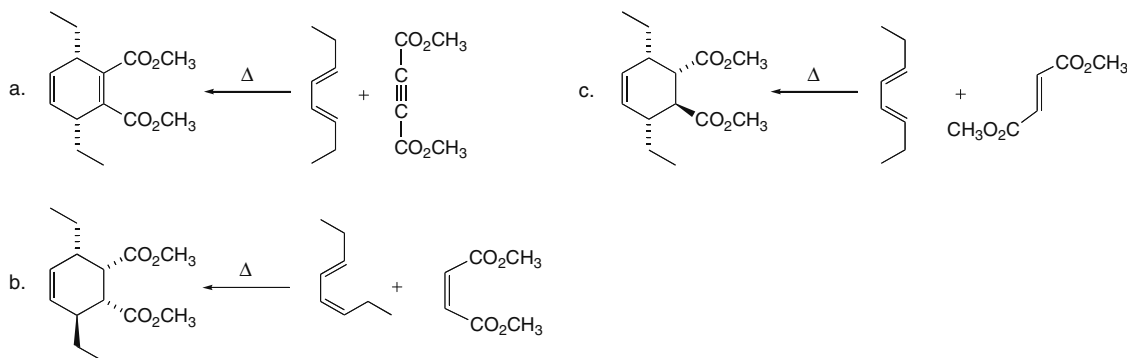
27.38 The Diels–Alder reaction is a thermal, suprafacial $[4 + 2]$ cycloaddition.



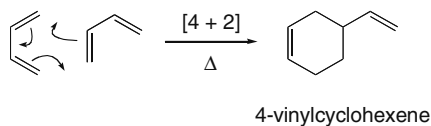
27.39 A photochemical $[2 + 2]$ cycloaddition is suprafacial.



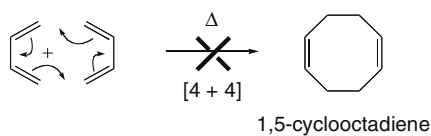
27.40 A thermal $[4 + 2]$ cycloaddition is suprafacial.



27.41 1,3-Butadiene can react with itself in a symmetry-allowed thermal $[4 + 2]$ cycloaddition to form 4-vinylcyclohexene.

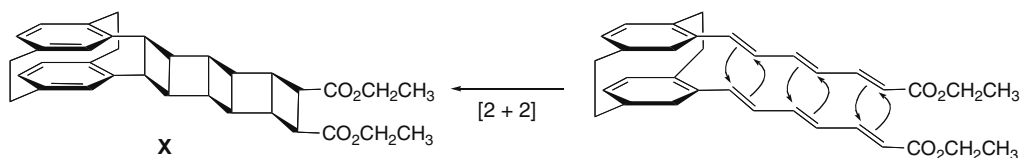


1,5-Cyclooctadiene would have to be formed from 1,3-butadiene by a $[4 + 4]$ cycloaddition, which is not allowed under thermal conditions.

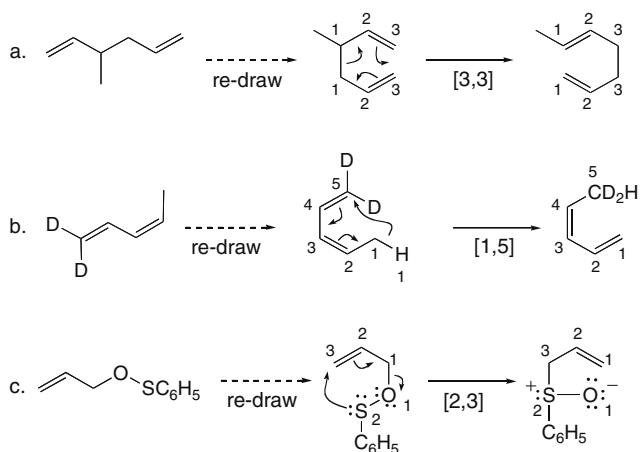


Pericyclic Reactions 27-17

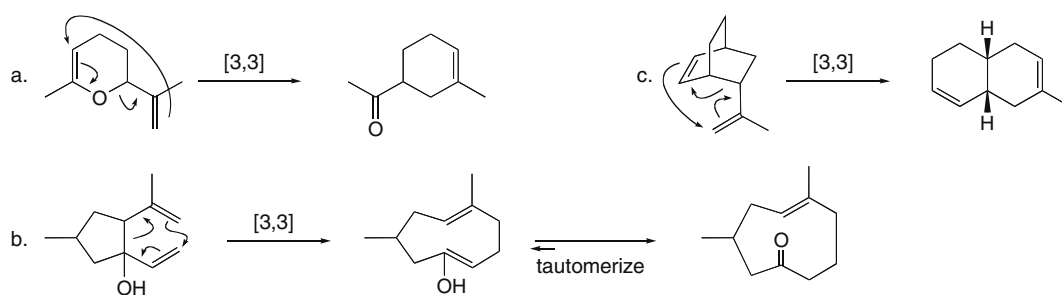
27.42 A series of three $[2 + 2]$ cycloadditions with *E* alkenes forms **X**.



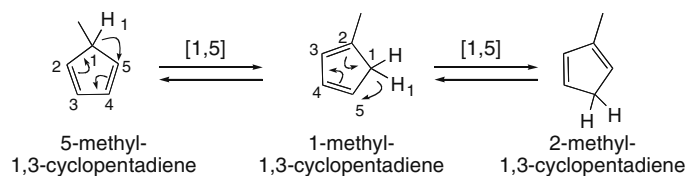
27.43 Re-draw the reactant and product to more clearly show the relative location of the bonds broken and formed.



27.44 Draw the products of each reaction.

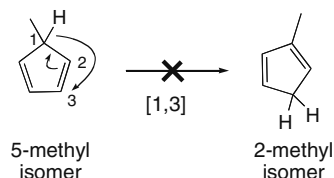


27.45 a. Two $[1,5]$ sigmatropic rearrangements occur.



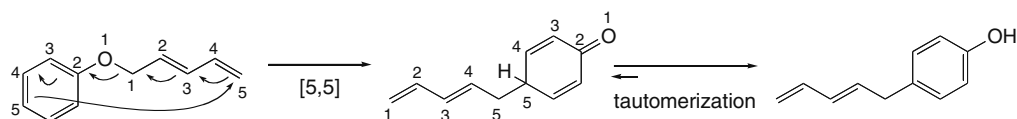
Chapter 27-18

b.

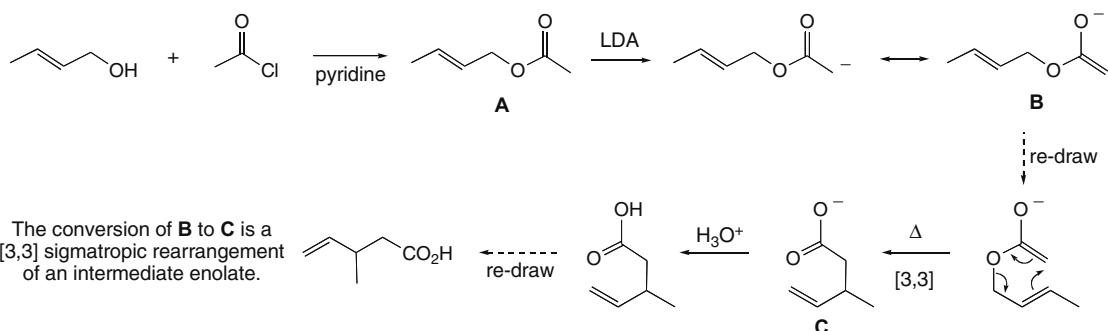


A [1,3] sigmatropic rearrangement requires photochemical conditions not thermal conditions, so 5-methyl-1,3-cyclopentadiene cannot rearrange directly to its 2-methyl isomer by a [1,3] shift.

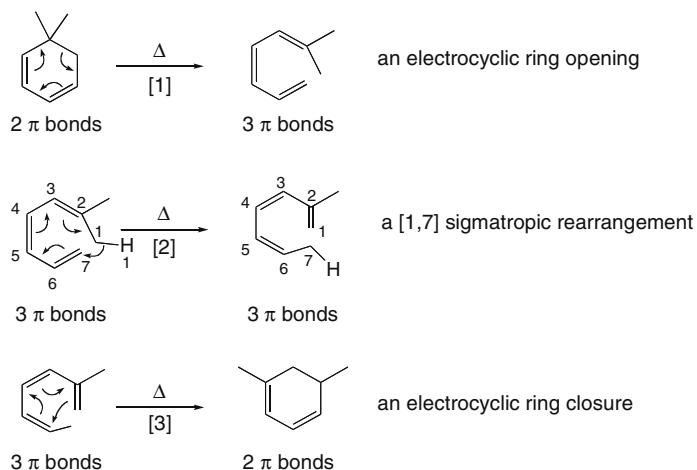
27.46



27.47

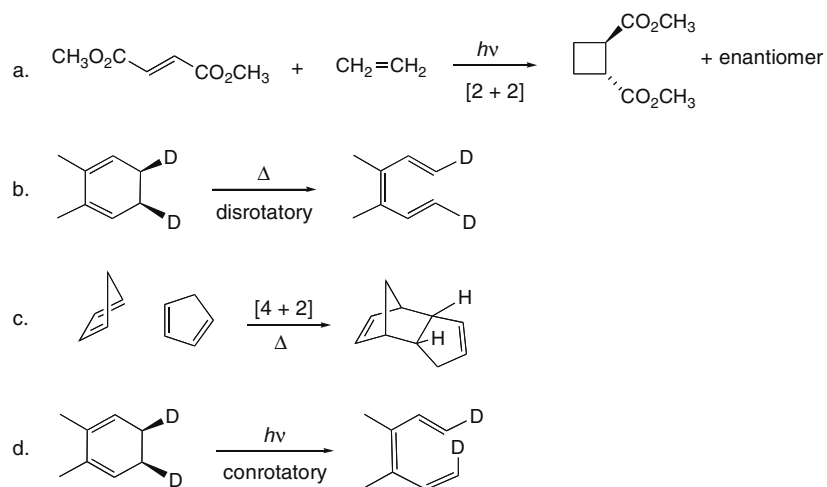


27.48 Use the definitions found in Answer 27.1.

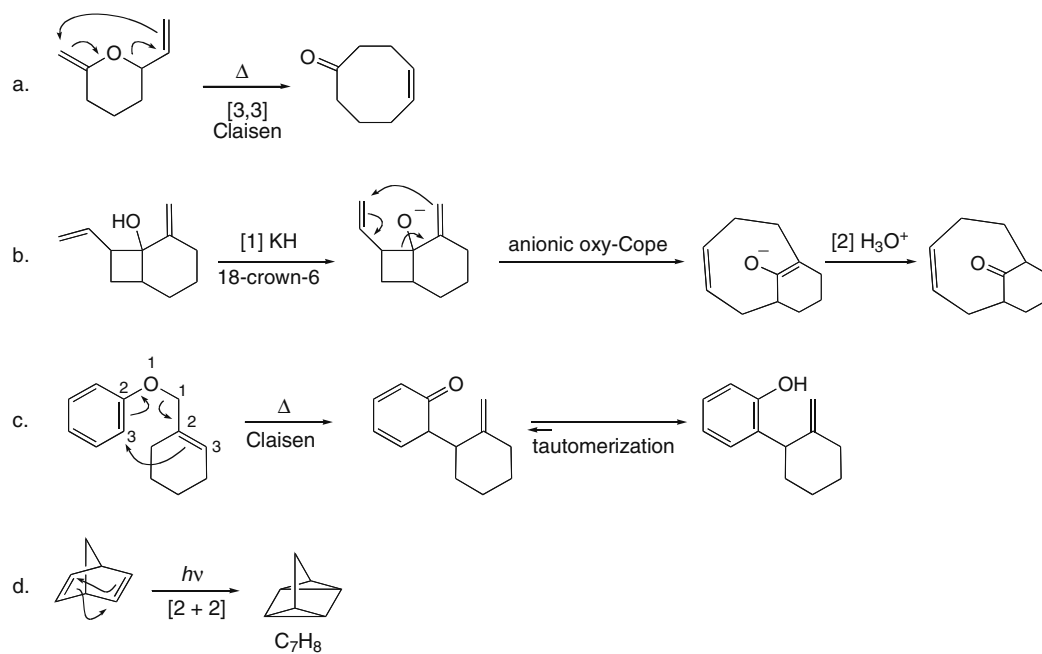


Pericyclic Reactions 27-19

27.49

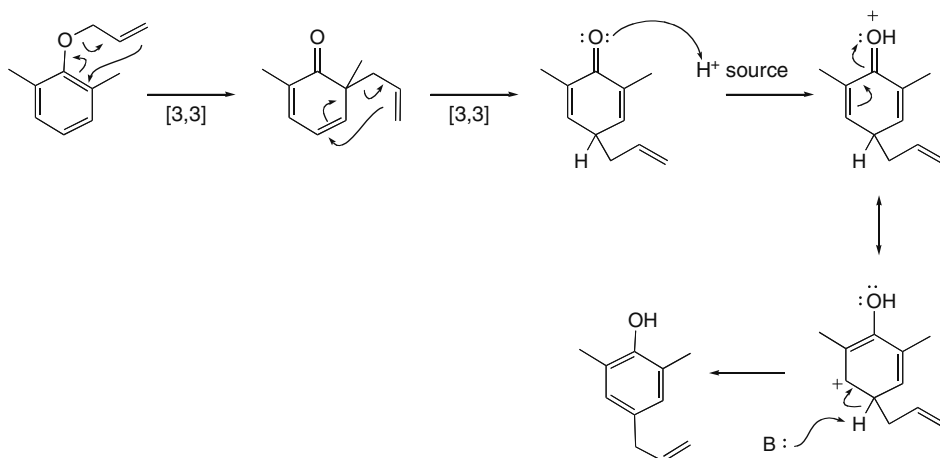


27.50

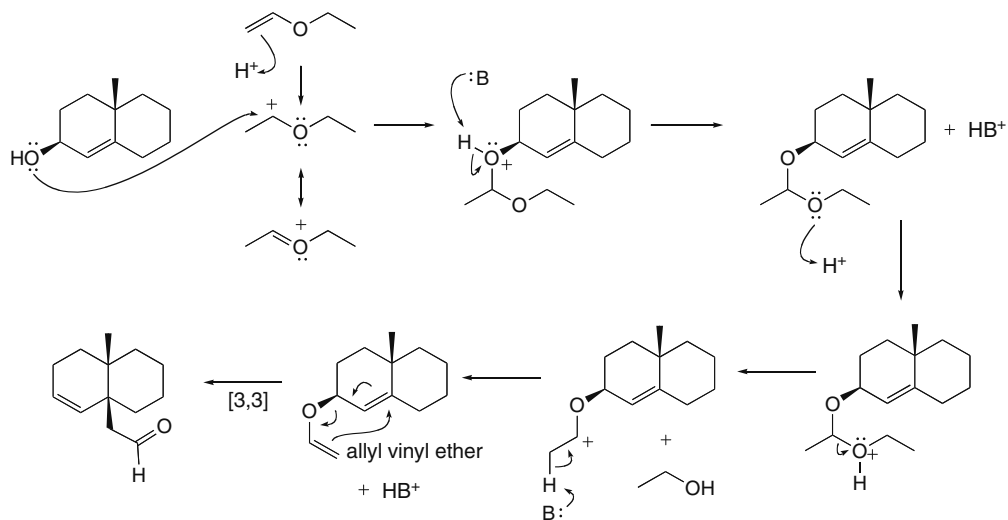


Chapter 27-20

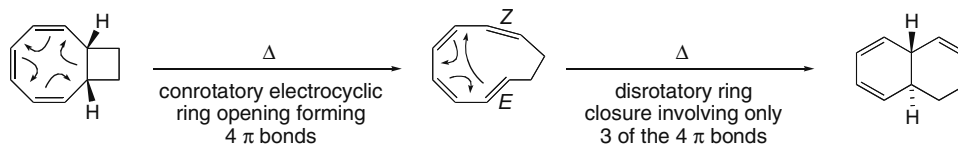
27.51 The mechanism consists of sequential [3,3] sigmatropic rearrangements, followed by tautomerization.



27.52

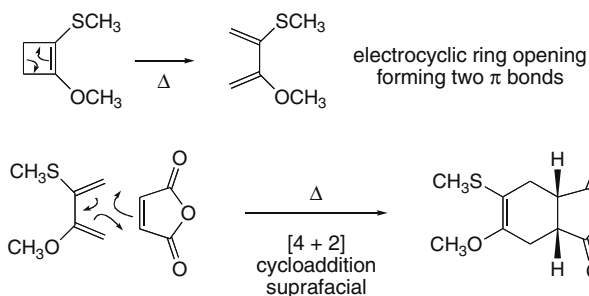


27.53

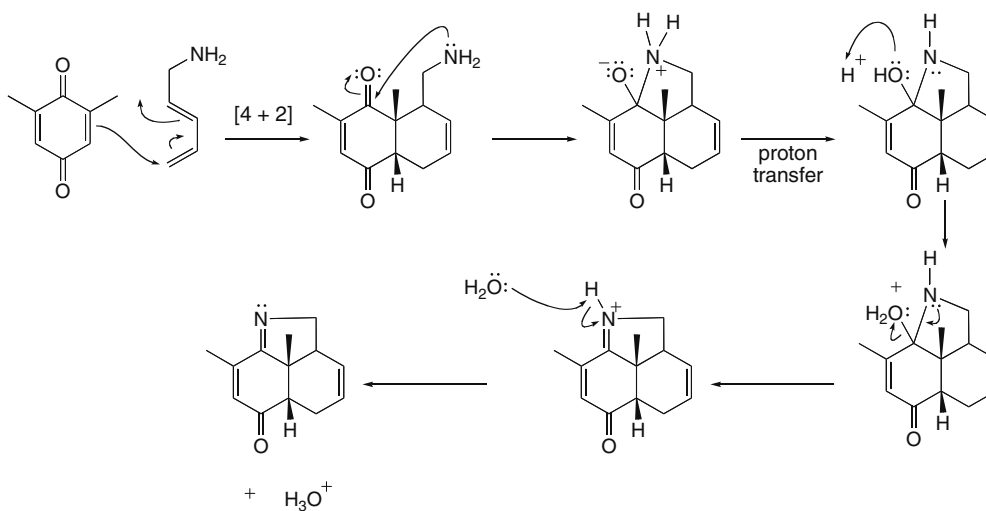


Pericyclic Reactions 27–21

27.54

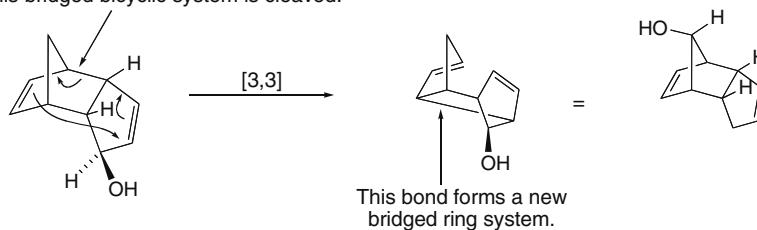


27.55 The mechanism consists of a [4 + 2] cycloaddition, followed by intramolecular imine formation.



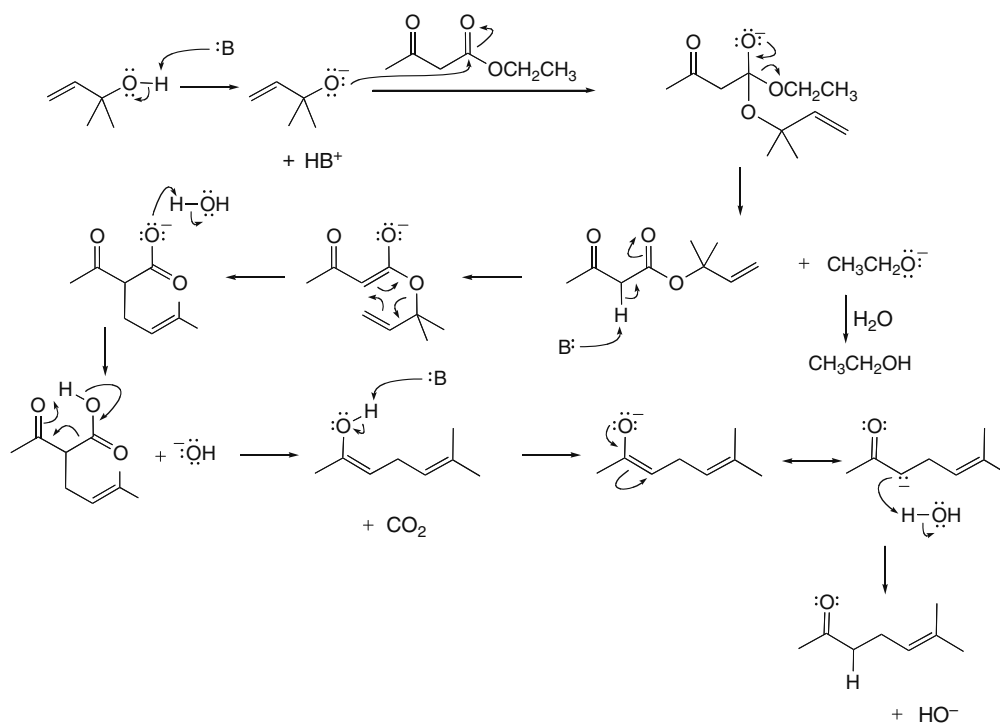
27.56

This bridged bicyclic system is cleaved.



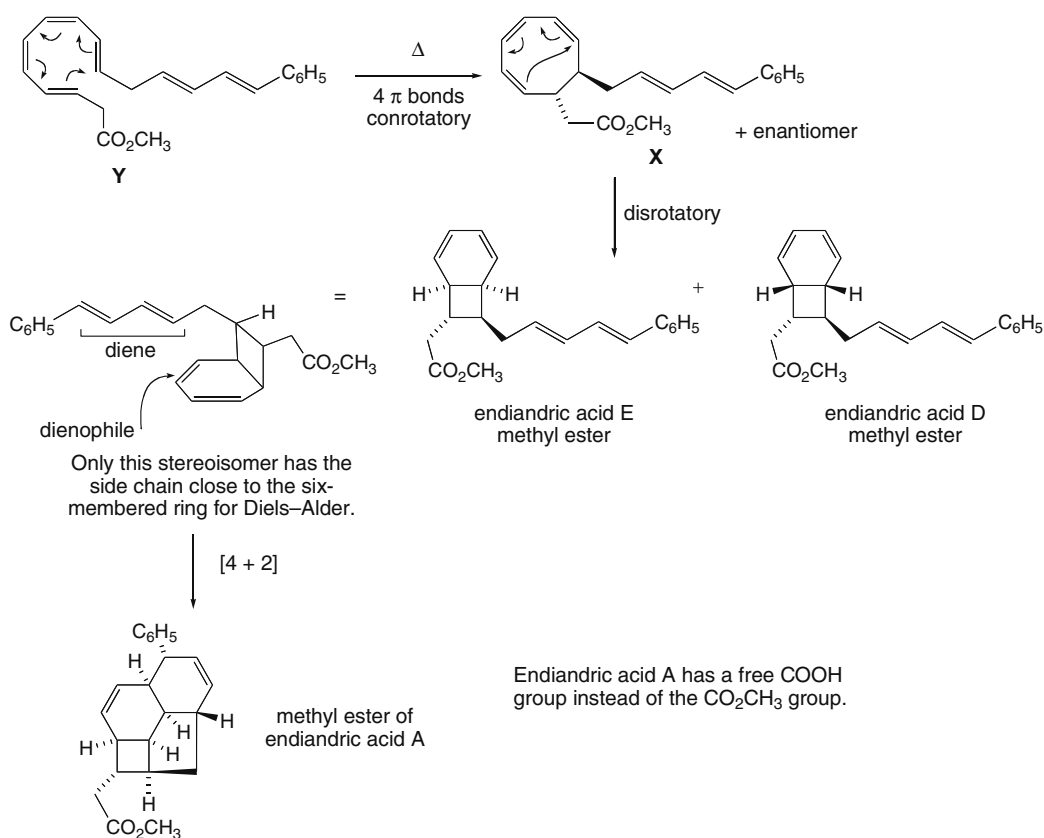
Chapter 27-22

27.57

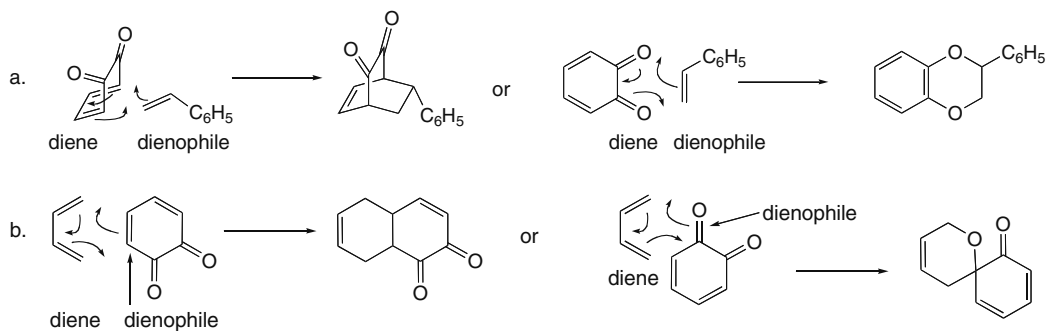


Pericyclic Reactions 27–23

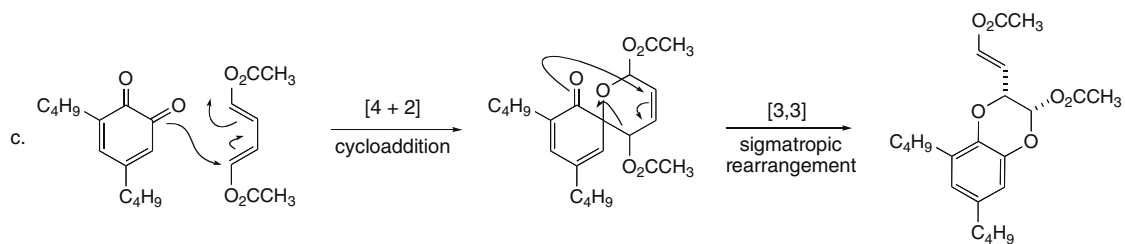
27.58 Conrotatory cyclization of **Y** using four π bonds forms **X**. Disrotatory ring closure of **X** can occur in two ways—on the top face or bottom face of the eight-membered ring to form diastereomers.



27.59



Chapter 27–24



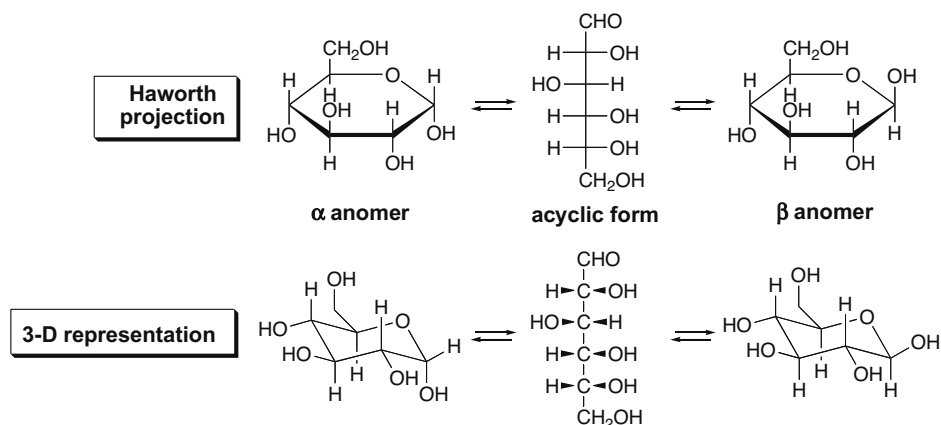
Chapter 28 Carbohydrates

Chapter Review

Important terms

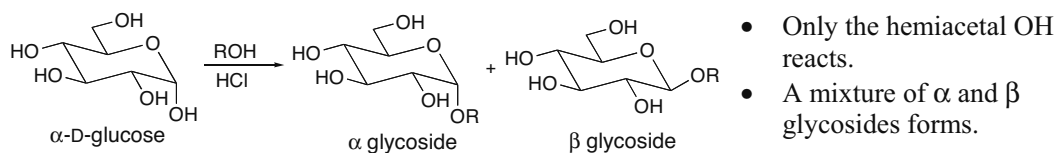
- **Aldose** A monosaccharide containing an aldehyde (28.2)
- **Ketose** A monosaccharide containing a ketone (28.2)
- **D-Sugar** A monosaccharide with the O bonded to the stereogenic center farthest from the carbonyl group drawn on the right in the Fischer projection (28.2C)
- **Epimers** Two diastereomers that differ in configuration around one stereogenic center only (28.3)
- **Anomers** Monosaccharides that differ in configuration at only the hemiacetal OH group (28.6)
- **Glycoside** An acetal derived from a monosaccharide hemiacetal (28.7)

Acyclic, Haworth, and 3-D representations for D-glucose (28.6)

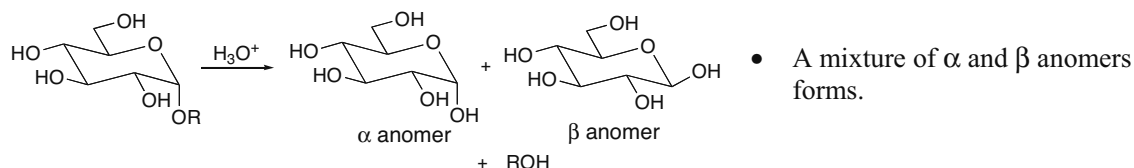


Reactions of monosaccharides involving the hemiacetal

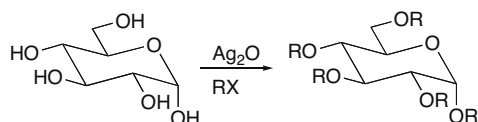
[1] Glycoside formation (28.7A)



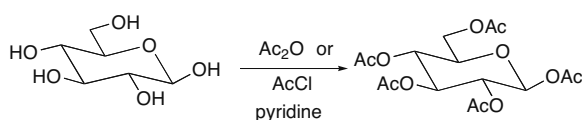
[2] Glycoside hydrolysis (28.7B)



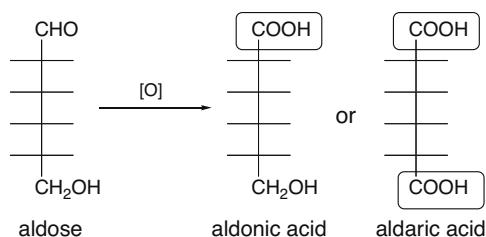
Chapter 28-2

Reactions of monosaccharides at the OH groups**[1] Ether formation (28.8)**

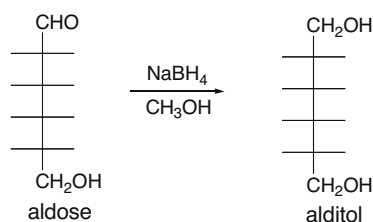
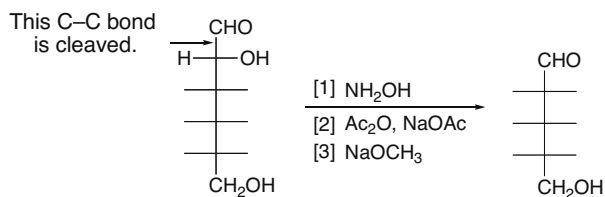
- All OH groups react.
- The stereochemistry at all stereogenic centers is retained.

[2] Ester formation (28.8)

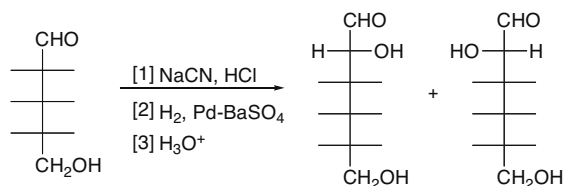
- All OH groups react.
- The stereochemistry at all stereogenic centers is retained.

Reactions of monosaccharides at the carbonyl group**[1] Oxidation of aldoses (28.9B)**

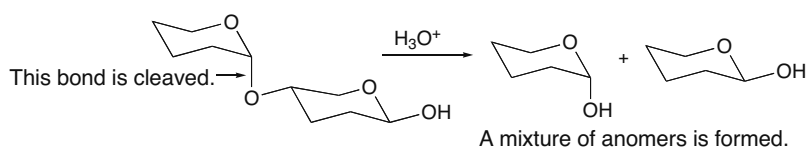
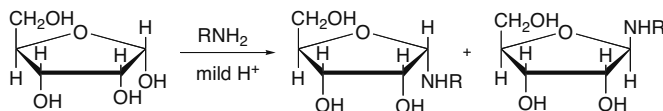
- Aldonic acids are formed using:
 - Ag_2O , NH_4OH
 - Cu^{2+}
 - Br_2 , H_2O
- Aldaric acids are formed with HNO_3 , H_2O .

[2] Reduction of aldoses to alditols (28.9A)**[3] Wohl degradation (28.10A)**

- The C1-C2 bond is cleaved to shorten an aldose chain by one carbon.
- The stereochemistry at all other stereogenic centers is retained.
- Two epimers at C2 form the same product.

[4] Kiliani–Fischer synthesis (28.10B)

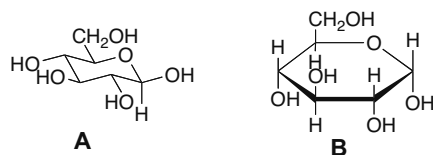
- One carbon is added to the aldehyde end of an aldose.
- Two epimers at C2 are formed.

Other reactions**[1] Hydrolysis of disaccharides (28.12)****[2] Formation of *N*-glycosides (28.14B)**

- Two anomers are formed.

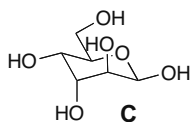
Practice Test on Chapter Review

1. a. How are the following two representations related to each other?



1. **A** and **B** are anomers of each other.
2. **A** and **B** are epimers of each other.
3. **A** and **B** are diastereomers of each other.
4. Statements [1] and [2] are both true.
5. Statements [1], [2], and [3] are all true.

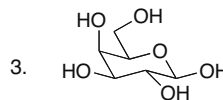
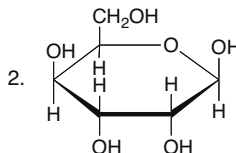
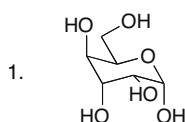
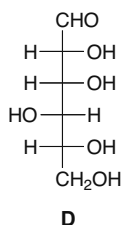
b. Which of the following statements is (are) true about monosaccharide **C**?



1. **C** is a D-sugar.
2. The β anomer is drawn.
3. **C** is an aldohexose.
4. Statements [1] and [2] are both true.
5. Statements [1], [2], and [3] are all true.

Chapter 28-4

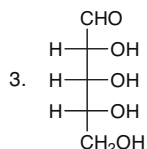
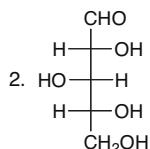
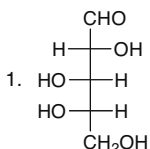
c. Which of the following are different representations for monosaccharide **D**?



4. Both [1] and [2] are representations for **D**.

5. Compounds [1], [2], and [3] all represent **D**.

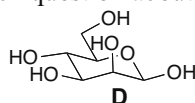
d. Which aldoses give an optically active compound upon reaction with NaBH_4 in CH_3OH ?



4. Both [1] and [2] give an optically active product.

5. Compounds [1], [2], and [3] all give optically active products.

2. Answer each question about monosaccharide **D** as True (T) or False (F).



a. **D** is a D-sugar.

b. **D** is drawn as an α anomer.

c. **D** is an aldohexose.

d. Reduction of **D** with NaBH_4 in CH_3OH forms an optically inactive alditol.

e. Oxidation of **D** with Br_2 , H_2O forms an optically active aldonic acid.

f. Oxidation of **D** with HNO_3 forms an optically active aldaric acid.

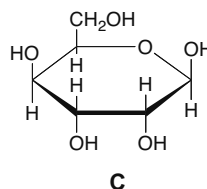
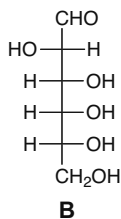
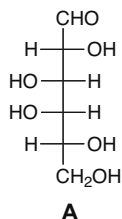
g. C2 has the *R* configuration.

h. Treatment of **D** with CH_3OH , HCl forms two products.

i. Treatment of **D** with Ag_2O , and CH_3I (excess) forms two products.

j. An epimer of **D** at C3 has an axial OH group.

3. Answer the following questions about the three monosaccharides (**A–C**) drawn below.



a. Draw the α anomer of **A** in a Haworth projection.

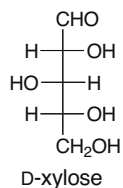
b. Draw the β anomer of **B** in a three-dimensional representation using a chair conformation.

c. Convert **C** into the acyclic form of the monosaccharide using a Fischer projection.

d. What two aldoses yield **A** in a Wohl degradation?

Carbohydrates 28–5

4. Draw the product of each reaction with the starting material D-xylose.

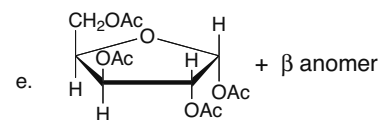
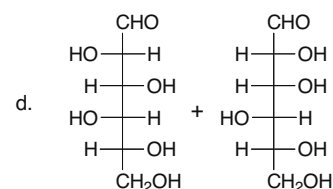
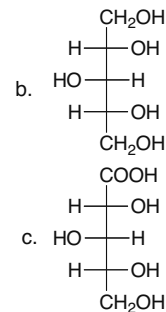
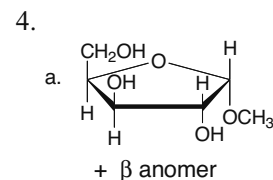
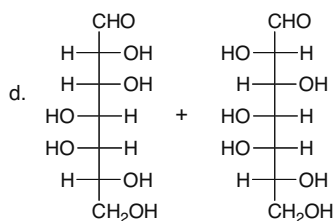
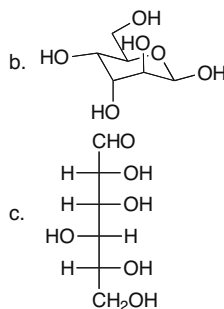
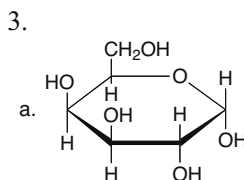


- CH_3OH , HCl
- NaBH_4 , CH_3OH
- Br_2 , H_2O
- [1] NaCN , HCl ; [2] H_2 , Pd-BaSO_4 ; [3] H_3O^+
- Ac_2O , pyridine

Answers to Practice Test

- 5
 - 5
 - 4
 - 1

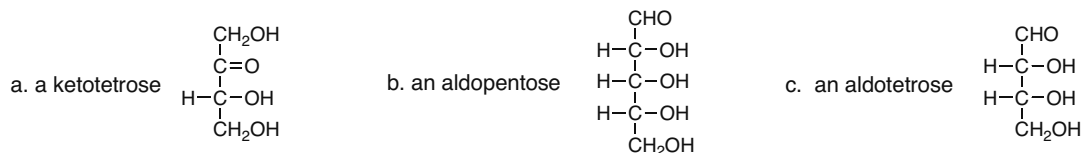
- T
 - F
 - T
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 - T



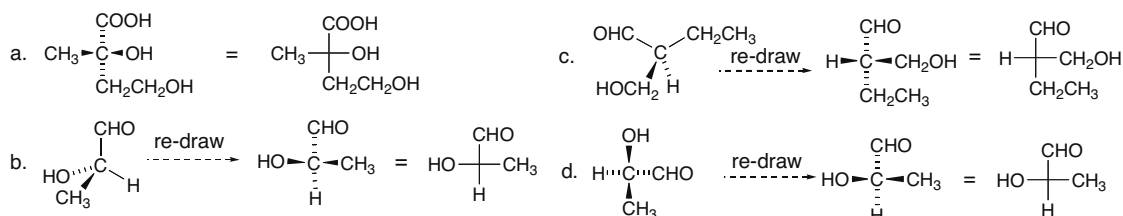
Answers to Problems

- 28.1** A *ketose* is a monosaccharide containing a ketone. An *aldose* is a monosaccharide containing an aldehyde. A monosaccharide is called: a *triose* if it has three C's; a *tetrose* if it has four C's; a *pentose* if it has five C's; a *hexose* if it has six C's, and so forth.

Chapter 28-6

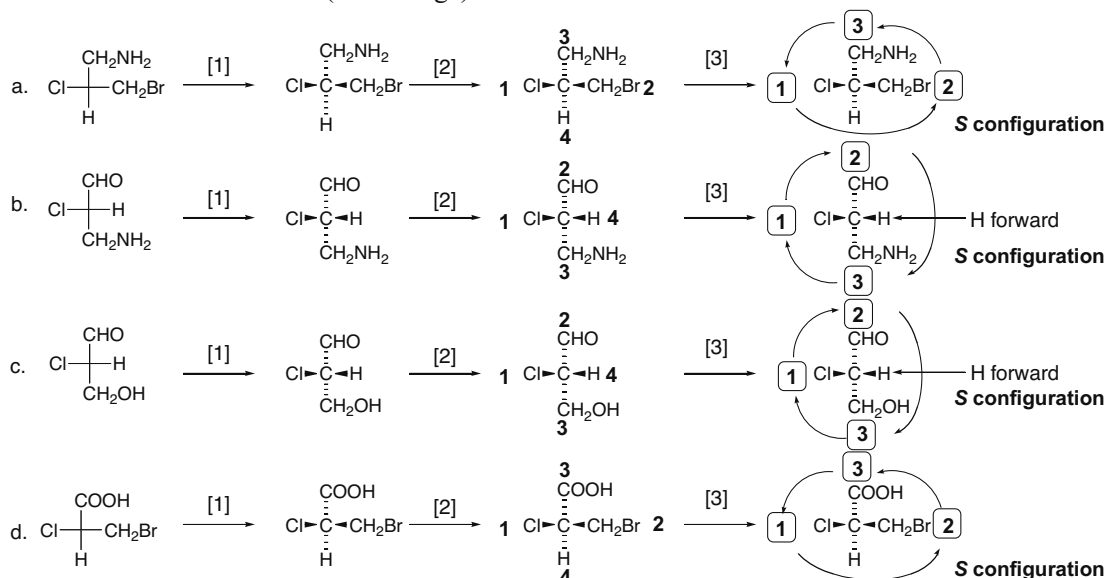


28.2 Rotate and re-draw each molecule to place the horizontal bonds in front of the plane and the vertical bonds behind the plane. Then use a cross to represent the stereogenic center in a Fischer projection formula.



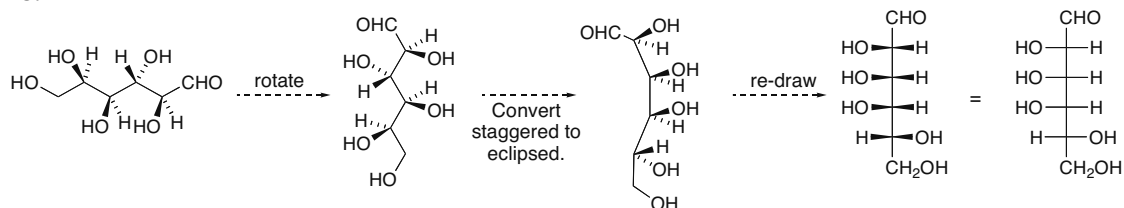
28.3 For each molecule:

- [1] Convert the Fischer projection formula to a representation with wedges and dashes.
- [2] Assign priorities (Section 5.6).
- [3] Determine *R* or *S* in the usual manner. Reverse the answer if priority group [4] is oriented forward (on a wedge).

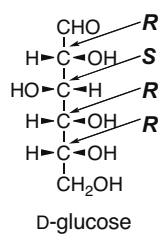


Carbohydrates 28-7

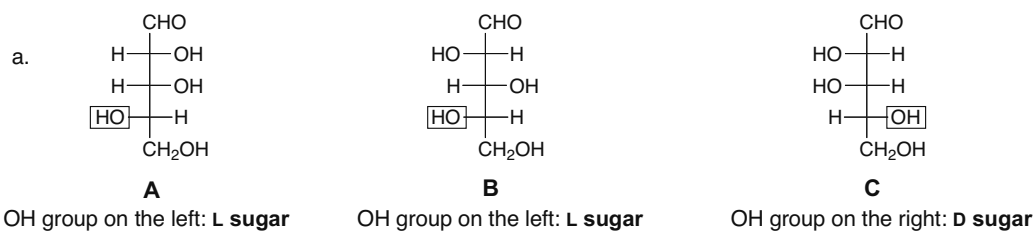
28.4



28.5

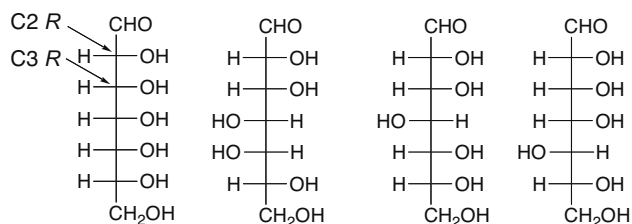


28.6 A D sugar has the OH group on the stereogenic center farthest from the carbonyl on the right. An L sugar has the OH group on the stereogenic center farthest from the carbonyl on the left.



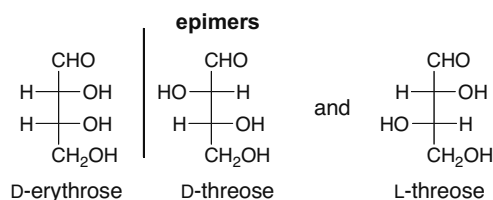
- b. **A** and **B** are diastereomers.
A and **C** are enantiomers.
B and **C** are diastereomers.

28.7 There are 32 aldoheptoses; 16 are D sugars.

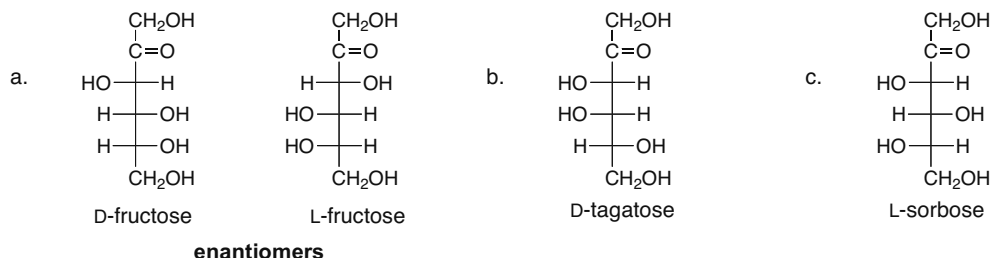


Chapter 28–8

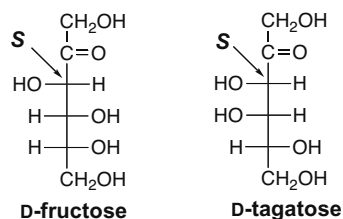
28.8 *Epimers* are two diastereomers that differ in the configuration around only one stereogenic center.



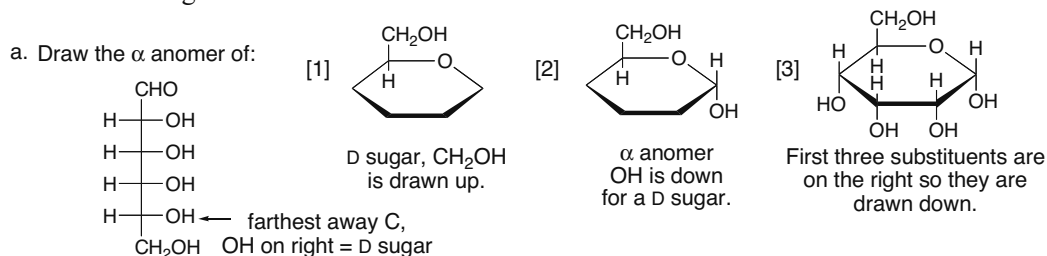
- 28.9**
- D-allose and L-allose: **enantiomers**
 - D-altrose and D-gulose: **diastereomers** but not epimers
 - D-galactose and D-talose: **epimers**
 - D-mannose and D-fructose: **constitutional isomers**
 - D-fructose and D-sorbose: **diastereomers** but not epimers
 - L-sorbose and L-tagatose: **epimers**

28.10

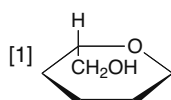
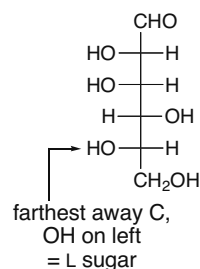
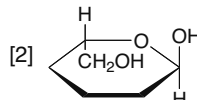
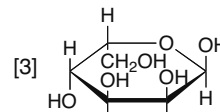
enantiomers

28.11

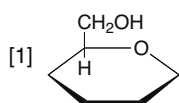
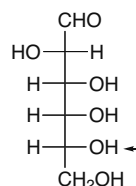
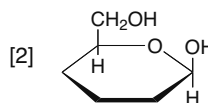
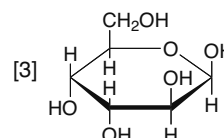
- 28.12** Step [1]: Place the O atom in the upper right corner of a hexagon, and add the CH₂OH group on the first carbon counterclockwise from the O atom.
 Step [2]: Place the anomeric carbon on the first carbon clockwise from the O atom.
 Step [3]: Add the substituents at the three remaining stereogenic centers, clockwise around the ring.



Carbohydrates 28-9

b. Draw the α anomer of:L sugar, CH_2OH is drawn down.The α anomer has the OH and CH_2OH trans. In an L sugar, the OH must be drawn up.

The first two substituents are on the left so they are drawn up. The third is on the right, drawn down.

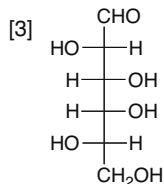
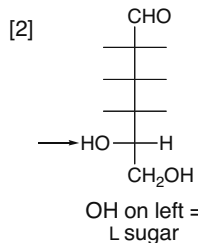
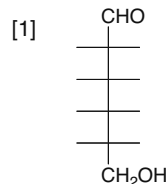
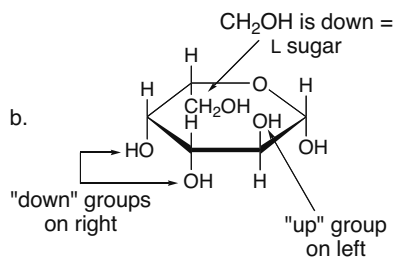
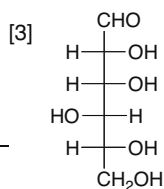
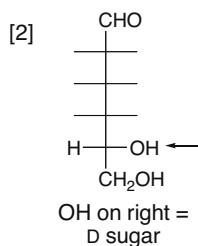
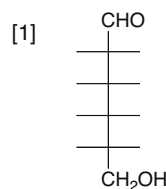
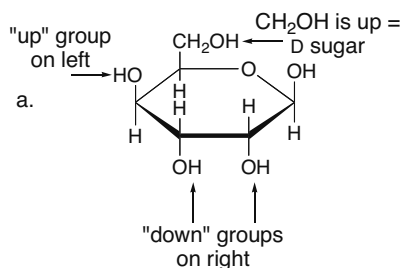
c. Draw the β anomer of:D sugar, CH_2OH is drawn up. β anomer
OH is up for a D sugar.

The first substituent is on the left so it is drawn up. The other two are on the right, drawn down.

28.13 To convert each Haworth projection into its acyclic form:[1] Draw the C skeleton with the CHO on the top and the CH_2OH on the bottom.[2] Draw in the OH group farthest from the $\text{C}=\text{O}$.A CH_2OH group drawn up means a D sugar; a CH_2OH group drawn down means an L sugar.

[3] Add the three other stereogenic centers, counterclockwise around the ring.

“Up” groups go on the left, and “down” groups go on the right.

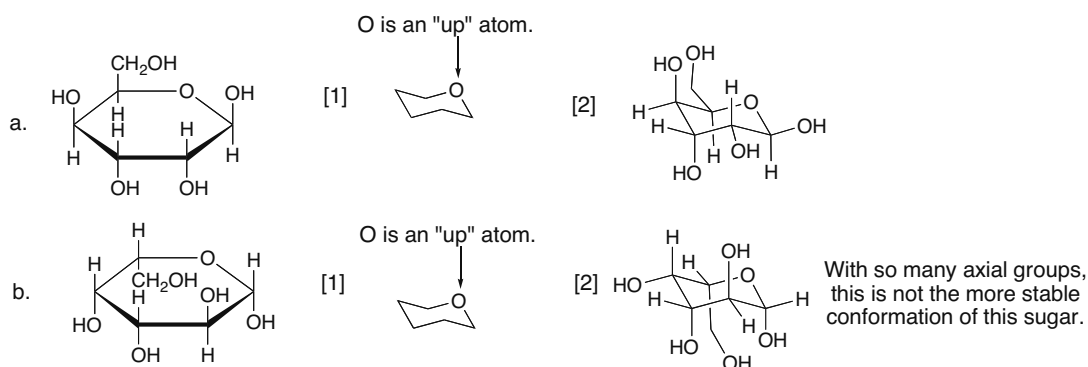


Chapter 28–10

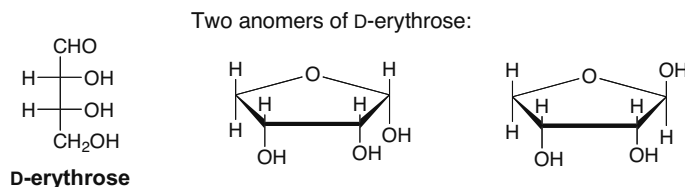
28.14 To convert a Haworth projection into a 3-D representation with a chair cyclohexane:

[1] Draw the pyranose ring as a chair with the O as an “up” atom.

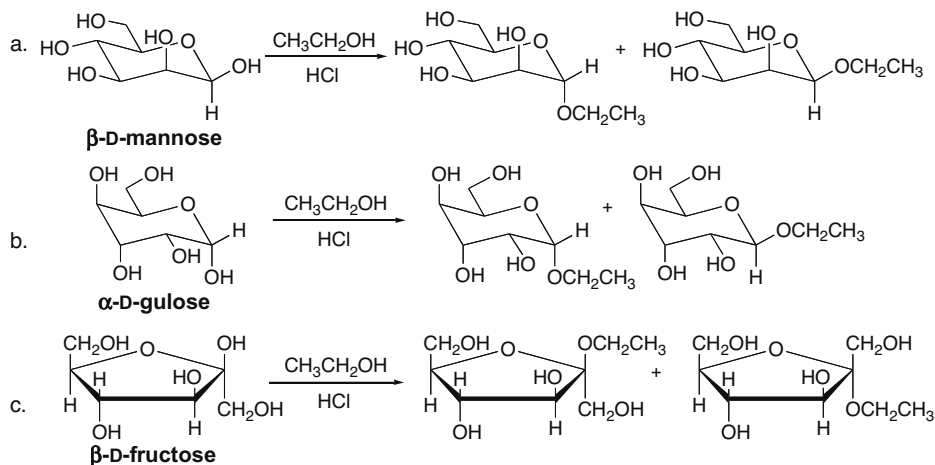
[2] Add the substituents around the ring.



28.15 Cyclization always forms a new stereogenic center at the anomeric carbon, so two different anomers are possible.

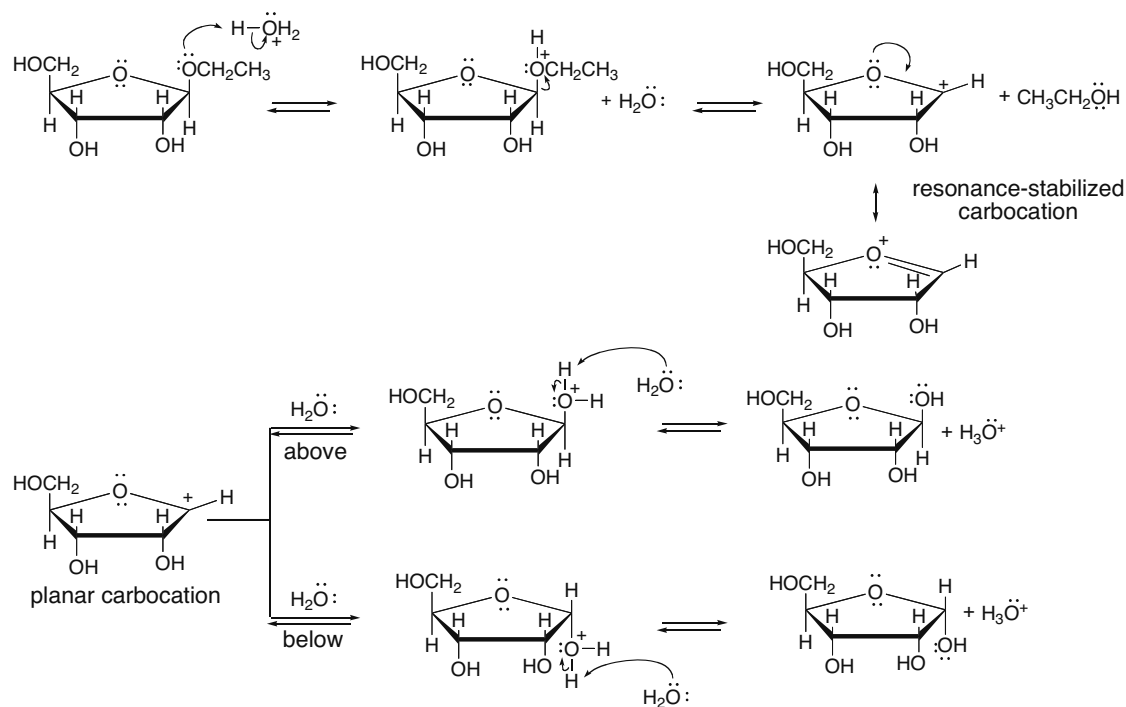


28.16



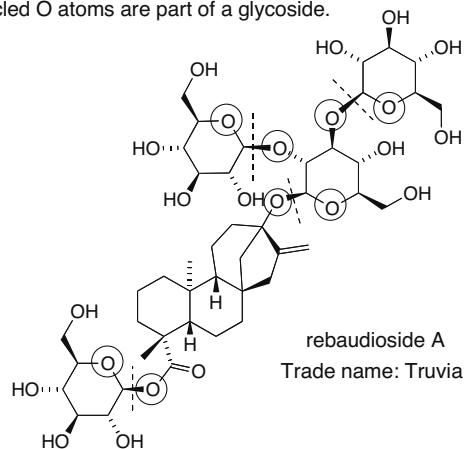
Carbohydrates 28-11

28.17

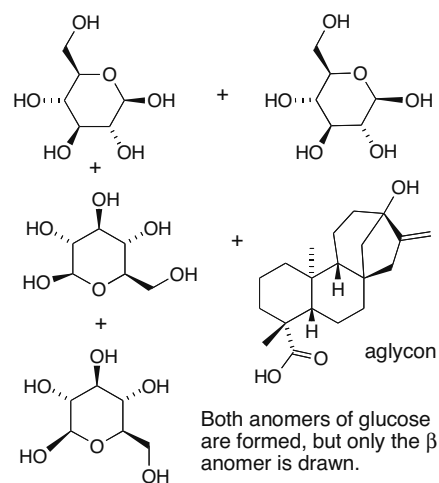


28.18

a. All circled O atoms are part of a glycoside.

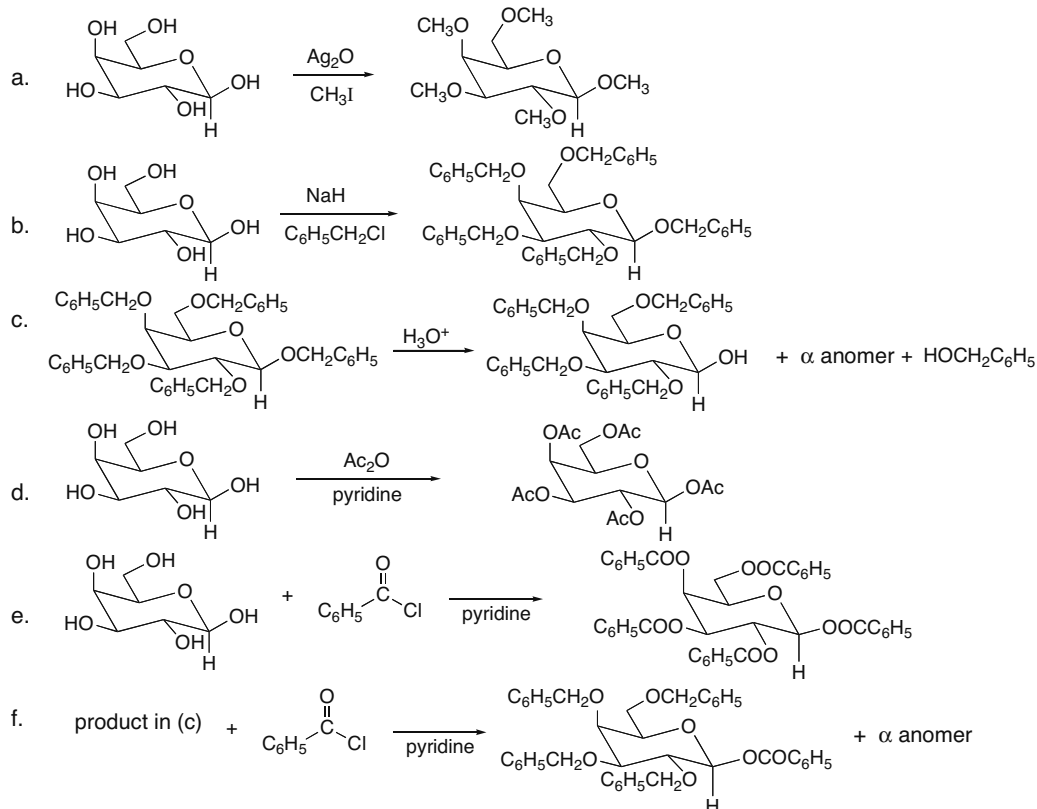


b. Hydrolysis of rebaudioside A breaks each bond indicated with a dashed line and forms four molecules of glucose and the aglycon drawn.

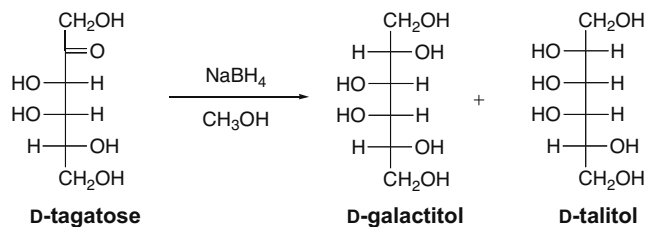


Chapter 28–12

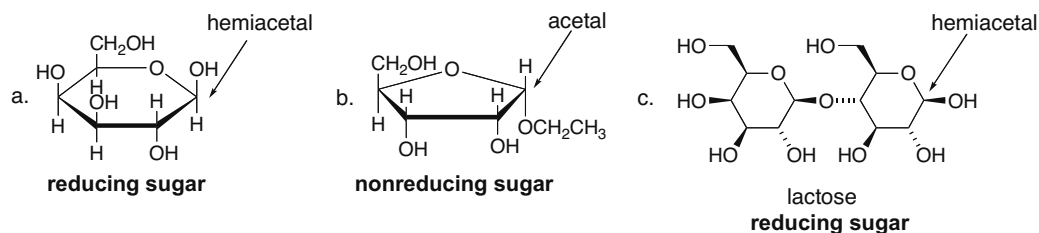
28.19



28.20

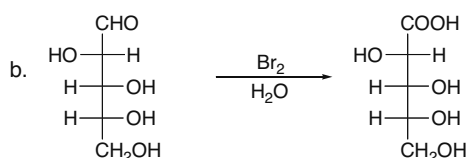
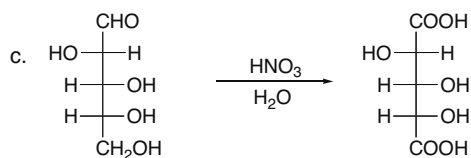
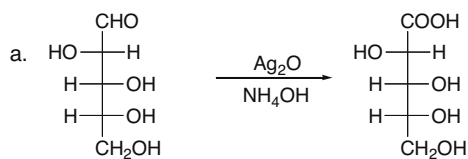


28.21 Carbohydrates containing a hemiacetal are in equilibrium with an acyclic aldehyde, making them reducing sugars. Glycosides are acetals, so they are not in equilibrium with any acyclic aldehyde, making them nonreducing sugars.

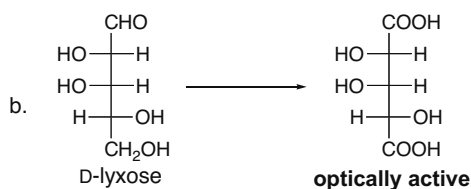
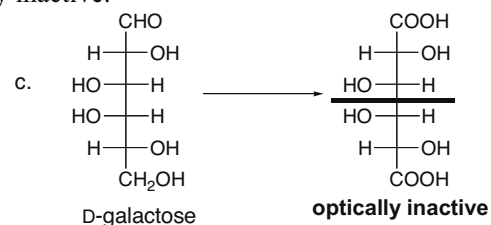


Carbohydrates 28-13

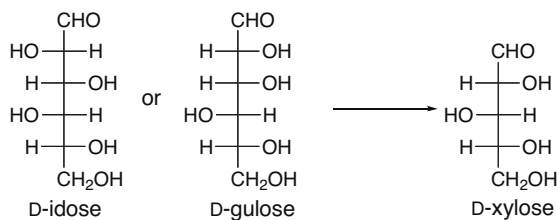
28.22



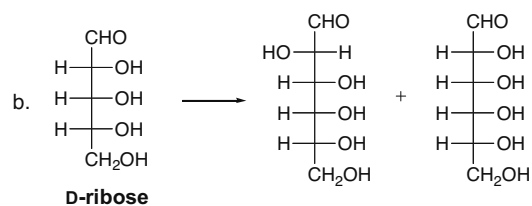
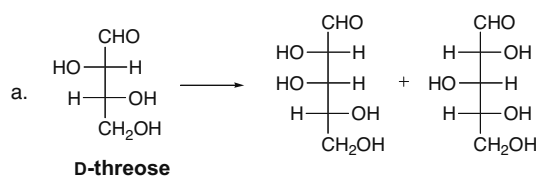
28.23 Molecules with a plane of symmetry are optically inactive.



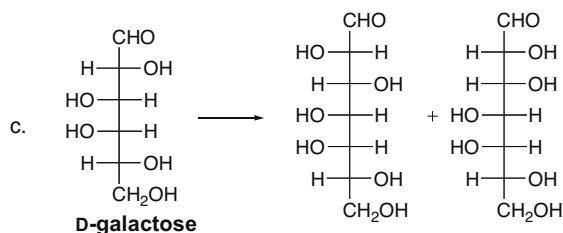
28.24



28.25

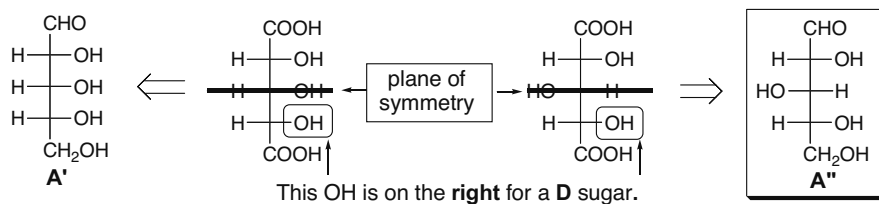


Chapter 28–14

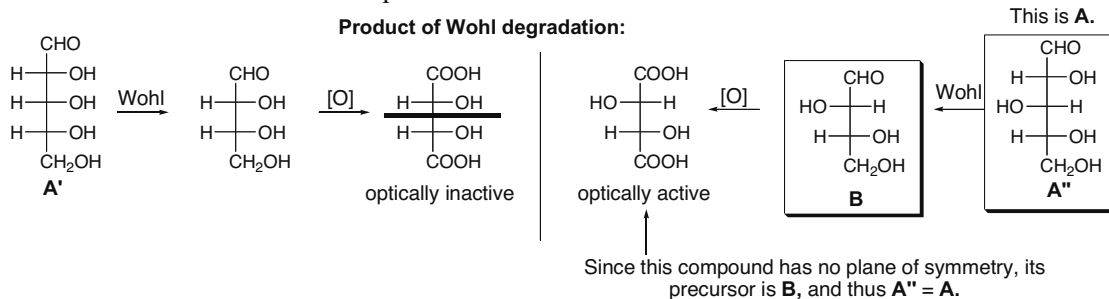


28.26

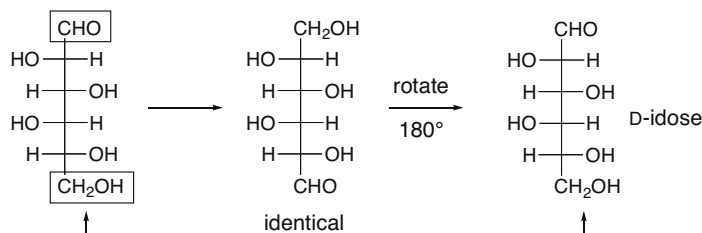
Possible optically inactive D-aldaric acids:



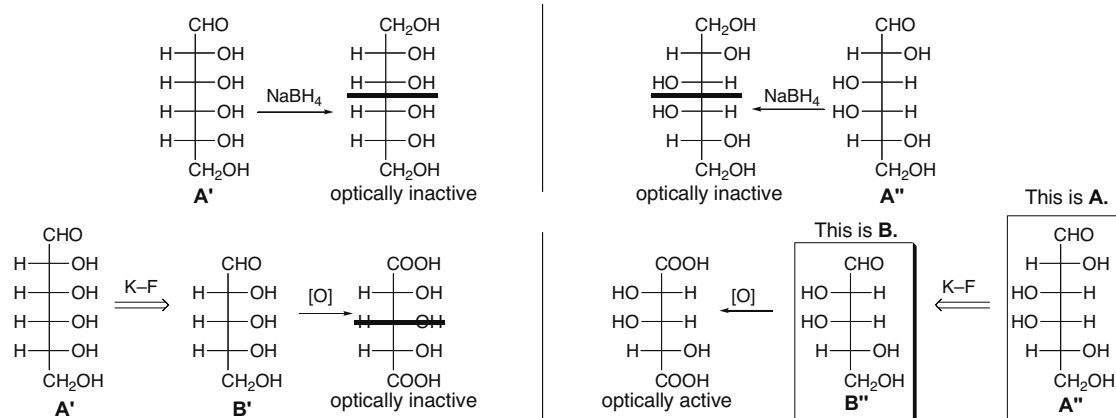
There are two possible structures for the D-aldopentose (**A'** and **A''**), and the Wohl degradation determines which structure corresponds to **A**.



28.27

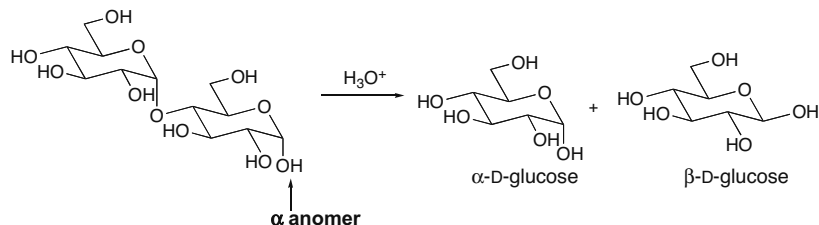


28.28

Optically inactive alditols formed from NaBH_4 reduction of a D-aldohexose.

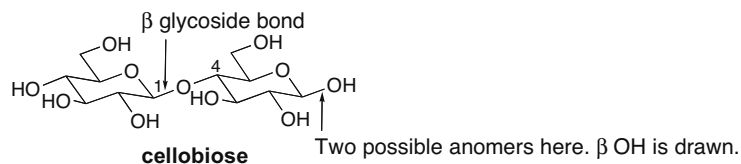
Two D-aldohexoses (**A'** and **A''**) give optically inactive alditols on reduction. **A''** is formed from **B''** by Kiliani-Fischer synthesis. Since **B''** affords an optically active aldaric acid on oxidation, **B''** is **B** and **A''** is **A**. The alternate possibility (**A'**) is formed from an aldopentose **B'** that gives an optically inactive aldaric acid on oxidation.

28.29



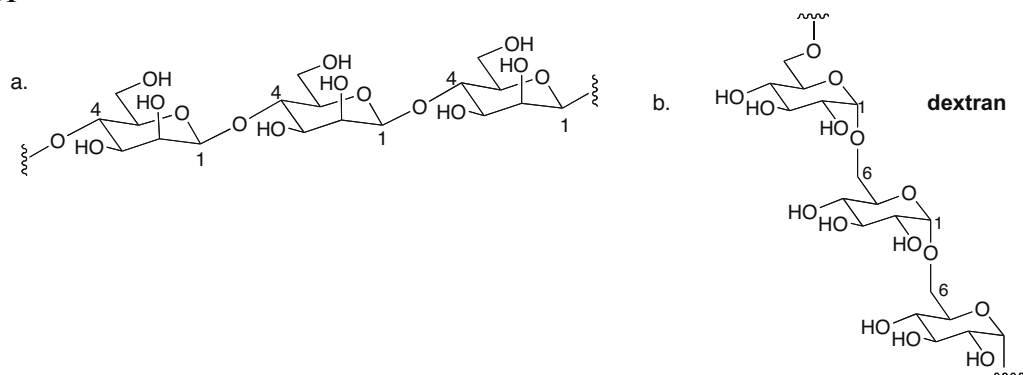
The same products are formed on hydrolysis of the α and β anomers of maltose.

28.30

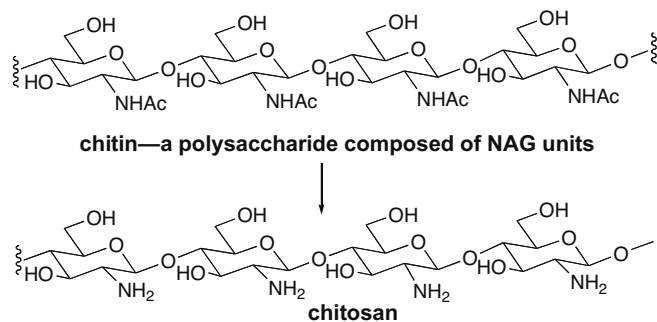


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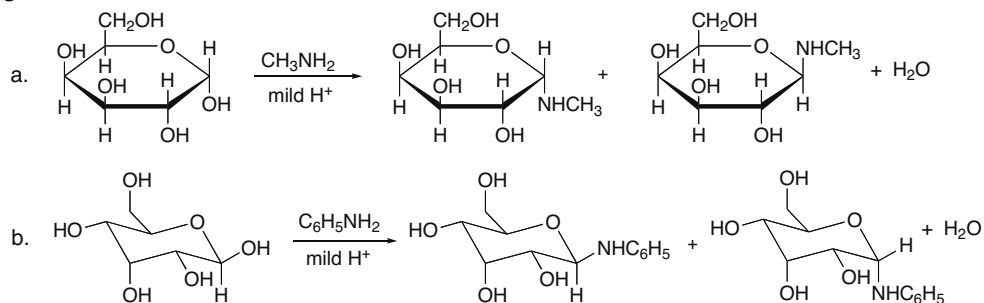
28.31



28.32

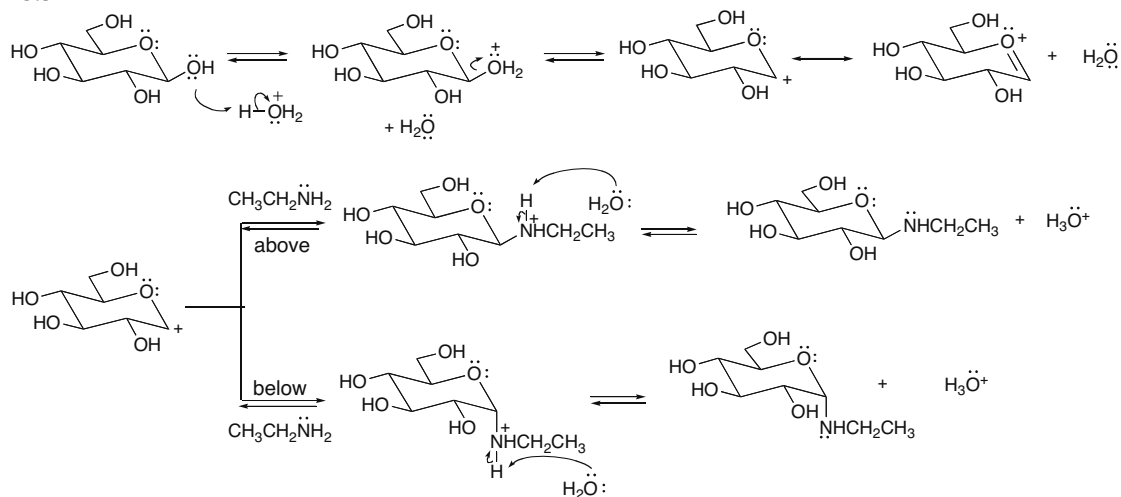


28.33

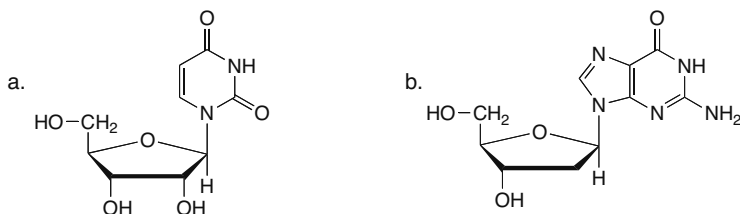


Carbohydrates 28-17

28.34

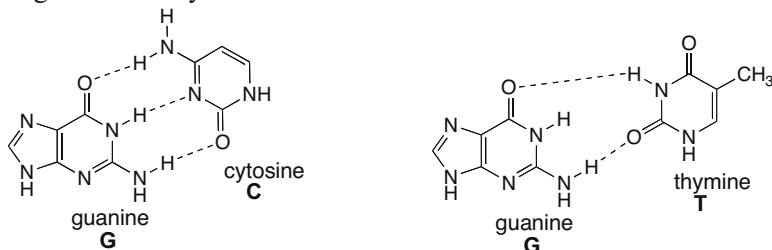


28.35



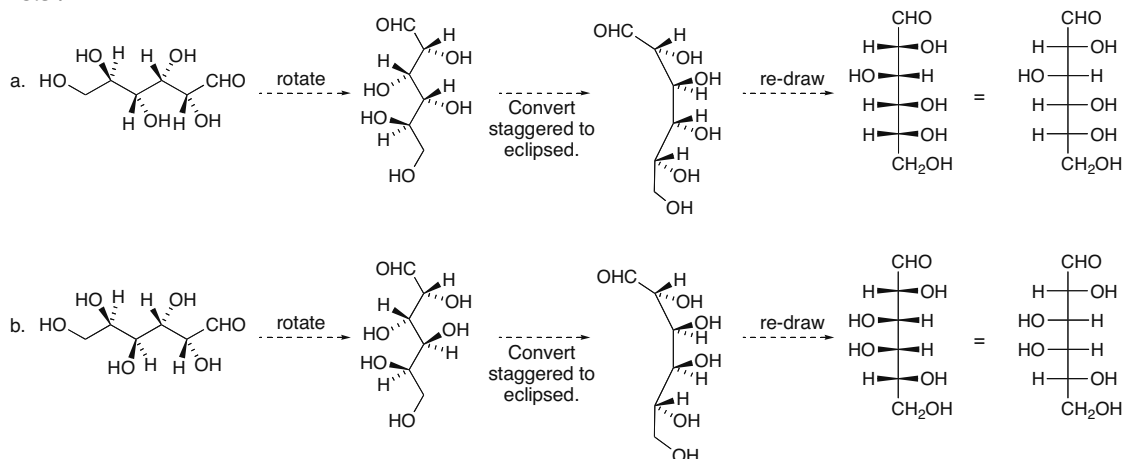
28.36

- Two purine bases (A and G) are both bicyclic bases. Therefore they are too big to hydrogen bond to each other on the inside of the DNA double helix.
- Hydrogen bonding between guanine and cytosine has three hydrogen bonds, whereas between guanine and thymine there are only two. This makes hydrogen bonding between guanine and cytosine more favorable.

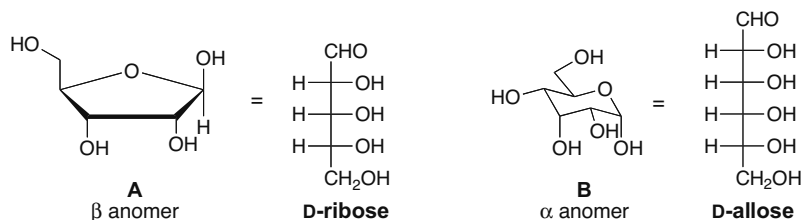
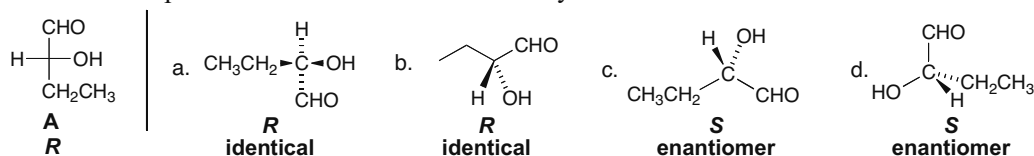


Chapter 28–18

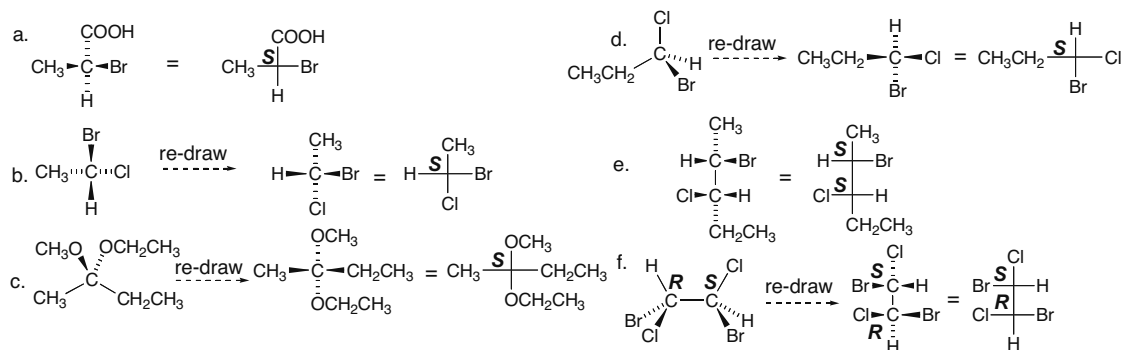
28.37



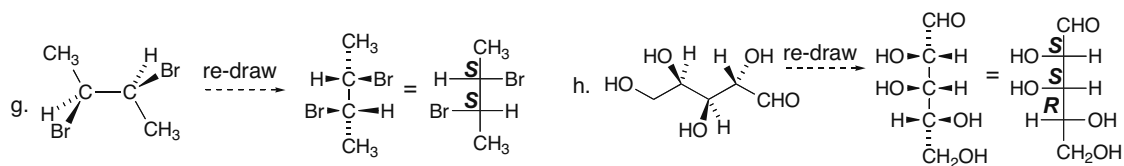
28.38

28.39 Label the compounds with *R* or *S* and then classify.

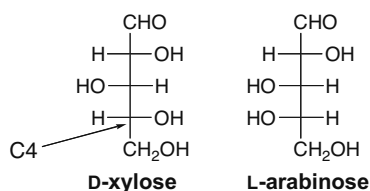
28.40 Use the directions from Answer 28.2 to draw each Fischer projection.



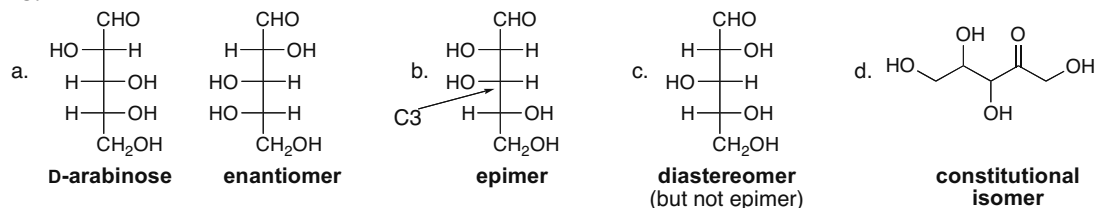
Carbohydrates 28-19



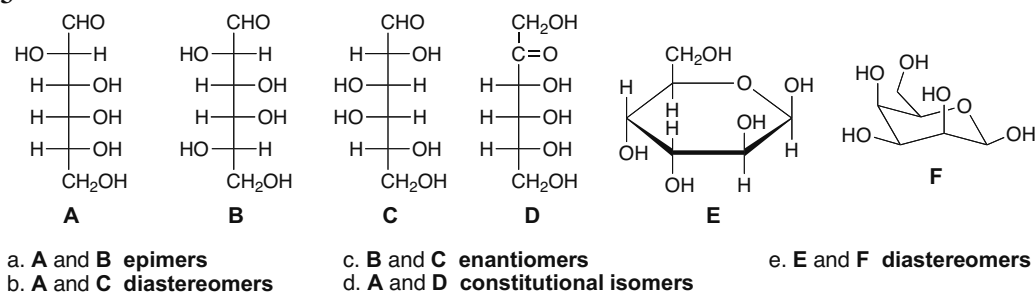
28.41 *Epimers* are two diastereomers that differ in the configuration around only one stereogenic center.



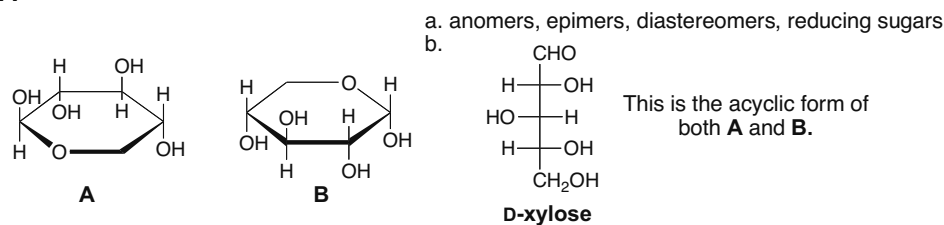
28.42



28.43

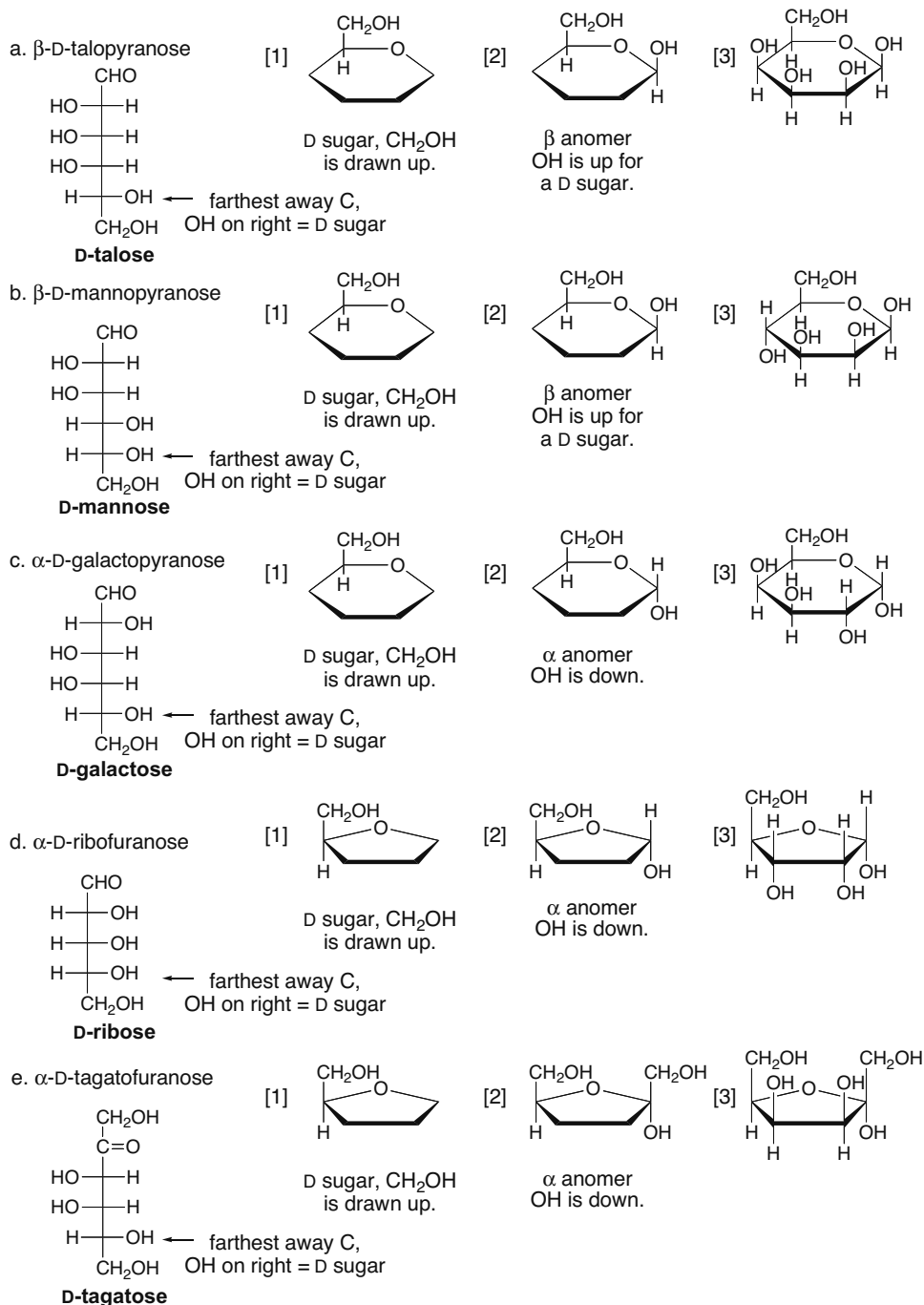


28.44



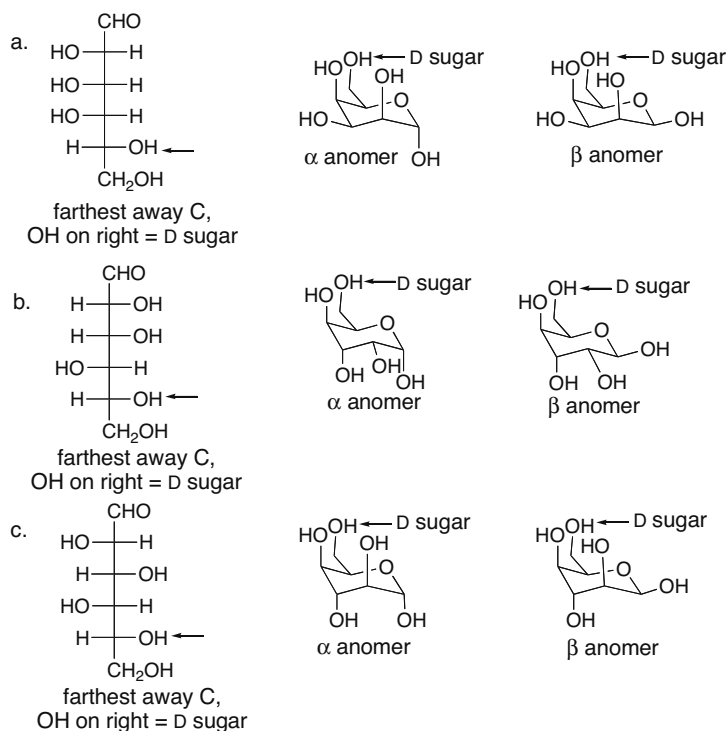
Chapter 28–20

28.45 Use the directions from Answer 28.12.

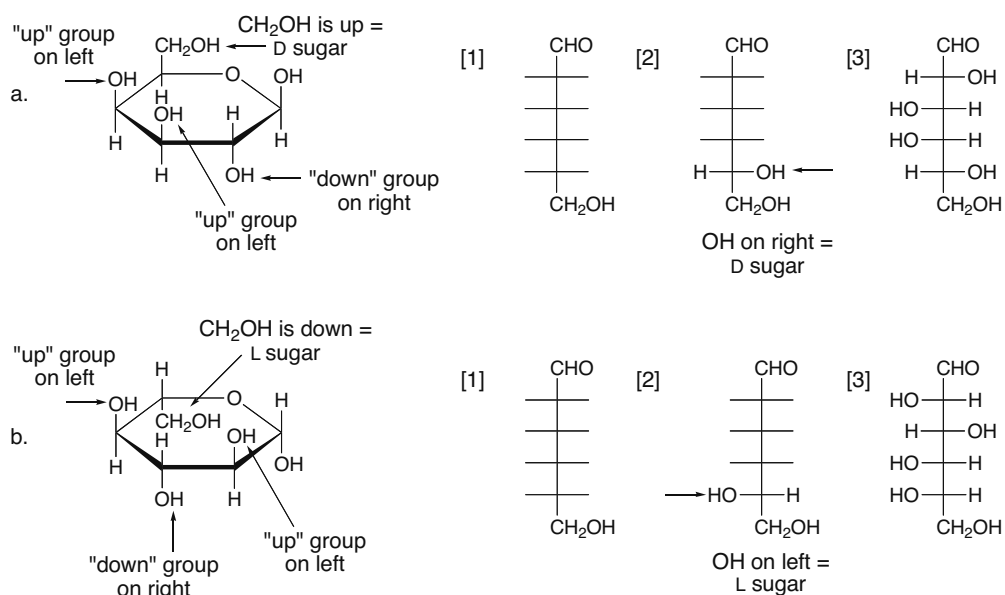


Carbohydrates 28-21

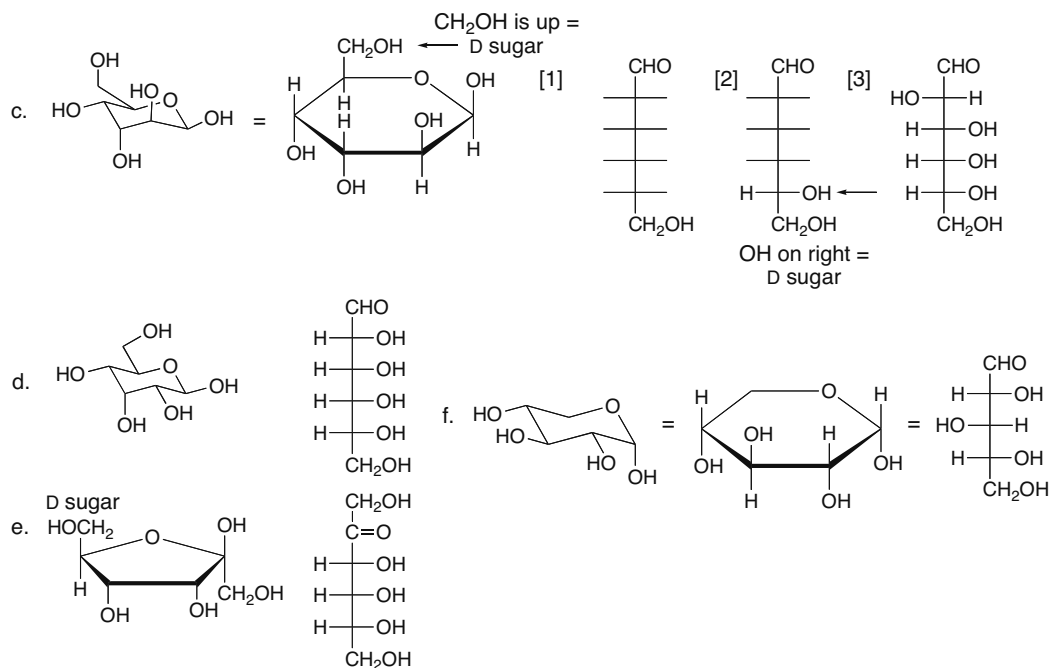
28.46



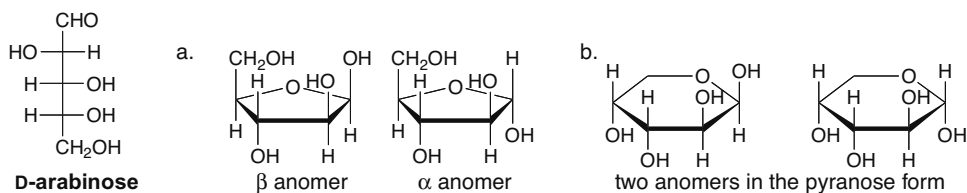
28.47 Use the directions from Answer 28.13.



Chapter 28-22

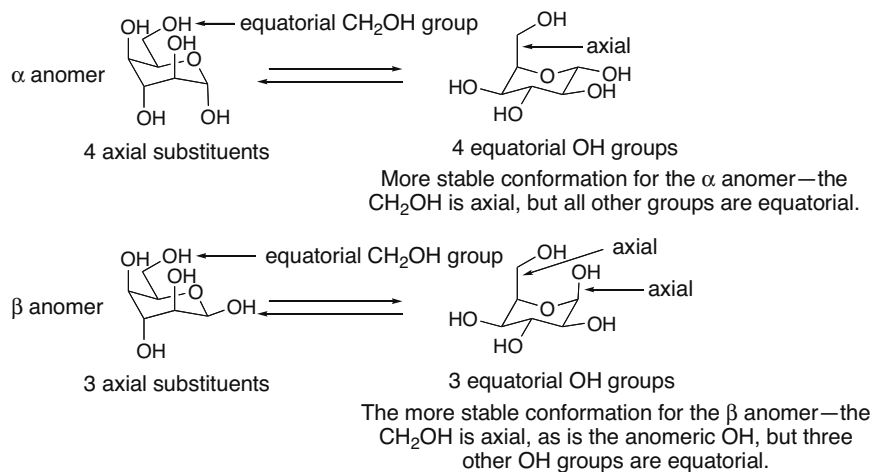


28.48

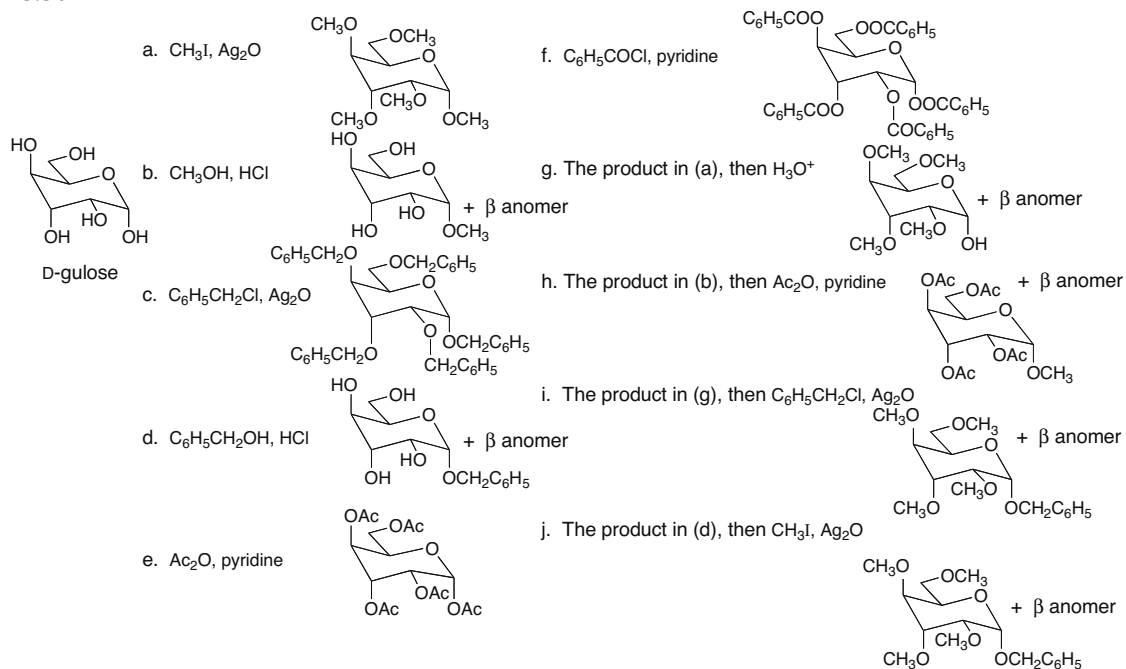


28.49

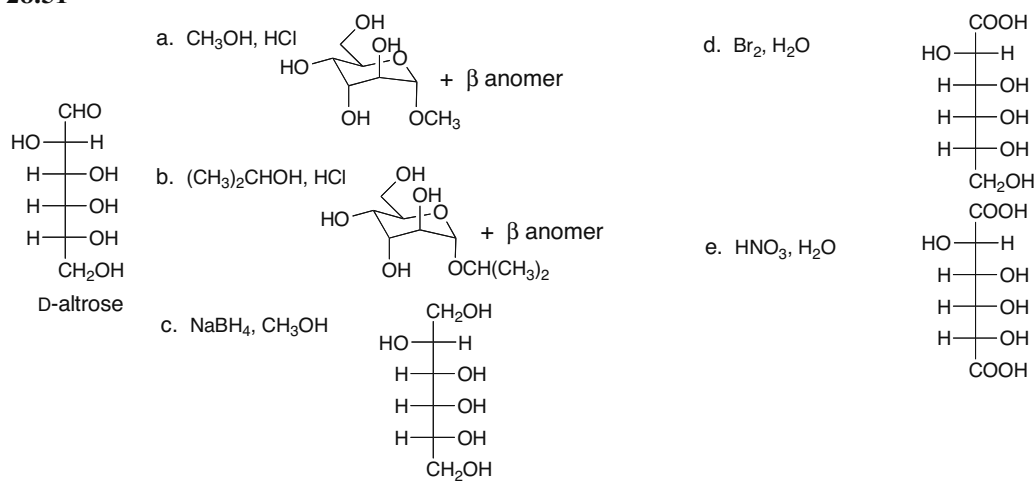
Two anomers of D-idose, as well as two conformations of each anomer:



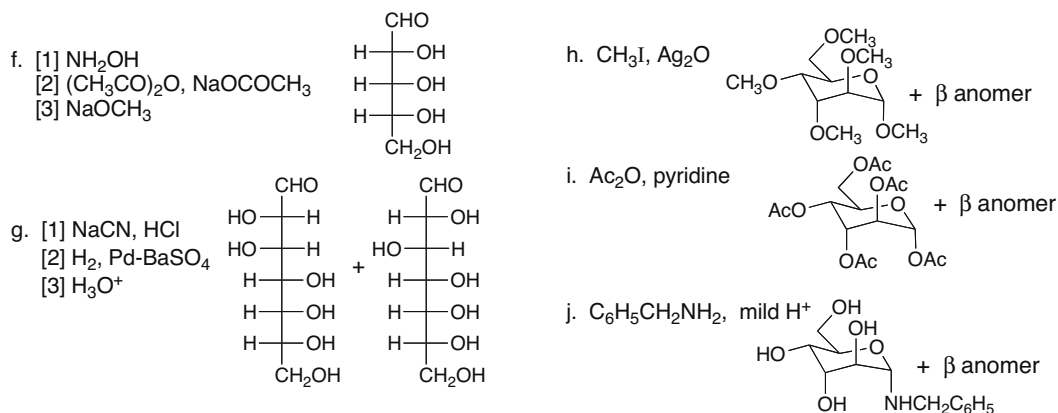
28.50



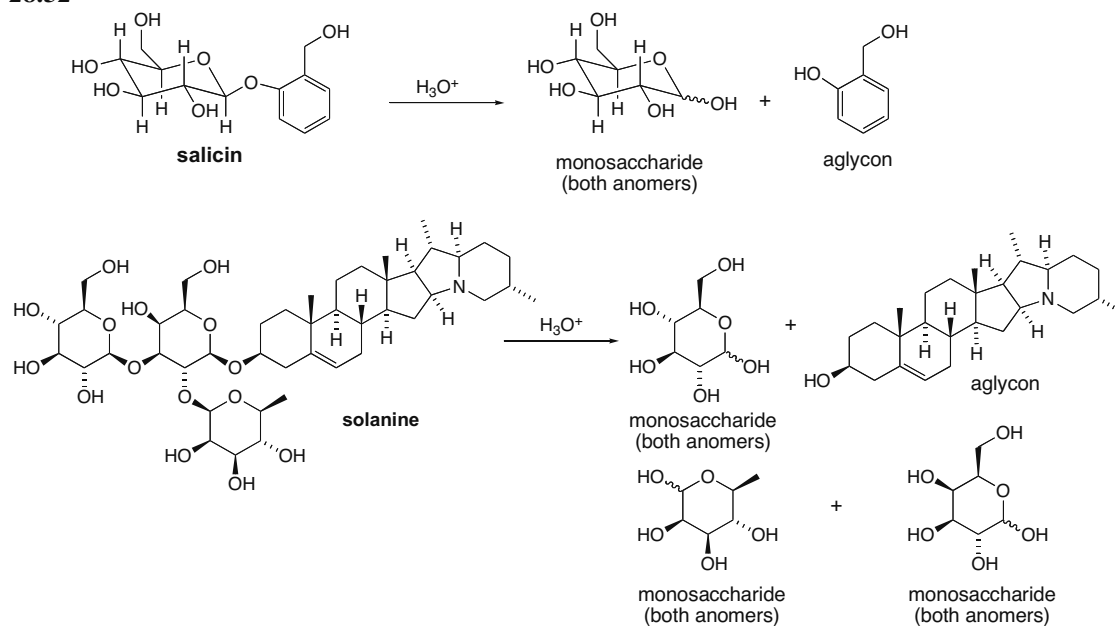
28.51



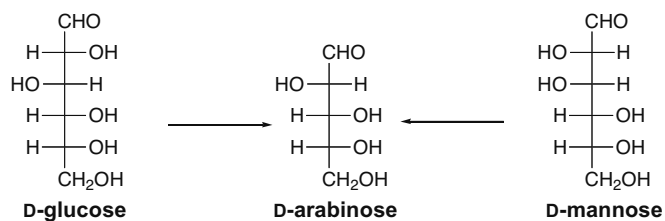
Chapter 28–24



28.52

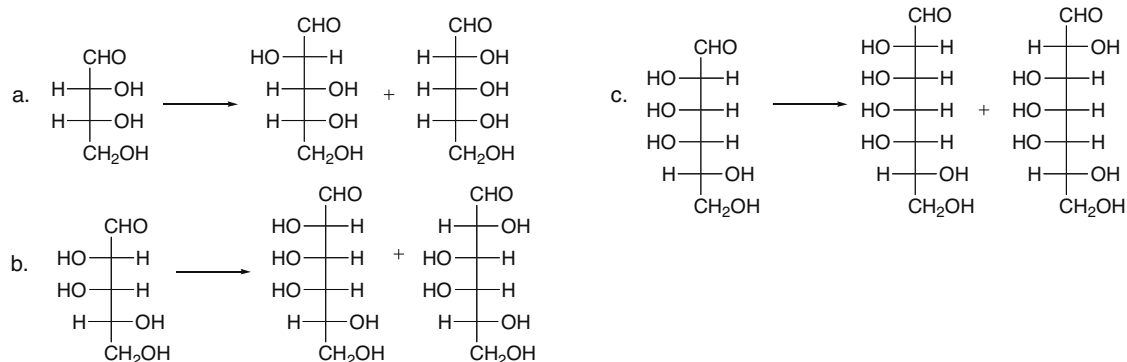


28.53

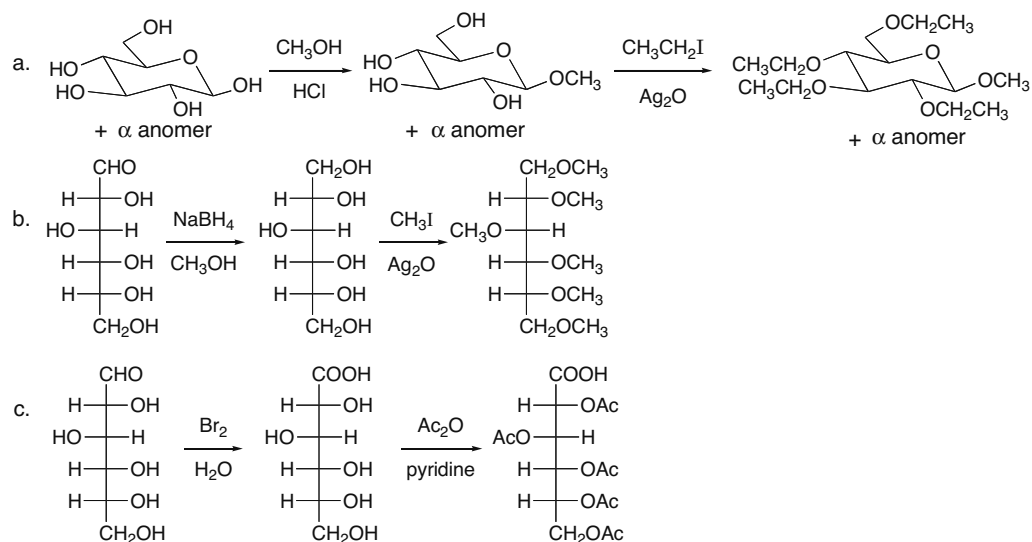


Carbohydrates 28-25

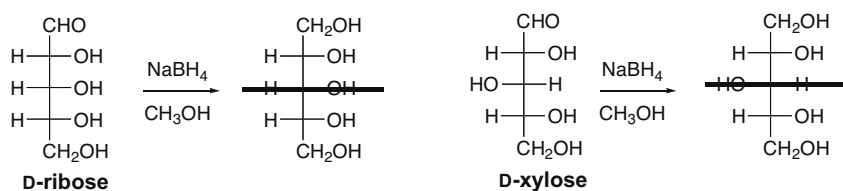
28.54



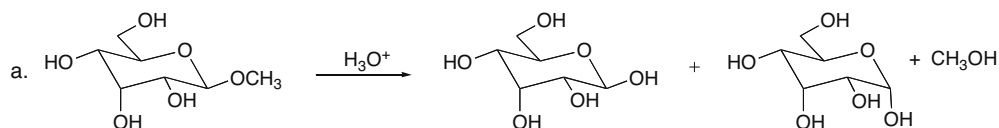
28.55



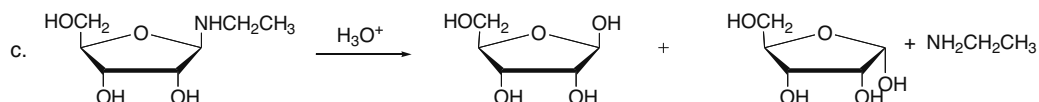
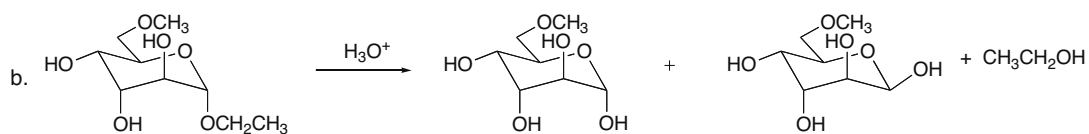
28.56 Molecules with a plane of symmetry are optically inactive.



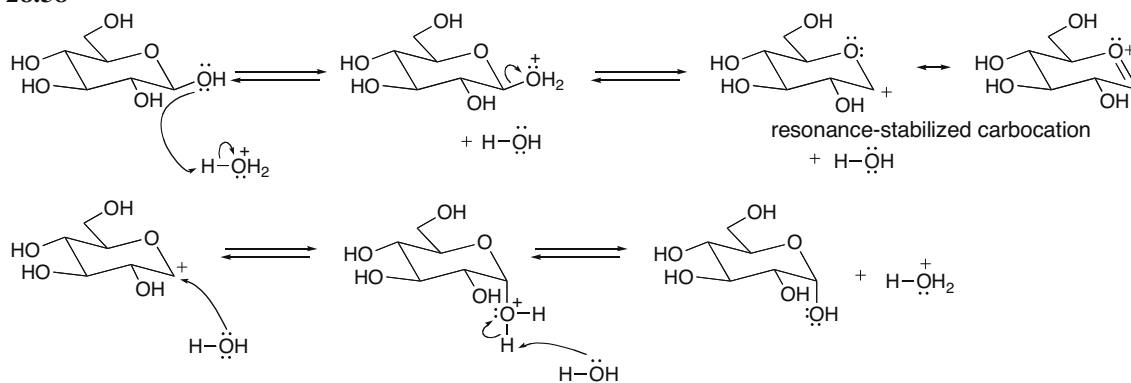
28.57



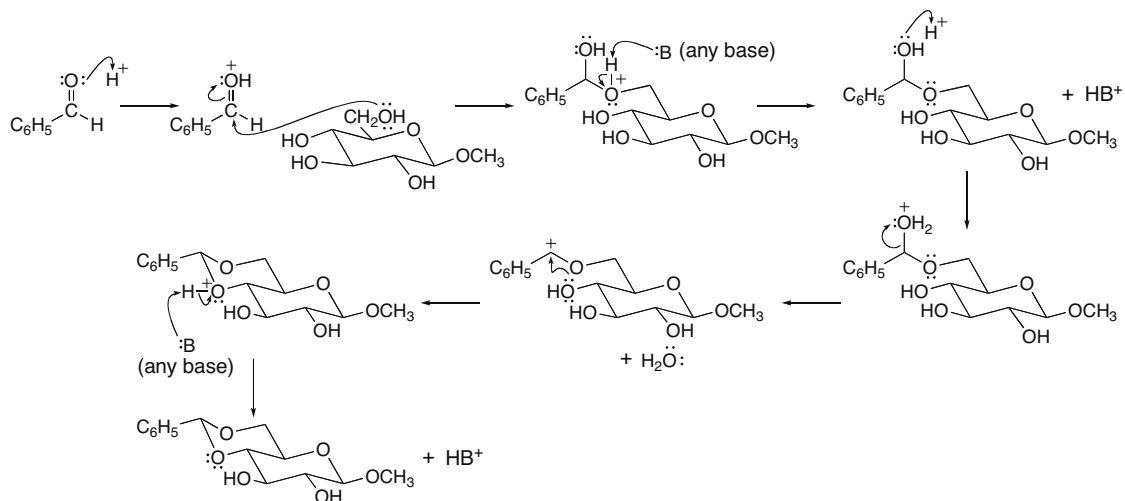
Chapter 28–26



28.58

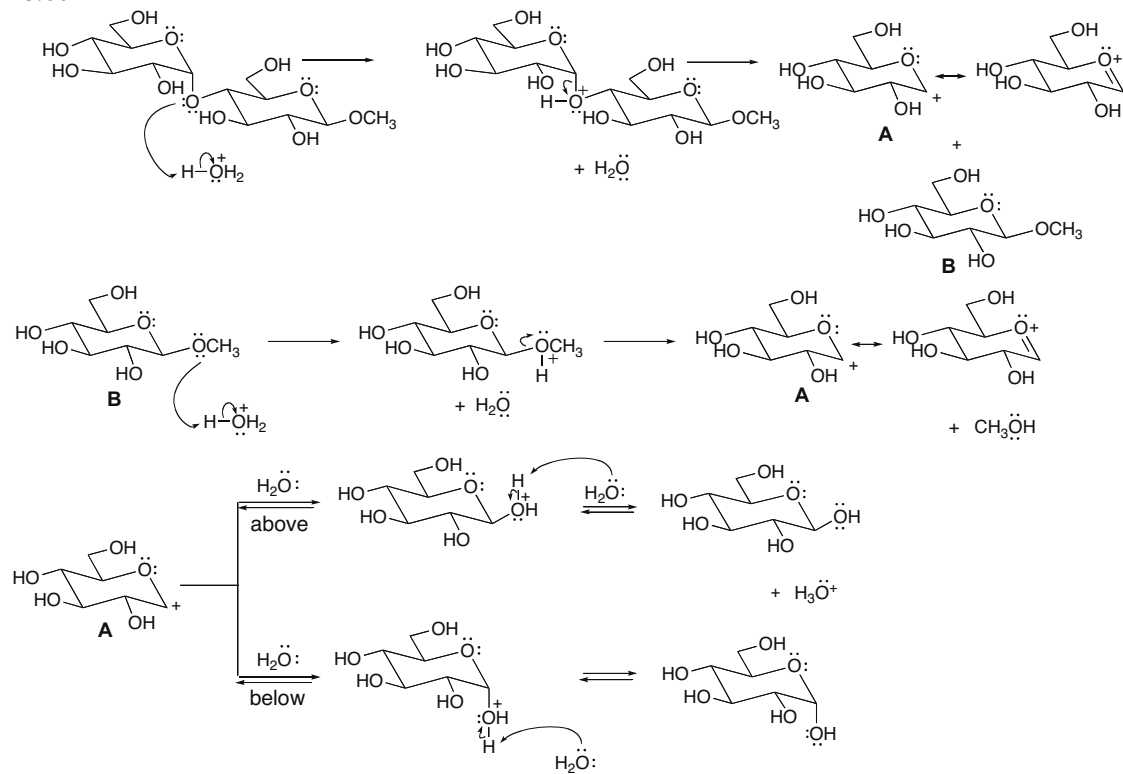


28.59

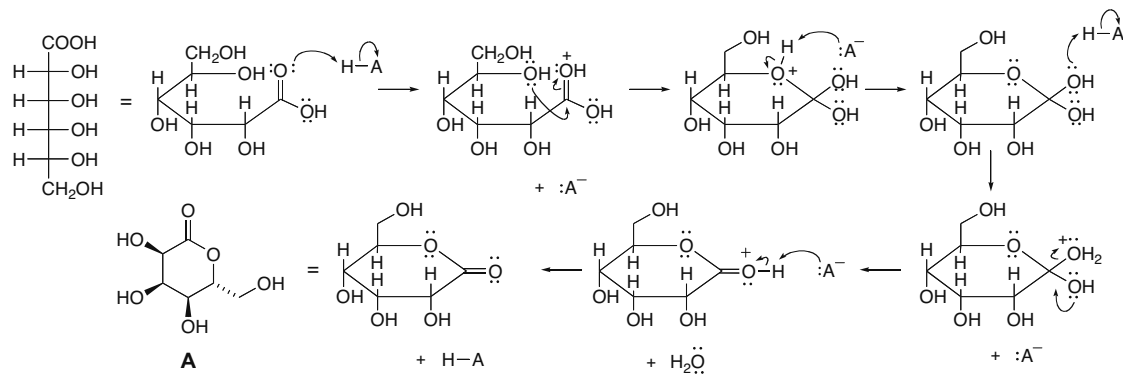


Carbohydrates 28-27

28.60

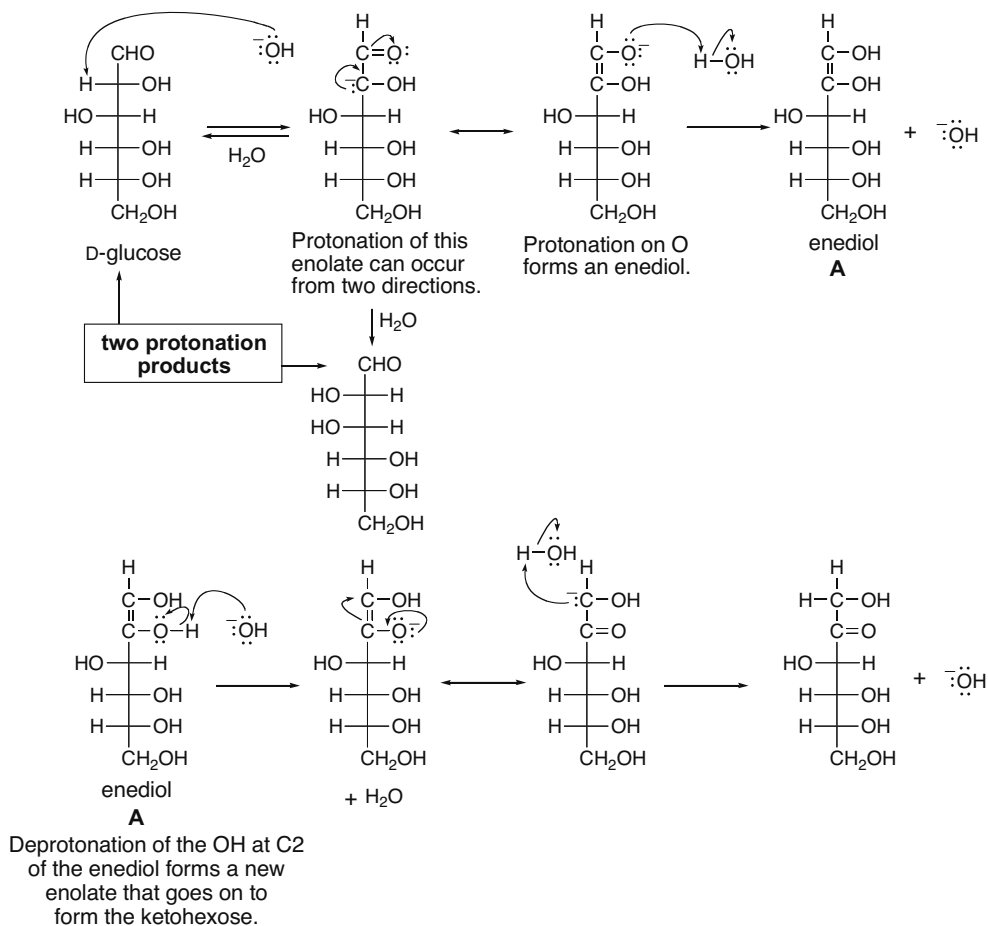


28.61



Chapter 28–28

28.62

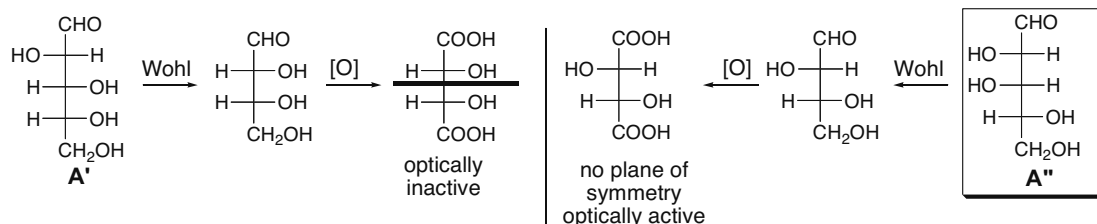


28.63

Two D-aldopentoses (**A'** and **A''**) yield optically active aldaric acids when oxidized.

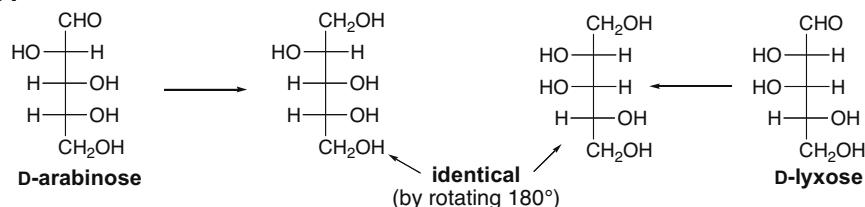
Optically active D-aldaric acids:





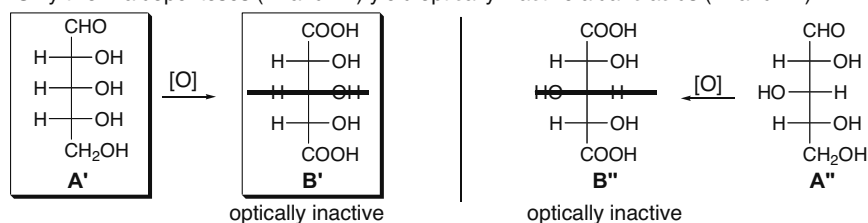
Only **A''** undergoes Wohl degradation to an aldotetrose that is oxidized to an optically active aldaric acid, so **A''** is the structure of the D-aldopentose in question.

28.64

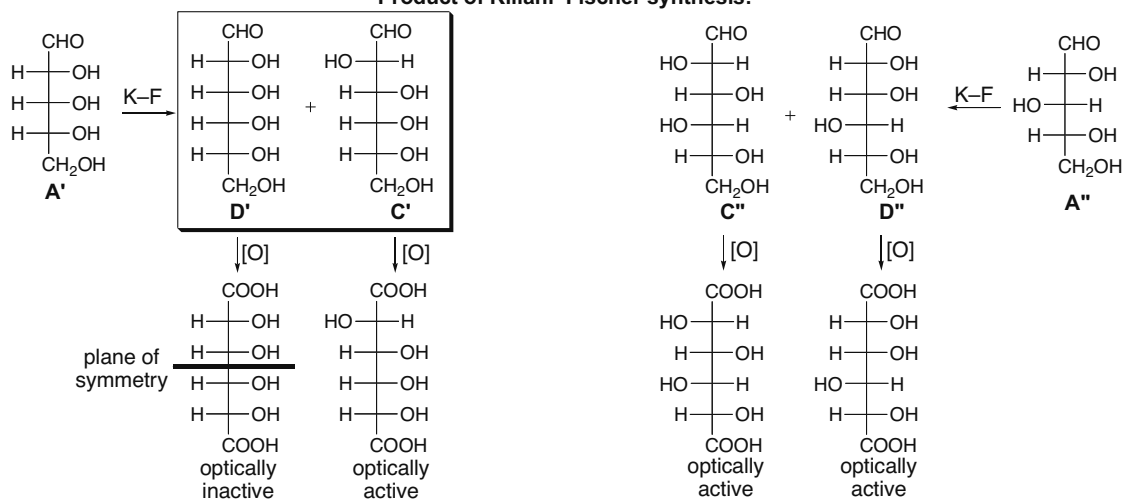


28.65

Only two D-aldopentoses (**A'** and **A''**) yield optically inactive aldaric acids (**B'** and **B''**).



Product of Kiliani–Fischer synthesis:

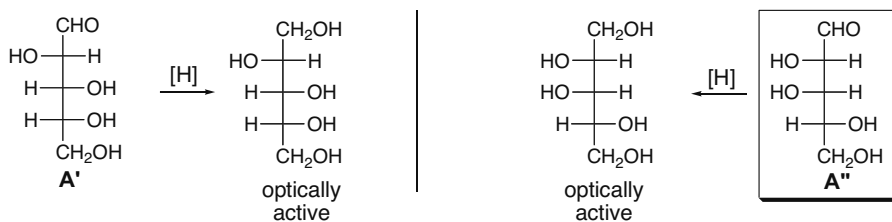


Chapter 28–30

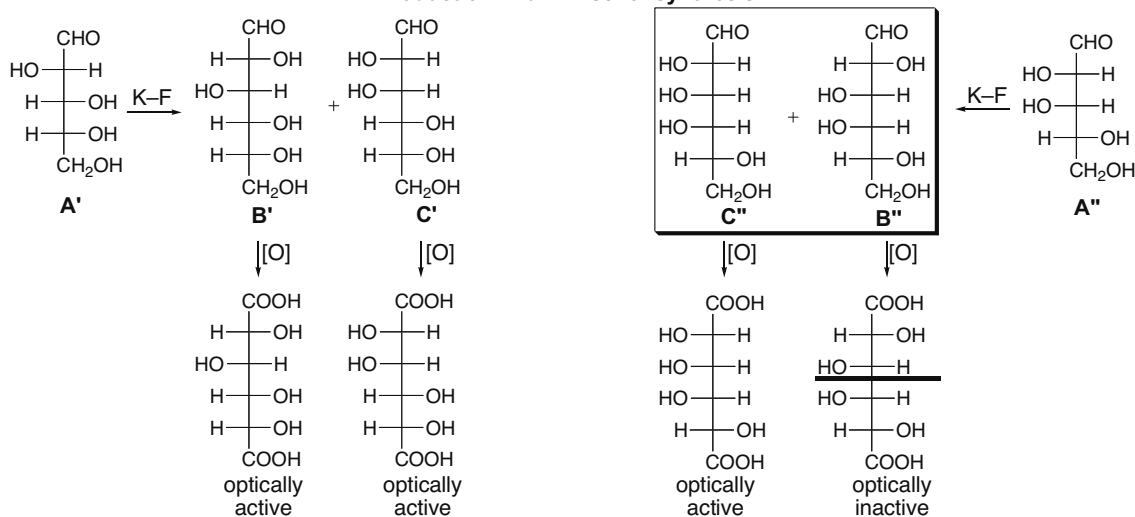
Only **A'** fits the criteria. Kiliani–Fischer synthesis of **A'** forms **C'** and **D'**, which are oxidized to one optically active and one optically inactive aldaric acid. A similar procedure with **A''** forms two optically active aldaric acids. Thus, the structures of **A–D** correspond to the structures of **A'–D'**.

28.66

Only two D-aldopentoses (**A'** and **A''**) are reduced to optically active alditols.



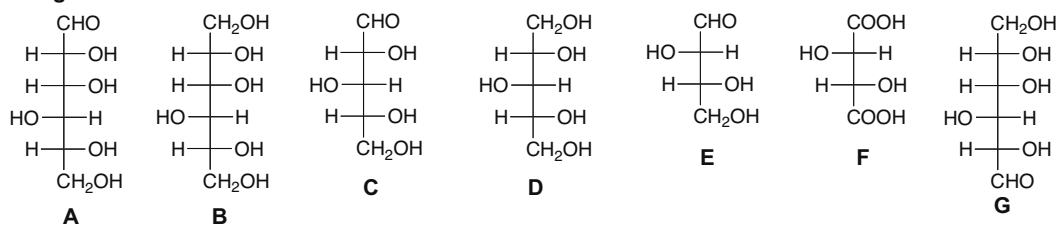
Product of Kiliani–Fischer synthesis:



Only **A''** fits the criteria. Kiliani–Fischer synthesis of **A''** forms **B''** and **C''**, which are oxidized to one optically inactive and one optically active diacid. A similar procedure with **A'** forms two optically active diacids. Thus, the structures of **A–C** correspond to **A'–C'**.

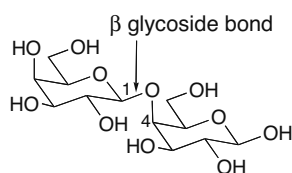
28.67

D-gulose

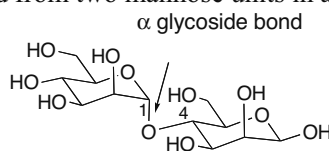


Carbohydrates 28-31

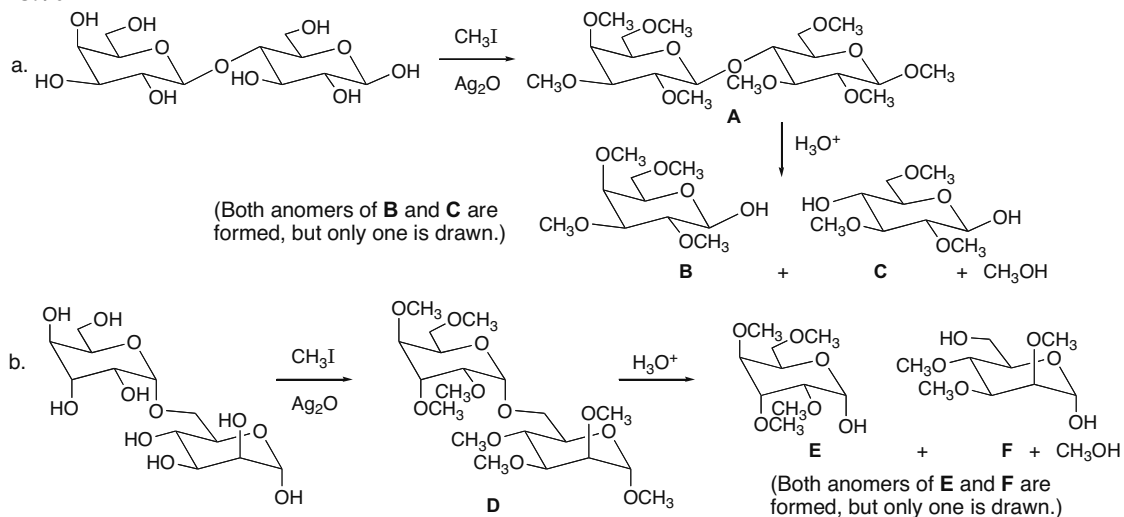
28.68 A disaccharide formed from two galactose units in a 1 $\rightarrow$ 4- β -glycosidic linkage:



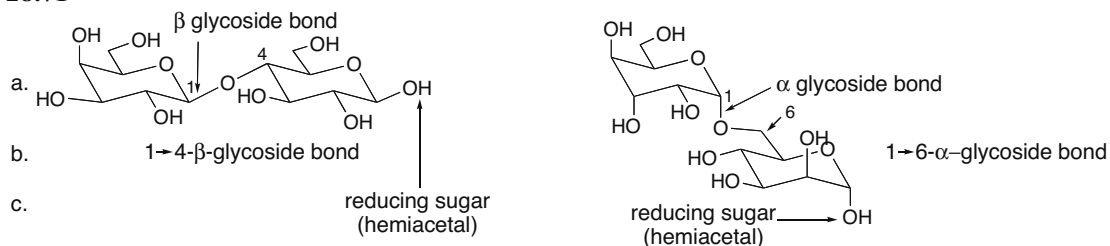
28.69 A disaccharide formed from two mannose units in a 1 $\rightarrow$ 4- α -glycosidic linkage:



28.70

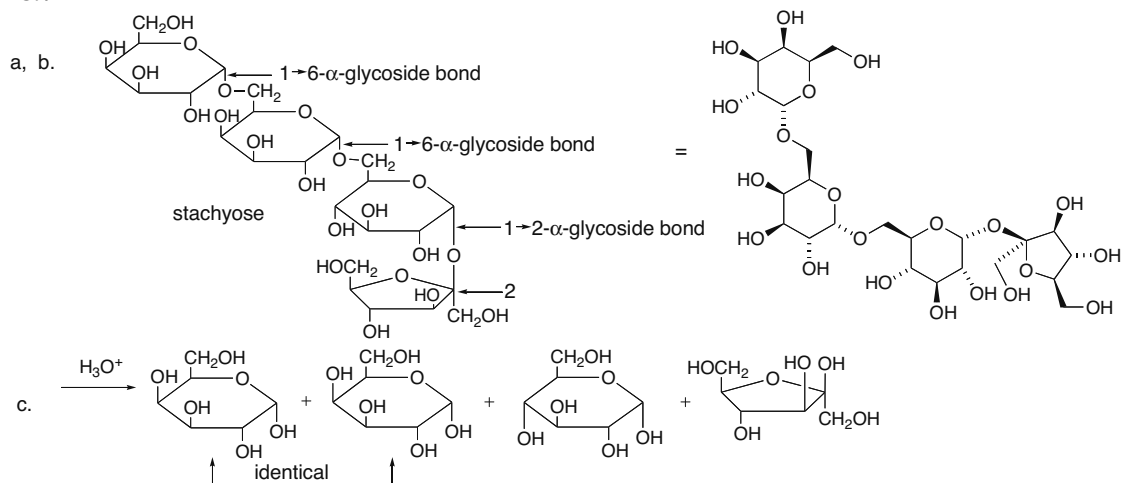


28.71

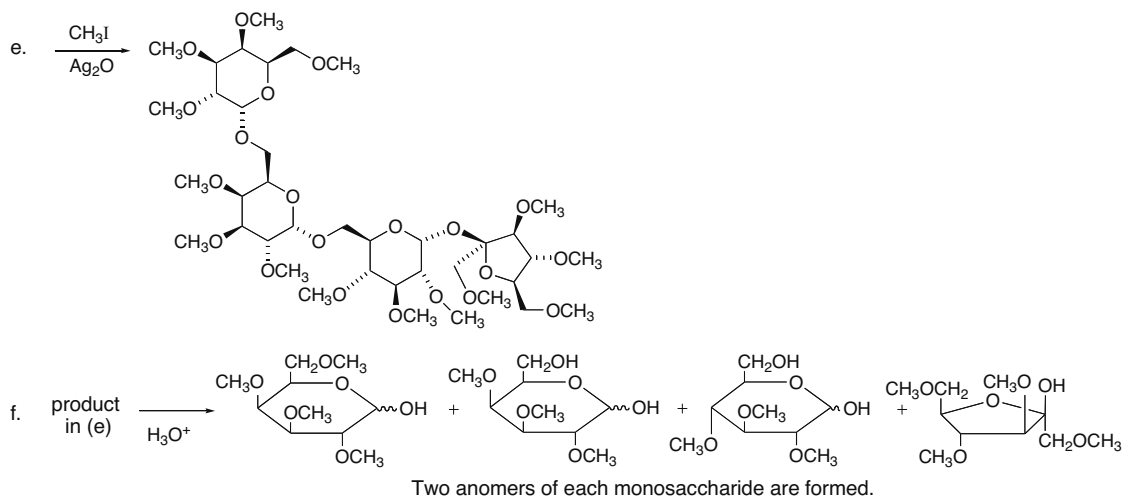


Chapter 28–32

28.72

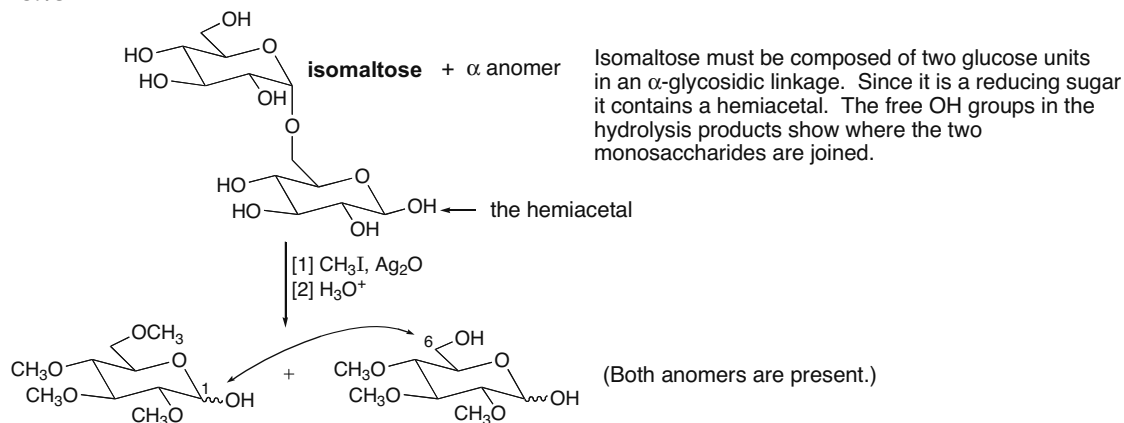


d. Stachyose is not a reducing sugar since it contains no hemiacetal.

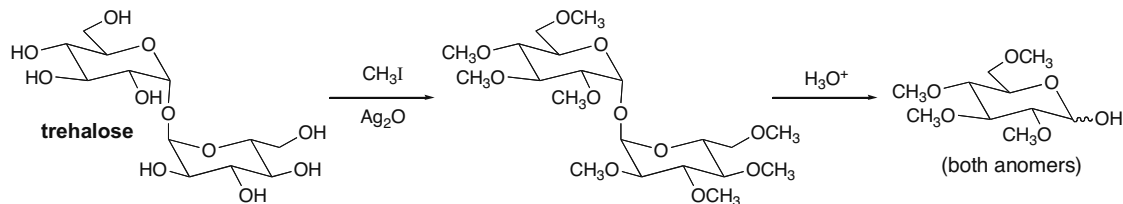


Carbohydrates 28-33

28.73

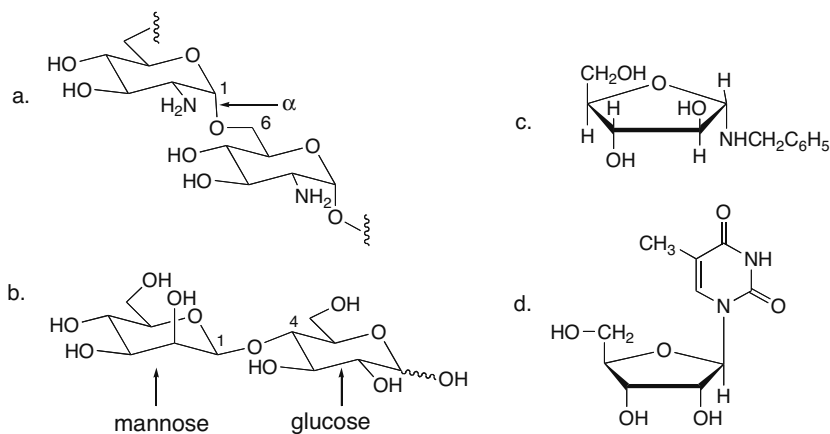


28.74



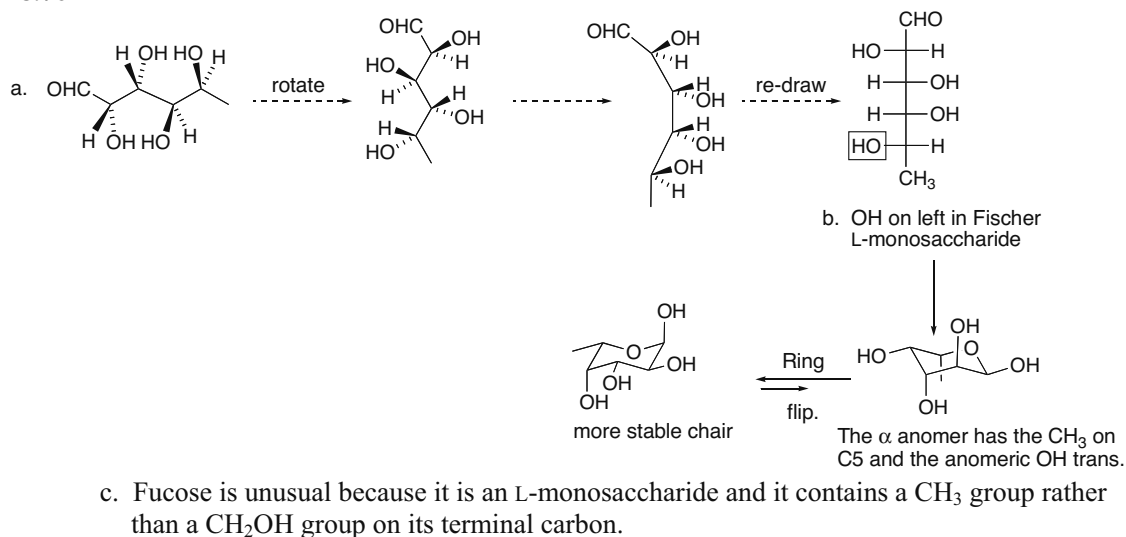
Trehalose must be composed of D-glucose units only, joined in an α -glycosidic linkage. Since trehalose is nonreducing it contains no hemiacetal. Since there is only one product formed after methylation and hydrolysis, the two anomeric C's must be joined.

28.75

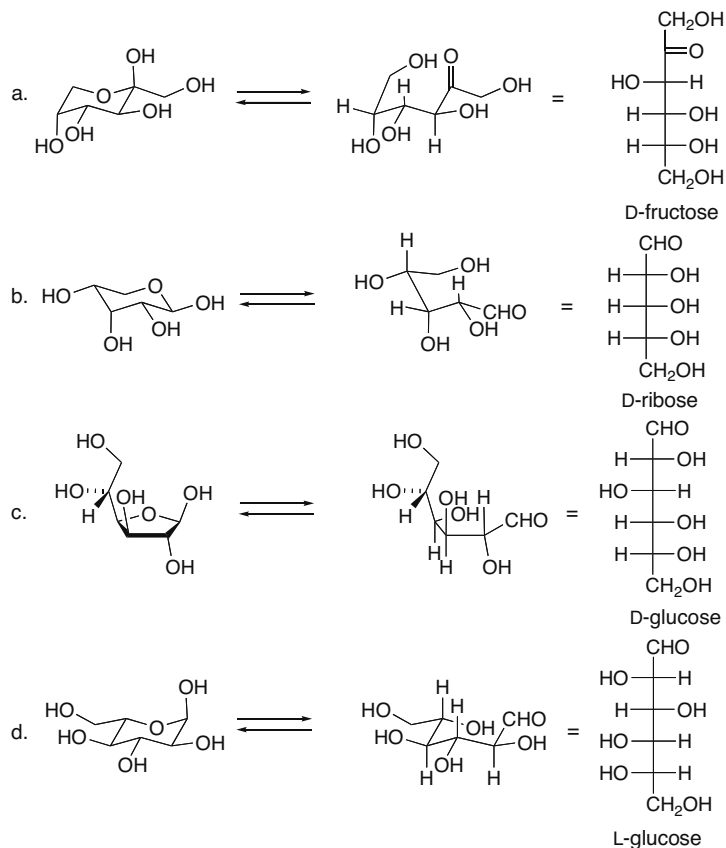


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28.76

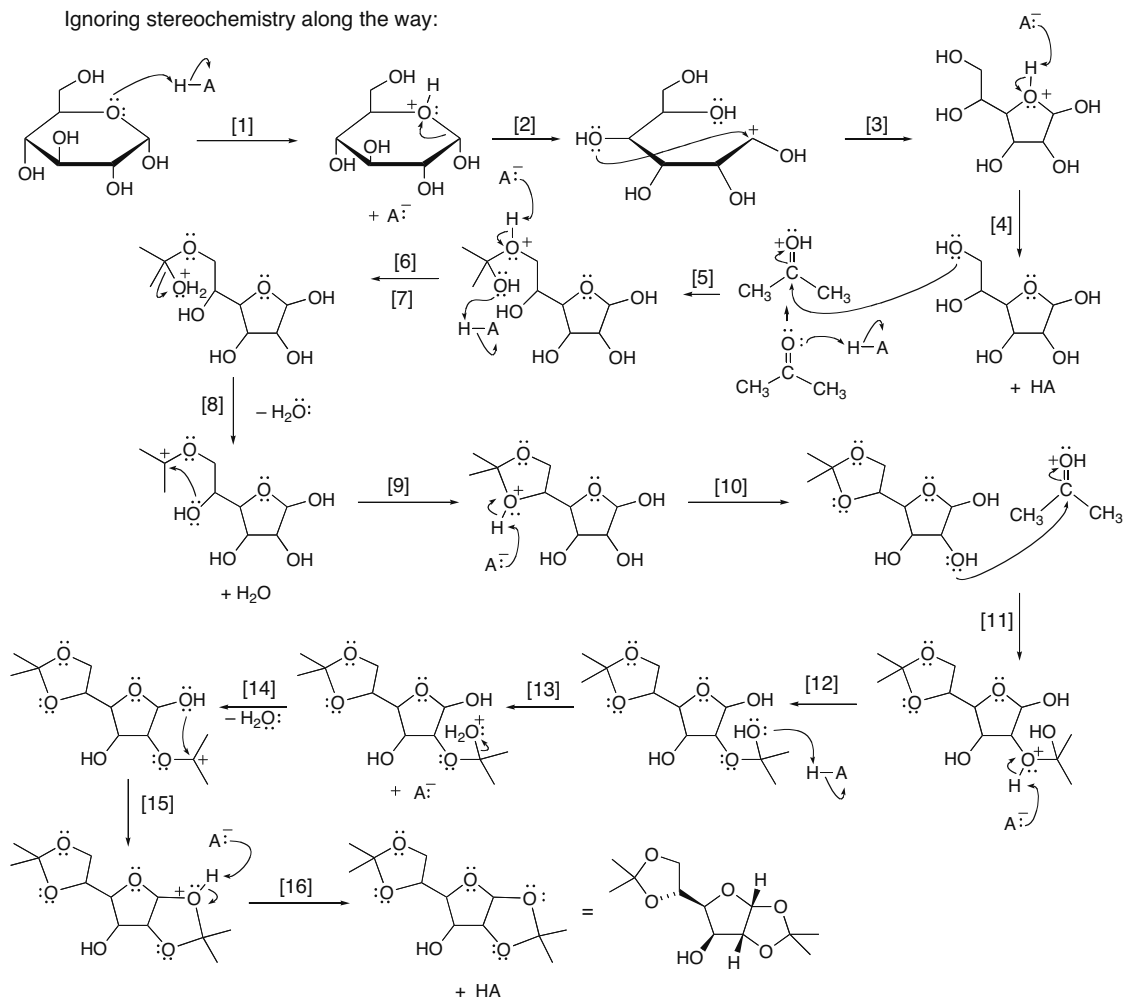


28.77



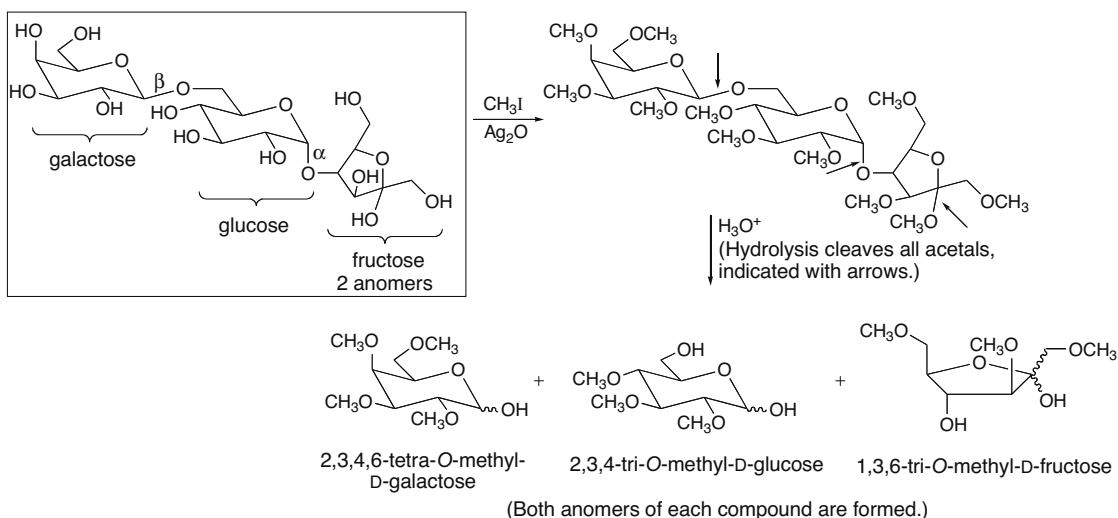
28.78

Ignoring stereochemistry along the way:



Chapter 28–36

28.79 The hydrolysis data suggest that the trisaccharide has D-galactose on one end and D-fructose on the other. D-Galactose must be joined to its adjacent sugar by a β -glycosidic linkage. D-Fructose must be joined to its adjacent sugar by an α -glycosidic linkage.

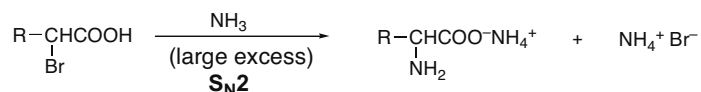


Chapter 29 Amino Acids and Proteins

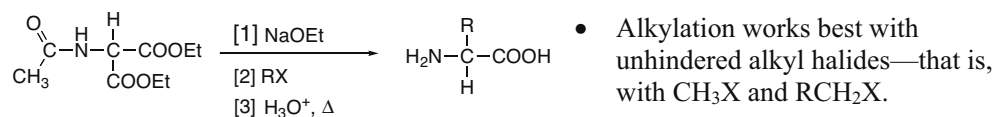
Chapter Review

Synthesis of amino acids (29.2)

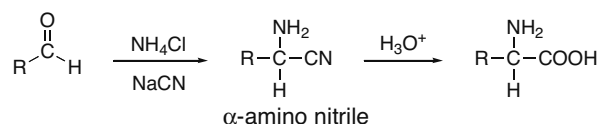
[1] From α -halo carboxylic acids by S_N2 reaction



[2] By alkylation of diethyl acetamidomalonate



[3] Strecker synthesis

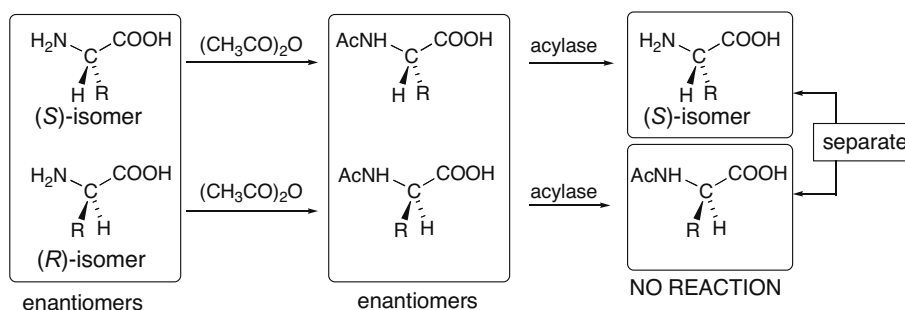


Preparation of optically active amino acids

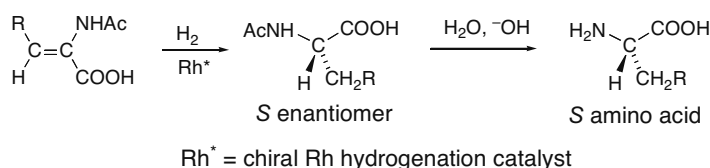
[1] Resolution of enantiomers by forming diastereomers (29.3A)

- Convert a racemic mixture of amino acids into a racemic mixture of *N*-acetyl amino acids [(*S*)- and (*R*)- $\text{CH}_3\text{CONHCH(R)COOH}$].
- React the enantiomers with a chiral amine to form a mixture of diastereomers.
- Separate the diastereomers.
- Regenerate the amino acids by protonation of the carboxylate salt and hydrolysis of the *N*-acetyl group.

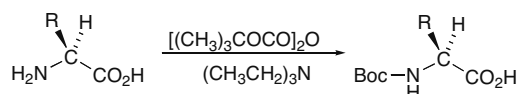
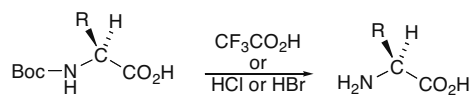
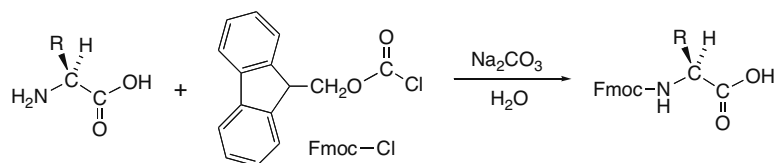
[2] Kinetic resolution using enzymes (29.3B)

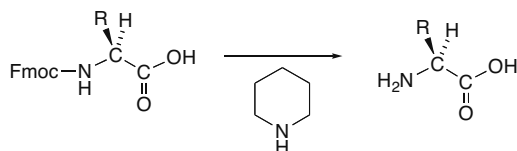
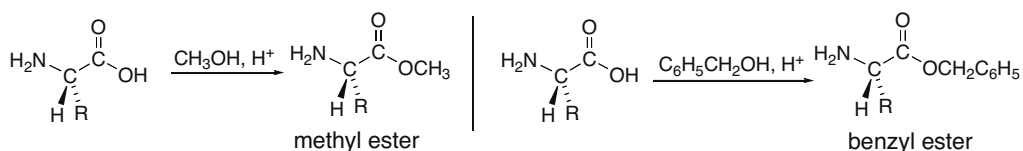
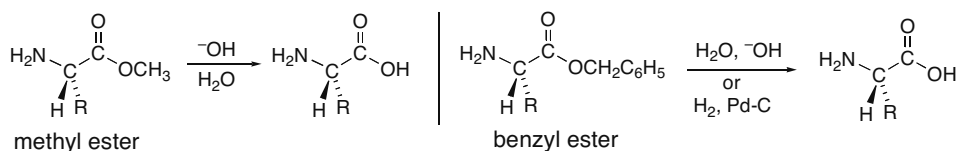
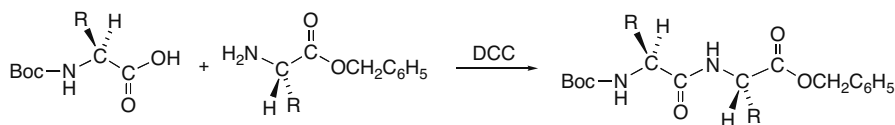


Chapter 29-2

[3] By enantioselective hydrogenation (29.4)**Summary of methods used for peptide sequencing (29.6)**

- Complete hydrolysis of all amide bonds in a peptide gives the identity and amount of the individual amino acids.
- Edman degradation identifies the N-terminal amino acid. Repeated Edman degradations can be used to sequence a peptide from the N-terminal end.
- Cleavage with carboxypeptidase identifies the C-terminal amino acid.
- Partial hydrolysis of a peptide forms smaller fragments that can be sequenced. Amino acid sequences common to smaller fragments can be used to determine the sequence of the complete peptide.
- Selective cleavage of a peptide occurs with trypsin and chymotrypsin to identify the location of specific amino acids (Table 29.2).

Adding and removing protecting groups for amino acids (29.7)**[1] Protection of an amino group as a Boc derivative****[2] Deprotection of a Boc-protected amino acid****[3] Protection of an amino group as an Fmoc derivative**

[4] Deprotection of an Fmoc-protected amino acid**[5] Protection of a carboxy group as an ester****[6] Deprotection of an ester group****Synthesis of dipeptides (29.7)****[1] Amide formation with DCC****[2] Four steps are needed to synthesize a dipeptide:**

- Protect** the amino group of one amino acid using a Boc or Fmoc group.
- Protect** the carboxy group of the second amino acid using an ester.
- Form the amide bond with **DCC**.
- Remove both protecting groups** in one or two reactions.

Summary of the Merrifield method of peptide synthesis (29.8)

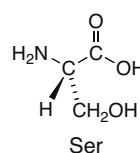
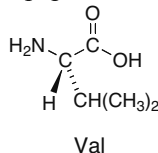
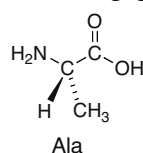
- Attach an Fmoc-protected amino acid to a polymer derived from polystyrene.
- Remove the Fmoc protecting group.
- Form the amide bond with a second Fmoc-protected amino acid using DCC.
- Repeat steps [2] and [3].
- Remove the protecting group and detach the peptide from the polymer.

Chapter 29-4

Practice Test on Chapter Review

1. a. Which statement is true about the peptide Ala-Gly-Tyr-Phe?
1. The N-terminal amino acid is Ala.
 2. The N-terminal amino acid is Phe.
 3. The peptide contains four peptide bonds.
 4. Statements [1] and [3] are true.
 5. Statements [2] and [3] are true.
- b. Which of the following peptides is hydrolyzed by trypsin?
1. Glu-Ser-Gly-Arg
 2. Arg-Gln-Trp-Asp
 3. Glu-Val-Leu-Lys
 4. Peptides [1] and [2] are hydrolyzed.
 5. Peptides [1], [2], and [3] are all hydrolyzed.
- c. In which types of protein structure is hydrogen bonding observed?
1. α -helix
 2. β -pleated sheet
 3. 3° structure
 4. Hydrogen bonding is present in [1] and [2].
 5. Hydrogen bonding is present in [1], [2], and [3].

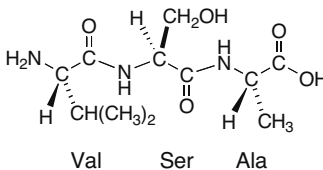
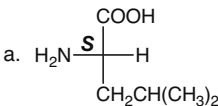
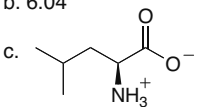
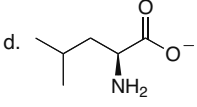
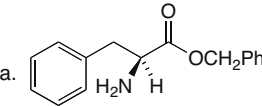
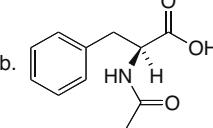
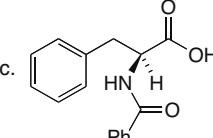
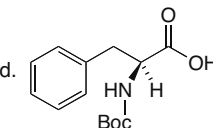
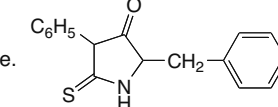
2. Answer the following questions about peptides.



- a. Draw the structure of the following tripeptide: Val-Ser-Ala.
 - b. Give the three-letter abbreviation for the N-terminal amino acid.
 - c. Give the three-letter abbreviation for the C-terminal amino acid.
3. Answer the following questions about the amino acid leucine (2-amino-4-methylpentanoic acid), which has pK_a 's of 2.33 and 9.74 for its ionizable functional groups.
- a. Draw a Fischer projection for L-leucine and label the stereogenic center as *R* or *S*.
 - b. What is the *pI* of leucine?
 - c. Draw the structure of the predominant form of leucine at its isoelectric point.
 - d. Draw the structure of the predominant form of leucine at pH 10.
 - e. Is leucine an acidic, basic, or neutral amino acid?
4. What product is formed when the amino acid phenylalanine is treated with each reagent?
- a. PhCH₂OH, H⁺
 - b. Ac₂O, pyridine
 - c. PhCOCl, pyridine
 - d. (Boc)₂O
 - e. C₆H₅N=C=S

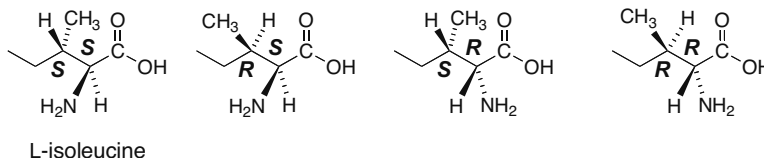
5. Draw the amino acids and peptide fragments formed when the octapeptide Tyr–Gly–Ala–Lys–Val–Ser–Phe–Met is treated with each reagent or enzyme:
- chymotrypsin
 - trypsin
 - carboxypeptidase
 - $\text{C}_6\text{H}_5\text{N}=\text{C}=\text{S}$

Answers to Practice Test

1. a. 1 b. 2 c. 5 2. a  b. Val c. Ala 3. a.  b. 6.04 c.  d.  e. neutral	4. a.  b.  c.  d.  e. 	5.a. Tyr, Gly–Ala–Lys–Val–Ser–Phe, Met b. Tyr–Gly–Ala–Lys, Val–Ser–Phe–Met c. Tyr–Gly–Ala–Lys–Val–Ser–Phe, Met d. Tyr, Gly–Ala–Lys–Val–Ser–Phe–Met

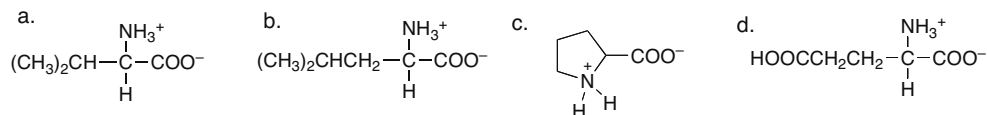
Answers to Problems

29.1



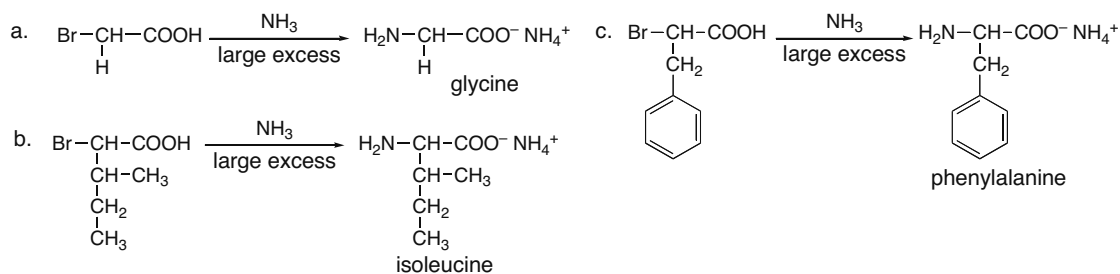
Chapter 29-6

29.2

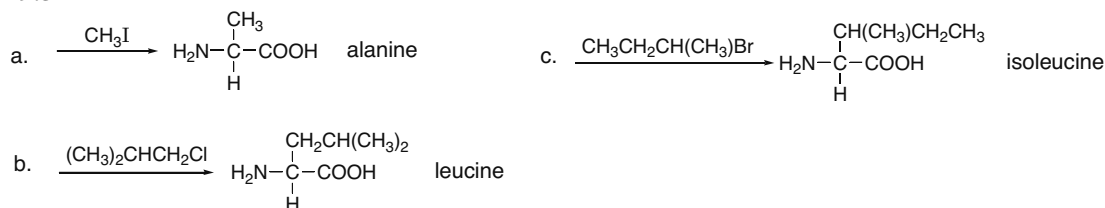


29.3 In an amino acid, the electron-withdrawing carboxy group destabilizes the ammonium ion ($-\text{NH}_3^+$), making it more readily donate a proton; that is, it makes it a stronger acid. Also, the electron-withdrawing carboxy group removes electron density from the amino group ($-\text{NH}_2$) of the conjugate base, making it a weaker base than a 1° amine, which has no electron-withdrawing group.

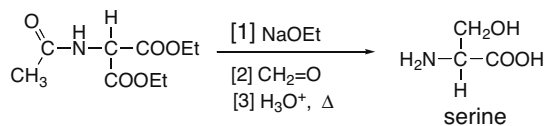
29.4 The most direct way to synthesize an α -amino acid is by **$\text{S}_\text{N}2$ reaction of an α -halo carboxylic acid with a large excess of NH_3** .



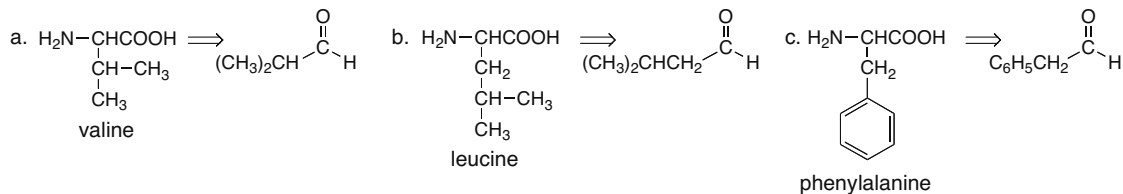
29.5



29.6

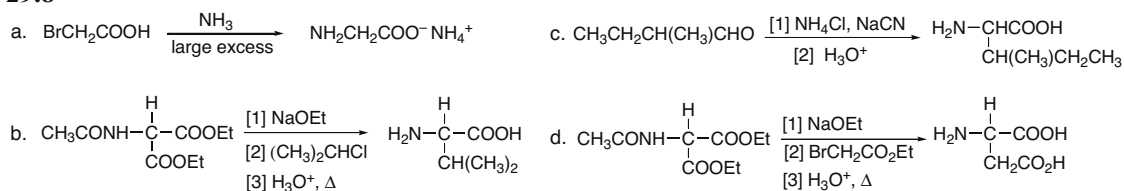


29.7

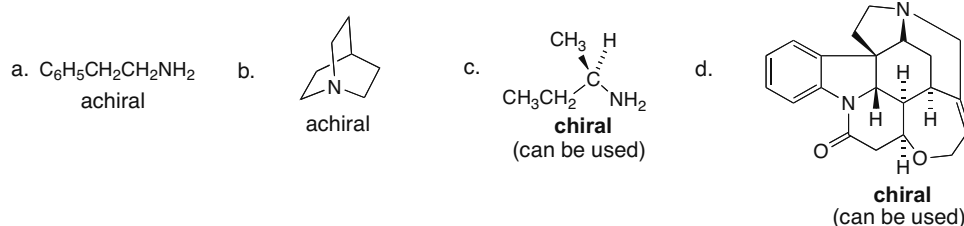


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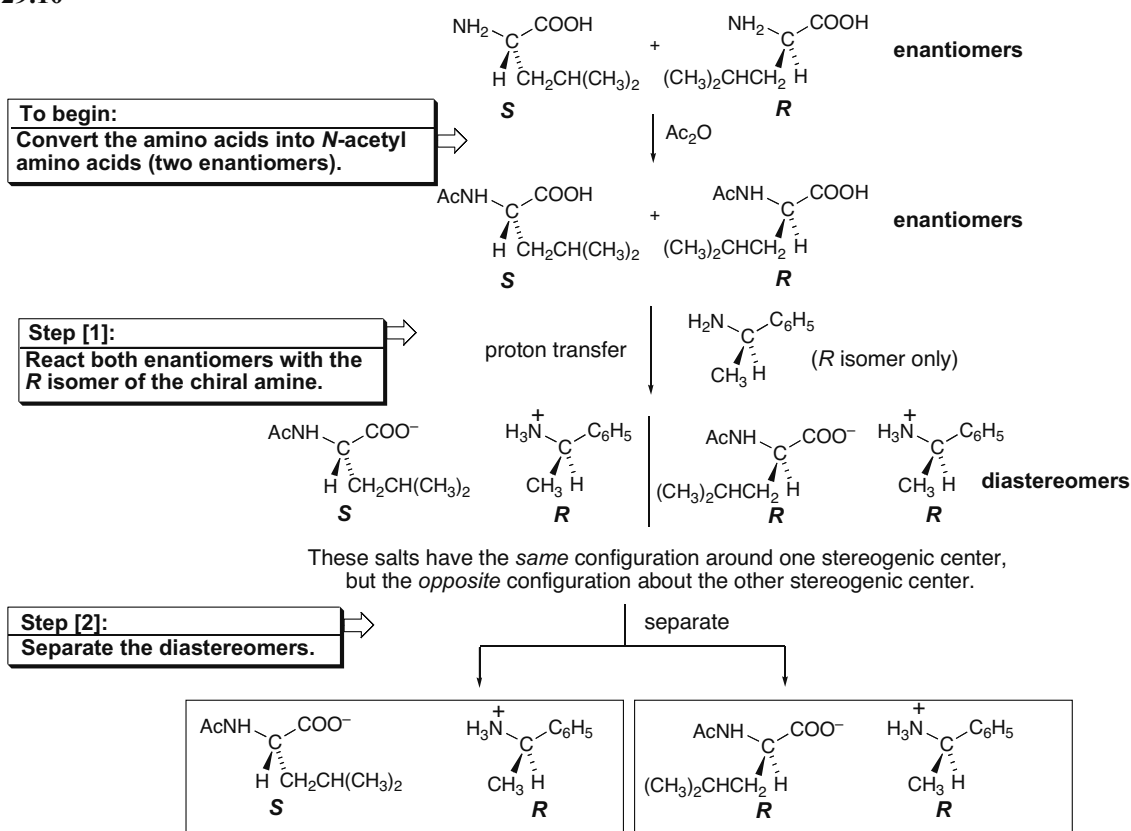
29.8



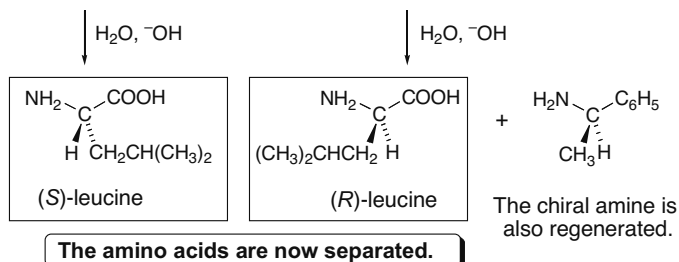
29.9 A chiral amine must be used to resolve a racemic mixture of amino acids.



29.10



Step [3]:
Regenerate the amino acid by hydrolysis of the amide.


$$\begin{array}{c} \text{COOH} \\ | \\ \text{H}_2\text{N}-\text{C}-\text{H} \\ | \\ \text{CH}_2\text{CH}(\text{CH}_3)_2 \end{array} \xrightarrow[\text{[2] acylase}]{\text{[1] } (\text{CH}_3\text{CO})_2\text{O}} \begin{array}{c} \text{H}_2\text{N}-\text{C}-\text{COOH} \\ | \quad \quad | \\ \text{H} \quad \quad \text{CH}_2\text{CH}(\text{CH}_3)_2 \end{array} + \begin{array}{c} \text{CH}_3-\text{C}-\text{NH}-\text{C}-\text{COOH} \\ || \quad \quad | \\ (\text{CH}_3)_2\text{CHCH}_2 \quad \text{H} \end{array}$$

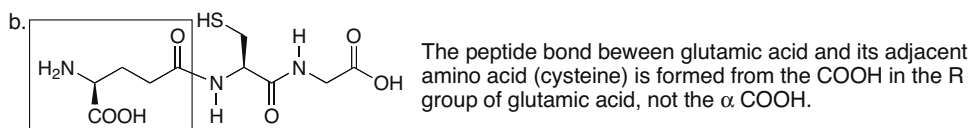
(mixture of enantiomers) (S)-leucine + *N*-acetyl-(*R*)-leucine

a. $\text{H}_2\text{N}-\underset{\text{CH}_3}{\text{CHCOOH}} \Rightarrow \begin{array}{c} \text{H} \quad \text{NHAc} \\ \diagdown \quad / \\ \text{C}=\text{C} \\ / \quad \diagdown \\ \text{H} \quad \text{COOH} \end{array}$ b. $\text{H}_2\text{N}-\underset{\begin{array}{c} \text{CH}_2 \\ | \\ \text{CH}-\text{CH}_3 \\ | \\ \text{CH}_3 \end{array}}{\text{CHCOOH}} \Rightarrow \begin{array}{c} (\text{CH}_3)_2\text{CH} \quad \text{NHAc} \\ \diagdown \quad / \\ \text{C}=\text{C} \\ / \quad \diagdown \\ \text{H} \quad \text{COOH} \end{array}$ c. $\text{H}_2\text{N}-\underset{\begin{array}{c} \text{CH}_2 \\ | \\ \text{CH}_2 \\ | \\ \text{CONH}_2 \end{array}}{\text{CHCOOH}} \Rightarrow \begin{array}{c} \text{H}_2\text{NCOCH}_2 \quad \text{NHAc} \\ \diagdown \quad / \\ \text{C}=\text{C} \\ / \quad \diagdown \\ \text{H} \quad \text{COOH} \end{array}$

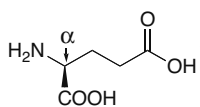
a. $\text{H}_2\text{N}-\text{CH}(\text{CH}_3)_2-\text{C}(=\text{O})\text{OH} \quad \text{H}_2\text{N}-\text{CH}(\text{CH}_2\text{CH}_2\text{COOH})-\text{C}(=\text{O})\text{OH} \longrightarrow \text{H}_2\text{N}-\text{CH}(\text{CH}_3)_2-\text{C}(=\text{O})-\text{NH}-\text{CH}(\text{CH}_2\text{CH}_2\text{COOH})-\text{C}(=\text{O})\text{OH}$
Val **Glu** **Val-Glu**
 N-terminal C-terminal

b. $\text{H}_2\text{N}-\text{CH}(\text{H})-\text{C}(=\text{O})\text{OH} \quad \text{H}_2\text{N}-\text{CH}(\text{CH}_2\text{pyrrole})-\text{C}(=\text{O})\text{OH} \quad \text{H}_2\text{N}-\text{CH}(\text{CH}_2\text{CH}_3)_2-\text{C}(=\text{O})\text{OH} \longrightarrow \text{H}_2\text{N}-\text{CH}(\text{H})-\text{C}(=\text{O})-\text{NH}-\text{CH}(\text{CH}_2\text{pyrrole})-\text{C}(=\text{O})-\text{NH}-\text{CH}(\text{CH}_2\text{CH}_3)_2-\text{C}(=\text{O})\text{OH}$
Gly **His** **Leu** **Gly-His-Leu**
 N-terminal C-terminal

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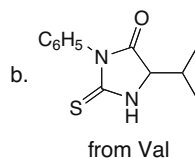
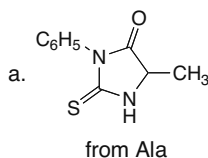


α COOH This comes from the amino acid glutamic acid.



This carboxy group is used to form the amide bond in the peptide, not the α COOH, as is usual. That's what makes glutathione's structure unusual.

29.18



29.19 Determine the sequence of the octapeptide as in Sample Problem 29.2. Look for overlapping sequences in the fragments.



29.20 Trypsin cleaves peptides at amide bonds with a carbonyl group from Arg and Lys. Chymotrypsin cleaves at amide bonds with a carbonyl group from Phe, Tyr, and Trp.

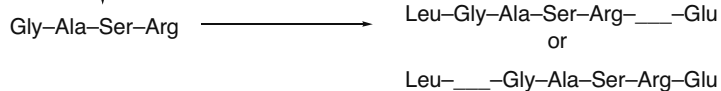
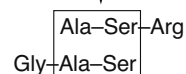
- a. [1] Gly-Ala-Phe-Leu-Lys + Ala
[2] Phe-Tyr-Gly-Cys-Arg + Ser
[3] Thr-Pro-Lys + Glu-His-Gly-Phe-Cys-Trp-Val-Val-Phe
- b. [1] Gly-Ala-Phe + Leu-Lys-Ala
[2] Phe + Tyr + Gly-Cys-Arg-Ser
[3] Thr-Pro-Lys-Glu-His-Gly-Phe + Cys-Trp + Val-Val-Phe

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29.21

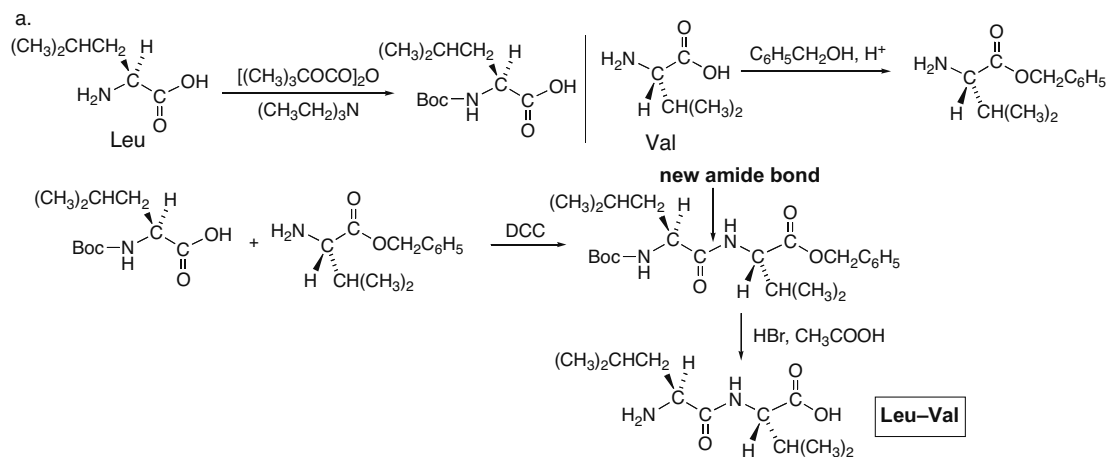
Edman degradation gives N-terminal amino acid: $\longrightarrow$ Leu-____-____-____-____-____-____
 Carboxypeptidase identifies the C-terminal amino acid: $\longrightarrow$ Leu-____-____-____-____-____-____-Glu

Partial hydrolysis
common amino acids

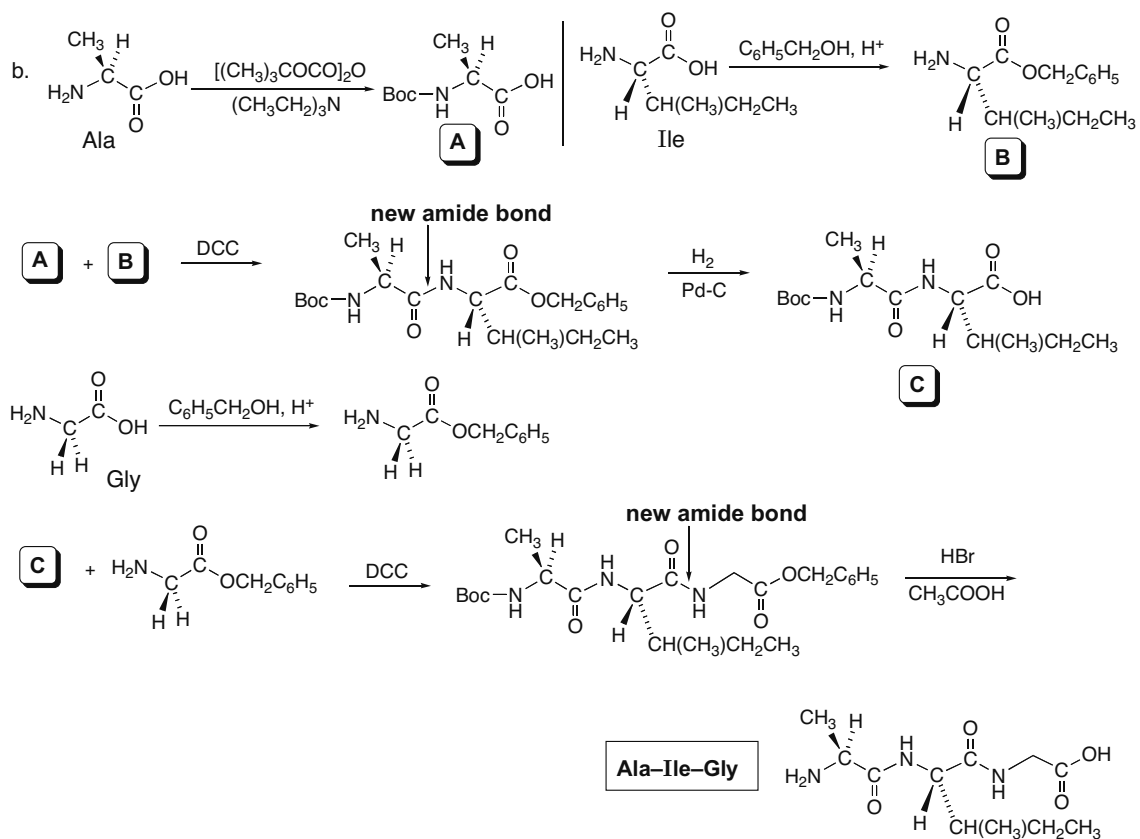


Cleavage by trypsin is after Arg and yields a dipeptide; therefore, this must be the peptide: $\longrightarrow$ Leu-Gly-Ala-Ser-Arg-Phe-Glu

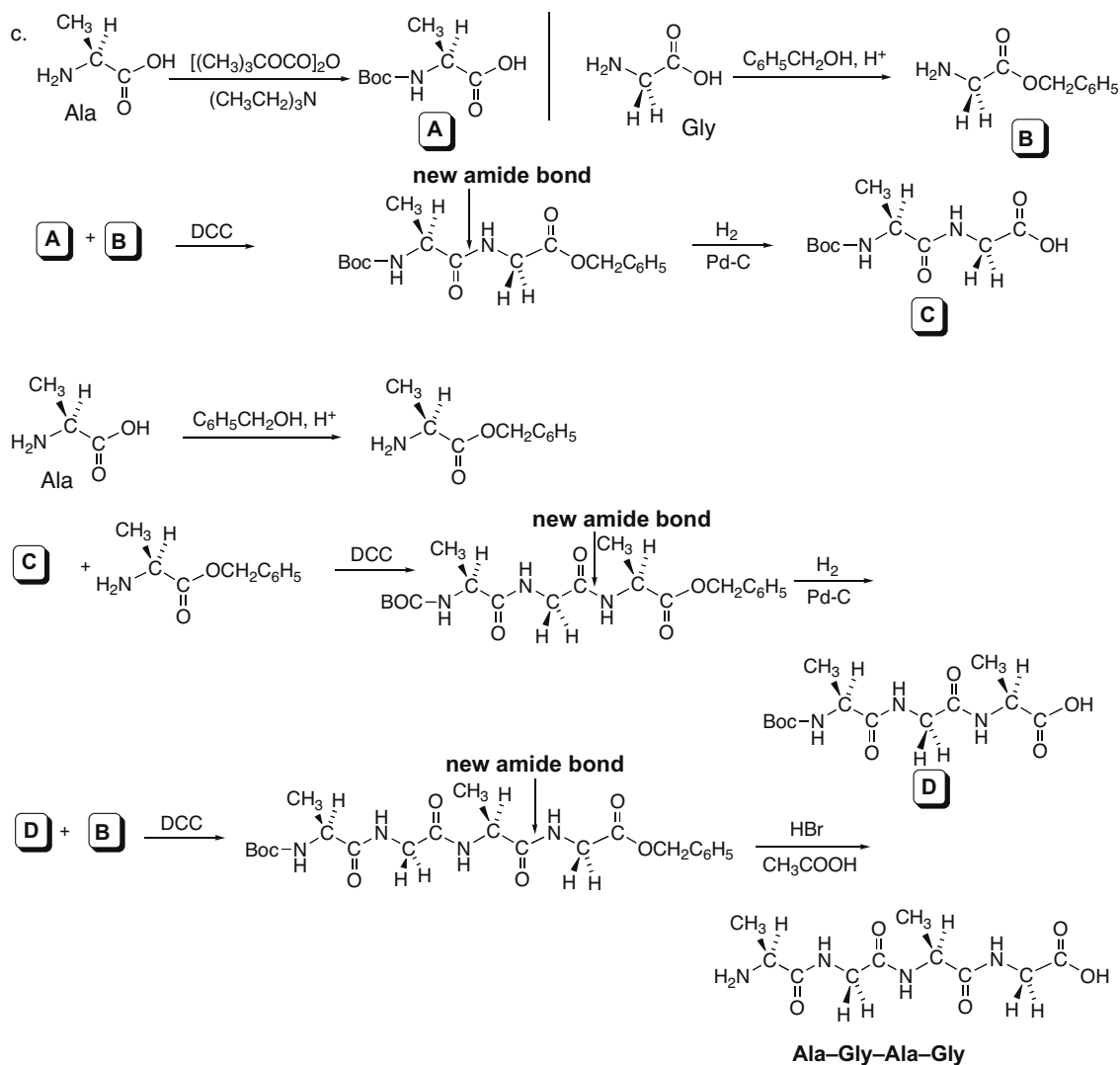
29.22



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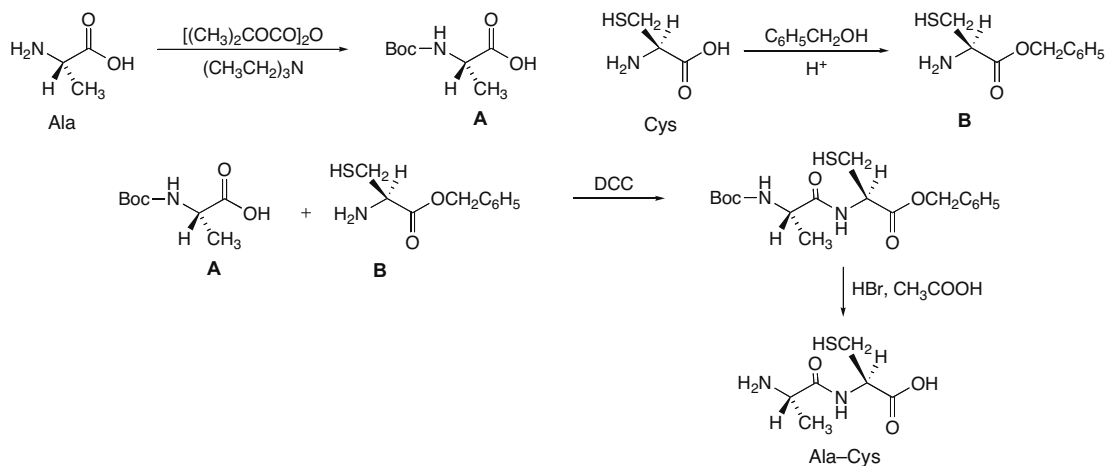


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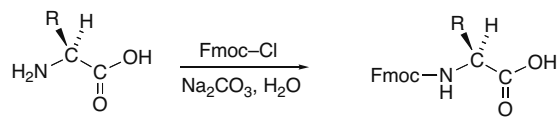


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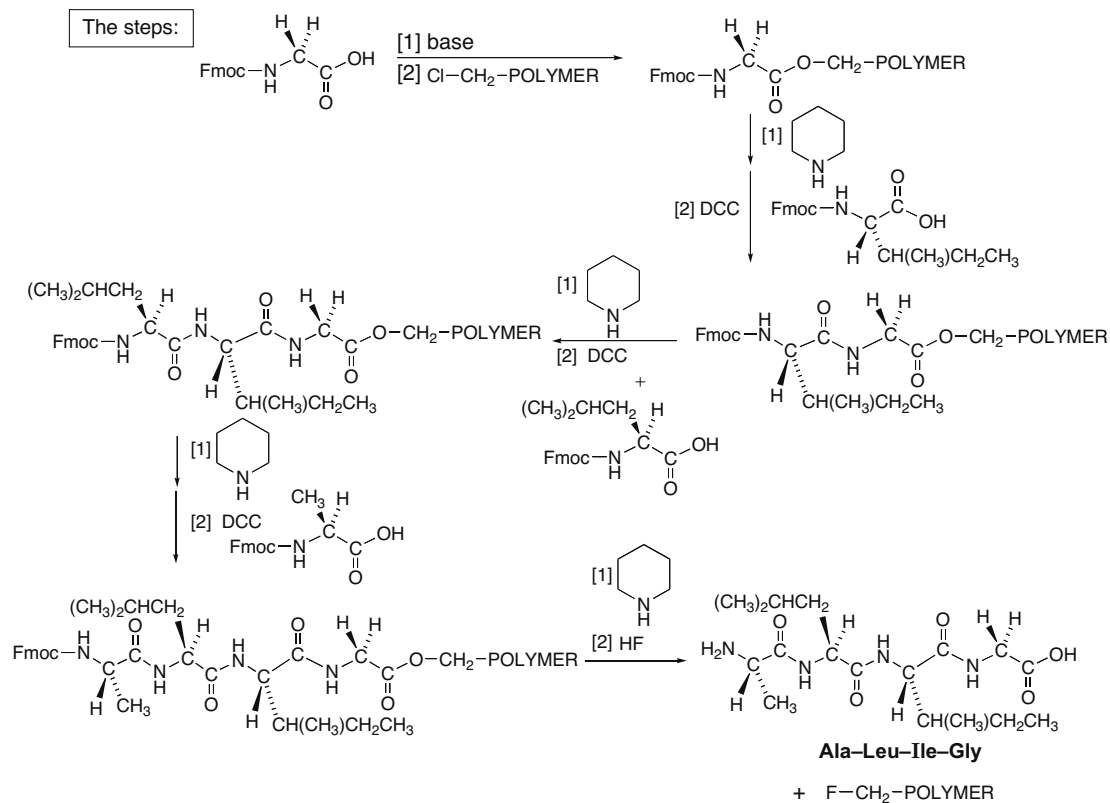
29.23 The dipeptide depicted in the 3-D model has alanine as the N-terminal amino acid and cysteine as the C-terminal amino acid.

**29.24**

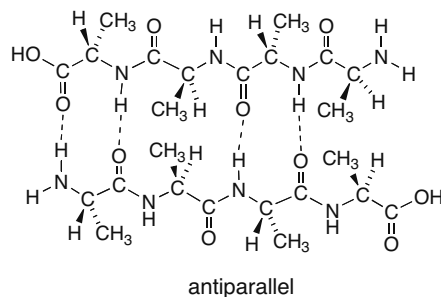
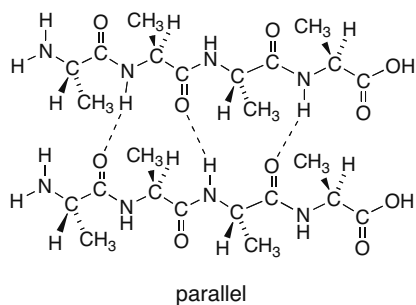
All Fmoc-protected amino acids are made by the following general reaction:



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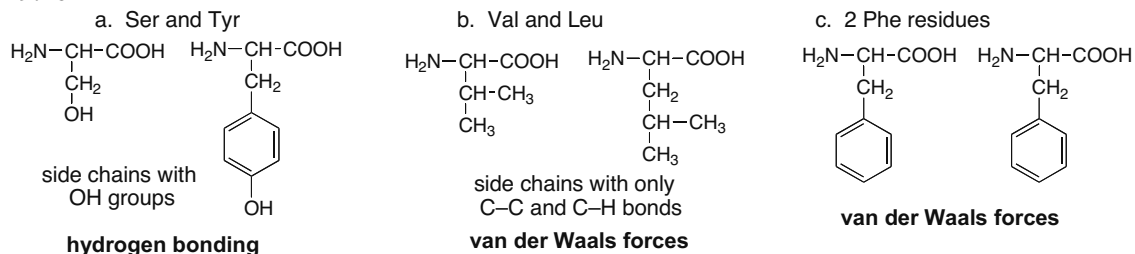


29.25 In a *parallel* β -pleated sheet, the strands run in the *same* direction from the N- to C-terminal amino acid. In an *antiparallel* β -pleated sheet, the strands run in the *opposite* direction.



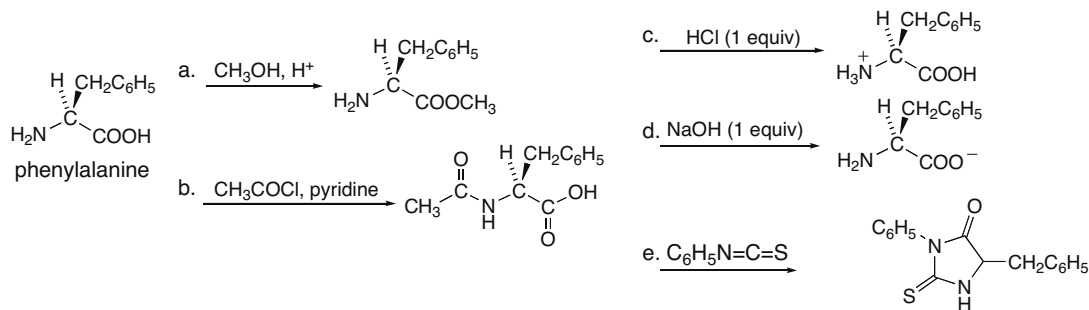
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29.26



- 29.27 a. The R group for glycine is a hydrogen. The R groups must be small to allow the β -pleated sheets to stack on top of each other. With large R groups, steric hindrance prevents stacking.
- b. Silk fibers are water insoluble because most of the polar functional groups are in the interior of the stacked sheets. The β -pleated sheets are stacked one on top of another, so few polar functional groups are available for hydrogen bonding to water.

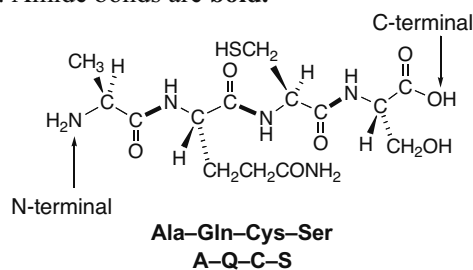
29.28



29.29

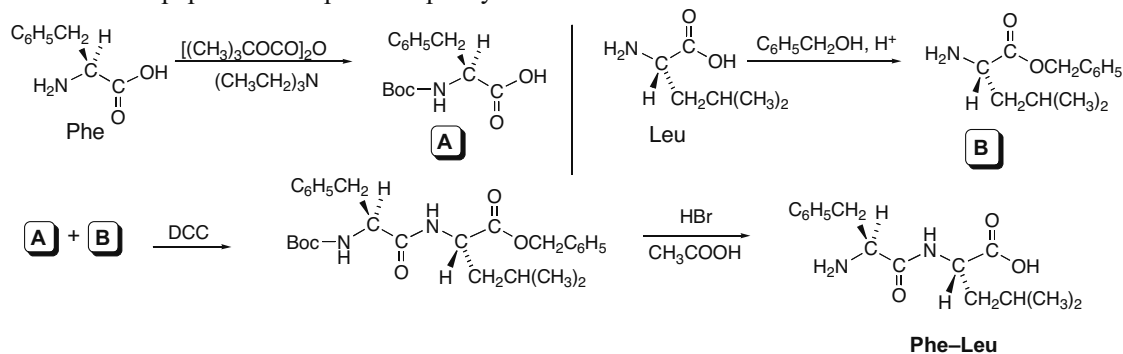
- a. N-terminal amino acid: alanine
C-terminal amino acid: serine
- b. A–Q–C–S

- c. Amide bonds are **bold**.

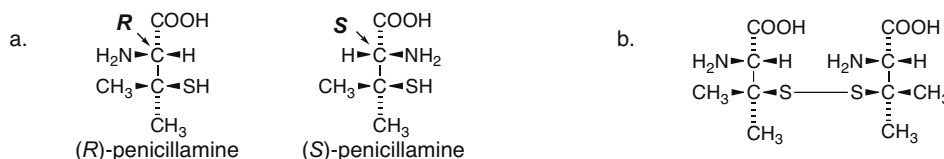


Amino Acids and Proteins 29-17

29.30 The dipeptide is composed of phenylalanine and leucine.



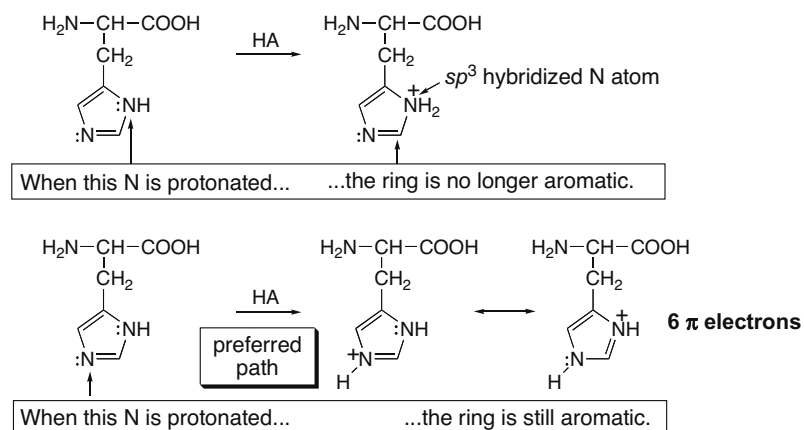
29.31



29.32 Amino acids are insoluble in diethyl ether because amino acids are highly polar; they exist as salts in their neutral form. Diethyl ether is weakly polar, so amino acids are *not* soluble in it. *N*-Acetyl amino acids are soluble because they are polar but not salts.

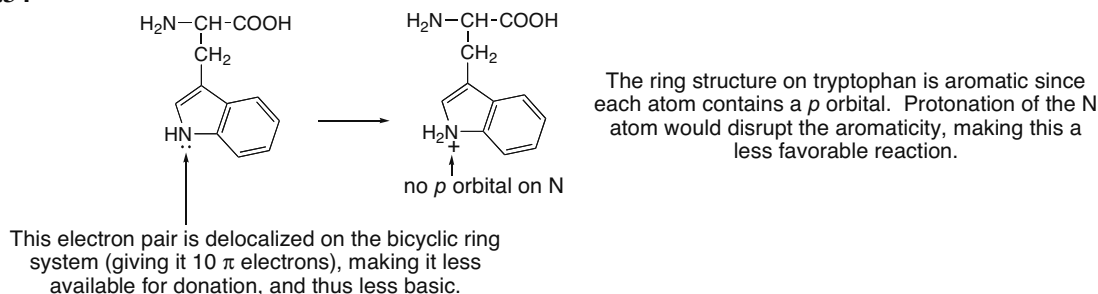


29.33 The electron pair on the N atom not part of a double bond is delocalized on the five-membered ring, making it less basic.

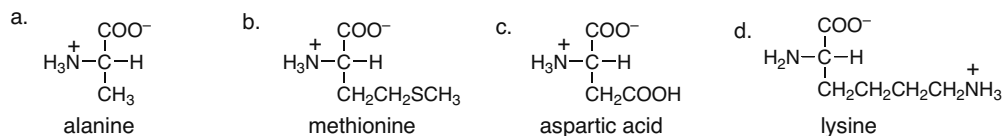


Chapter 29–18

29.34



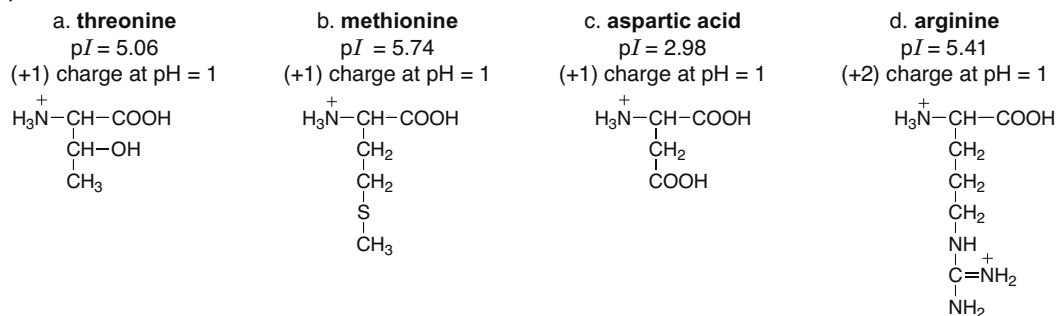
29.35 At its isoelectric point, each amino acid is neutral.



29.36

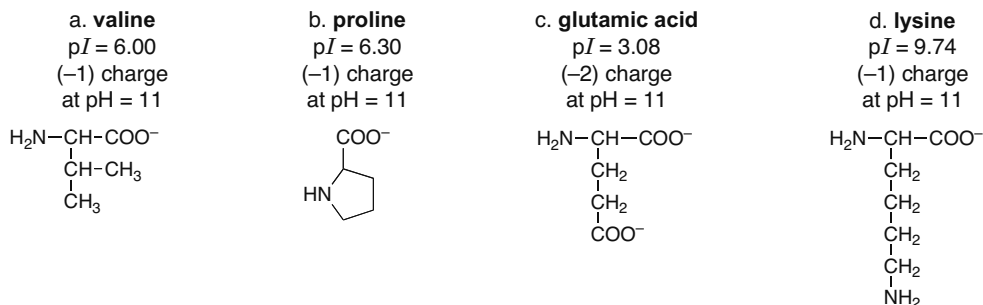
- a. [1] glutamic acid: use the pK_a 's 2.10 + 4.07
 [2] lysine: use the pK_a 's 8.95 + 10.53
 [3] arginine: use the pK_a 's 9.04 + 12.48
- b. In general, the pI of an acidic amino acid is lower than that of a neutral amino acid.
- c. In general, the pI of a basic amino acid is higher than that of a neutral amino acid.

29.37

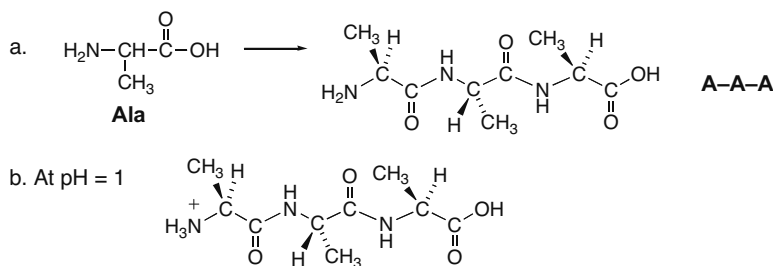


Amino Acids and Proteins 29-19

29.38



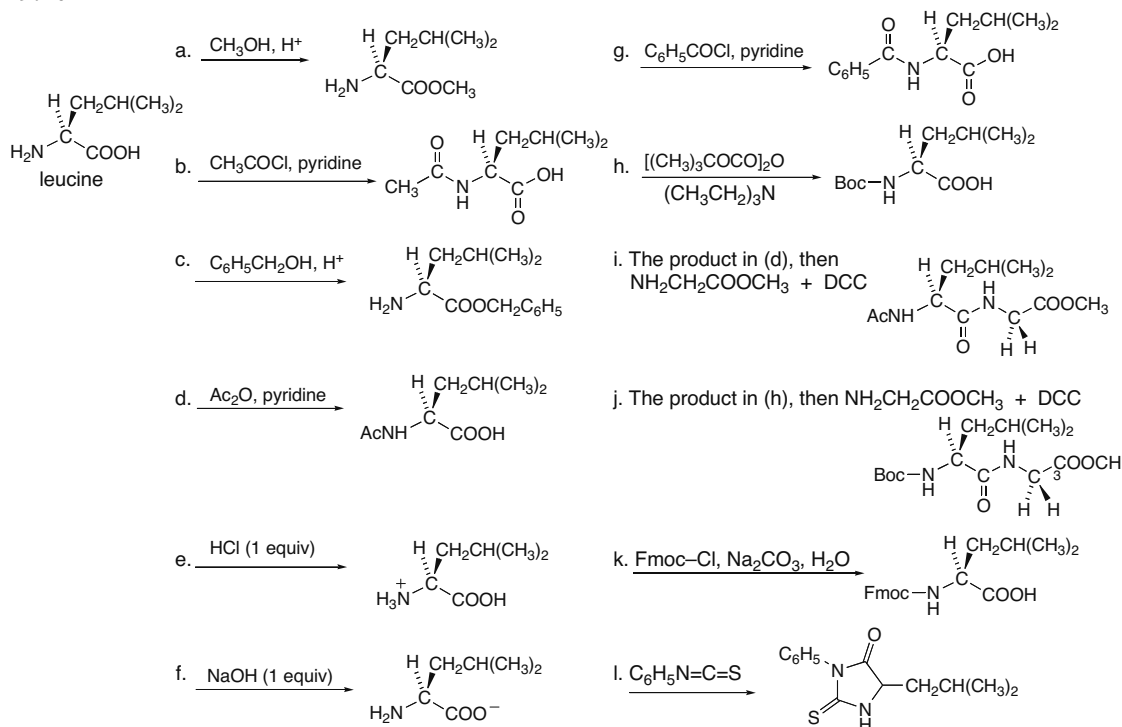
29.39 The terminal NH_2 and COOH groups are ionizable functional groups, so they can gain or lose protons in aqueous solution.



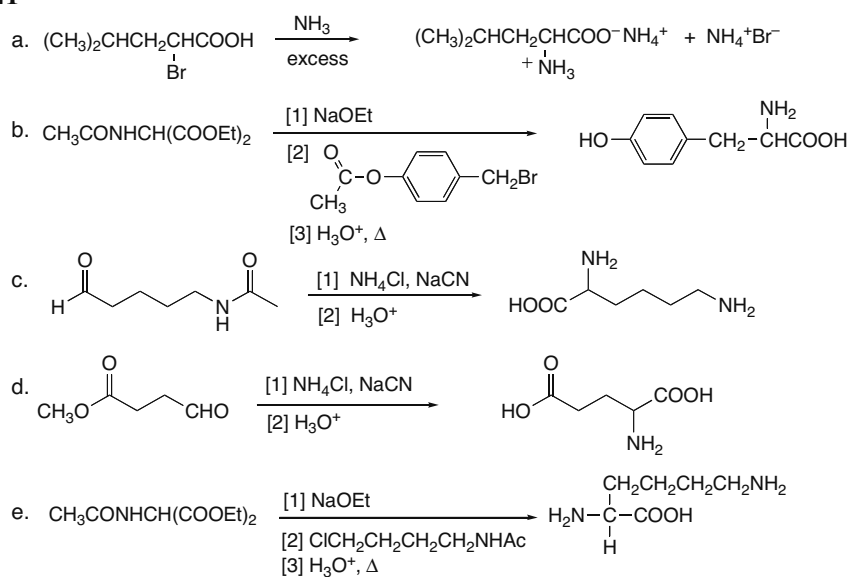
- c. The pK_a of the COOH of the tripeptide is higher than the pK_a of the COOH group of alanine, making it less acidic. This occurs because the COOH group in the tripeptide is farther away from the $-\text{NH}_3^+$ group. The positively charged $-\text{NH}_3^+$ group stabilizes the negatively charged carboxylate anion of alanine more than the carboxylate anion of the tripeptide because it is so much closer in alanine. The opposite effect is observed with the ionization of the $-\text{NH}_3^+$ group. In alanine, the $-\text{NH}_3^+$ is closer to the COO^- group, so it is more difficult to lose a proton, resulting in a higher pK_a . In the tripeptide, the $-\text{NH}_3^+$ is farther away from the COO^- , so it is less affected by its presence.

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29.40



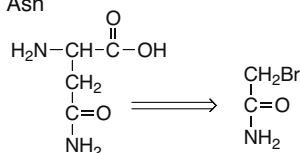
29.41



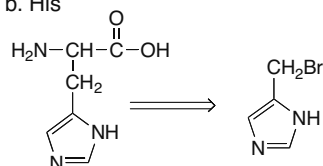
Amino Acids and Proteins 29–21

29.42

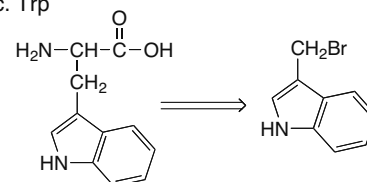
a. Asn



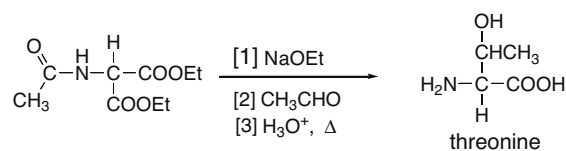
b. His



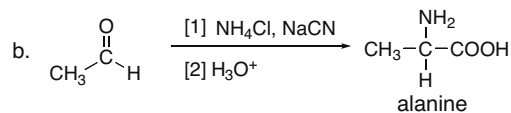
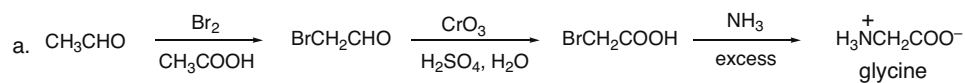
c. Trp



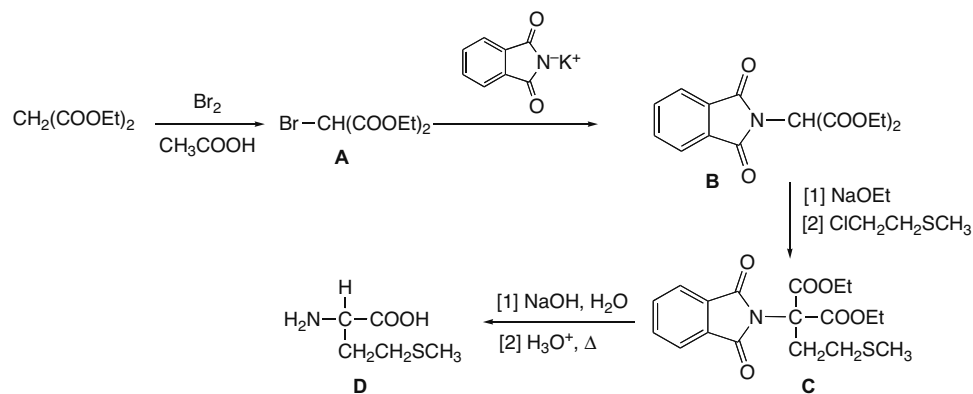
29.43



29.44

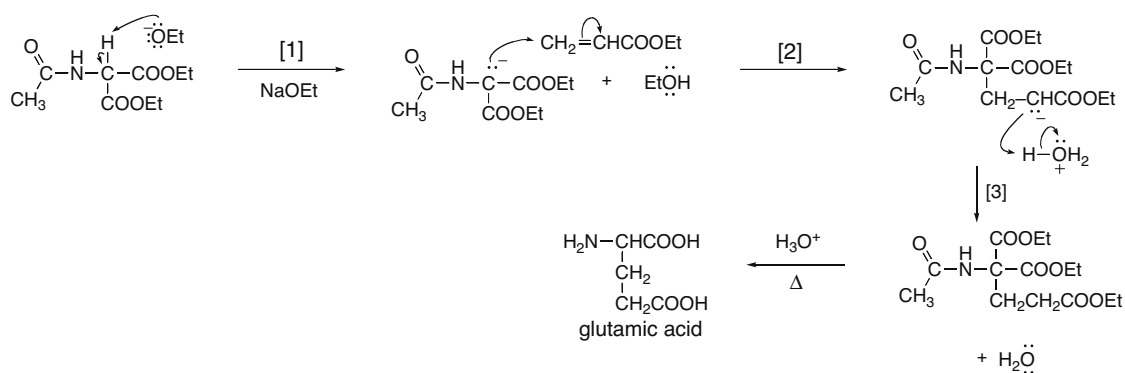


29.45

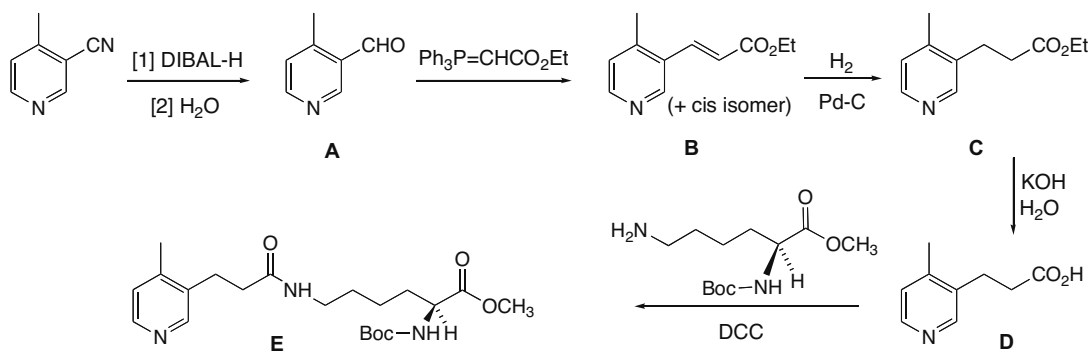


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29.46

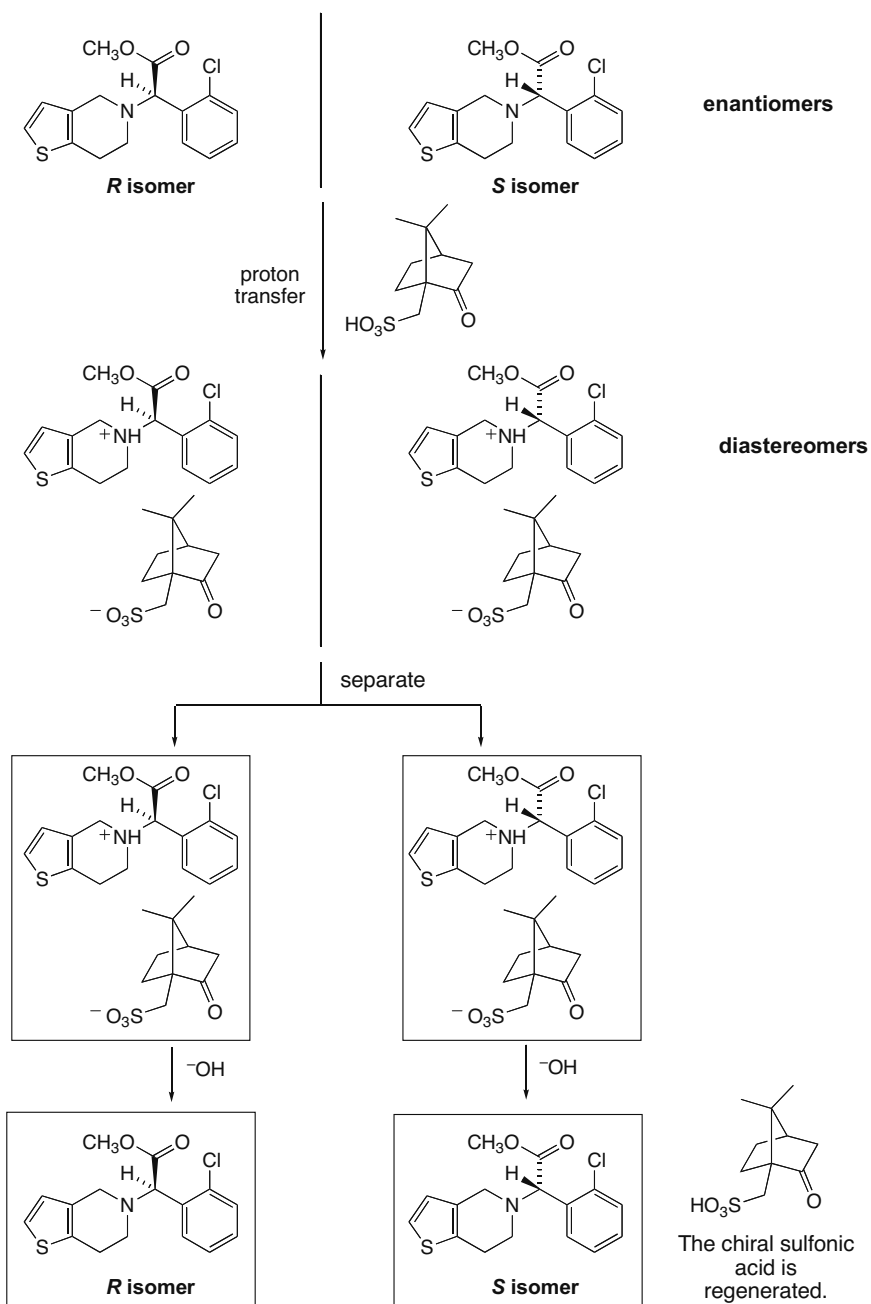


29.47



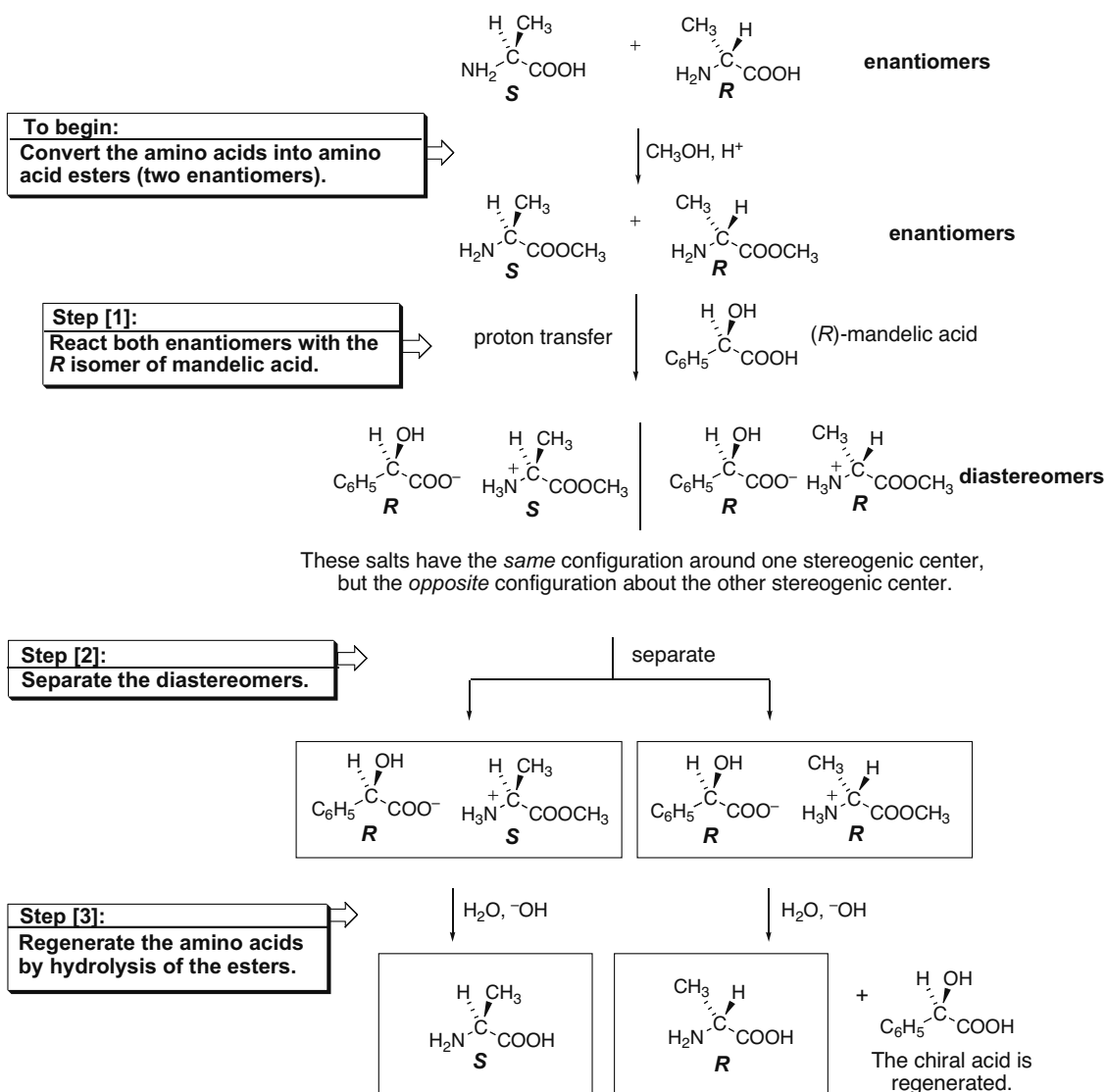
Amino Acids and Proteins 29–23

29.48



Chapter 29–24

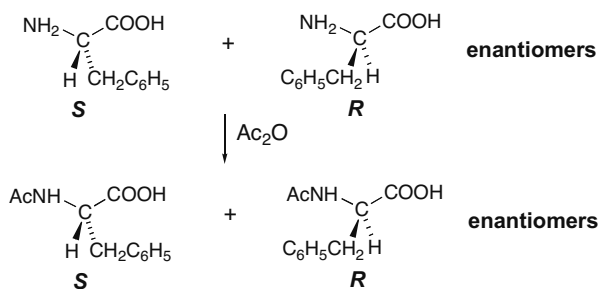
29.49



Amino Acids and Proteins 29–25

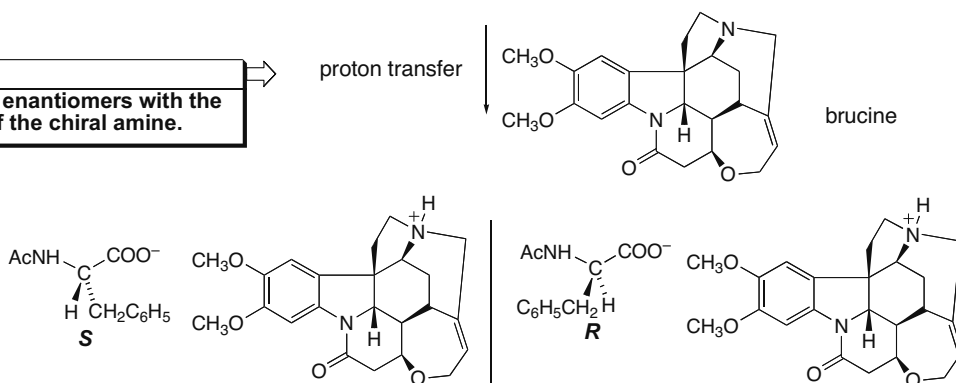
29.50

To begin:
Convert the amino acids into *N*-acetyl amino acids (two enantiomers).



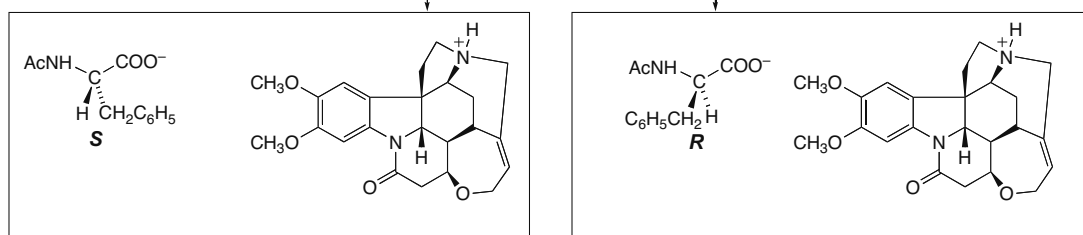
Step [1]:
React both enantiomers with the *R* isomer of the chiral amine.

proton transfer

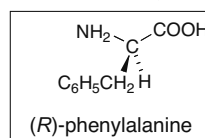
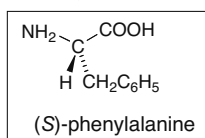


Step [2]:
Separate the diastereomers.

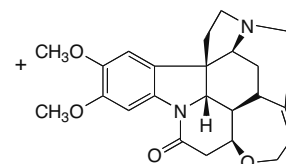
separate



Step [3]:
Regenerate the amino acid by hydrolysis of the amide.

 $\text{H}_2\text{O}, ^-\text{OH}$ $\text{H}_2\text{O}, ^-\text{OH}$ 

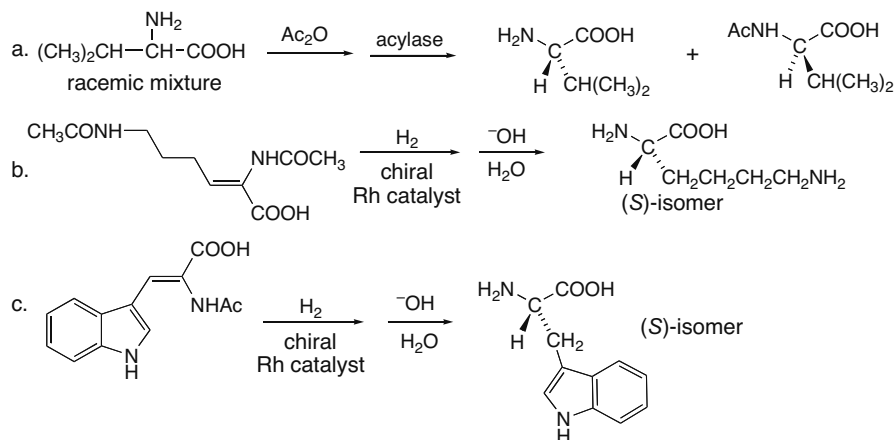
The amino acids are now separated.



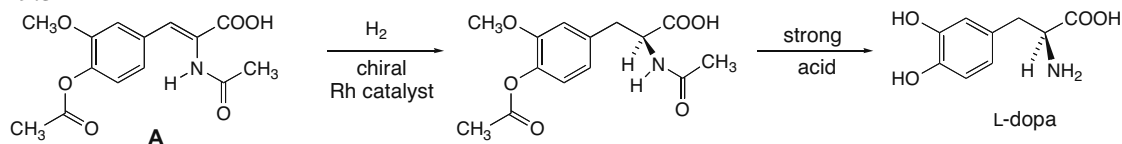
The chiral amine is also regenerated.

Chapter 29–26

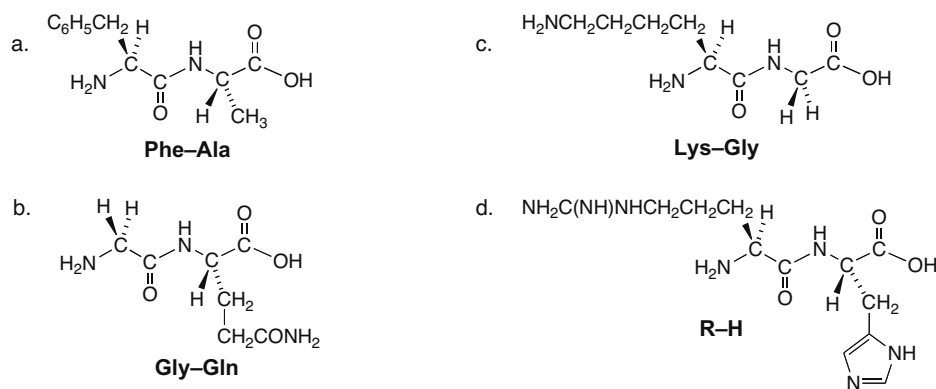
29.51



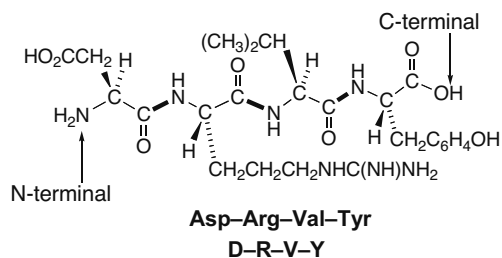
29.52



29.53

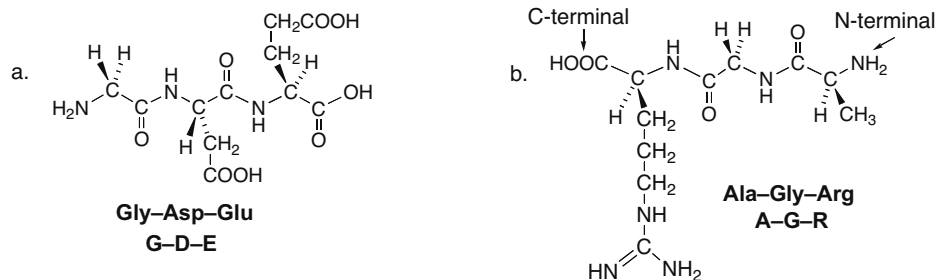


29.54 Amide bonds are bold lines (not wedges).

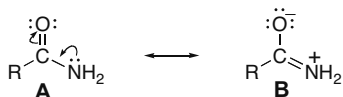


Amino Acids and Proteins 29–27

29.55 Name a peptide from the N-terminal to the C-terminal end.

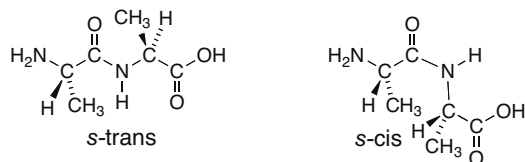


29.56 A peptide C–N bond is stronger than an ester C–O bond because the C–N bond has more double bond character due to resonance. Since N is more basic than O, an amide C–N bond is more stabilized by delocalization of the lone pair on N.



Structure **B** contributes greatly to the resonance hybrid and this shortens and strengthens the C–N bond.

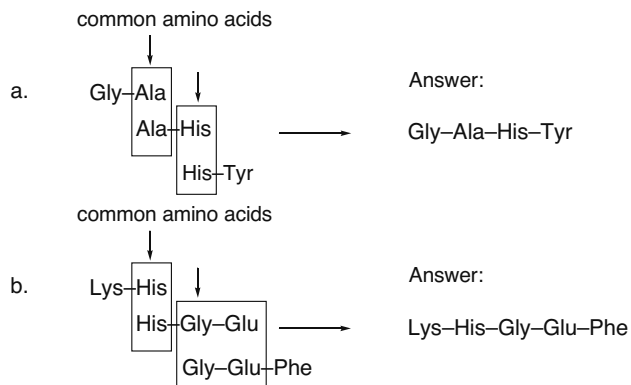
29.57



29.58

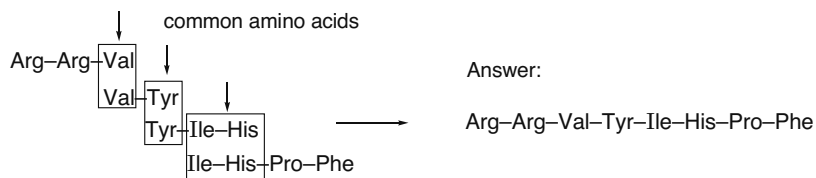
- A–P–F + L–K–W + S–G–R–G
- A–P–F–L–K + W–S–G–R + G
- A–P–F–L–K–W–S–G–R + G
- A + P–F–L–K–W–S–G–R–G

29.59

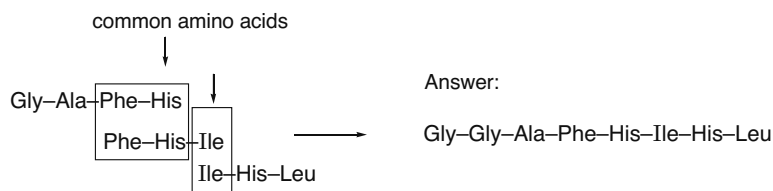


Chapter 29–28

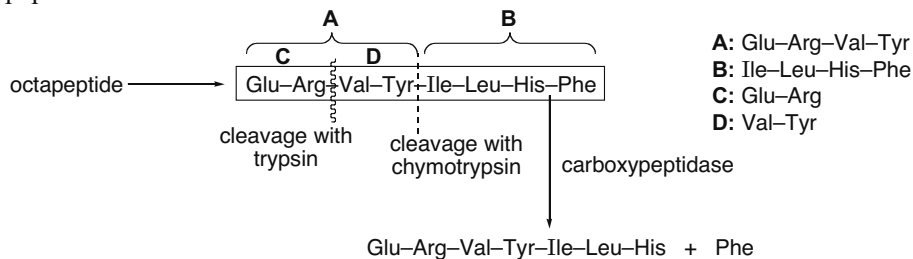
29.60



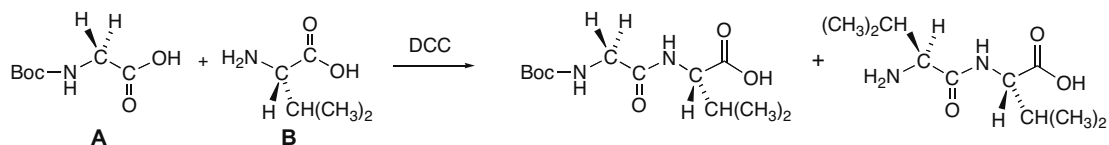
29.61 Gly is the N-terminal amino acid (from Edman degradation), and Leu is the C-terminal amino acid (from treatment with carboxypeptidase). Partial hydrolysis gives the rest of the sequence.



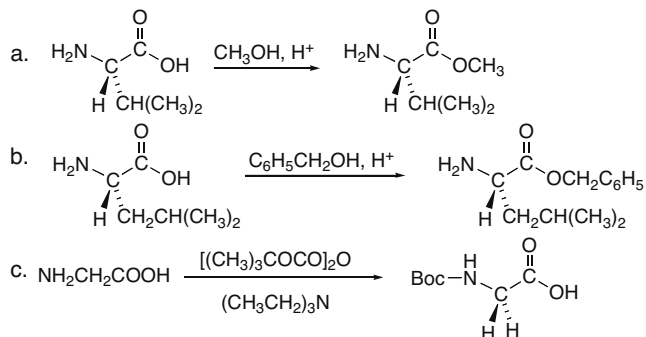
29.62 Edman degradation data give the N-terminal amino acid for the octapeptide and all smaller peptides.



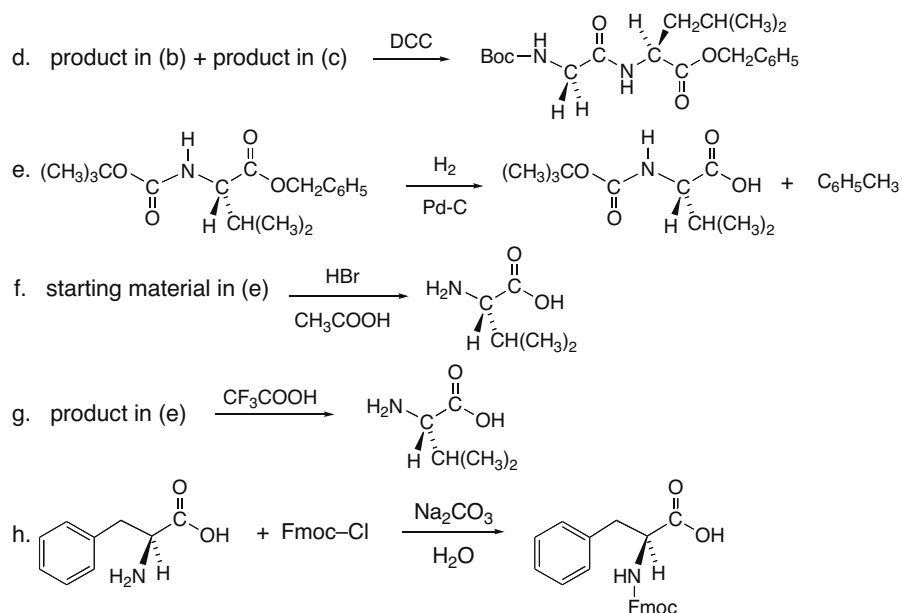
29.63 A and B can react to form an amide, or two molecules of B can form an amide.



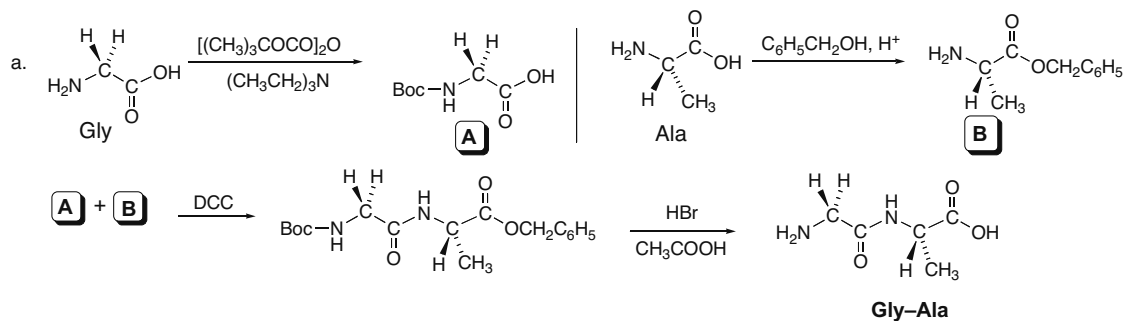
29.64



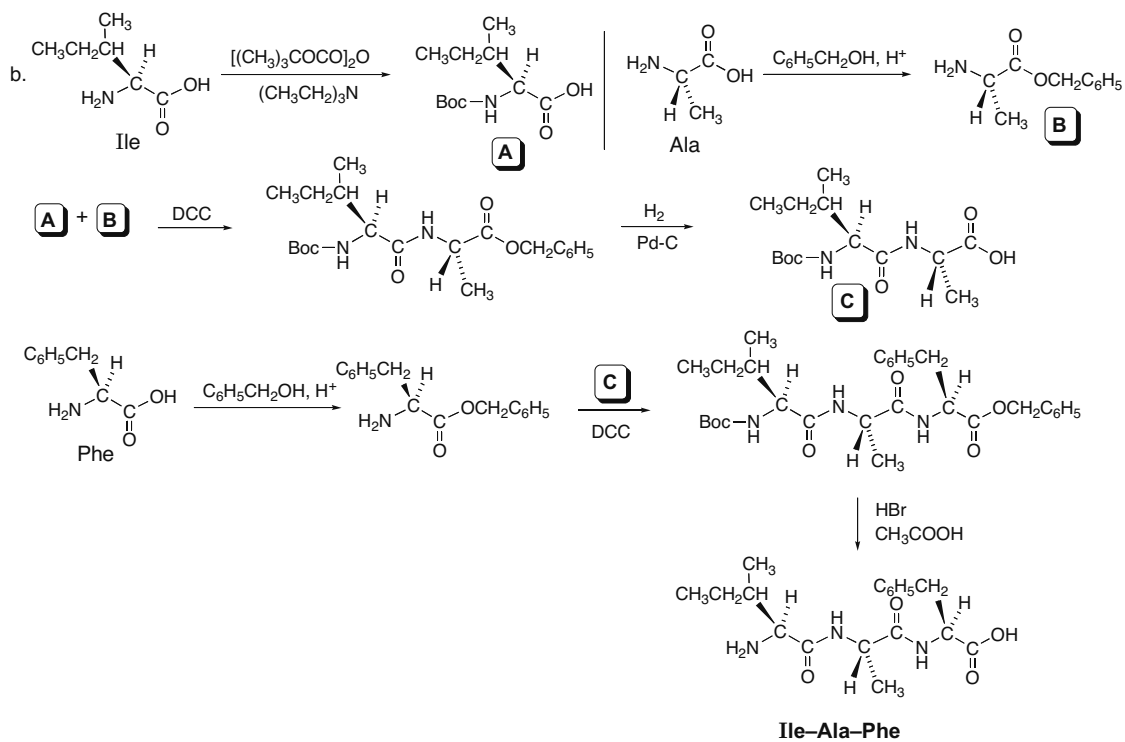
Amino Acids and Proteins 29–29



29.65

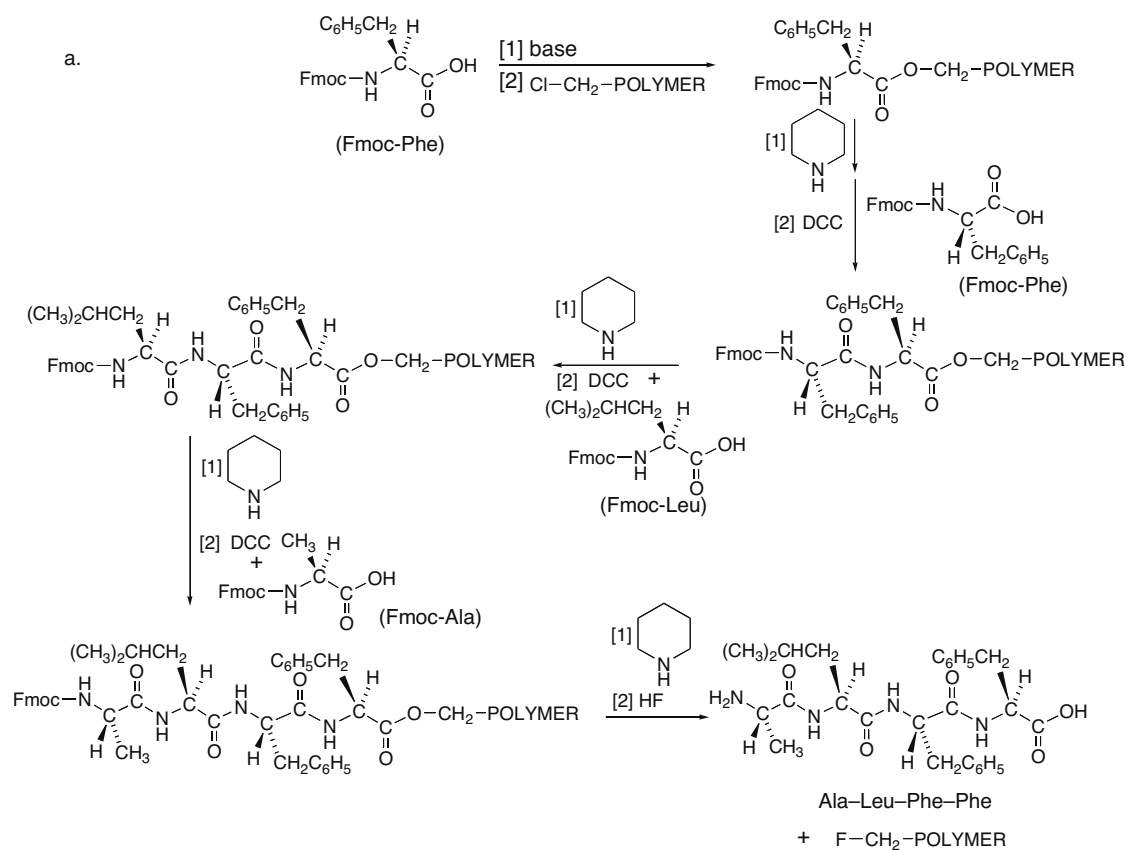


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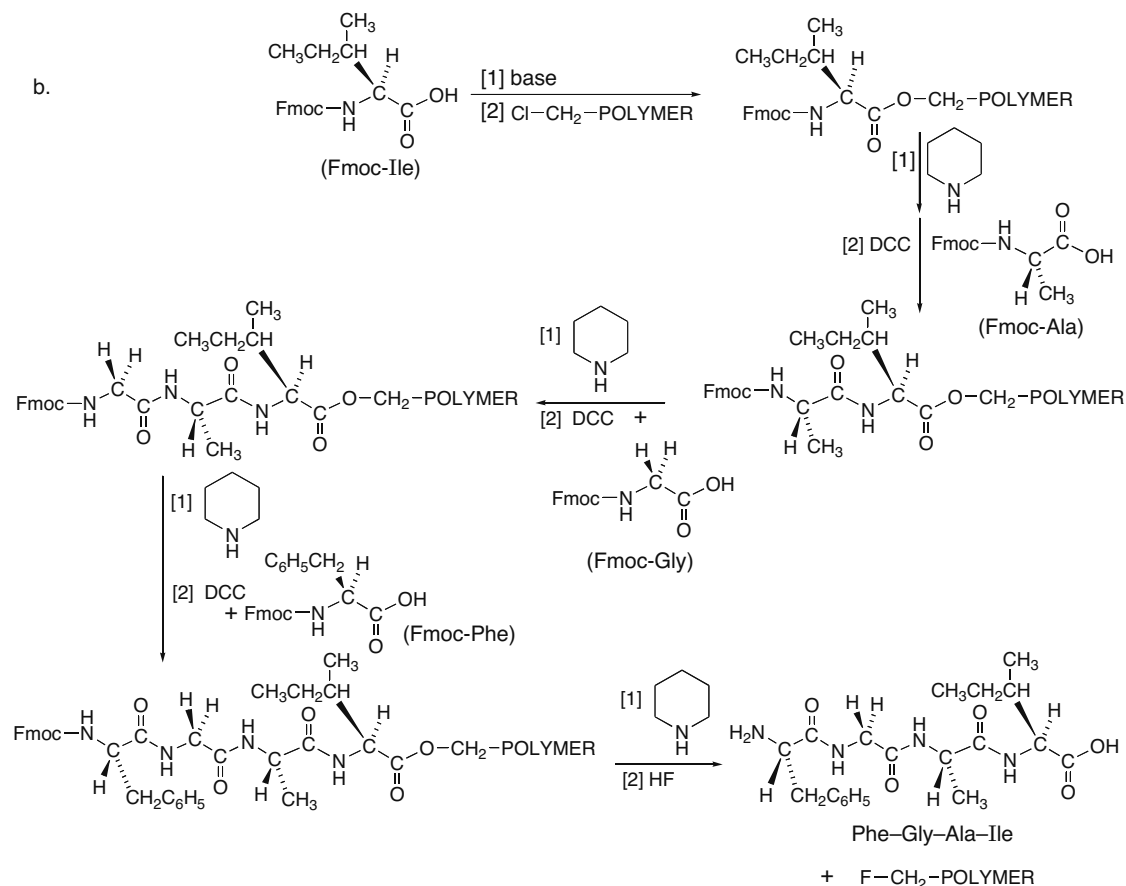


Amino Acids and Proteins 29–31

29.66 Make all the Fmoc derivatives as described in Problem 29.24.

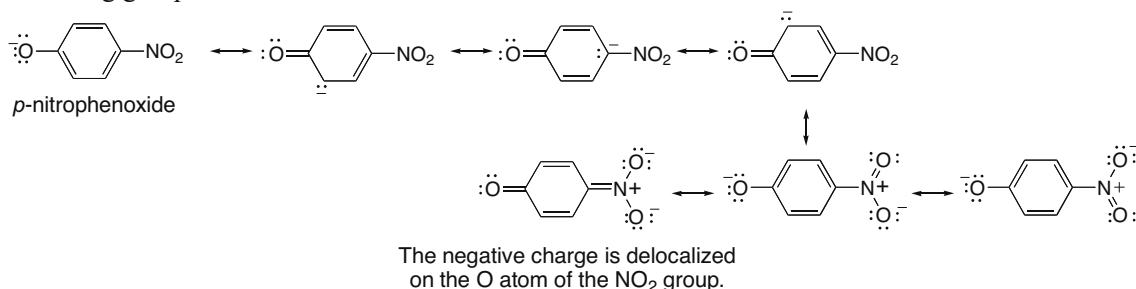


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29.67

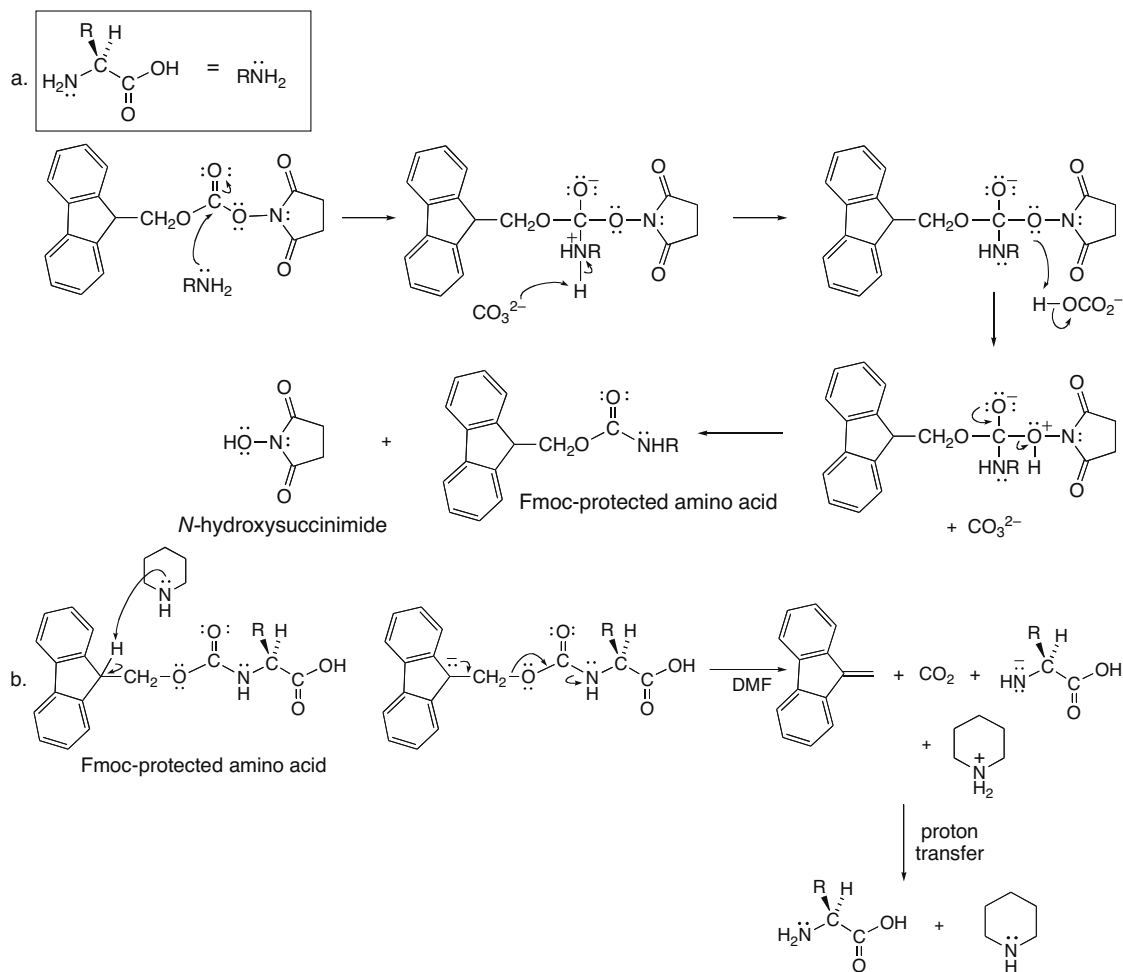
- a. A *p*-nitrophenyl ester activates the carboxy group of the first amino acid to amide formation by converting the OH group into a good leaving group, the *p*-nitrophenoxide group, which is highly resonance stabilized. In this case the electron-withdrawing NO₂ group further stabilizes the leaving group.



- b. The *p*-methoxyphenyl ester contains an electron-donating OCH₃ group, making CH₃OC₆H₄O[−] a poorer leaving group than NO₂C₆H₄O[−], so this ester does not activate the amino acid to amide formation as much.

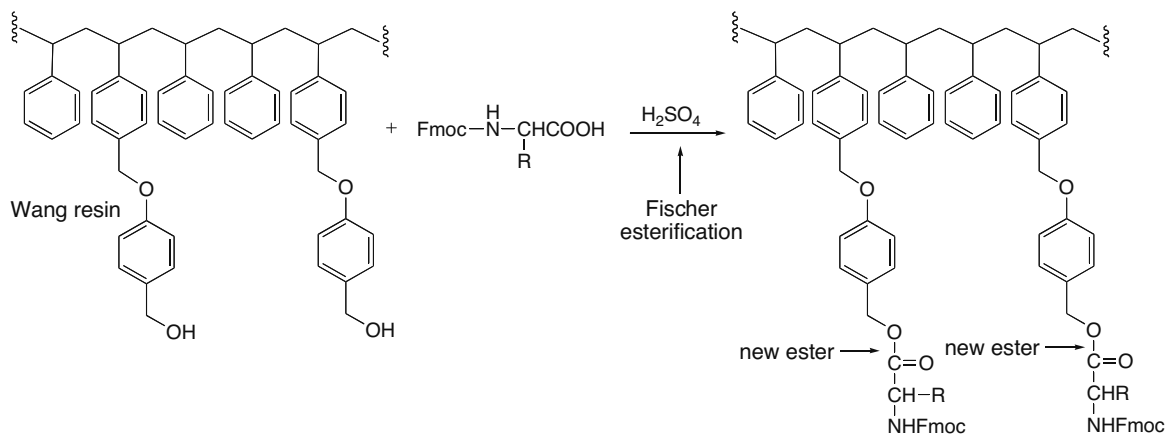
Amino Acids and Proteins 29–33

29.68



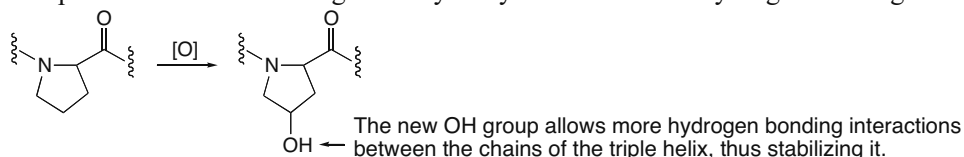
29.69 Reaction of the OH groups of the Wang resin with the COOH group of the Fmoc-protected amino acids would form esters by Fischer esterification. After the peptide has been synthesized, the esters can be hydrolyzed with aqueous acid or base, but the conditions cannot be too harsh to break the amide bond or cause epimerization.

Chapter 29–34

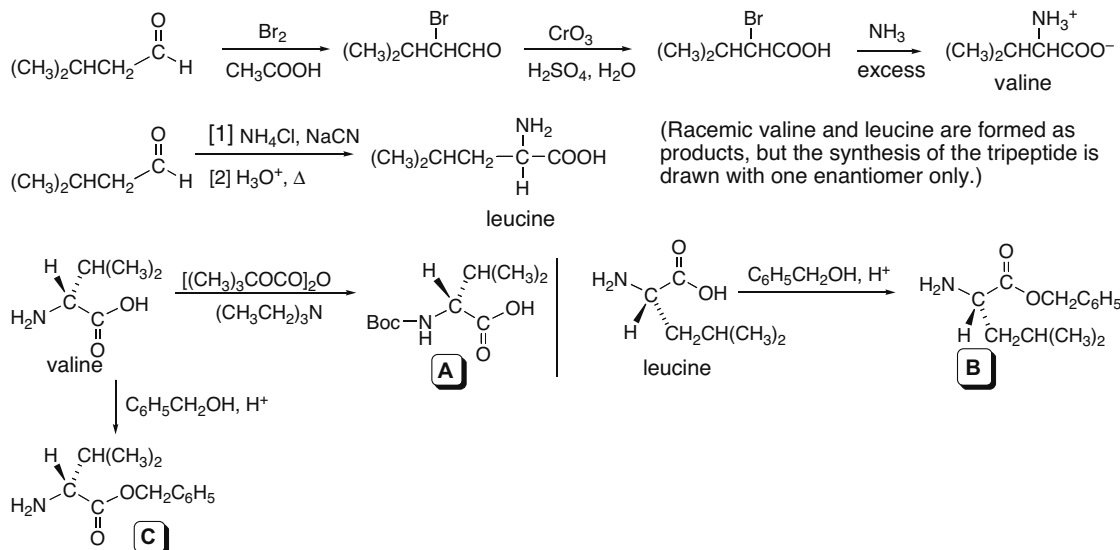


29.70 Amino acids commonly found in the interior of a globular protein have nonpolar or weakly polar side chains: isoleucine and phenylalanine. Amino acids commonly found on the surface have COOH, NH₂, and other groups that can hydrogen bond to water: aspartic acid, lysine, arginine, and glutamic acid.

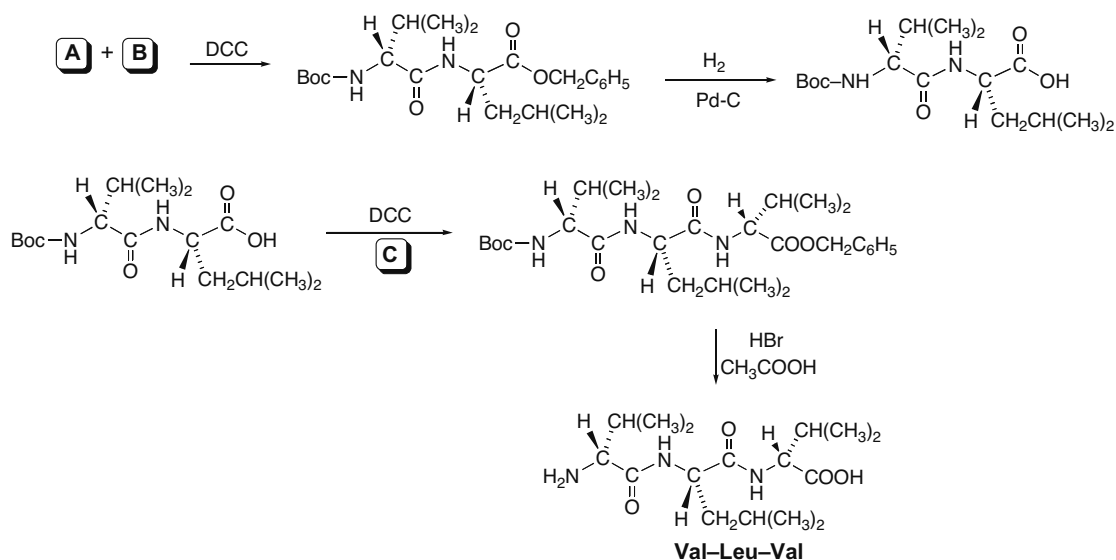
29.71 The proline residues on collagen are hydroxylated to increase hydrogen bonding interactions.



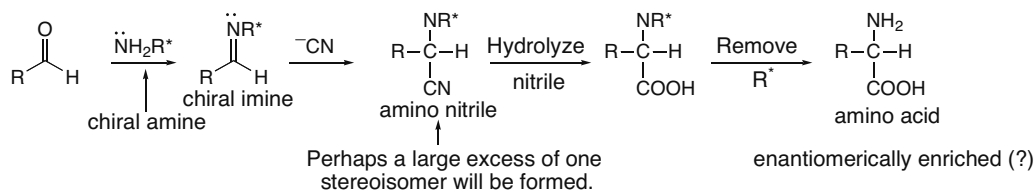
29.72



Amino Acids and Proteins 29–35

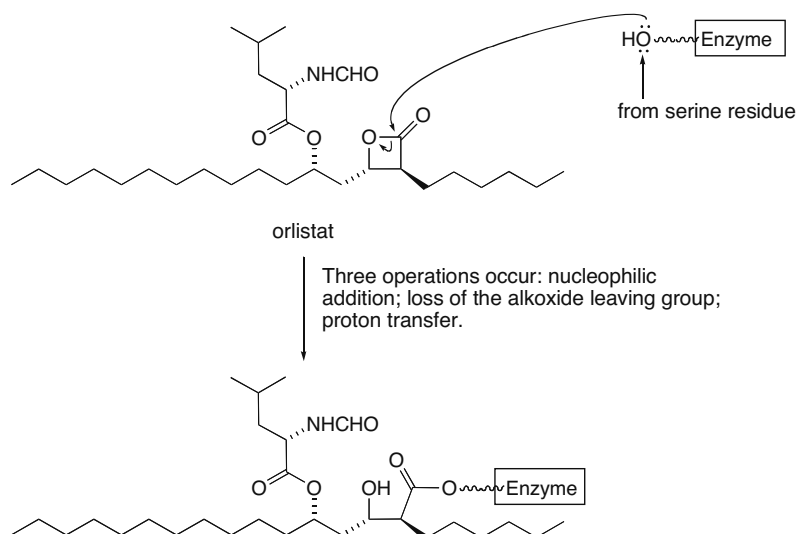


- 29.73** Perhaps using a chiral amine R^*NH_2 (or related chiral nitrogen-containing compound) to make a chiral imine, will now favor formation of one of the amino nitriles in the Strecker synthesis. Hydrolysis of the CN group and removal of R^* would then form the amino acid.

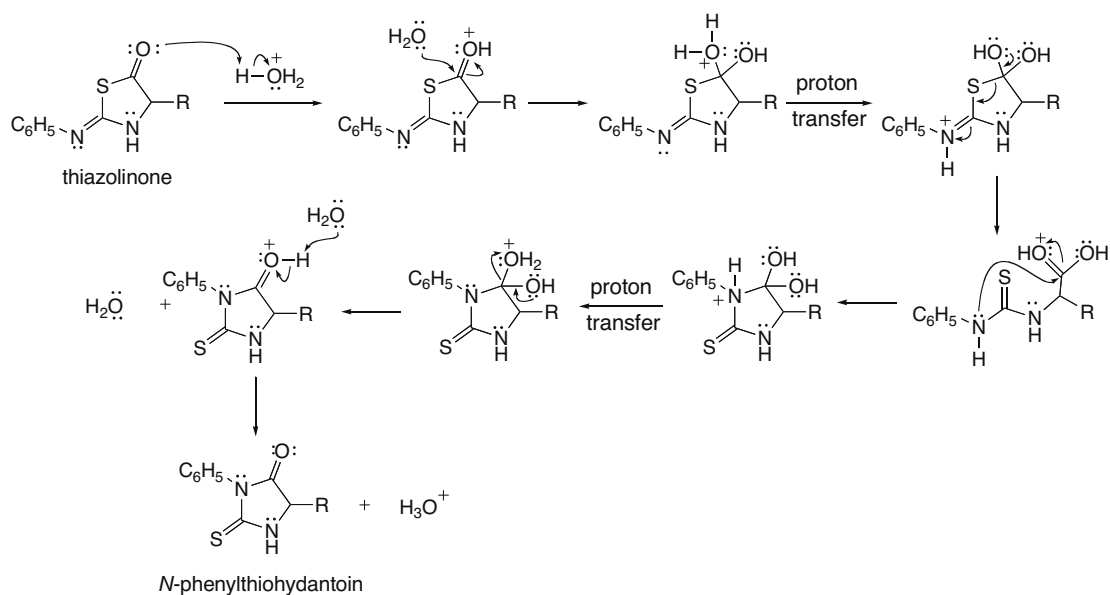


- 29.74** This reaction is similar to the reaction of penicillin with the glycopeptide transpeptidase enzyme discussed in Section 22.14. Serine has a nucleophilic OH, which can open the strained β -lactone to form a covalently bound, inactive enzyme.

Chapter 29–36



29.75

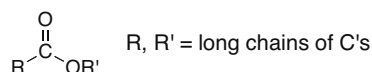


Chapter 30 Lipids

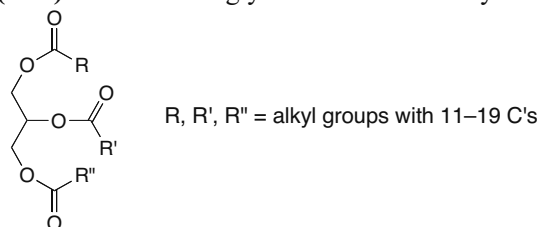
Chapter Review

Hydrolyzable lipids

[1] **Waxes (30.2)**—Esters formed from a long-chain alcohol and a long-chain carboxylic acid

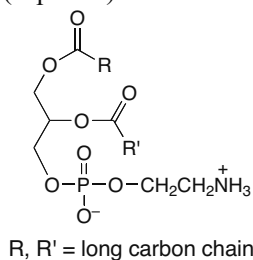


[2] **Triacylglycerols (30.3)**—Triesters of glycerol with three fatty acids

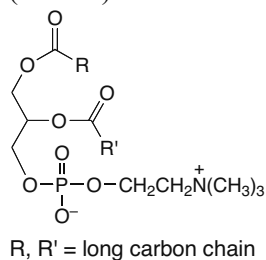


[3] **Phospholipids (30.4)**

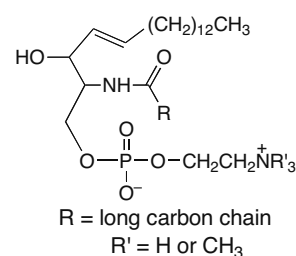
[a] **Phosphatidylethanolamine (cephalin)**



[b] **Phosphatidylcholine (lecithin)**



[c] **Sphingomyelin**



Nonhydrolyzable lipids

[1] **Fat-soluble vitamins (30.5)**—Vitamins A, D, E, and K

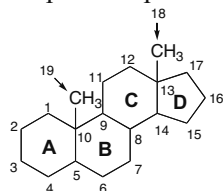
[2] **Eicosanoids (30.6)**—Compounds containing 20 carbons derived from arachidonic acid. There are four types: prostaglandins, thromboxanes, prostacyclins, and leukotrienes.

[3] **Terpenes (30.7)**—Lipids composed of repeating five-carbon units called isoprene units

Isoprene unit	Types of terpenes			
$\begin{array}{c} \text{C} \\ \\ \text{C}-\text{C} \\ \quad \\ \text{C} \quad \text{C} \end{array}$	[1] monoterpene	10 C's	[4] sesterterpene	25 C's
	[2] sesquiterpene	15 C's	[5] triterpene	30 C's
	[3] diterpene	20 C's	[6] tetraterpene	40 C's

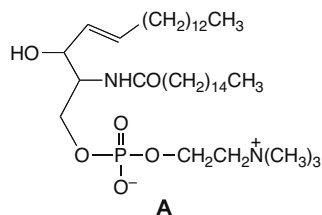
Chapter 30-2

[4] Steroids (30.8)—Tetracyclic lipids composed of three six-membered and one five-membered ring



Practice Test on Chapter Review

1. a. Which of the following compounds contains an ester?
 1. a wax
 2. a cephalin
 3. a sphingomyelin
 4. Both [1] and [2] contain esters.
 5. Compounds [1], [2], and [3] all contain esters.
- b. Which of the following compounds is an eicosanoid?
 1. a leukotriene
 2. a thromboxane
 3. a prostaglandin
 4. Both [1] and [2] are eicosanoids.
 5. Compounds [1], [2], and [3] are all eicosanoids.
- c. Which of the following statements is (are) true about **A**?

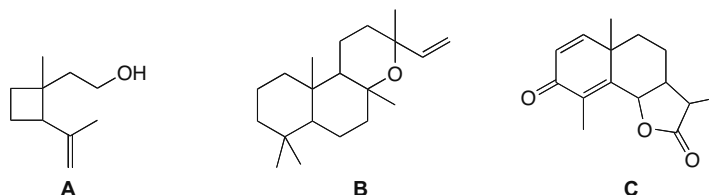


1. **A** is a lecithin.
 2. **A** is a phosphoacylglycerol.
 3. **A** has two tetrahedral stereogenic centers.
 4. Both [1] and [2] are true.
 5. Statements [1], [2], and [3] are all true.
2. Label each compound as a (1) hydrolyzable or (2) nonhydrolyzable lipid.

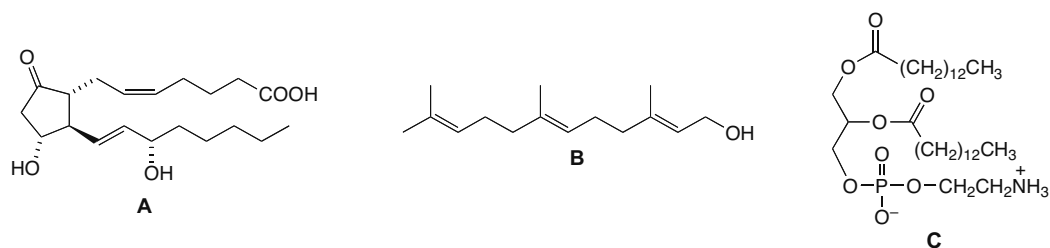
a. a triacylglycerol	e. oleic acid
b. vitamin A	f. PGE ₁
c. cholesterol	g. a wax
d. a lecithin	h. a phosphoacylglycerol

Lipids 30-3

3. For each compound: How many isoprene units does the compound contain? Classify the compound as a monoterpene, sesquiterpenoid, etc.



4. Answer True (T) or False (F) for each statement.
- Eicosanoids are biosynthesized from dimethylallyl diphosphate and isopentenyl diphosphate.
 - Prostaglandins are biosynthesized from arachidonic acid.
 - Fats have lower melting points than oils, and are generally solids at room temperature.
 - A cephalin is one type of phosphoacylglycerol.
 - Sphingomyelins possess a polar head and two nonpolar tails.
 - A sesterterpene contains six isoprene units.
 - The typical steroid skeleton has four six-membered rings joined with trans ring fusions.
 - Waxes are high molecular weight lipids formed from a fatty acid and a long-chain amine.
5. Which terms describe each compound: (a) hydrolyzable lipid; (b) triacylglycerol; (c) phosphoacylglycerol; (d) phospholipid; (e) nonhydrolyzable lipid; (f) prostaglandin; (g) terpenoid? More than one term may apply to a compound.



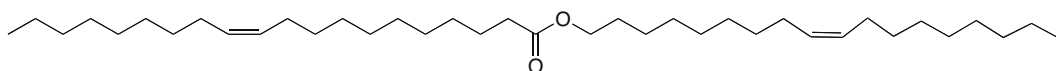
Answers to Practice Test

1. a. 4	2. a. 1	3. A : 2, monoterpene	4. a. F	5. A : e, f
b. 5	b. 2	B : 4, diterpene	b. T	B : e, g
c. 3	c. 2	C : 3, sesquiterpene	c. F	C : a, c, d
	d. 1		d. T	
	e. 2		e. T	
	f. 2		f. F	
	g. 1		g. F	
	h. 1		h. F	

Chapter 30-4

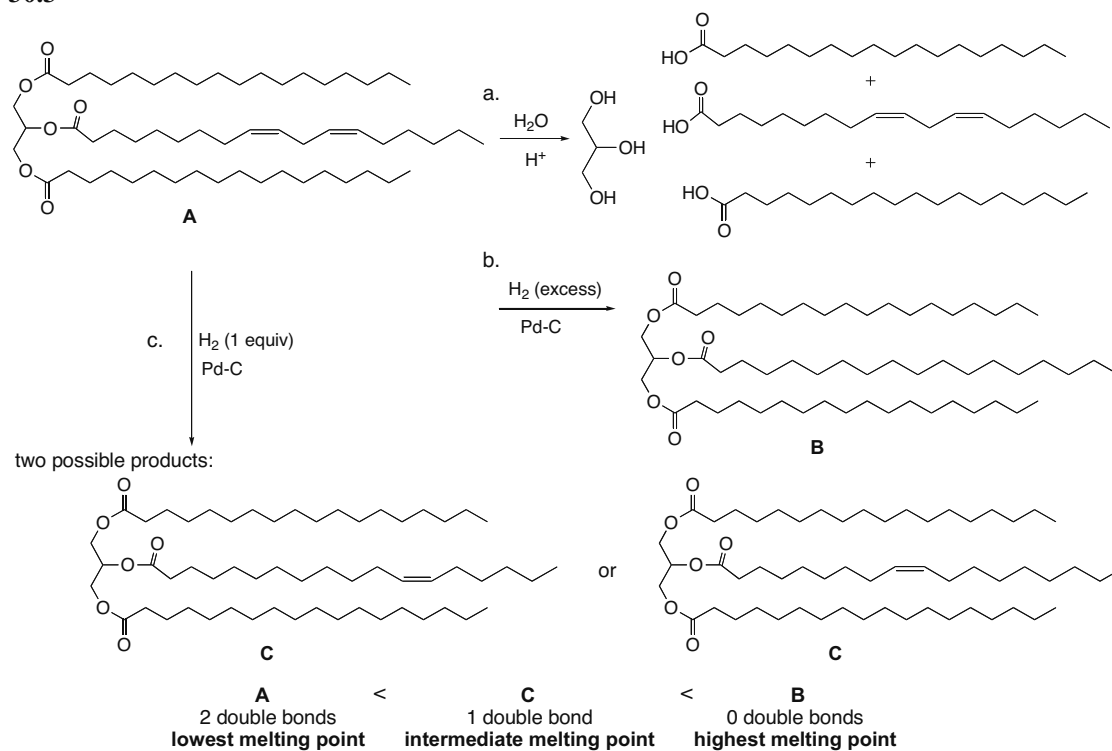
Answers to Problems

30.1 Join the carboxylic acid and alcohol together to form an ester.

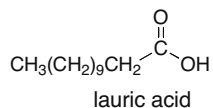


30.2 Eicosapentaenoic acid has 20 C's and 5 C=C's. Since an increasing number of double bonds decreases the melting point, eicosapentaenoic acid should have a melting point lower than arachidonic acid; that is, $< -49^{\circ}\text{C}$.

30.3



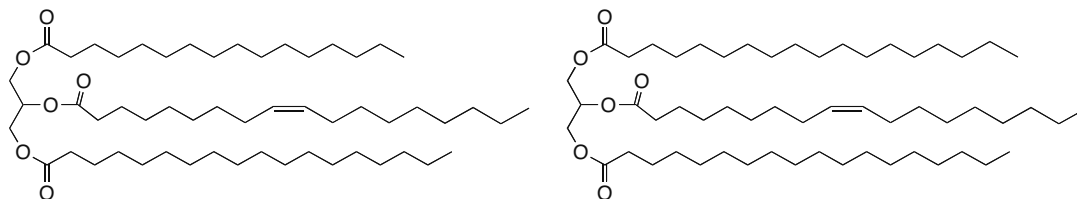
30.4



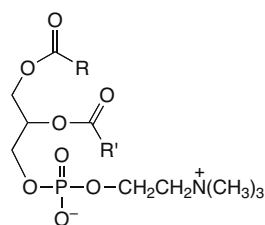
Lauric acid is a saturated fatty acid but has only 12 C's. The carbon chain is much shorter than palmitic acid (16 C's) and stearic acid (18 C's), making coconut oil a liquid at room temperature.

Lipids 30–5

30.5

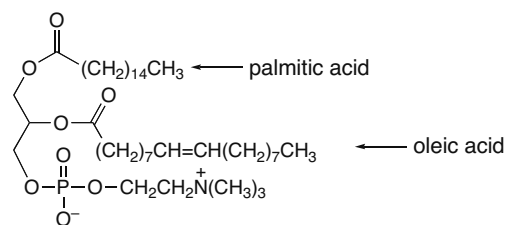


30.6 A lecithin is a type of phosphoacylglycerol. Two of the hydroxy groups of glycerol are esterified with fatty acids. The third OH group is part of a phosphodiester, which is also bonded to another low molecular weight alcohol.

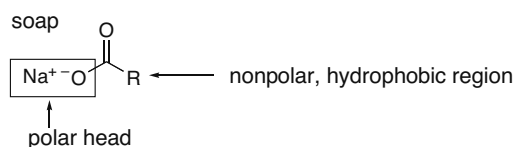
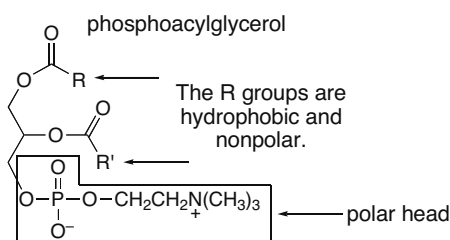


general structure
of a lecithin

one possibility:



30.7 Soaps and phosphoacylglycerols have hydrophilic and hydrophobic components. Both compounds have an ionic “head” that is attracted to polar solvents like H_2O . This head is small in size compared to the hydrophobic region, which consists of one or two long hydrocarbon chains. These nonpolar chains consist of only C–C and C–H bonds and exhibit only van der Waals forces.

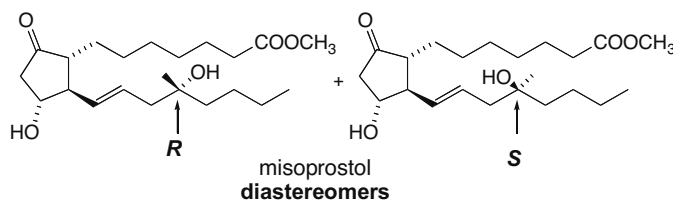


30.8 Phospholipids have a polar (ionic) head and two nonpolar tails. These two regions, which exhibit very different forces of attraction, allow the phospholipids to form a bilayer with a central hydrophobic region that serves as a barrier to agents crossing a cell membrane, while still possessing an ionic head to interact with the aqueous environment inside and outside the cell. Two different regions are needed in the molecule. Triacylglycerols have three polar, uncharged ester groups, but they are not nearly as polar as phospholipids. They do not have an ionic head with nonpolar tails and so they do not form bilayers. They are largely nonpolar C–C and C–H bonds so they are not attracted to an aqueous medium, making them H_2O insoluble.

Chapter 30–6

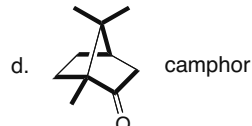
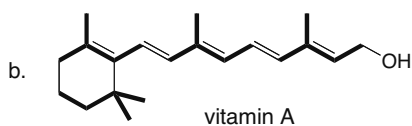
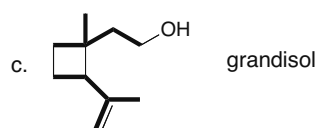
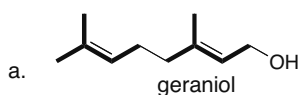
30.9 Fat-soluble vitamins are hydrophobic and therefore are readily stored in the fatty tissues of the body. Water-soluble vitamins, on the other hand, are readily excreted in the urine, so large concentrations cannot build up in the body.

30.10

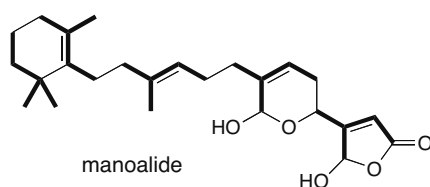


Only one tetrahedral stereogenic center is different in these two compounds.

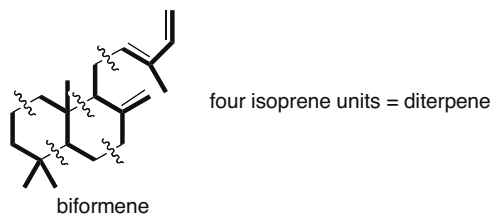
30.11 Isoprene units are shown in bold.



30.12

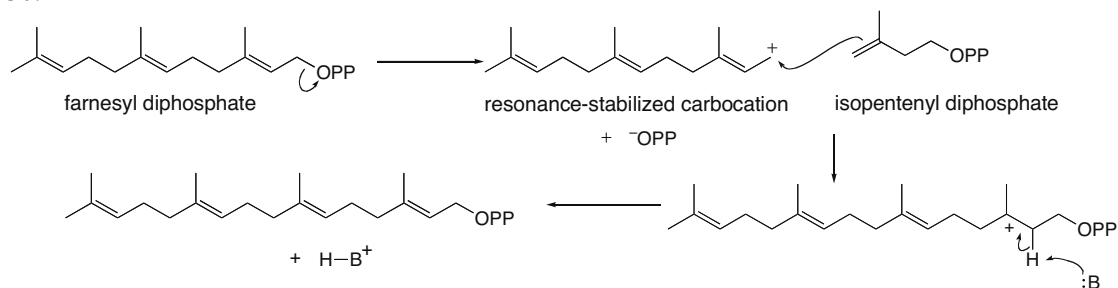


30.13

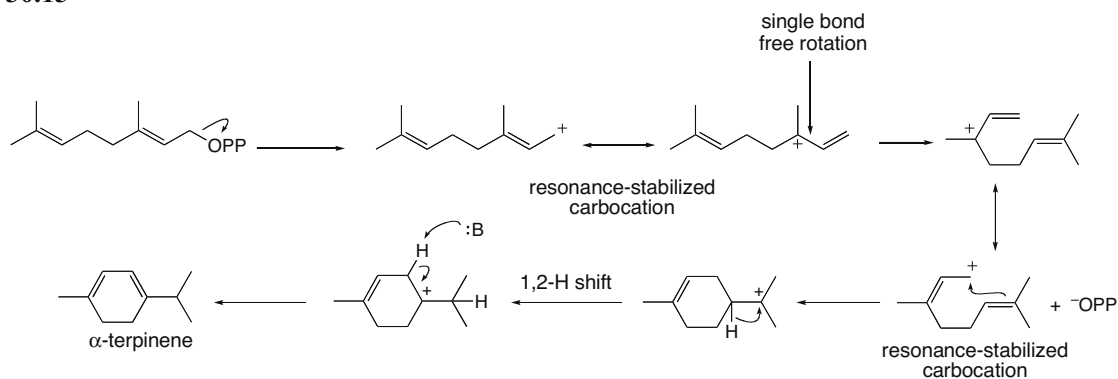


Lipids 30–7

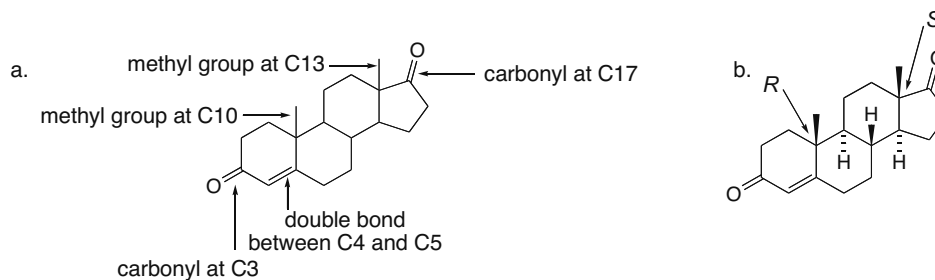
30.14



30.15

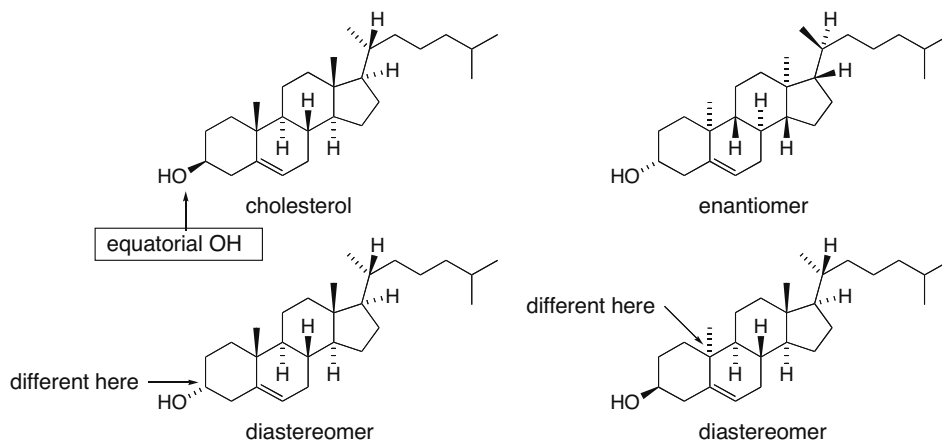


30.16

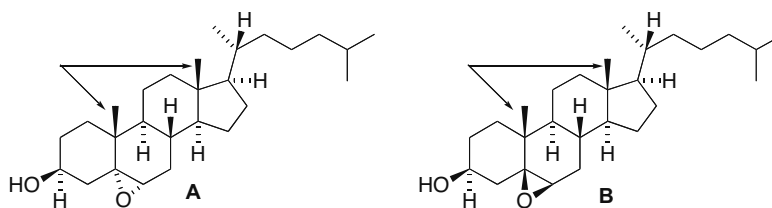


Chapter 30–8

30.17

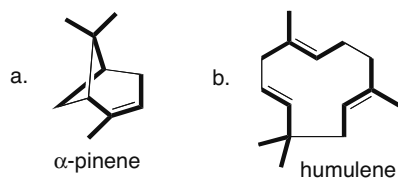


30.18

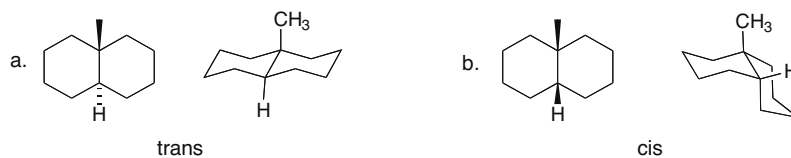


All four rings are in the same plane. The bulky CH_3 groups (arrows) are located above the plane. Epoxide **A** is favored, because it results from epoxidation below the plane, on the opposite side from the CH_3 groups that shield the top of the molecule somewhat to attack by reagents. In **B**, the epoxide ring is above the plane on the same side as the CH_3 groups. Formation of **B** would require epoxidation of the planar $\text{C}=\text{C}$ from the less accessible, more sterically hindered side of the double bond. This path is thus disfavored.

30.19

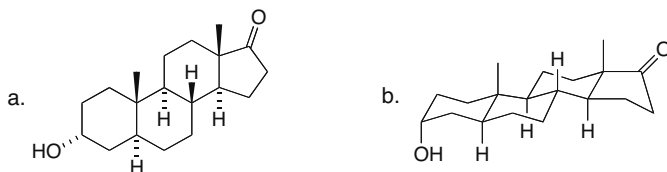


30.20

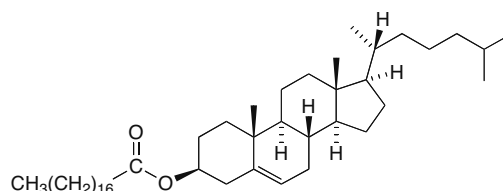


Lipids 30–9

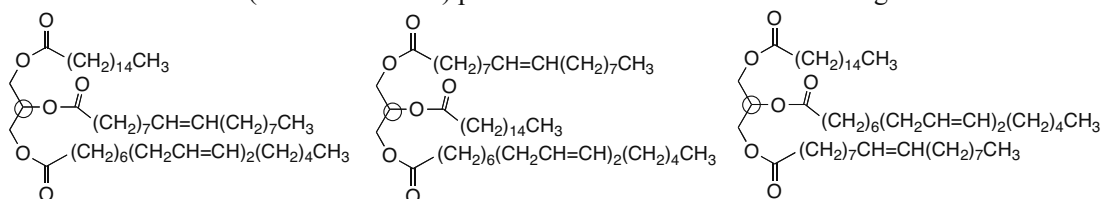
30.21



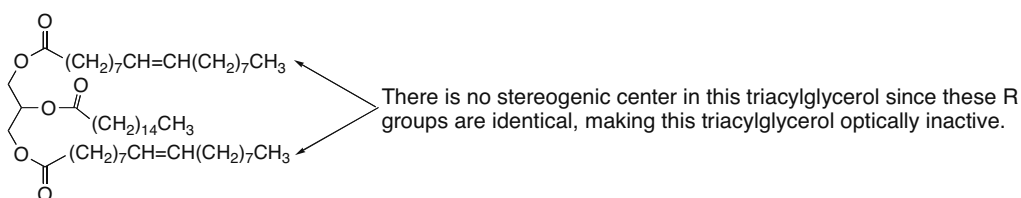
30.22



30.23 Each compound has one tetrahedral stereogenic center (circled), so there are two stereoisomers (two enantiomers) possible. All C=C's have the Z configuration.

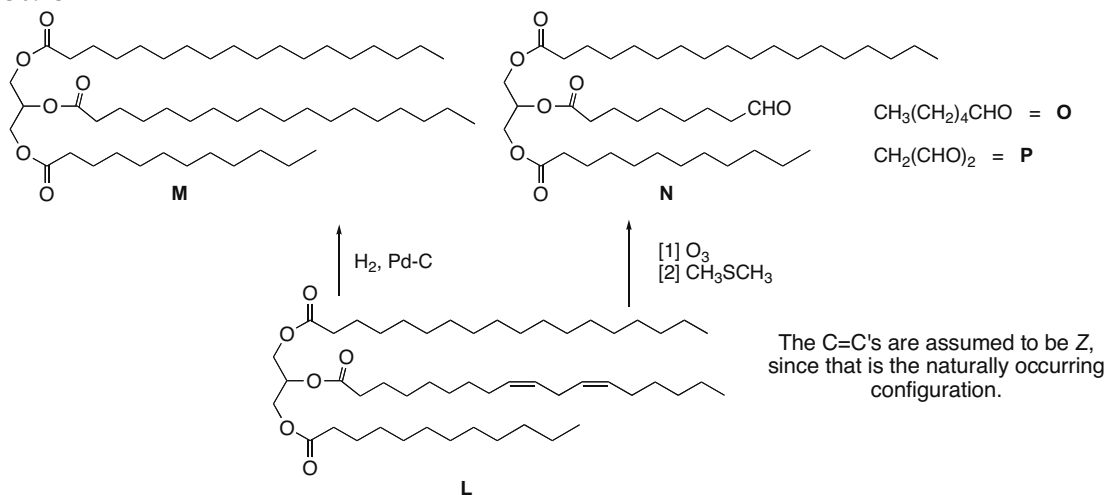


30.24

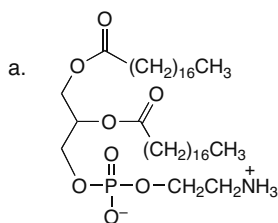


Chapter 30-10

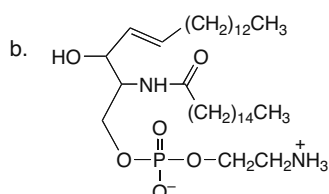
30.25



30.26 When $\text{R}'' = \text{CH}_2\text{CH}_2\text{NH}_3^+$, the compound is called a **phosphatidylethanolamine** or **cephalin**.

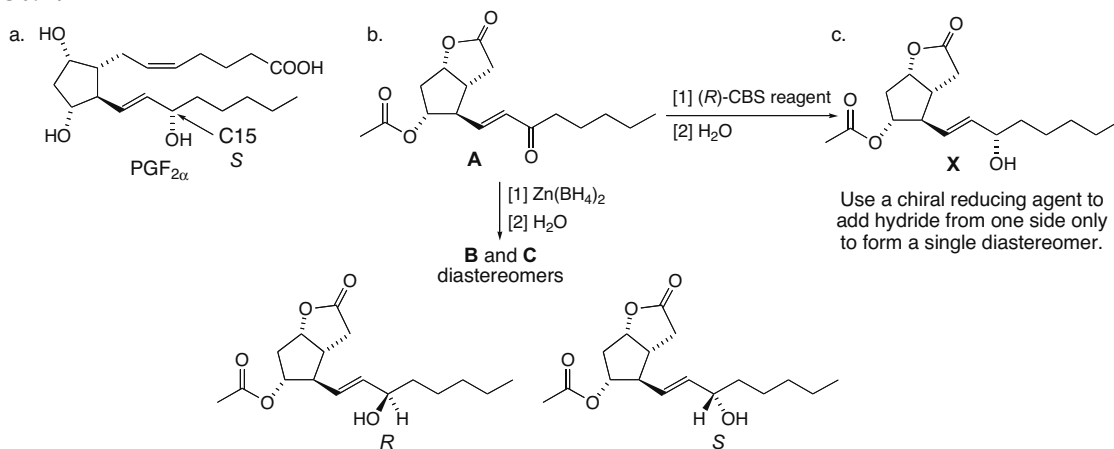


cephalin

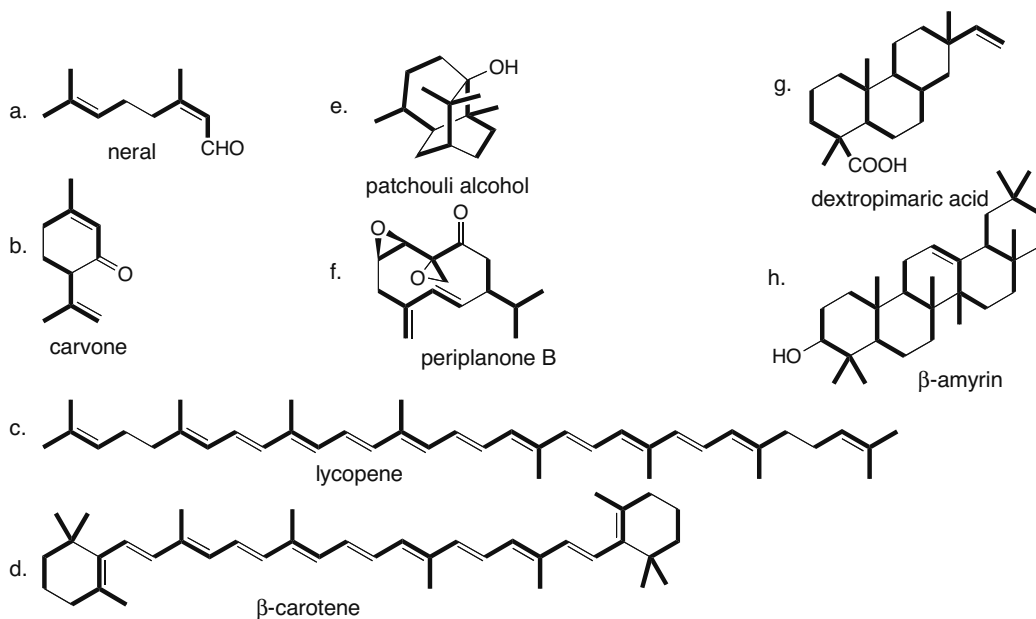


sphingomyelin

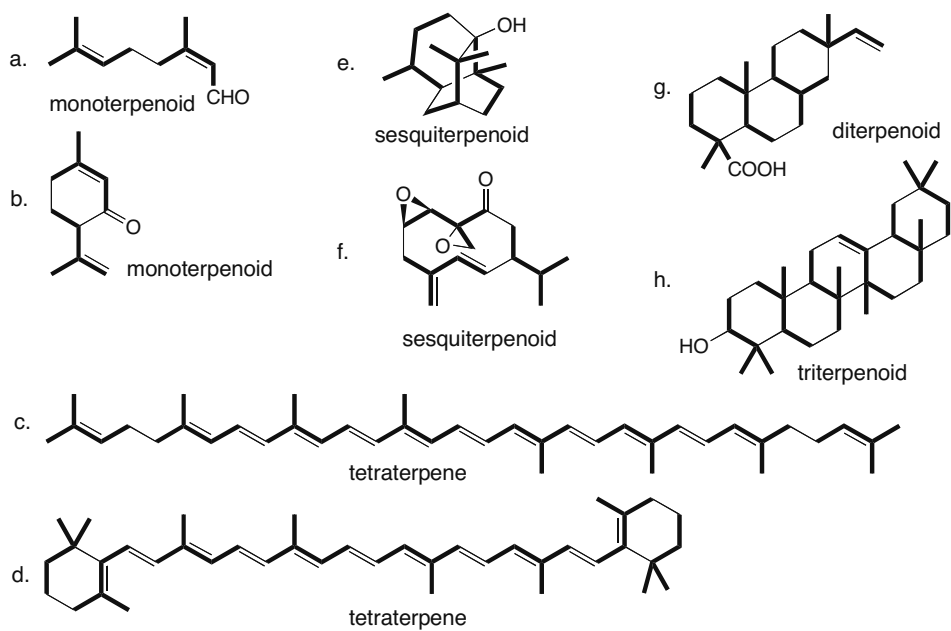
30.27



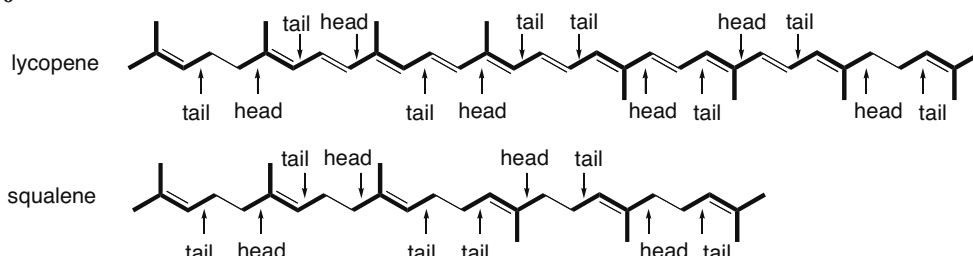
30.28



30.29 A *monoterpene* contains 10 carbons and two isoprene units; a *sesquiterpene* contains 15 carbons and three isoprene units, etc. See Table 30.5.



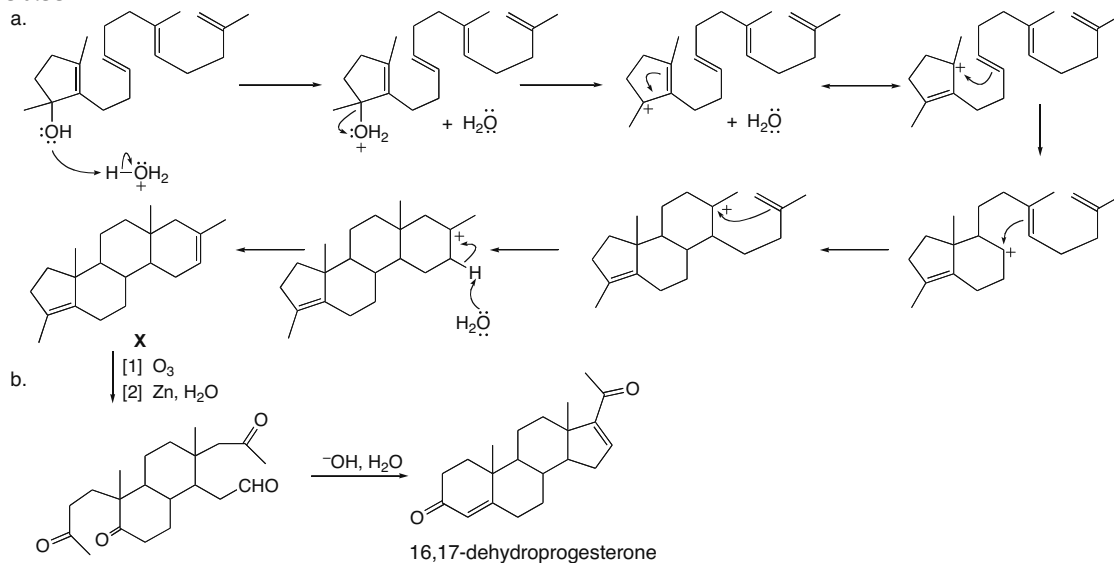
30.30



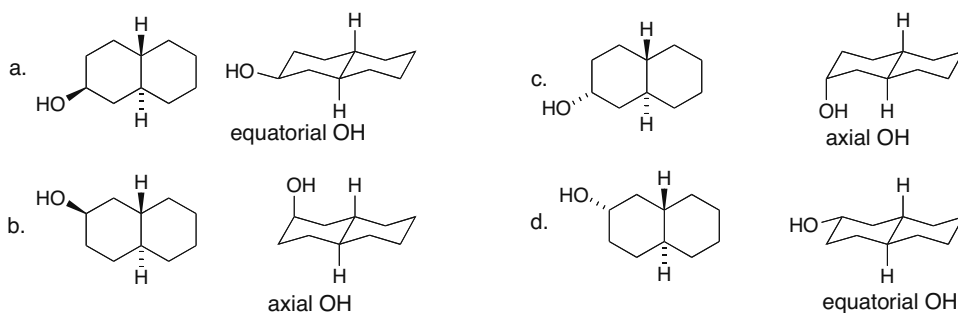
farnesyl diphosphate $\xrightarrow{\text{isopentenyl diphosphate}}$ geranylgeranyl diphosphate $\xrightarrow{\text{cyclization}}$ II $\xrightarrow{\text{cyclization}}$ 2° carbocation $\xrightarrow{\text{base (:B)}}$ flexibilene + OPP^-

Lipids 30-13

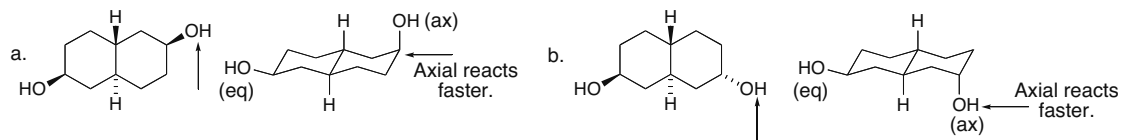
30.33



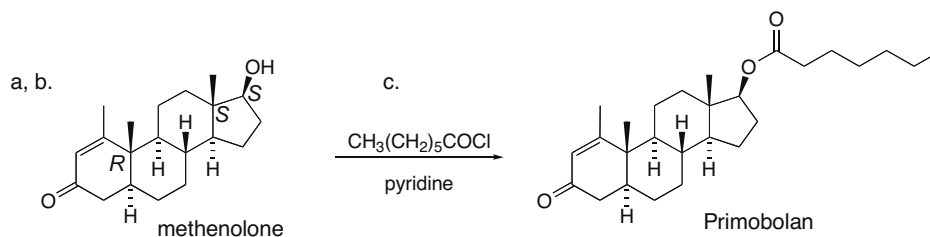
30.34



30.35

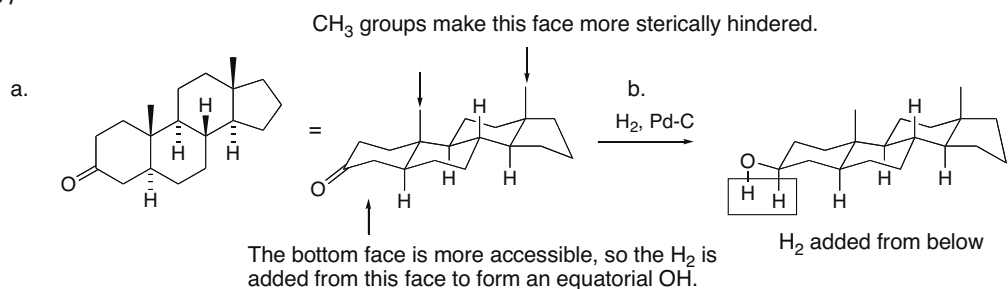


30.36

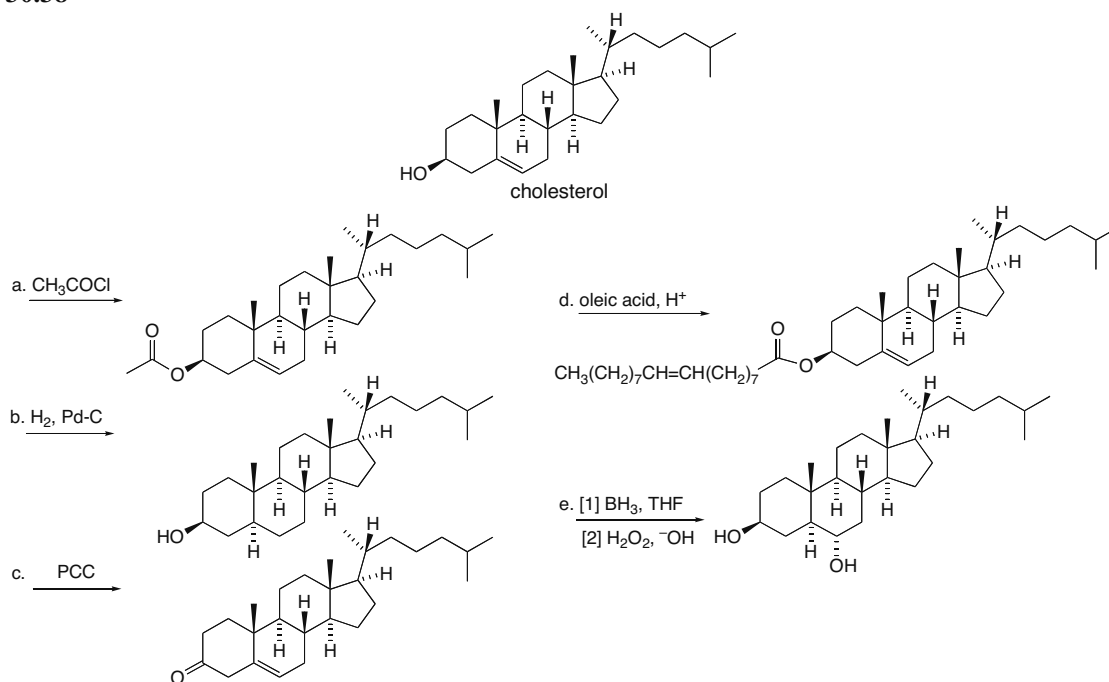


Chapter 30–14

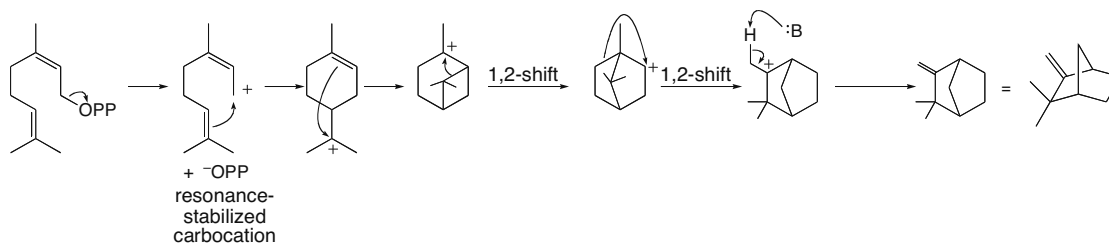
30.37



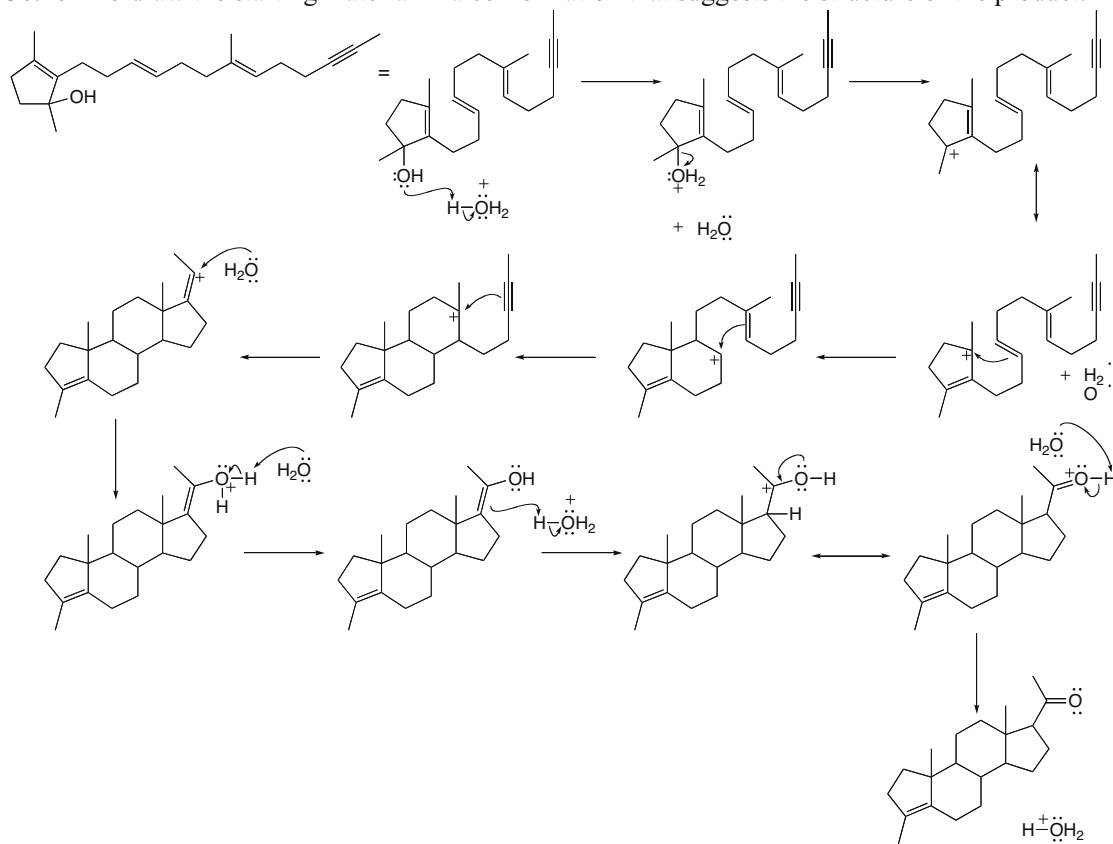
30.38



30.39

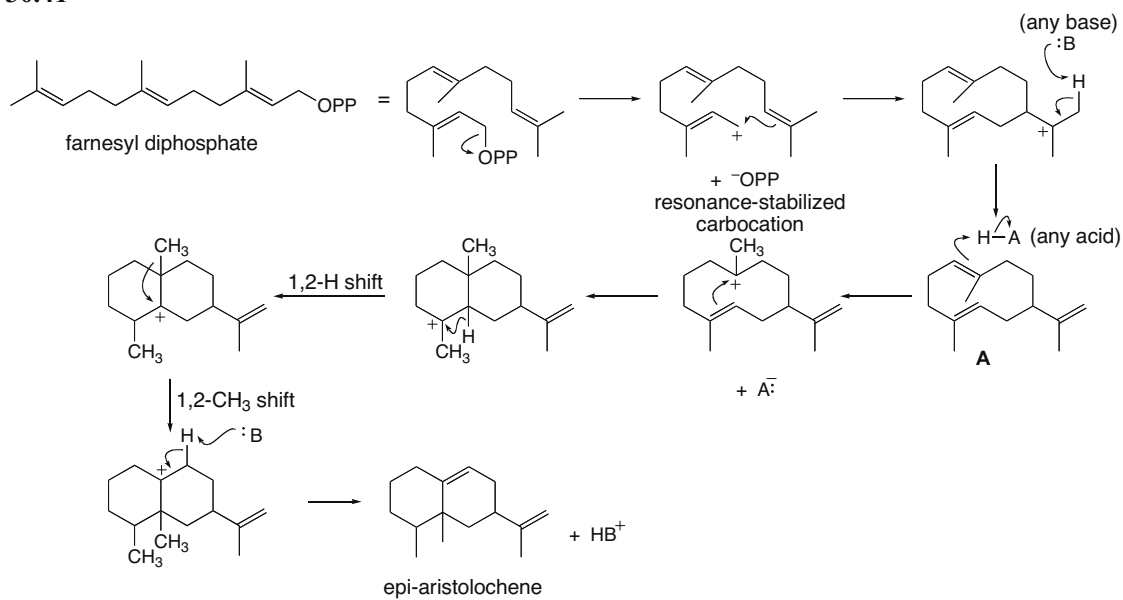


30.40 Re-draw the starting material in a conformation that suggests the structure of the product.



Chapter 30–16

30.41



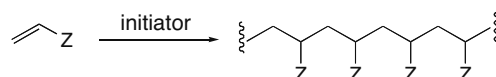
Chapter 31 Synthetic Polymers

Chapter Review

Chain-growth polymers—Addition polymers

[1] Chain-growth polymers with alkene starting materials (31.2)

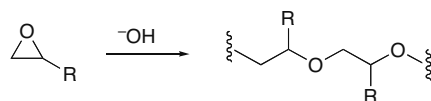
- General reaction:



- Mechanism—three possibilities, depending on the identity of Z:

Type	Identity of Z	Initiator	Comments
[1] radical polymerization	Z stabilizes a radical. Z = R, Ph, Cl, etc.	A source of radicals (ROOR)	Termination occurs by radical coupling or disproportionation. Chain branching occurs.
[2] cationic polymerization	Z stabilizes a carbocation. Z = R, Ph, OR, etc.	H–A or a Lewis acid (BF ₃ + H ₂ O)	Termination occurs by loss of a proton.
[3] anionic polymerization	Z stabilizes a carbanion. Z = Ph, COOR, COR, CN, etc.	An organolithium reagent (R–Li)	Termination occurs only when an acid or other electrophile is added.

[2] Chain-growth polymers with epoxide starting materials (31.3)

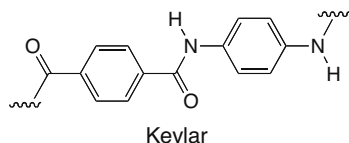
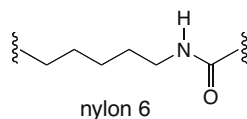


- The mechanism is S_N2.
- Ring opening occurs at the less substituted carbon of the epoxide.

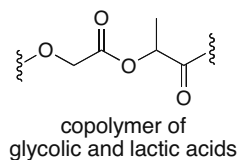
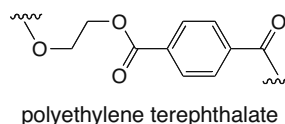
Chapter 31-2

Examples of step-growth polymers—Condensation polymers (31.6)

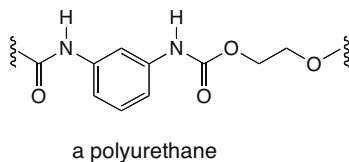
Polyamides



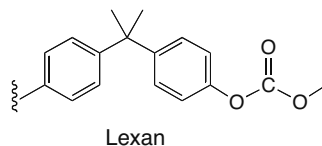
Polyesters



Polyurethanes



Polycarbonates



Structure and properties

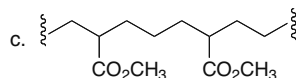
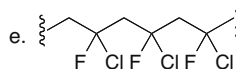
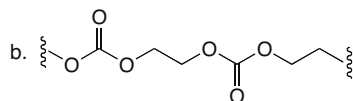
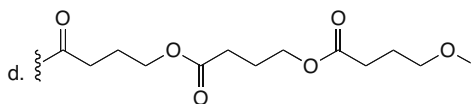
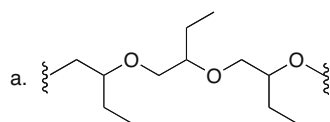
- Polymers prepared from monomers having the general structure $\text{CH}_2=\text{CHZ}$ can be **isotactic**, **syndiotactic**, or **atactic**, depending on the identity of Z and the method of preparation (31.4).
- **Ziegler–Natta catalysts** form polymers without significant branching. Polymers can be isotactic, syndiotactic, or atactic, depending on the catalyst. Polymers prepared from 1,3-dienes have the *E* or *Z* configuration, depending on the monomer (31.4, 31.5).
- Most polymers contain ordered crystalline regions and less ordered amorphous regions (31.7). The greater the crystallinity, the harder the polymer.
- **Elastomers** are polymers that stretch and can return to their original shape (31.5).
- **Thermoplastics** are polymers that can be molded, shaped, and cooled such that the new form is preserved (31.7).
- **Thermosetting polymers** are composed of complex networks of covalent bonds, so they cannot be melted to form a liquid phase (31.7).

Practice Test on Chapter Review

1. a. Which of the following statements is (are) true about chain-growth polymers?
 1. The reaction mechanism involves initiation, propagation, and termination.
 2. The reaction may occur with anionic, cationic, or radical intermediates.
 3. Epoxides can serve as monomers.
 4. Statements [1] and [2] are both true.
 5. Statements [1], [2], and [3] are all true.

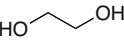
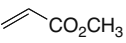
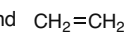
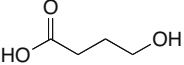
Synthetic Polymers 31–3

- b. Which of the following alkenes is likely to undergo anionic polymerization?
1. $\text{CH}_2=\text{CHCO}_2\text{CH}_3$
 2. $\text{CH}_2=\text{CHOCH}_3$
 3. $\text{CH}_2=\text{CHCH}_2\text{CO}_2\text{CH}_3$
 4. Both [1] and [2] will react.
 5. Compounds [1], [2], and [3] will all react.
- c. Which of the following compounds can serve as an initiator in cationic polymerization?
1. butyllithium
 2. $(\text{CH}_3)_3\text{COOC}(\text{CH}_3)_3$
 3. BF_3
 4. Both [1] and [2] can serve as initiators.
 5. Compounds [1], [2], and [3] can all serve as initiators.
- d. Which of the following statements is (are) true about step-growth polymers?
1. A small molecule such as H_2O or HCl is extruded during synthesis.
 2. Polycarbonates are an example of a step-growth polymer.
 3. Step-growth polymers are also called addition polymers.
 4. Statements [1] and [2] are both true.
 5. Statements [1], [2], and [3] are all true.
2. Label each statement as True (T) or False (F).
- a. A polyester is the most easily recycled polymer.
 - b. Natural rubber is a polymer of repeating isoprene units in which all double bonds have the *E* configuration.
 - c. A syndiotactic polymer has all *Z* groups bonded to the polymer chain on the same side.
 - d. A polyether can be formed by anionic polymerization of an epoxide.
 - e. An epoxy resin is a chain-growth polymer.
 - f. A branched polymer is more amorphous, giving it a higher T_m .
 - g. Polystyrene is a thermoplastic that can be melted and molded in shapes that are retained when the polymer is cooled.
 - h. A polyurethane is a condensation polymer.
 - i. Ziegler–Natta catalysts are used to form highly branched chain-growth polymers.
 - j. Using a feedstock from a renewable source is one method of green polymer synthesis.
3. What monomer(s) are needed to synthesize each polymer?



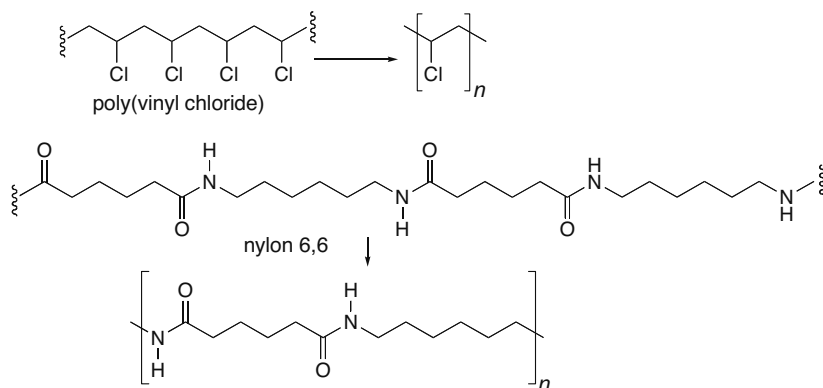
Chapter 31–4

Answers to Practice Test

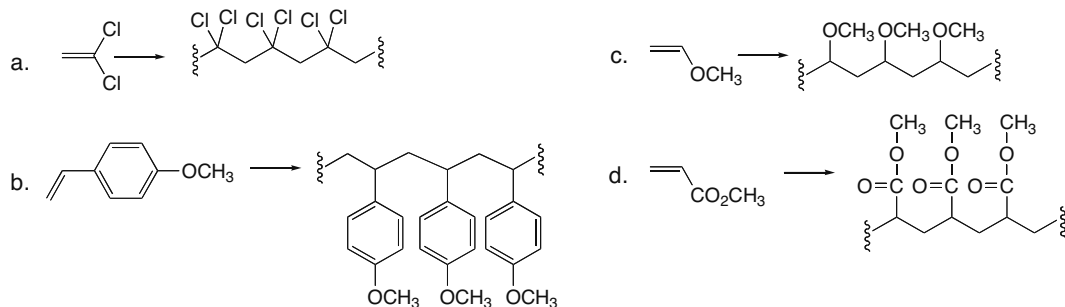
1. a. 5	2. a. T	f. F	3.
b. 1	b. F	g. T	a. 
c. 3	c. F	h. T	b.  and 
d. 4	d. T	i. F	c.  and 
	e. F	j. T	d. 
			e. 

Answers to Problems

31.1 Place brackets around the repeating unit that creates the polymer.

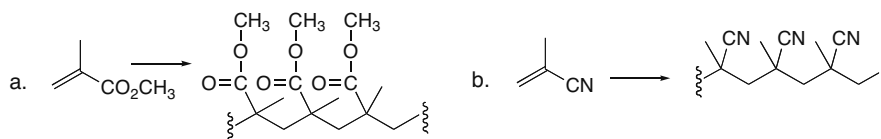


31.2 Draw each polymer formed by chain-growth polymerization.

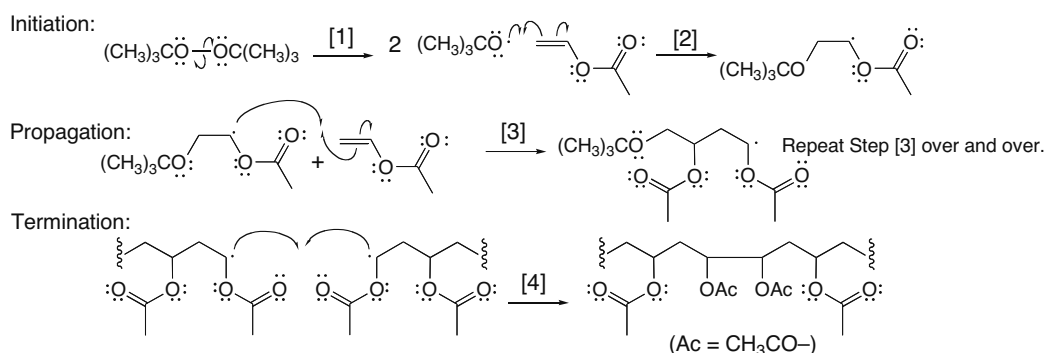


Synthetic Polymers 31–5

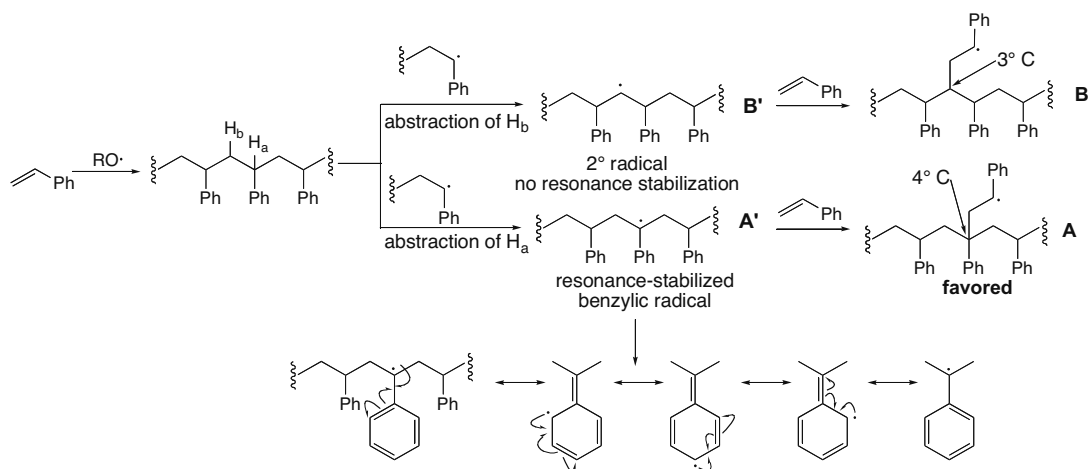
31.3 Draw each polymer formed by radical polymerization.



31.4 Use Mechanism 31.1 as a model of radical polymerization.

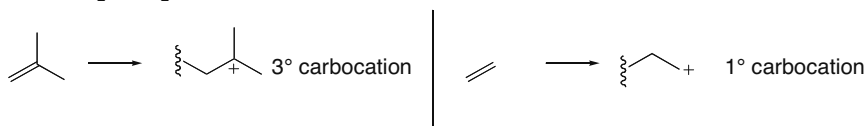


31.5 Radical polymerization forms a long chain of polystyrene with phenyl groups bonded to every other carbon. To form branches on this polystyrene chain, a radical on a second polymer chain abstracts a H atom. Abstraction of H_a forms a resonance-stabilized radical **A'**. The 2° radical **B'** (without added resonance stabilization) is formed by abstraction of H_b . Abstraction of H_a is favored, therefore, and this radical goes on to form products with 4° C's (**A**).

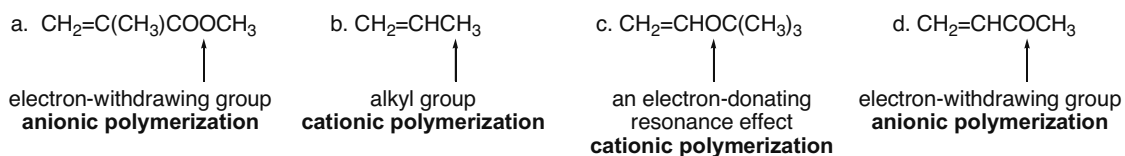


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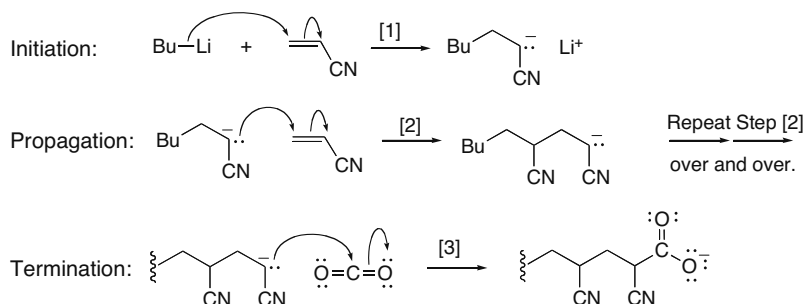
- 31.6** Cationic polymerization proceeds via a carbocation intermediate. Substrates that form more stable 3° carbocations react more readily in these polymerization reactions than substrates that form less stable 1° carbocations. $\text{CH}_2=\text{C}(\text{CH}_3)_2$ will form a more substituted carbocation than $\text{CH}_2=\text{CH}_2$.



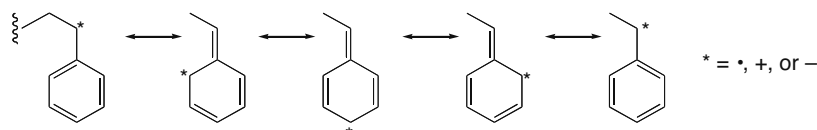
- 31.7** Cationic polymerization occurs with alkene monomers having substituents that can stabilize carbocations, such as alkyl groups and other electron-donor groups. Anionic polymerization occurs with alkene monomers having substituents that can stabilize a negative charge, such as COR, COOR, or CN.



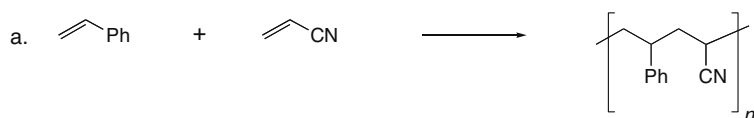
- 31.8** Use Mechanism 31.4 as a model of anionic polymerization.



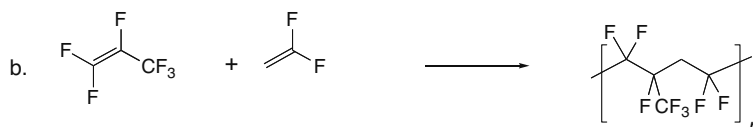
- 31.9** Styrene ($\text{CH}_2=\text{CHPh}$) can be polymerized by all three methods of chain-growth polymerization because a benzene ring can stabilize a radical, a carbocation, or a carbanion by resonance delocalization.



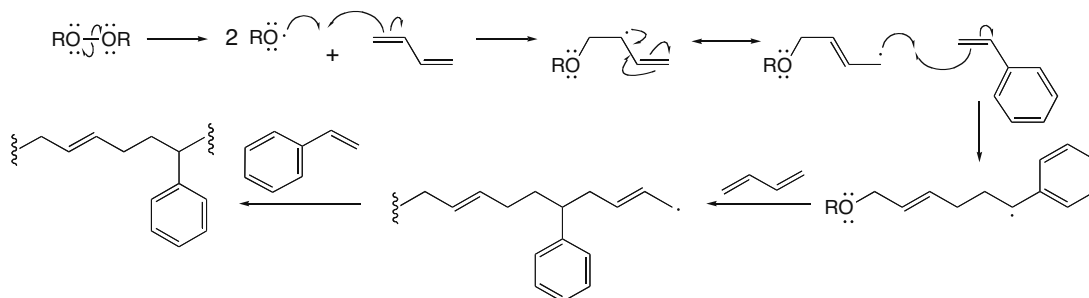
- 31.10** Draw the copolymers formed in each reaction.



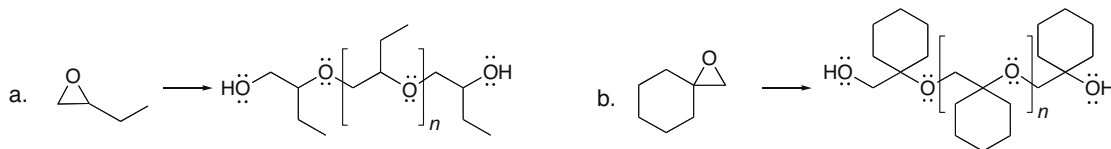
Synthetic Polymers 31-7



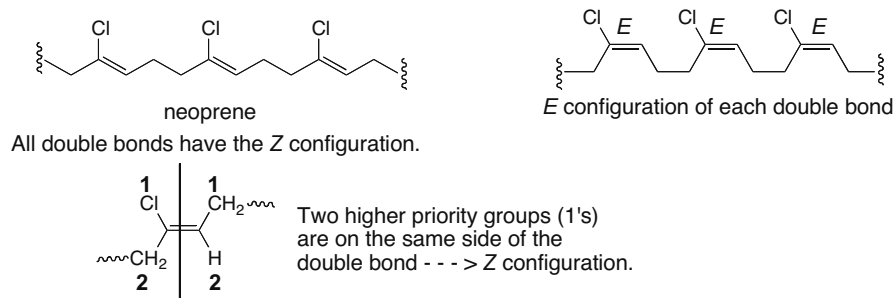
31.11



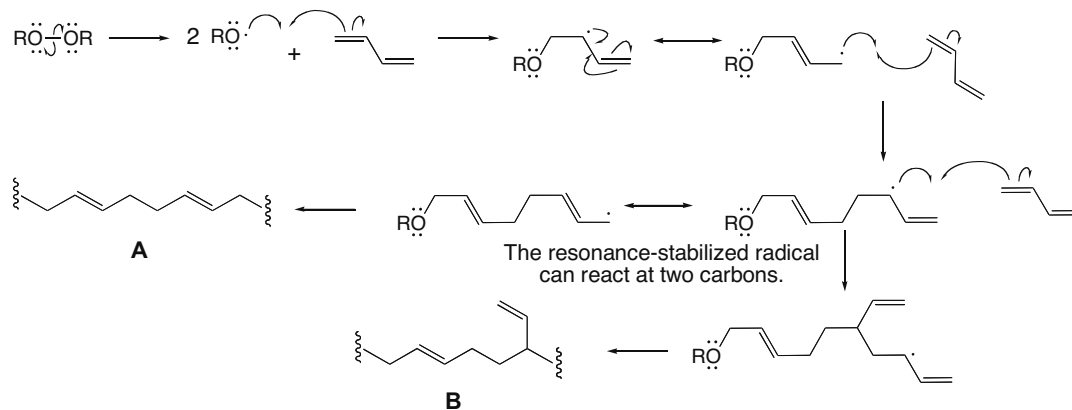
31.12



31.13

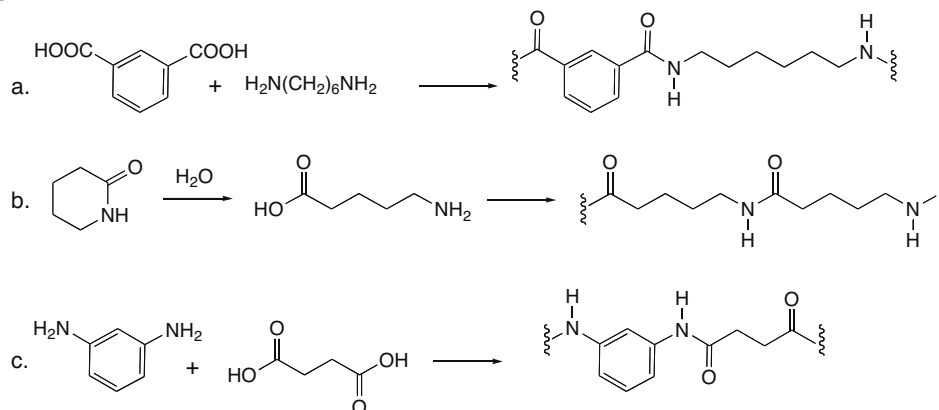


31.14

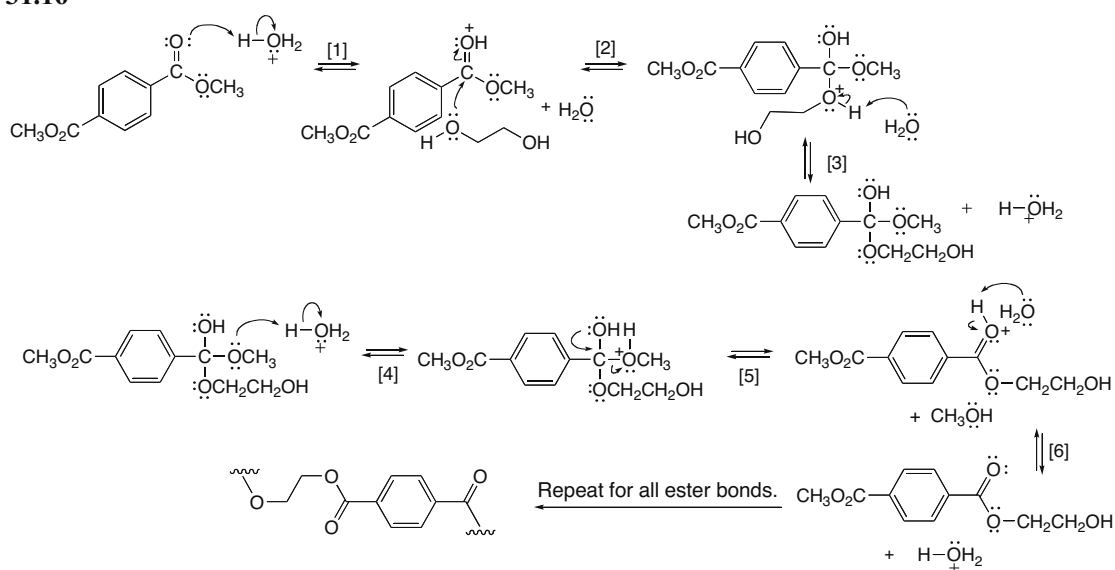


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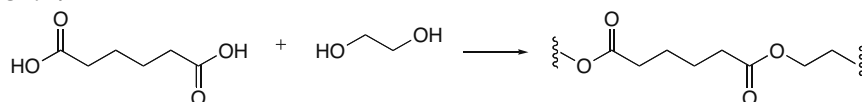
31.15



31.16



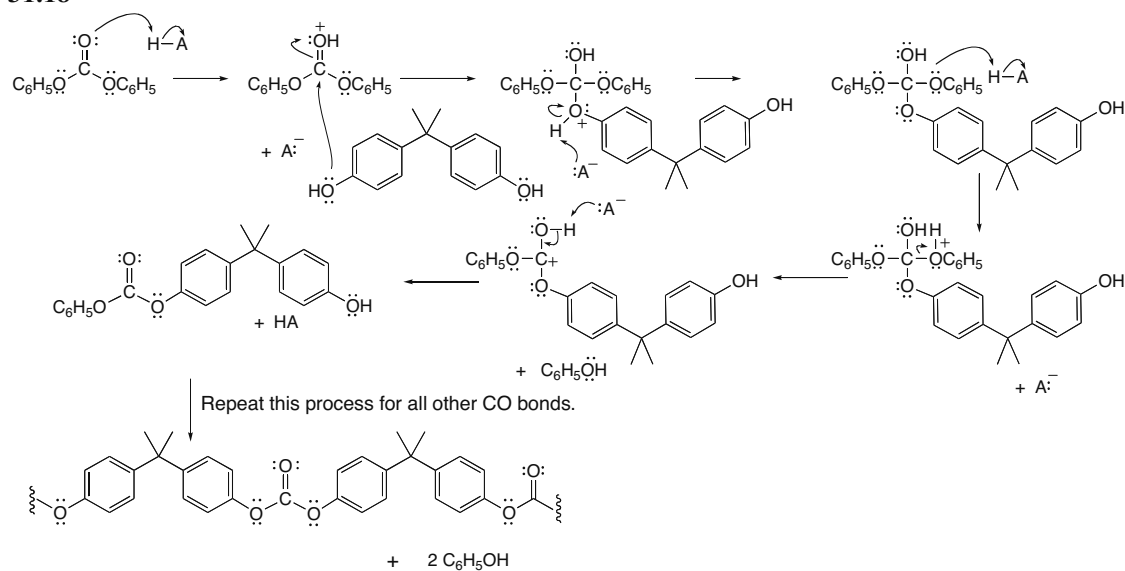
31.17



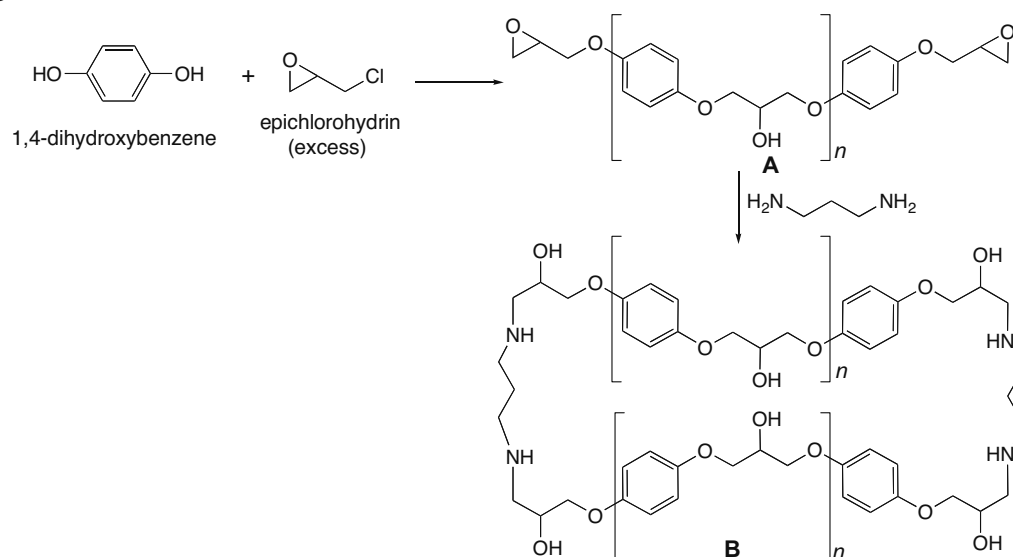
This compound is less suitable than either nylon 6,6 or PET for use in consumer products because esters are more easily hydrolyzed than amides, so this polyester is less stable than the polyamide nylon. This polyester has more flexible chains than PET, and this translates into a less strong fiber.

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31.18

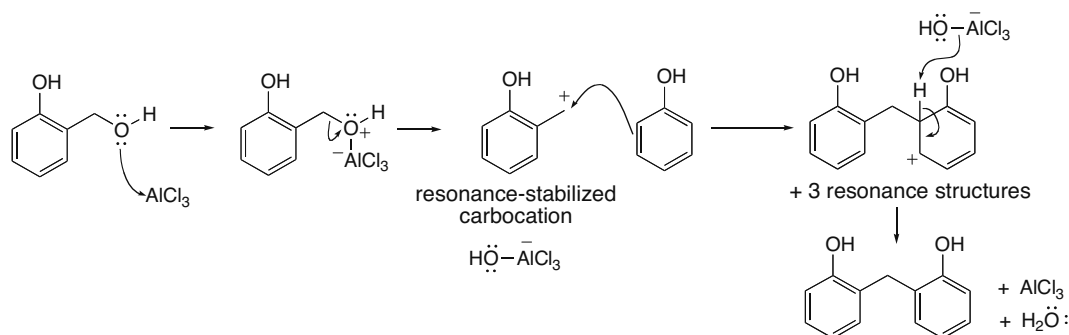


31.19

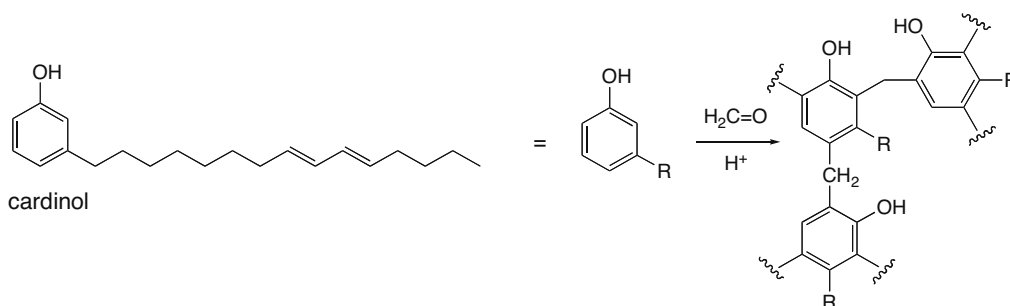


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31.20



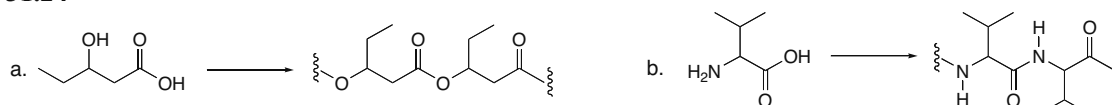
31.21



31.22 Chemical recycling of HDPE and LDPE is not easily done because these polymers are both long chains of CH_2 groups joined together in a linear fashion. Since there are only C–C bonds and no functional groups in the polymer chain, there are no easy methods to convert the polymers to their monomers. This process is readily accomplished only when the polymer backbone contains hydrolyzable functional groups.

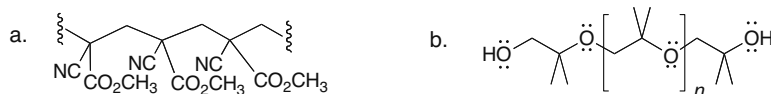
- 31.23**
- Combustion of polyethylene forms $\text{CO}_2 + \text{H}_2\text{O}$.
 - Combustion of polyethylene terephthalate forms $\text{CO}_2 + \text{H}_2\text{O}$.
 - These reactions are exothermic.
 - HDPE and PET must be separated from poly(vinyl chloride) prior to incineration because combustion of hydrocarbons (like HDPE) and oxygen-containing organics (like PET) releases only $\text{CO}_2 + \text{H}_2\text{O}$ into the atmosphere. Poly(vinyl chloride) also contains Cl atoms bonded to a hydrocarbon chain. On combustion this forms HCl, which cannot be released directly into the atmosphere, making incineration of halogen-containing polymers more laborious and more expensive.

31.24

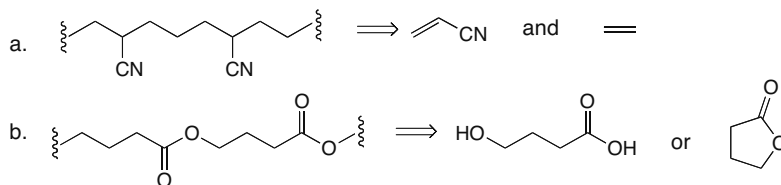


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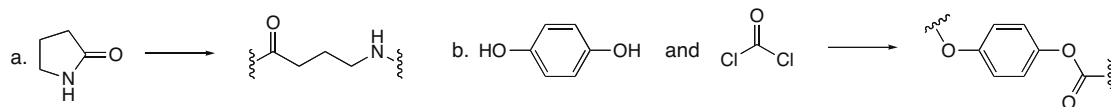
31.25



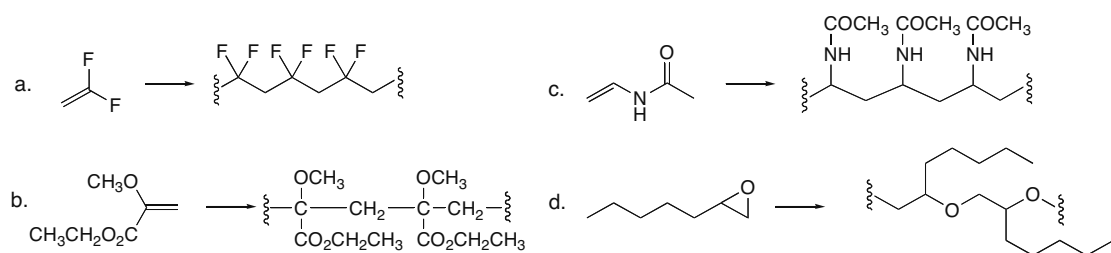
31.26



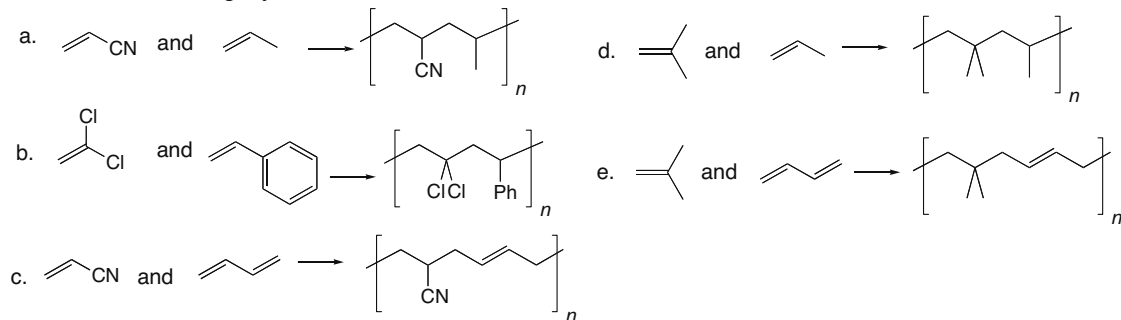
31.27



31.28 Draw the polymer formed by chain-growth polymerization as in Answer 31.2.

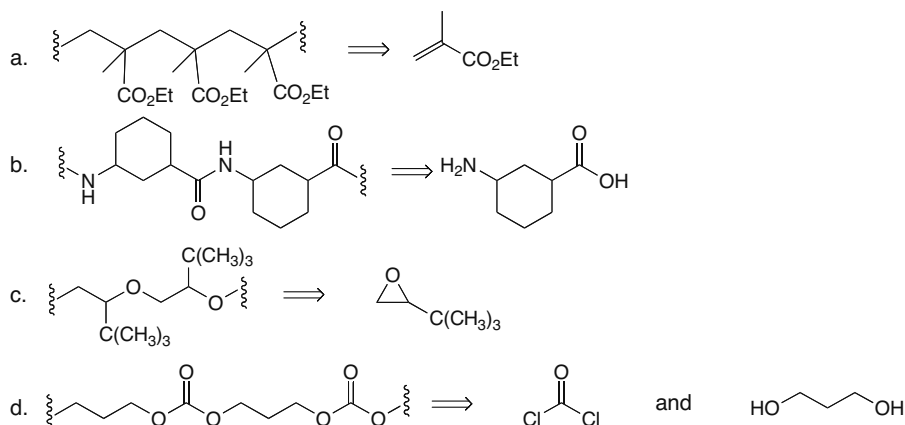


31.29 Draw the copolymers.

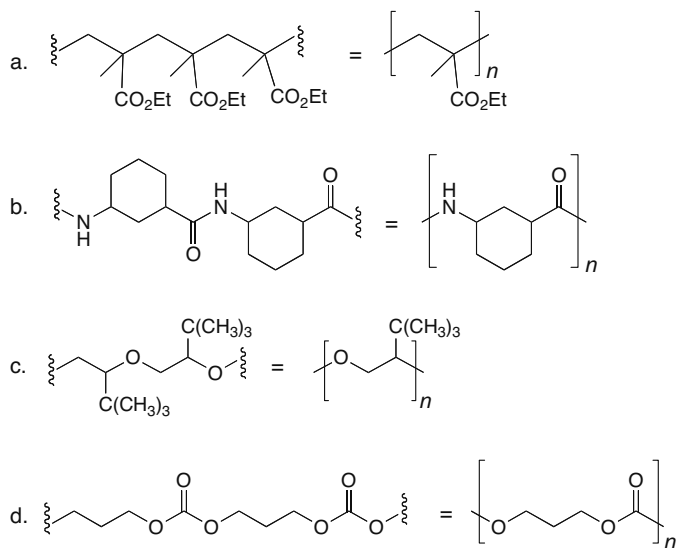


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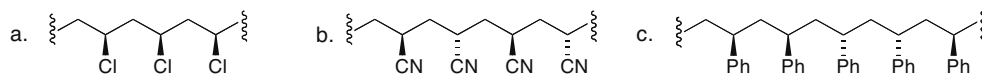
31.30



31.31

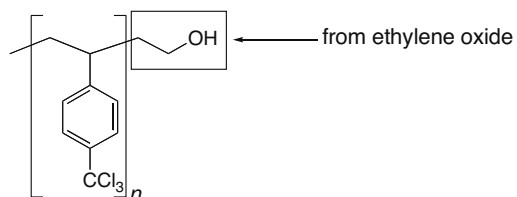


31.32 An **isotactic polymer** has all Z groups on the same side of the carbon backbone. A **syndiotactic polymer** has the Z groups alternating from one side of the carbon chain to the other. An **atactic polymer** has the Z groups oriented randomly along the polymer chain.

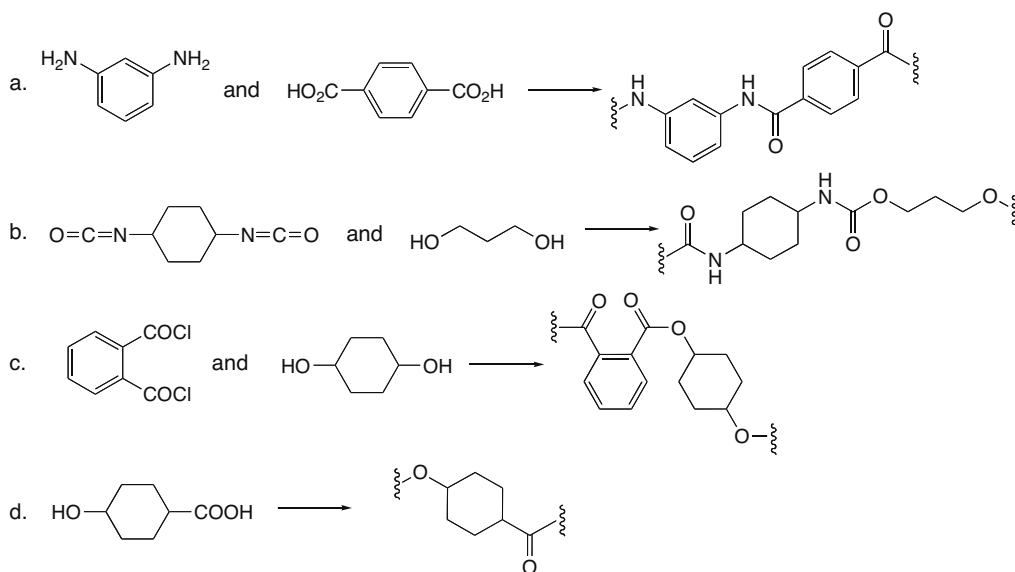


Synthetic Polymers 31–13

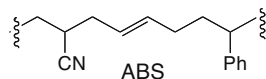
31.33



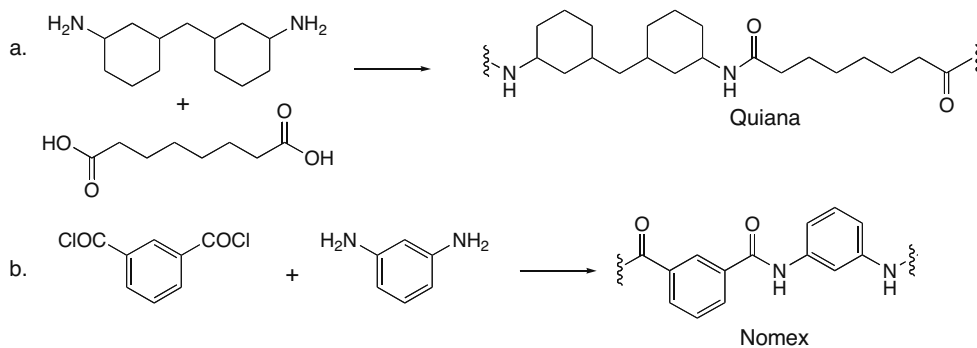
31.34



31.35

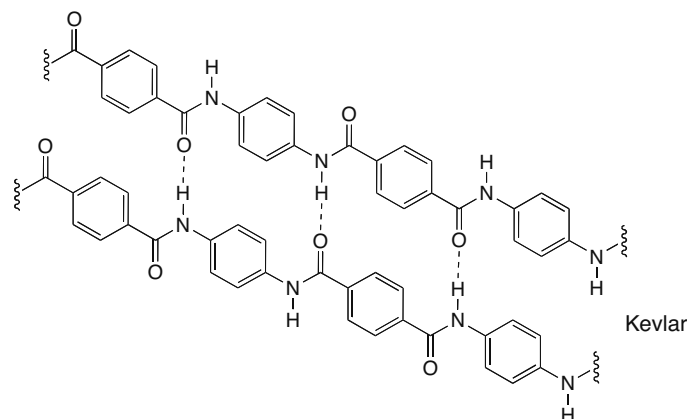


31.36

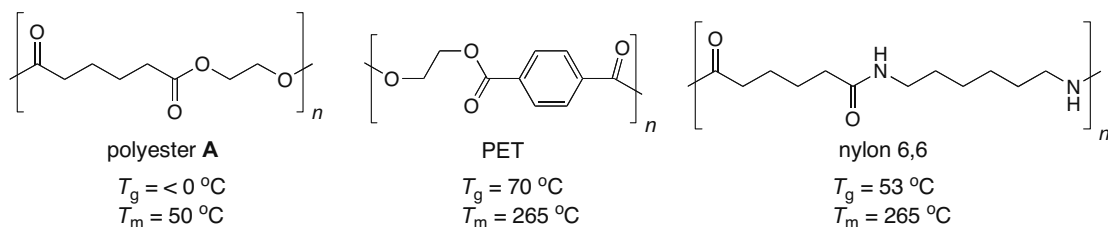


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31.37

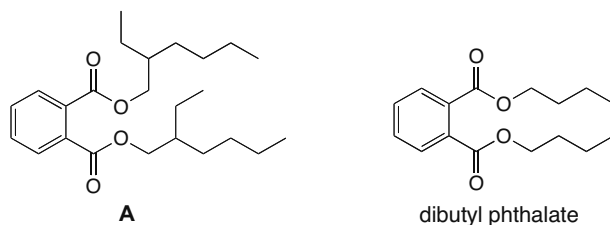


31.38



- Polyester **A** has a lower T_g and T_m than PET because its polymer chain is more flexible. There are no rigid benzene rings, so the polymer is less ordered.
- Polyester **A** has a lower T_g and T_m than nylon 6,6 because the N–H bonds of nylon 6,6 allow chains to hydrogen bond to each other, which makes the polymer more ordered.
- The T_m for Kevlar would be higher than that of nylon 6,6, because in addition to extensive hydrogen bonding between chains, each chain contains rigid benzene rings. This results in a more ordered polymer.

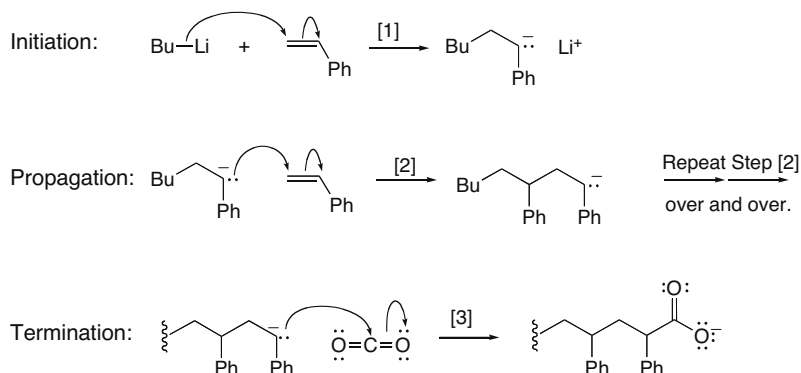
31.39



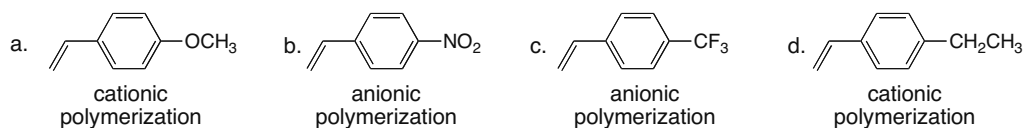
Diester **A** is often used as a plasticizer in place of dibutyl phthalate because it has a higher molecular weight, giving it a higher boiling point. **A** should therefore be less volatile than dibutyl phthalate, so it should evaporate from a polymer less readily.

Chapter 31–16

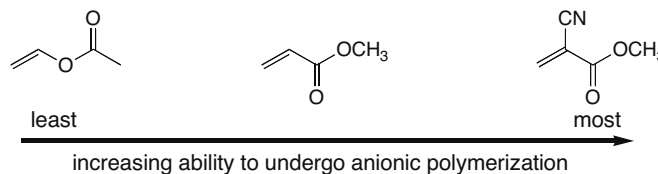
31.43



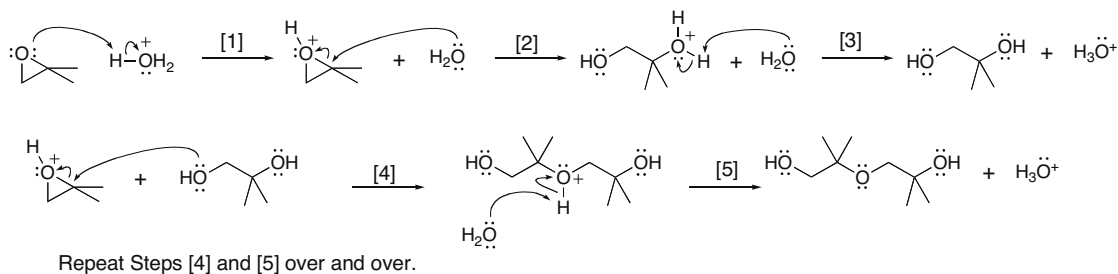
31.44 The substituent on styrene determines whether cationic or anionic polymerization is preferred. When the substituent stabilizes a carbocation, cationic polymerization will occur. When the substituent stabilizes a carbanion, anionic polymerization will occur.



31.45 The rate of anionic polymerization depends on the ability of the substituents on the alkene to stabilize an intermediate carbanion: the better a substituent stabilizes a carbanion, the faster anionic polymerization occurs.

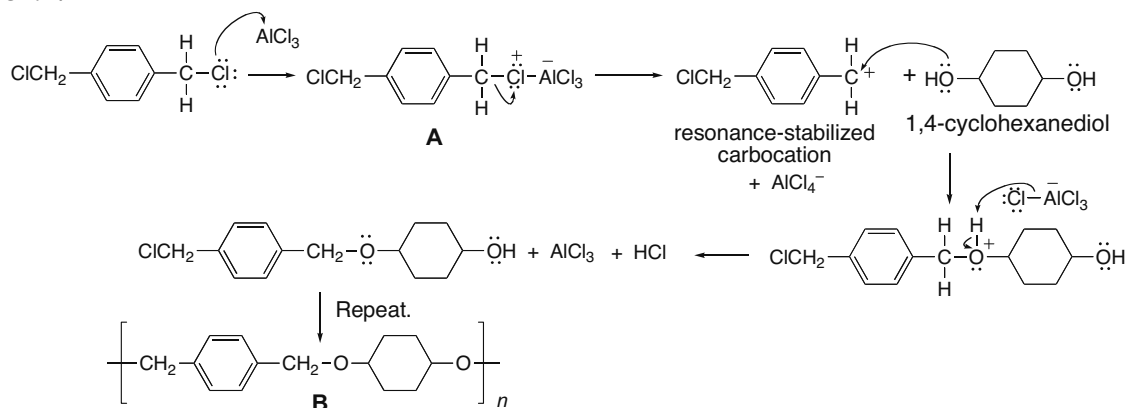


31.46 The reason for this selectivity is explained in Figure 9.9. In the ring opening of an unsymmetrical epoxide under acidic conditions, nucleophilic attack occurs at the carbon atom that is more able to accept a δ^+ in the transition state; that is, nucleophilic attack occurs at the more substituted carbon. The transition state having a δ^+ on a C with an electron-donating CH_3 group is more stabilized (lower in energy), permitting a faster reaction.

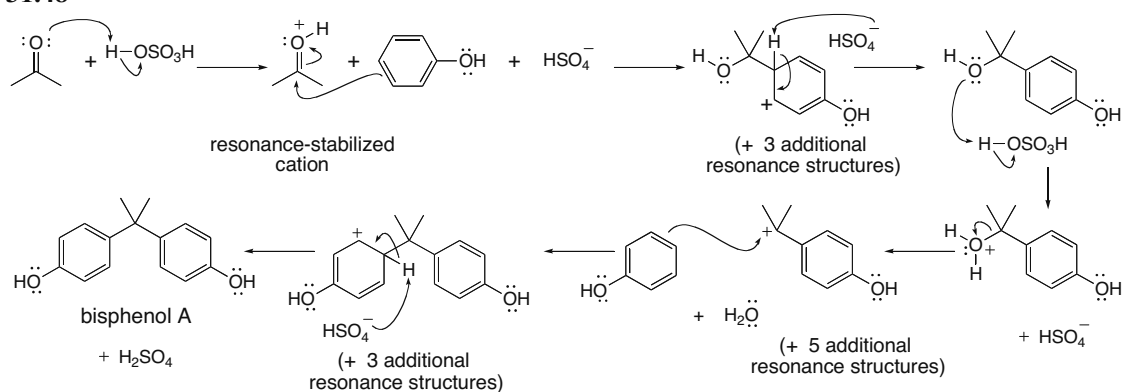


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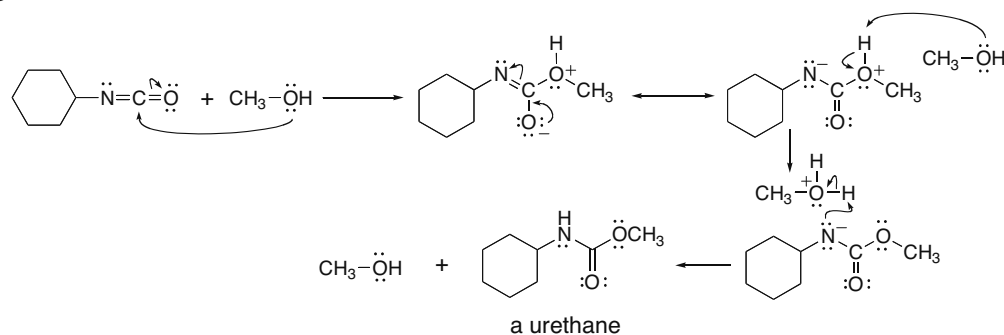
31.47



31.48

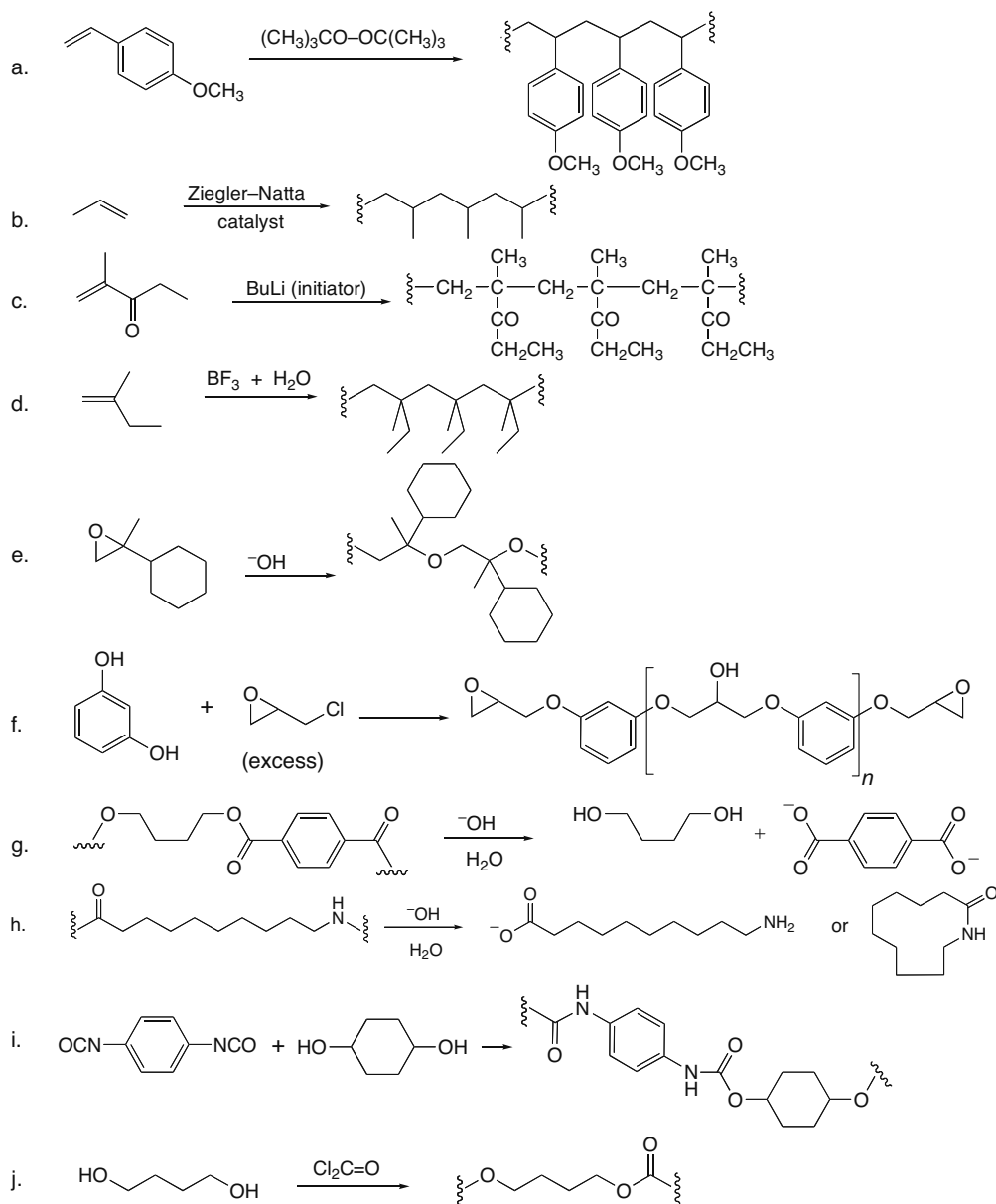


31.49



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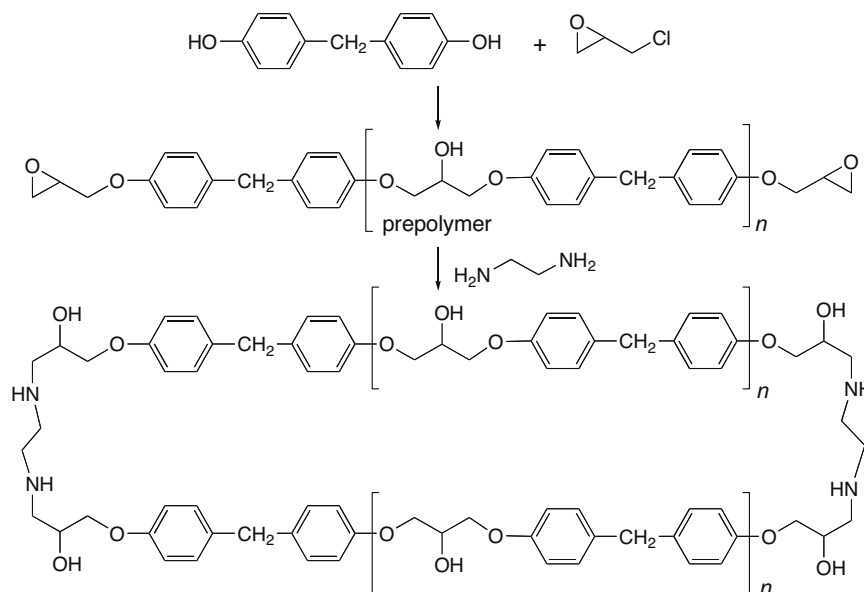
31.50



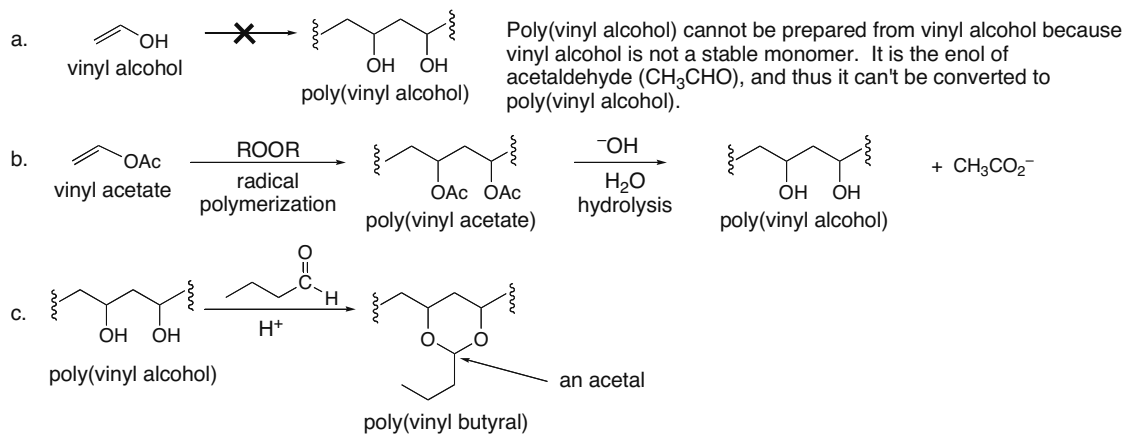
31.51 Polyethylene bottles are resistant to NaOH because they are hydrocarbons with no reactive sites. Polyester shirts and nylon stockings both contain functional groups. Nylon contains amides and polyester contains esters, two functional groups that are susceptible to hydrolysis with aqueous NaOH. Thus, the polymers are converted to their monomer starting materials, creating a hole in the garment.

Synthetic Polymers 31–19

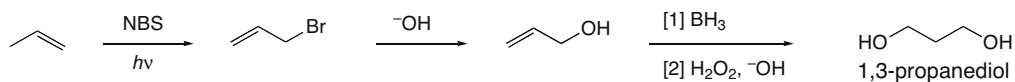
31.52



31.53

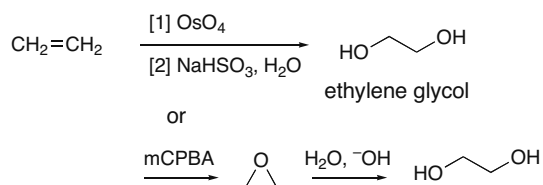
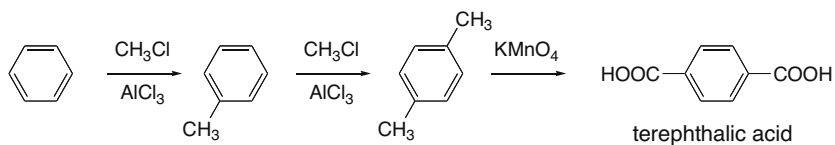


31.54

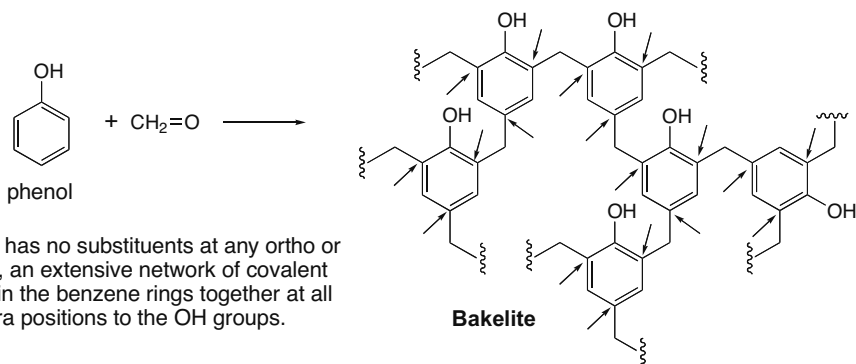


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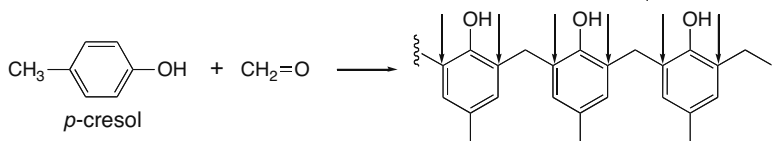
31.55



31.56

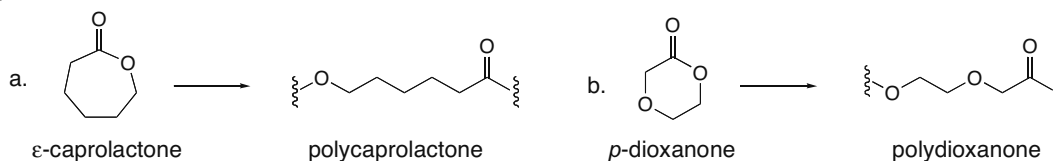


Since phenol has no substituents at any ortho or para position, an extensive network of covalent bonds can join the benzene rings together at all ortho and para positions to the OH groups.



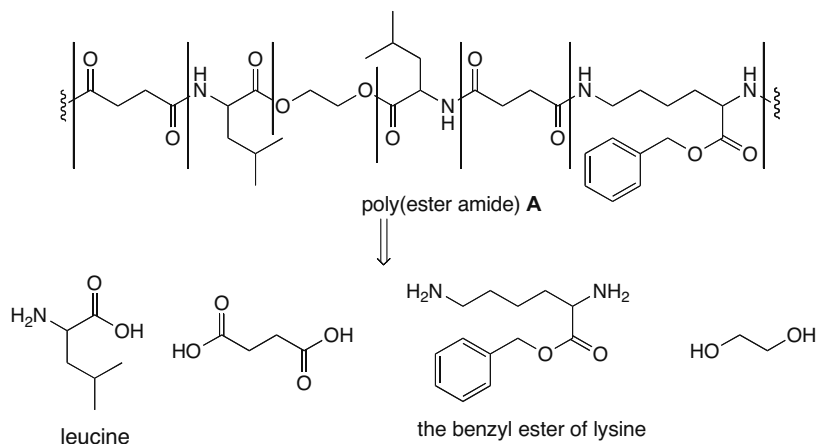
Since *p*-cresol has a CH_3 group at the para position to the OH group, new bonds can be formed only at two ortho positions, so that a less extensive three-dimensional network can form.

31.57

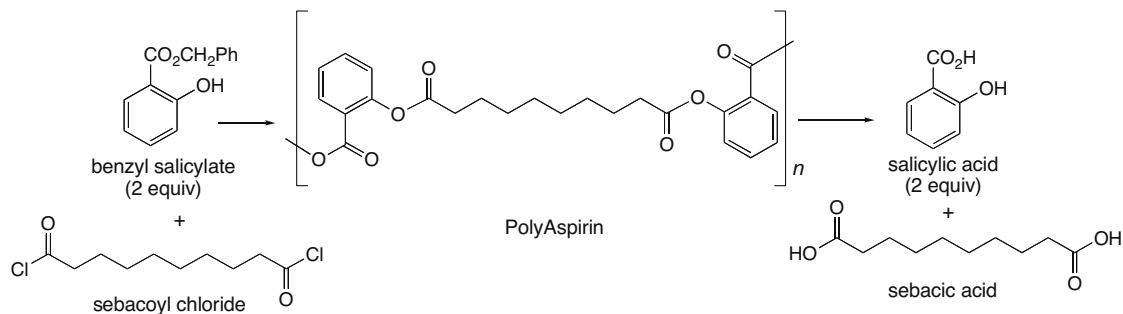


Synthetic Polymers 31–21

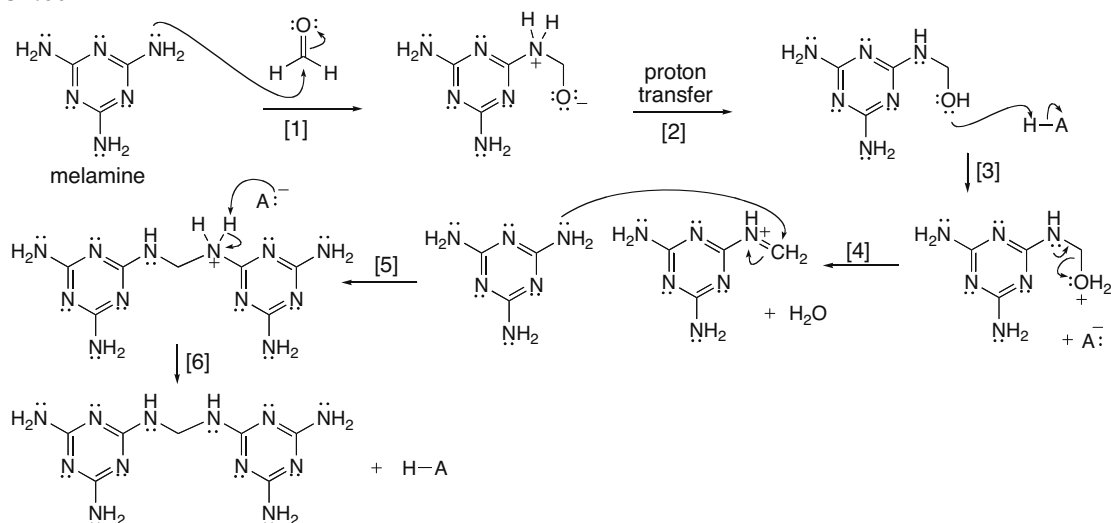
31.58



31.59

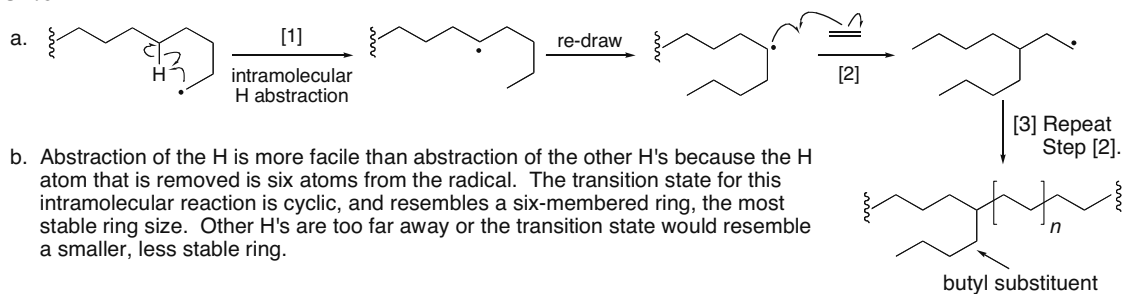


31.60



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31.61



31.62

