Respiratory System

- Consists of the respiratory and conducting zones
- Respiratory zone:
  - Site of gas exchange
  - Consists of bronchioles, alveolar ducts, and alveoli

Respiratory System

- Conducting zone:
  - Conduits for air to reach the sites of gas exchange
  - Includes all other respiratory structures (e.g., nose, nasal cavity, pharynx, trachea)
- Respiratory muscles – diaphragm and other muscles that promote ventilation

Respiratory System

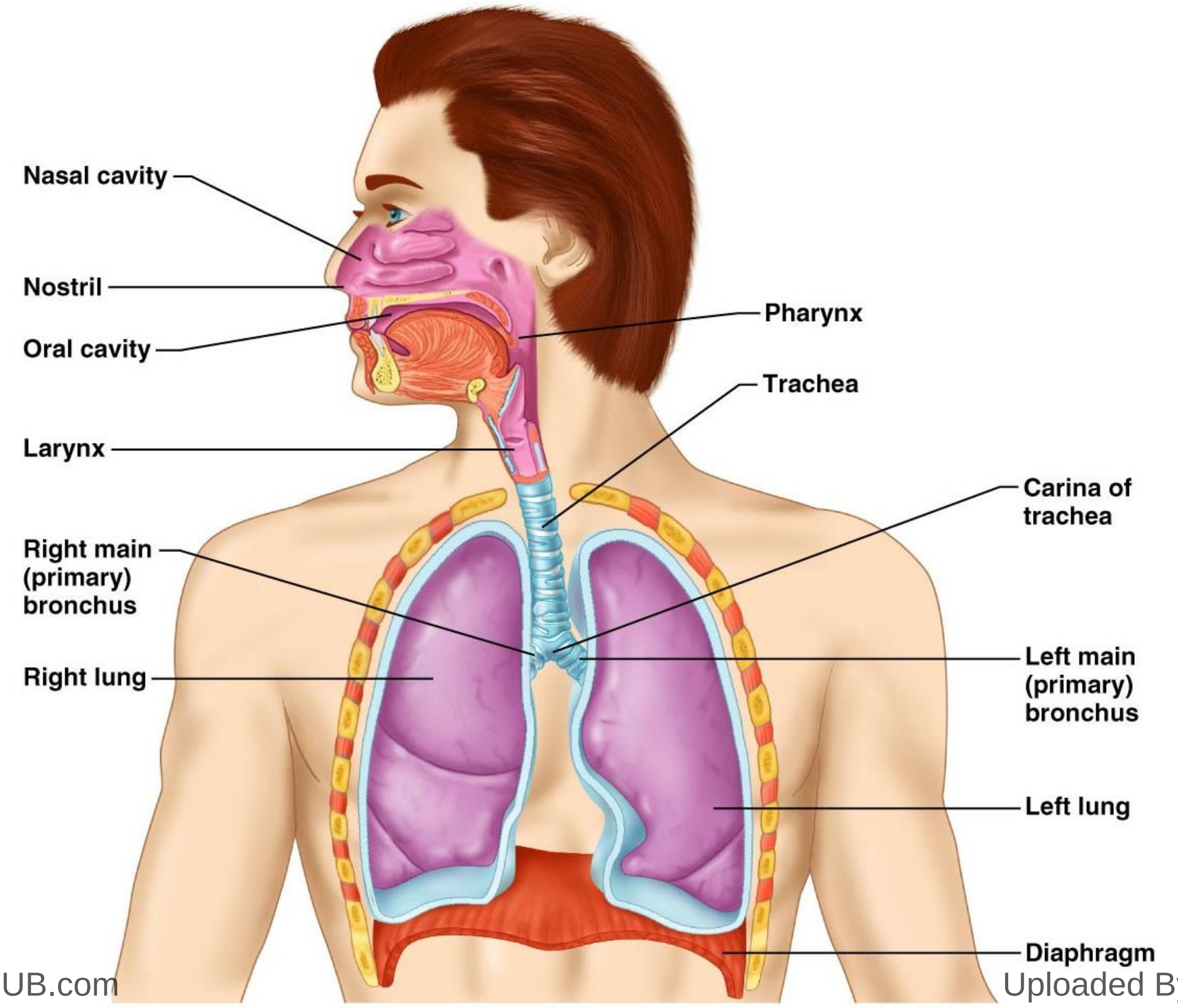


Figure 22.1

(a) The respiratory system

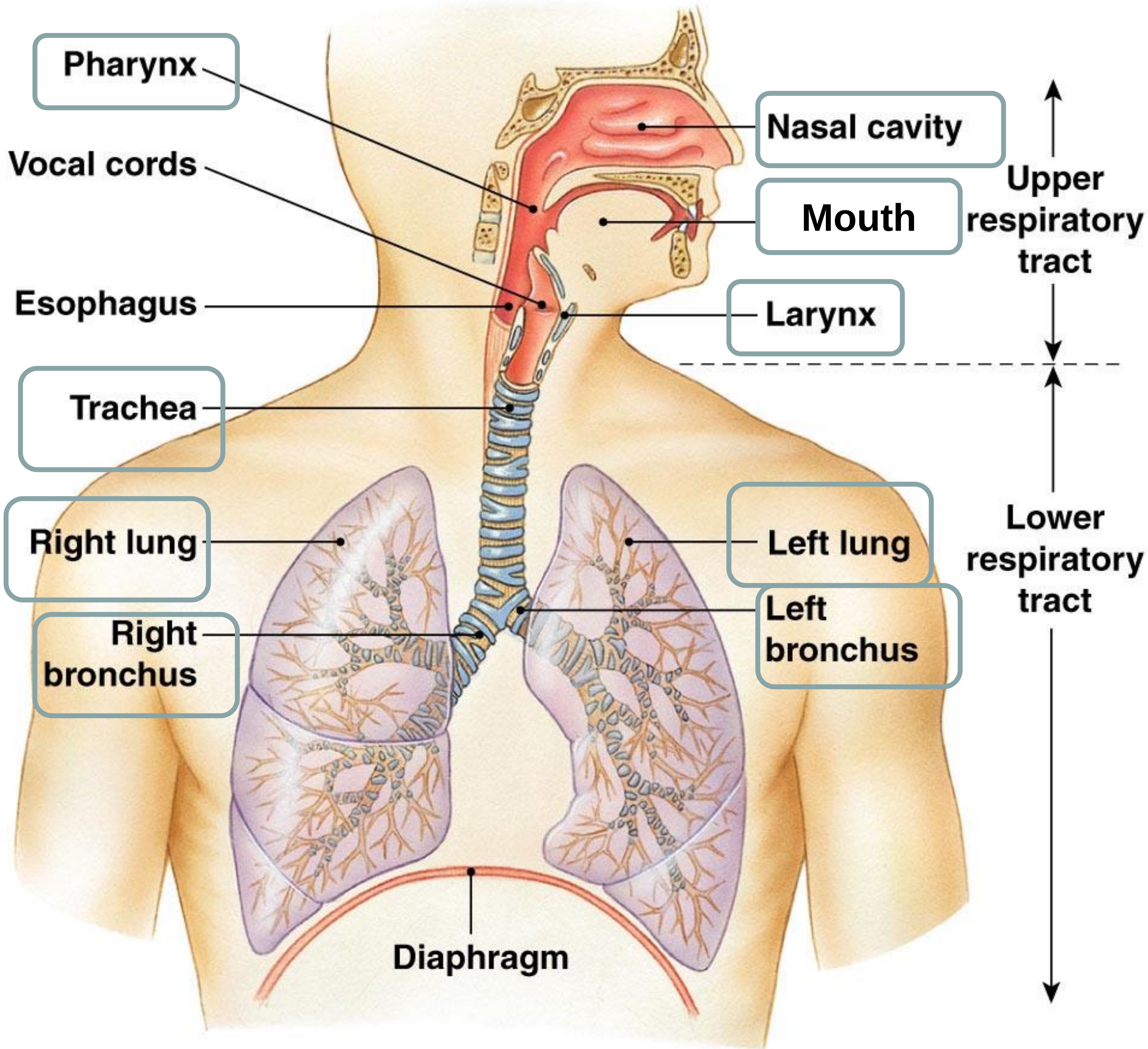


Figure 17-2a

(b) Muscles used for ventilation

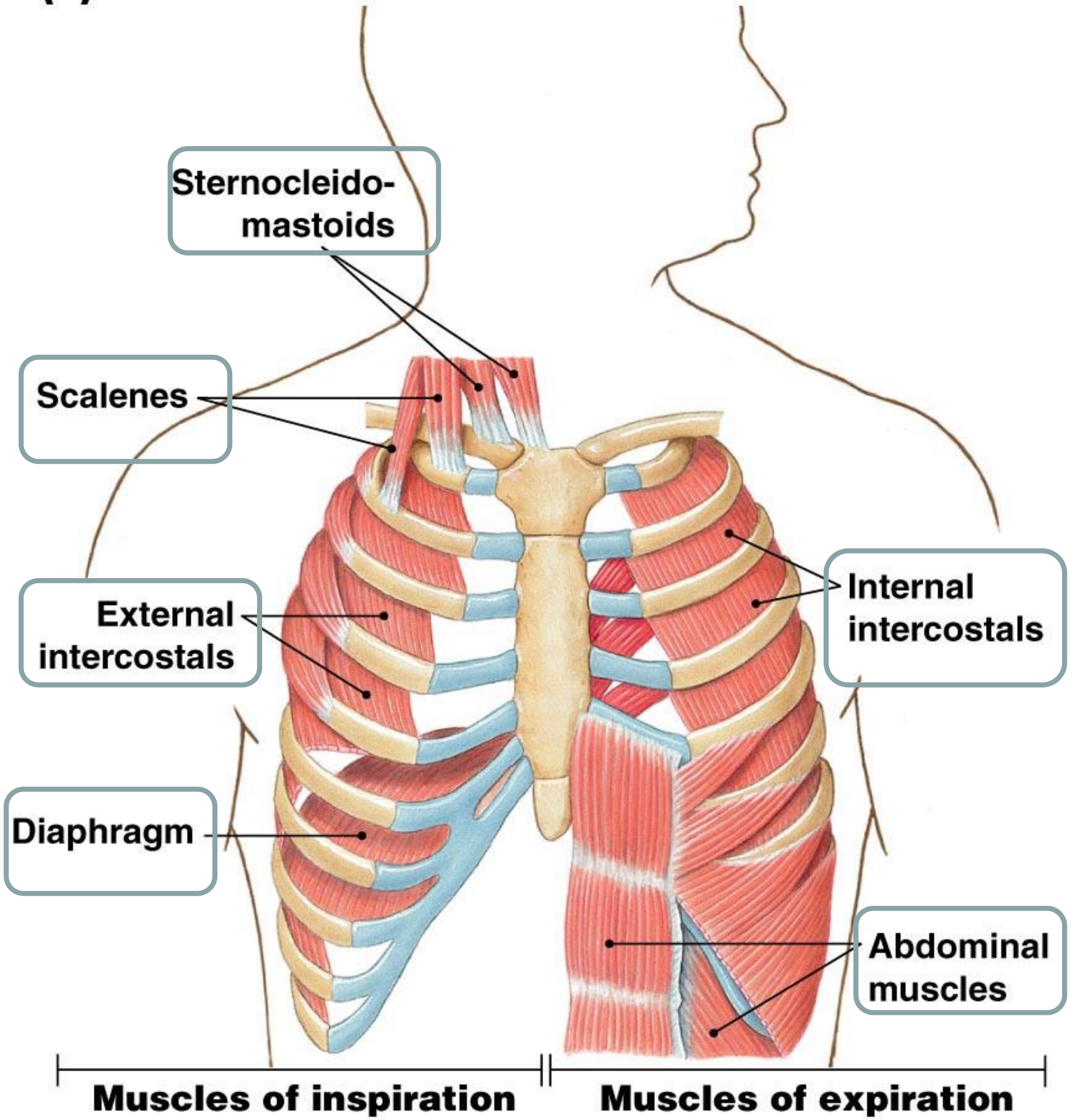


Figure 17-2b

(e) Branching of airways

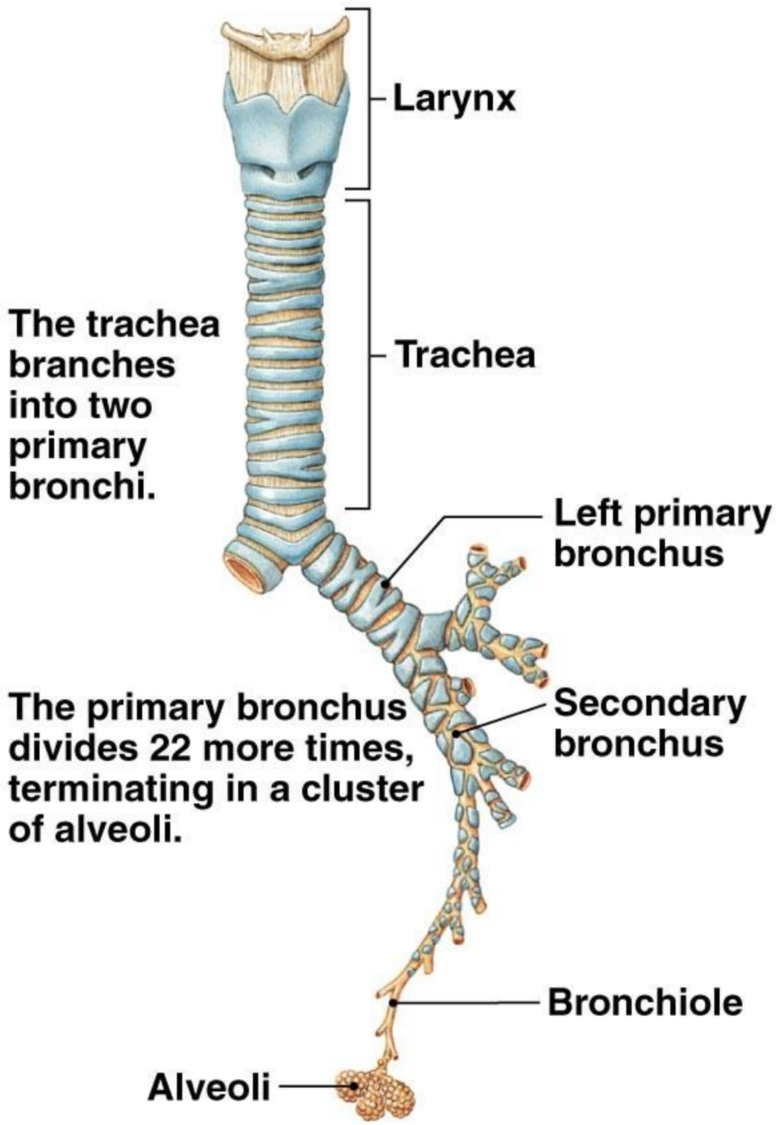
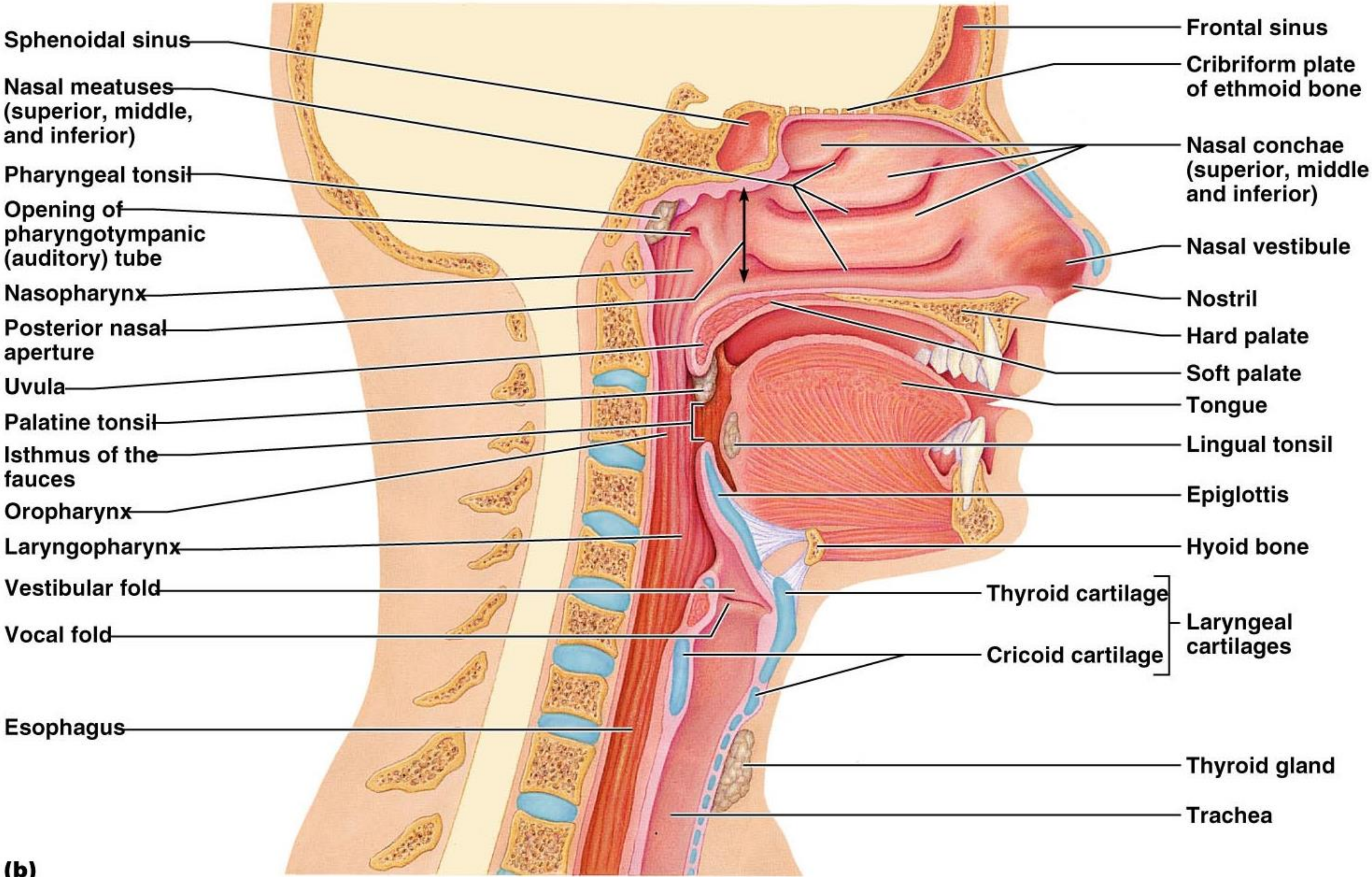


Figure 17-2e

Nasal Cavity



Nasal Cavity

- Inspired air is:
  - Humidified by the high water content in the nasal cavity
  - Warmed by rich plexuses of capillaries
- Ciliated mucosal cells remove contaminated mucus

Paranasal Sinuses

- Sinuses in bones that surround the nasal cavity
- Sinuses lighten the skull and help to warm and moisten the air

Pharynx

- Funnel-shaped tube of skeletal muscle that connects to the:
  - Nasal cavity and mouth superiorly
  - Larynx and esophagus inferiorly
- Extends from the base of the skull to the level of the sixth cervical vertebra

Pharynx

- It is divided into three regions

  1. Nasopharynx: Lies posterior to the nasal cavity, inferior to the sphenoid, and superior to the level of the soft palate

  - Closes during swallowing to prevent food from entering the nasal cavity
  - Pharyngotympanic (auditory) tubes open into the lateral walls

Pharynx

2. Oropharynx: Extends inferiorly from the level of the soft palate to the epiglottis

-Serves as a common passageway for food and air

3. Laryngopharynx: Serves as a common passageway for food and air

-Lies posterior to the upright epiglottis

-Extends to the larynx, where the respiratory and digestive pathways diverge

Larynx (Voice Box)

- Attaches to the hyoid bone and opens into the laryngopharynx superiorly
- Continuous with the trachea posteriorly
- The three functions of the larynx are:
  - To provide a patent airway
  - To act as a switching mechanism to route air and food into the proper channels
  - To function in voice production

Framework of the Larynx

- Cartilages (hyaline) of the larynx
  - Shield-shaped anterosuperior thyroid cartilage with a midline laryngeal prominence (Adam’s apple)
  - Signet ring–shaped anteroinferior cricoid cartilage
  - Three pairs of small arytenoid, cuneiform, and corniculate cartilages
- Epiglottis – elastic cartilage that covers the laryngeal inlet during swallowing

Framework of the Larynx

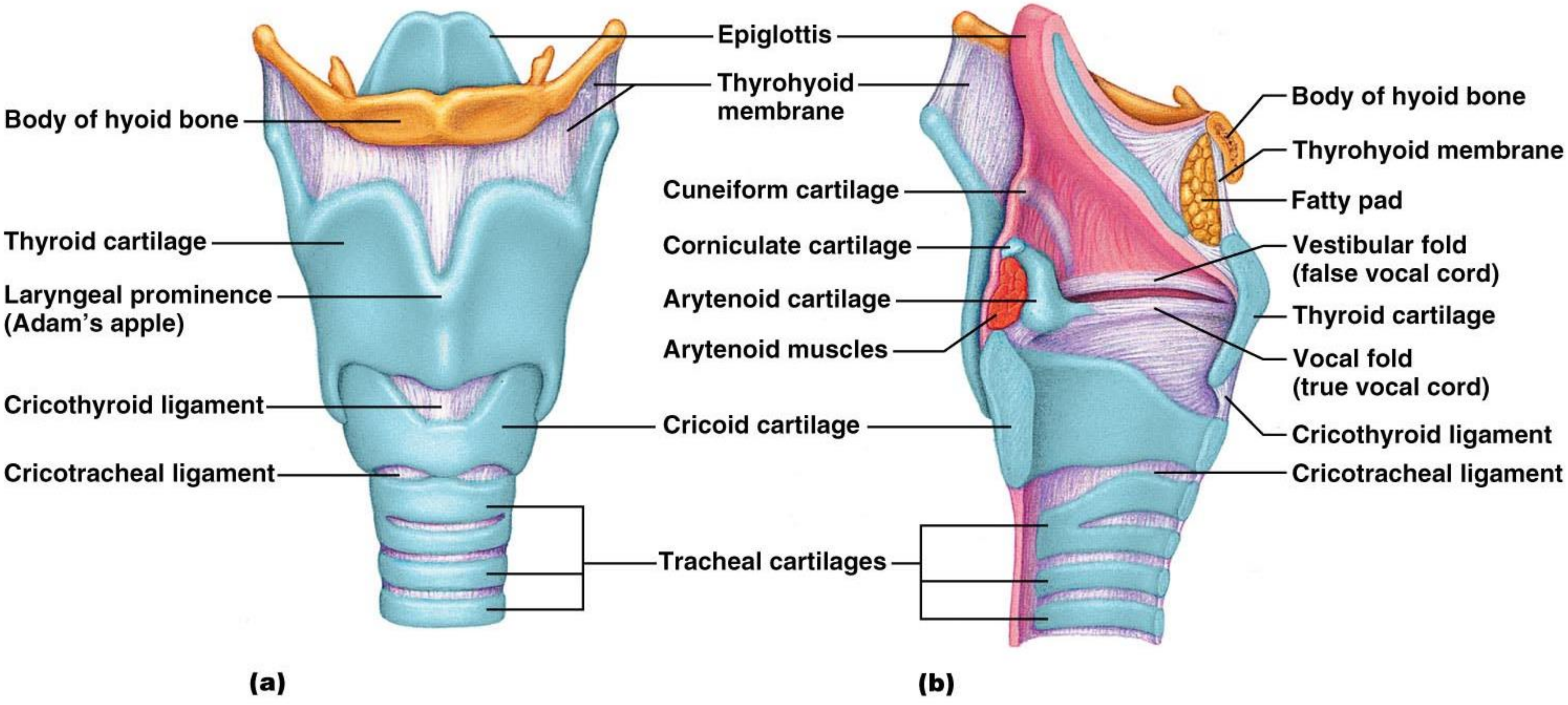


Figure 22.4a, b

Vocal Production

- Speech – intermittent release of expired air while opening and closing the glottis
- Pitch – determined by the length and tension of the vocal cords
- Loudness – depends upon the force at which the air rushes across the vocal cords
- The pharynx resonates, amplifies, and enhances sound quality
- Sound is “shaped” into language by action of the pharynx, tongue, soft palate, and lips

Movements of Vocal Cords

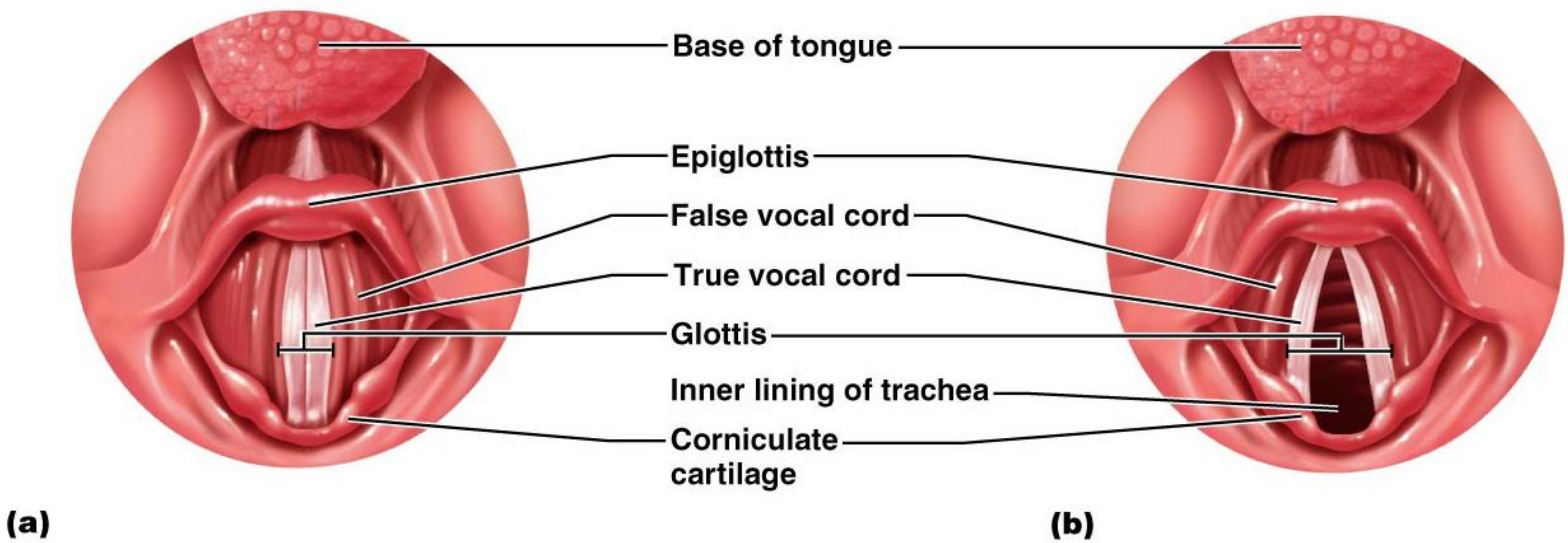


Figure 22.5

Trachea

- Flexible and mobile tube extending from the larynx into the mediastinum
- Composed of three layers
  - Mucosa – made up of goblet cells and ciliated epithelium
  - Submucosa – connective tissue deep to the mucosa
  - Adventitia – outermost layer made of C-shaped rings of hyaline cartilage

Trachea

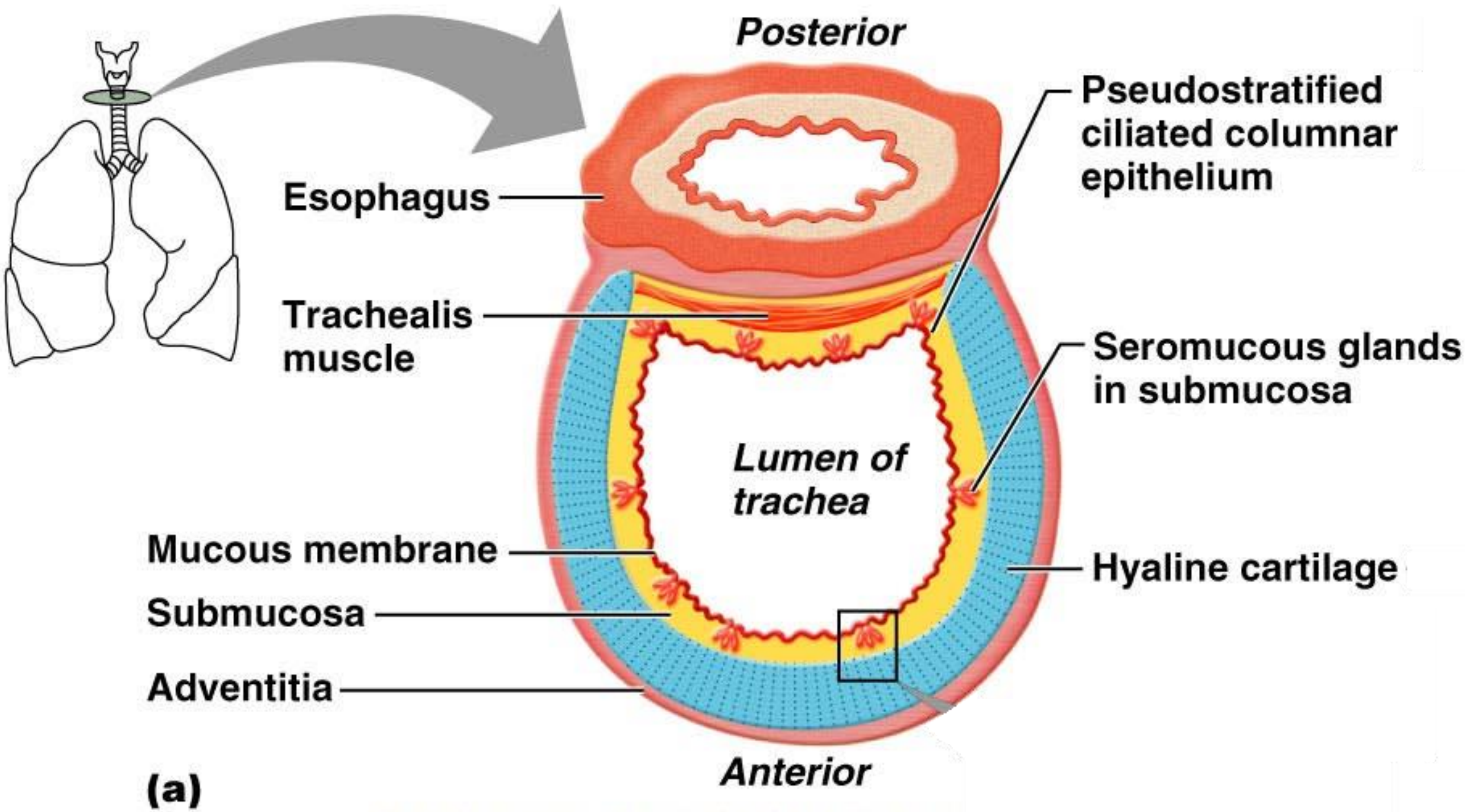
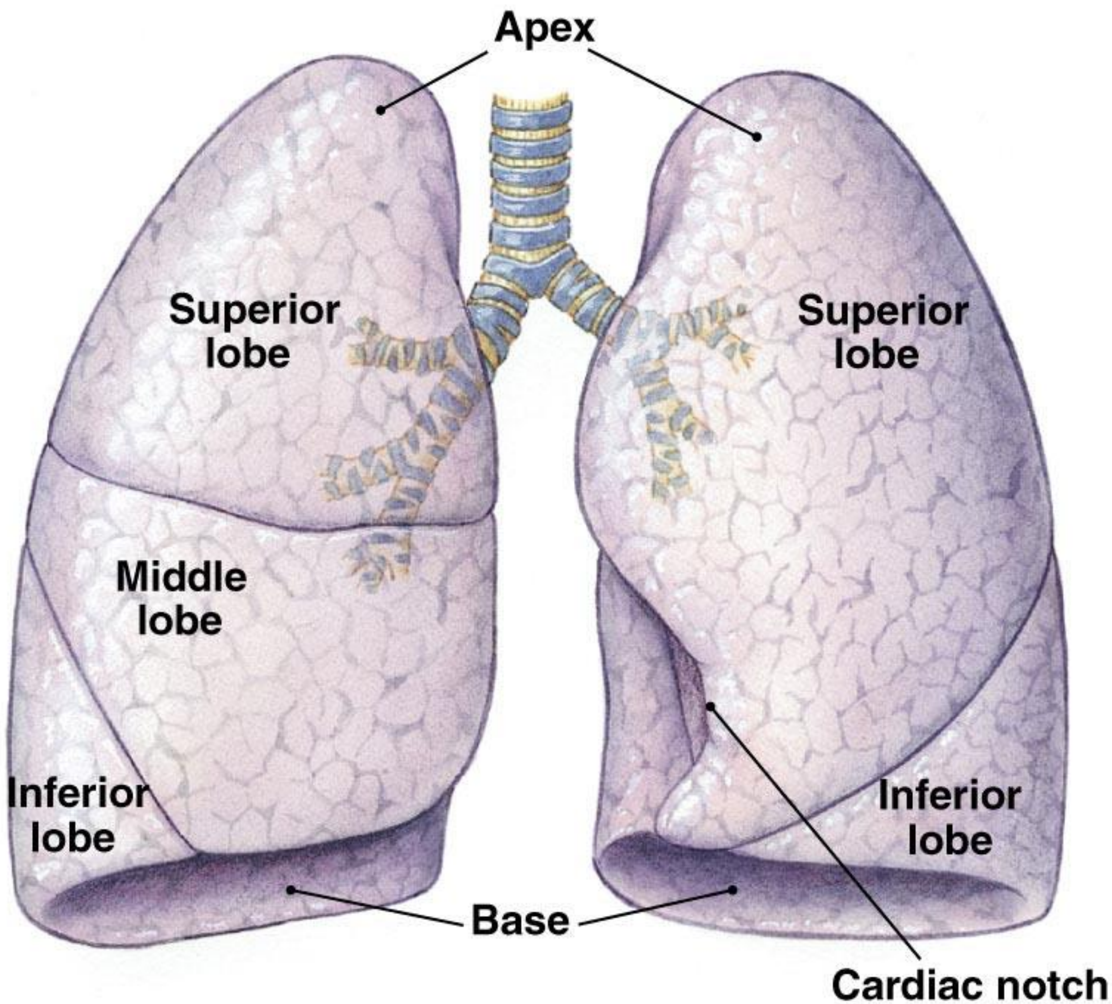


Figure 22.6a

(c) External anatomy of lungs



Right lung is divided into three lobes.

Left lung is divided into two lobes.

Figure 17-2c

Respiratory Membrane

- This air-blood barrier is composed of:
  - Alveolar and capillary walls
  - Their fused basal laminas
- Alveolar walls:
  - Are a single layer of type I epithelial cells
  - Permit gas exchange by simple diffusion
  - Secrete angiotensin converting enzyme (ACE)
- Type II cells secrete surfactant

Major Functions of the Respiratory System

- To supply the body with oxygen and dispose of carbon dioxide
- Respiration – four distinct processes must happen
  - **Pulmonary ventilation** – moving air into and out of the lungs
  - **External respiration** – gas exchange between the lungs and the blood

Major Functions of the Respiratory System

- **Transport** – transport of oxygen and carbon dioxide between the lungs and tissues

- **Internal respiration** – gas exchange between systemic blood vessels and tissues

The External respiration can be subdivided into 4 integrated process

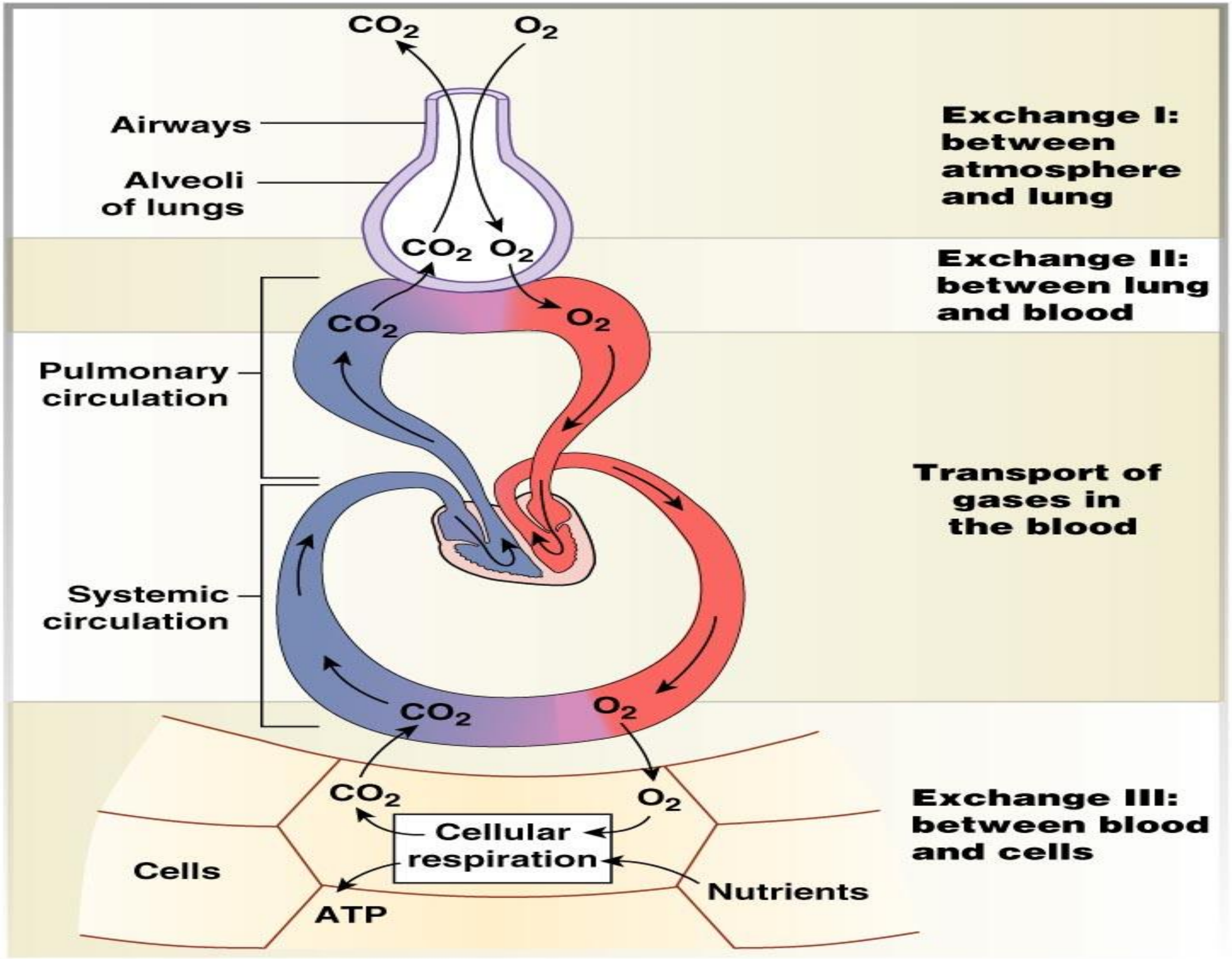


Figure 17-1

Functions of the Pleural Fluid

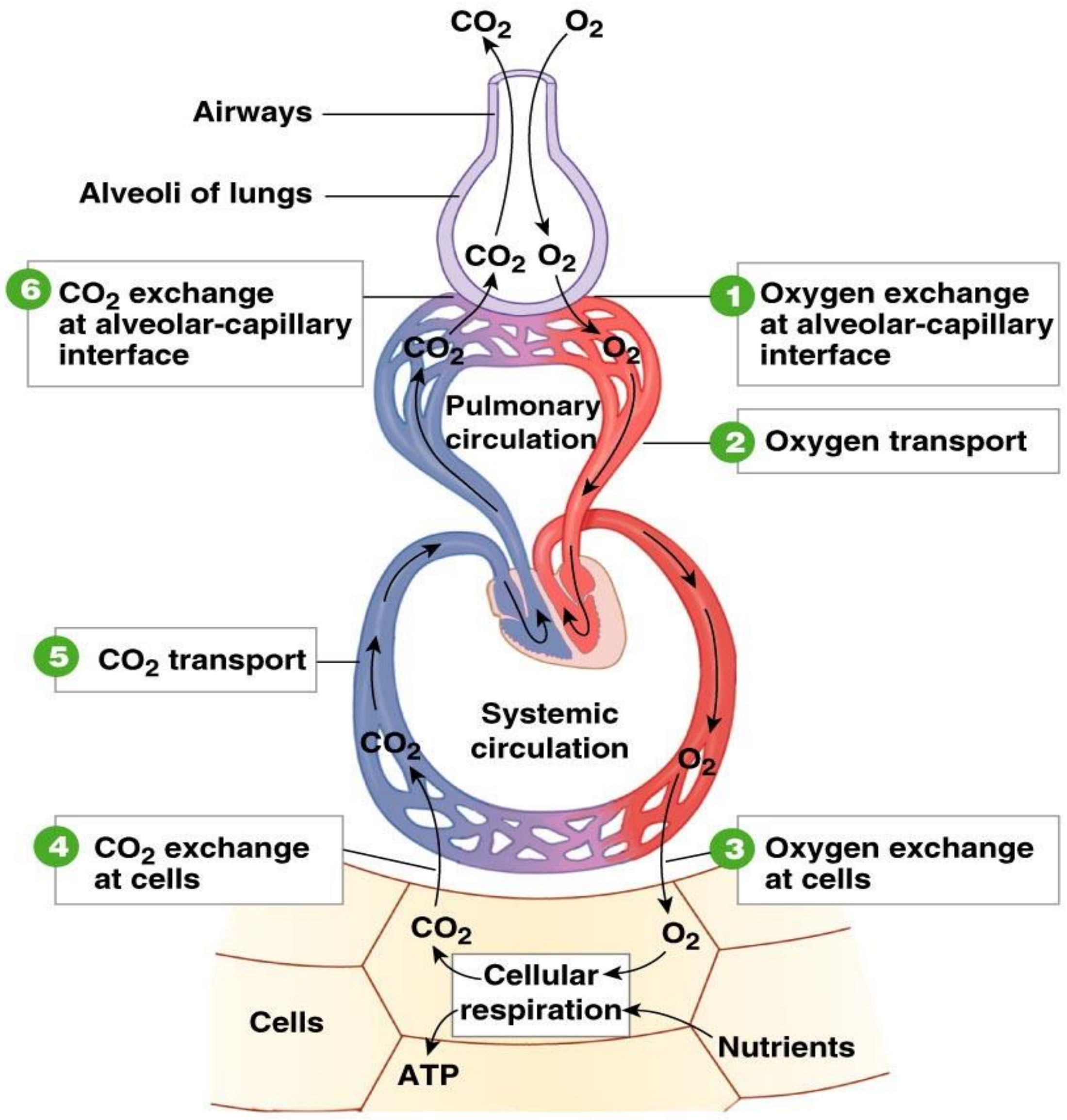
The **lungs** are contained within a double-walled **Pleural sac** that contains a small quantity of **pleural fluid.**

Why Pleural fluid is important?

- First function is: it creates a moist, slippery surface so that opposing membranes can slide across one another as the lungs moves within the thorax.

- The second important function of pleural fluid is to hold the lungs tight against the thoracic wall.

The transport and exchange of O_2 and CO_2



Diffusion and Solubility of Gases

Diffusion rate α $\frac{\text{Surface area} \times \text{Concentration gradient}}{\text{membrane thickness} \times \text{membrane resistance (constant)}}$

Three major factors influences the diffusion in the lungs:

1. Concentration gradient,
2. Surface area
3. Membrane thickness
4. We can also add the diffusion distance (diffusion is most rapid over short distances.)

TABLE 18-1 Normal Blood Values in Pulmonary Medicine

	ARTERIAL	VENOUS
P_{O_2}	95 mm Hg (85–100)	40 mm Hg
P_{CO_2}	40 mm Hg (35–45)	46 mm Hg
pH	7.4 (7.38–7.42)	7.37

Pressure Relationships in the Thoracic Cavity

- Respiratory pressure is always described relative to atmospheric pressure
- **Atmospheric pressure (P_{atm})**
  - Pressure exerted by the air surrounding the body
  - Negative respiratory pressure is less than P_{atm}
  - Positive respiratory pressure is greater than P_{atm}

Pressure Relationships in the Thoracic Cavity

- **Intrapulmonary pressure (P_{pul})** – pressure within the alveoli
- **Intrapleural pressure (P_{ip})** – pressure within the pleural cavity

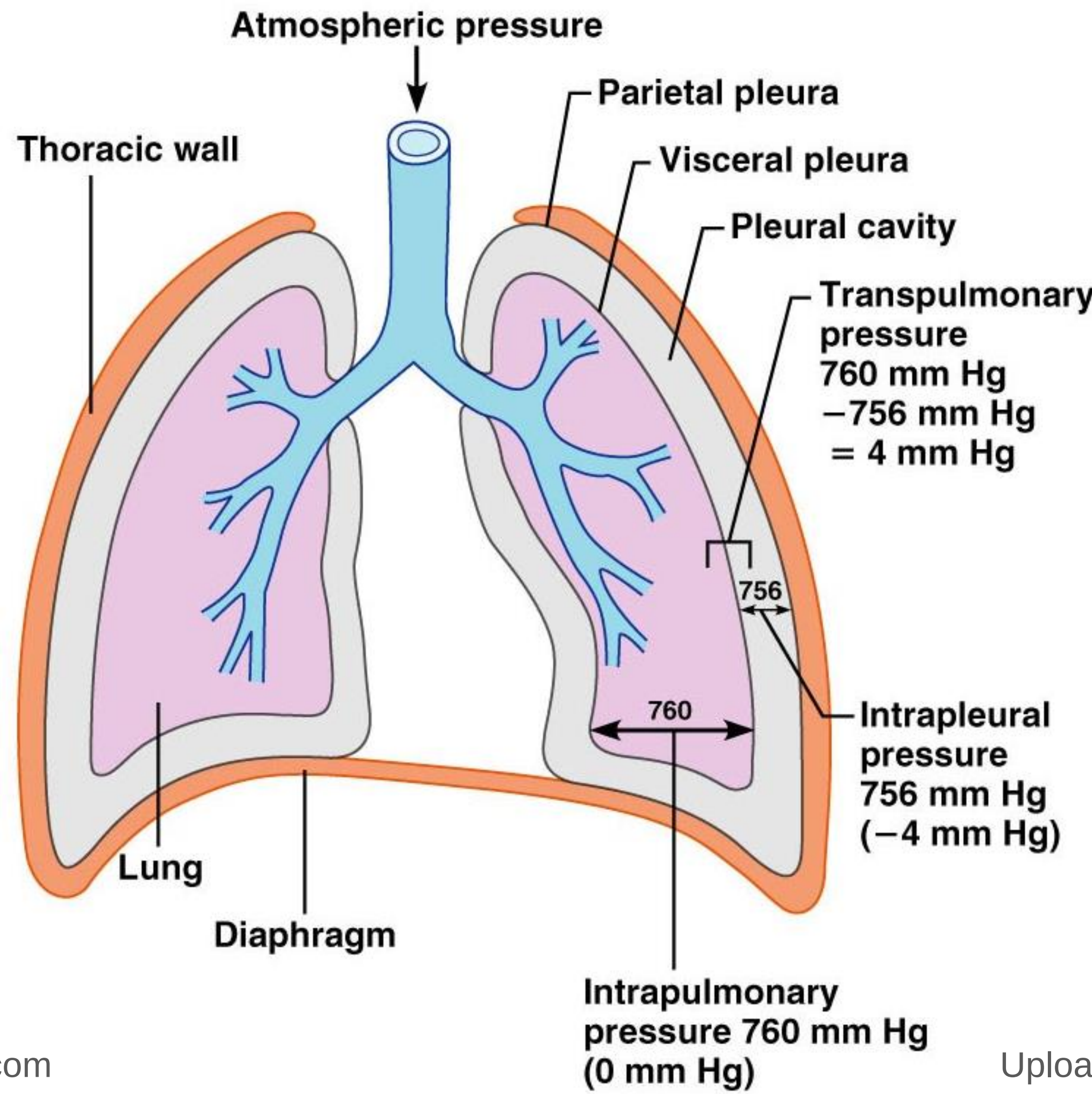
Pressure Relationships

- Intrapulmonary pressure and intrapleural pressure fluctuate with the phases of breathing
- Intrapulmonary pressure always eventually equalizes itself with atmospheric pressure
- Intrapleural pressure is always less than intrapulmonary pressure and atmospheric pressure

Pressure Relationships

- Two forces act to pull the lungs away from the thoracic wall, promoting lung collapse
  - Elasticity of lungs causes them to assume smallest possible size
  - Surface tension of alveolar fluid draws alveoli to their smallest possible size
- Opposing force – elasticity of the chest wall pulls the thorax outward to enlarge the lungs

Pressure Relationships



Pulmonary Ventilation

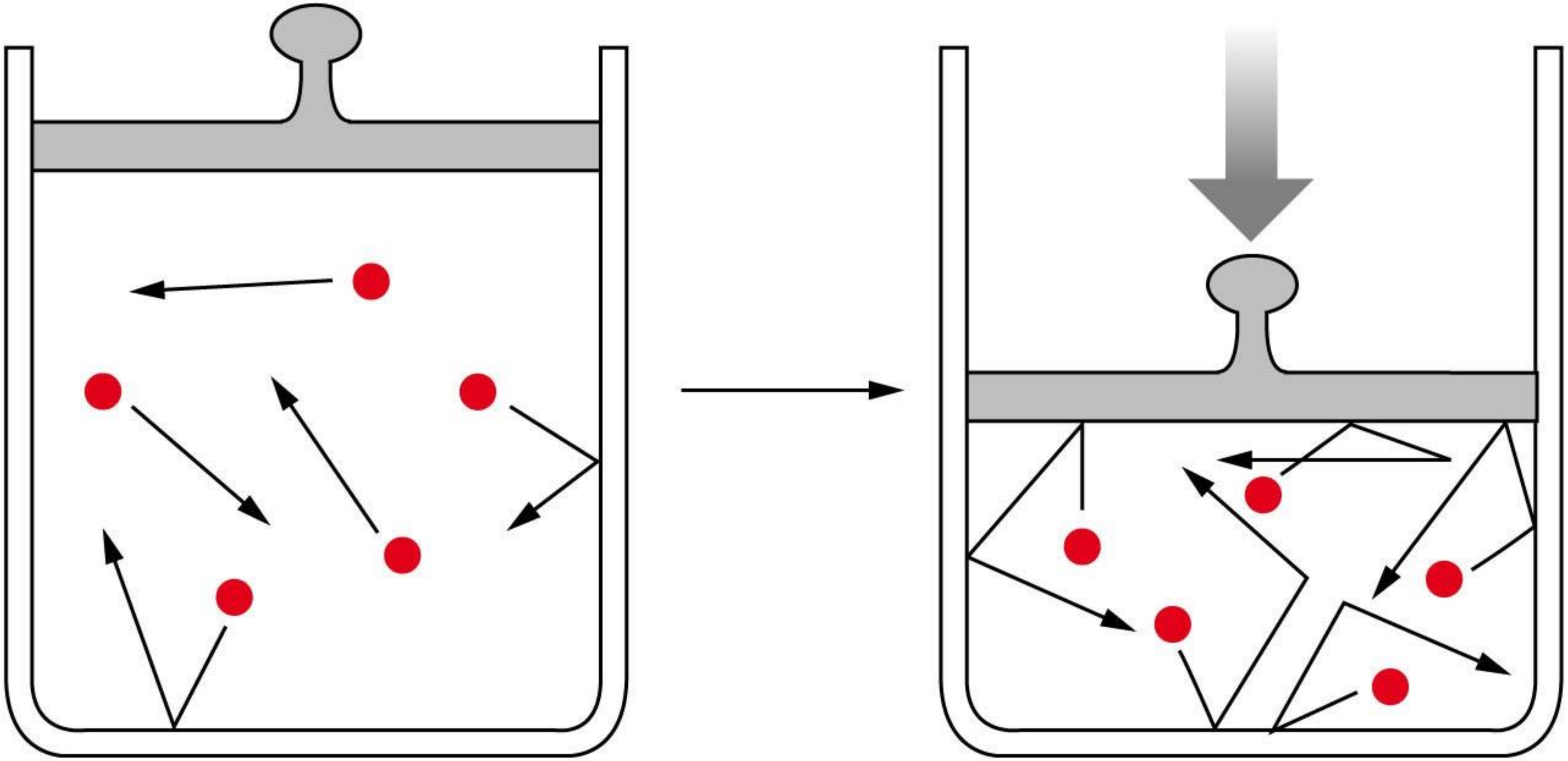
- A mechanical process that depends on volume changes in the thoracic cavity
- Volume changes lead to pressure changes, which lead to the flow of gases to equalize pressure

TABLE 17-1 Gas Laws

1. The total pressure of a mixture of gases is the sum of the pressures of the individual gases (Dalton's law).
2. Gases, singly or in a mixture, move from areas of higher pressure to areas of lower pressure.
3. If the volume of a container of gas changes, the pressure of the gas will change in an inverse manner (Boyle's law).

Boyle's Law: $P_1V_1 = P_2V_2$

Decreasing volume increases collisions and increases pressure.



$V_1 = 1.0\ L$
$P_1 = 100\ mm\ Hg$

$V_2 = 0.5\ L$
$P_2 = 200\ mm\ Hg$

Figure 17-5

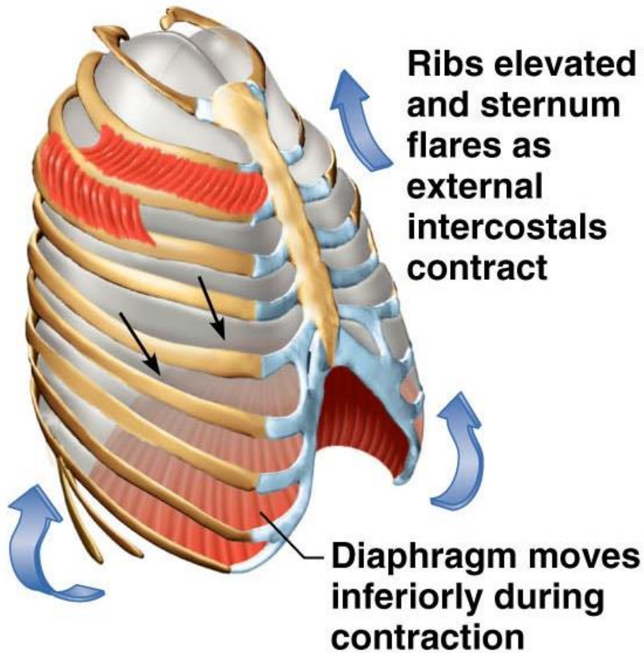
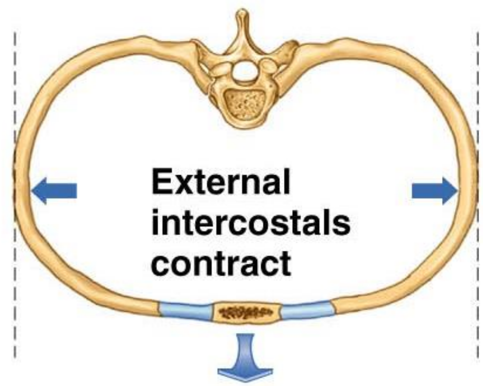
Breathing

- Breathing, or pulmonary ventilation, consists of two phases
  - **Inspiration** – air flows into the lungs
  - **Expiration** – gases exit the lungs

Inspiration

- The diaphragm and external intercostal muscles (inspiratory muscles) contract and the rib cage rises
- The lungs are stretched and intrapulmonary volume increases
- Intrapulmonary pressure drops below atmospheric pressure (–1 mm Hg)
- Air flows into the lungs, down its pressure gradient, until Ppul pressure = atmospheric pressure

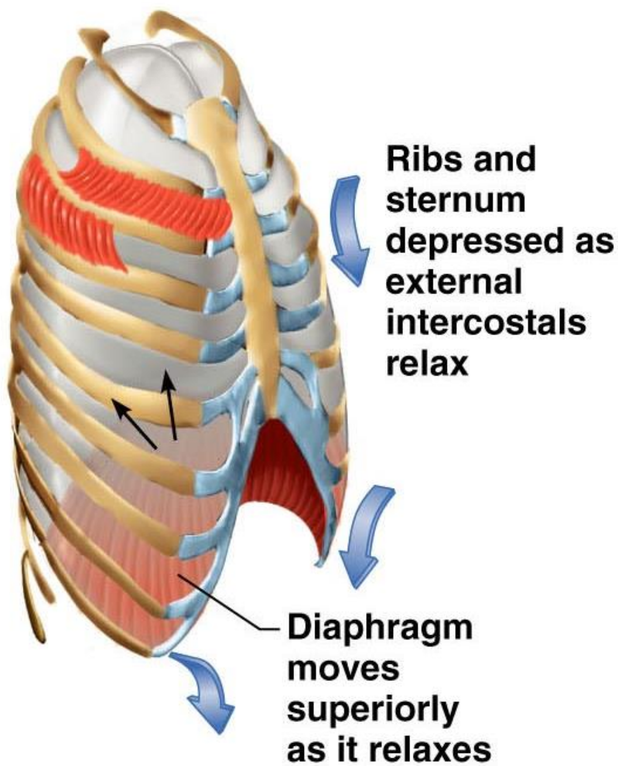
Inspiration

	Sequence of events	Changes in anterior-posterior and superior-inferior dimensions	Changes in lateral dimensions
Inspiration	① Inspiratory muscles contract (diaphragm descends; rib cage rises) ↓ ② Thoracic cavity volume increases ↓ ③ Lungs stretched; intrapulmonary volume increases ↓ ④ Intrapulmonary pressure drops (to –1 mm Hg) ↓ ⑤ Air (gases) flows into lungs down its pressure gradient until intrapulmonary pressure is 0 (equal to atmospheric pressure)		

Expiration

- Inspiratory muscles relax and the rib cage descends due to gravity
- Thoracic cavity volume decreases
- Elastic lungs recoil passively and intrapulmonary volume decreases
- Intrapulmonary pressure rises above atmospheric pressure (+1 mm Hg)
- Gases flow out of the lungs down the pressure gradient until intrapulmonary pressure is 0

Expiration

<table>
<tr><th></th><th>Sequence of events</th><th>Changes in anterior-posterior and superior-inferior dimensions</th><th>Changes in lateral dimensions</th></tr>
<tr><td>Expiration</td><td>
① Inspiratory muscles relax (diaphragm rises; rib cage descends due to recoil of costal cartilages)
↓
② Thoracic cavity volume decreases
↓
③ Elastic lungs recoil passively; intrapulmonary volume decreases
↓
④ Intrapulmonary pressure rises (to +1 mm Hg)
↓
⑤ Air (gases) flows out of lungs down its pressure gradient until intrapulmonary pressure is 0
</td><td>


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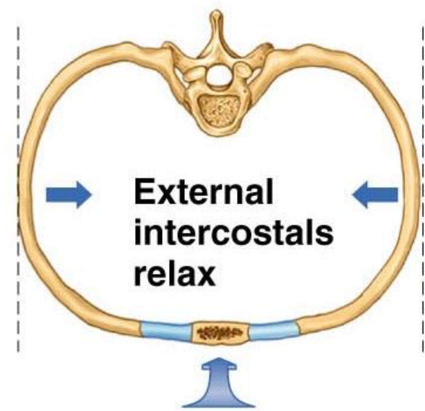

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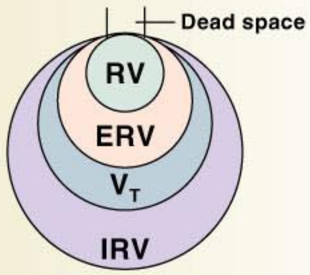
</table>

Figure 22.13.2

Respiratory Volumes

- **Tidal volume (TV)** – air that moves into and out of the lungs with each breath (approximately 500 ml)
- **Inspiratory reserve volume (IRV)** – air that can be inspired forcibly beyond the tidal volume (2100–3200 ml)
- **Expiratory reserve volume (ERV)** – air that can be evacuated from the lungs after a tidal expiration (1000–1200 ml)
- **Residual volume (RV)** – air left in the lungs after strenuous expiration (1200 ml)

The four lung volumes

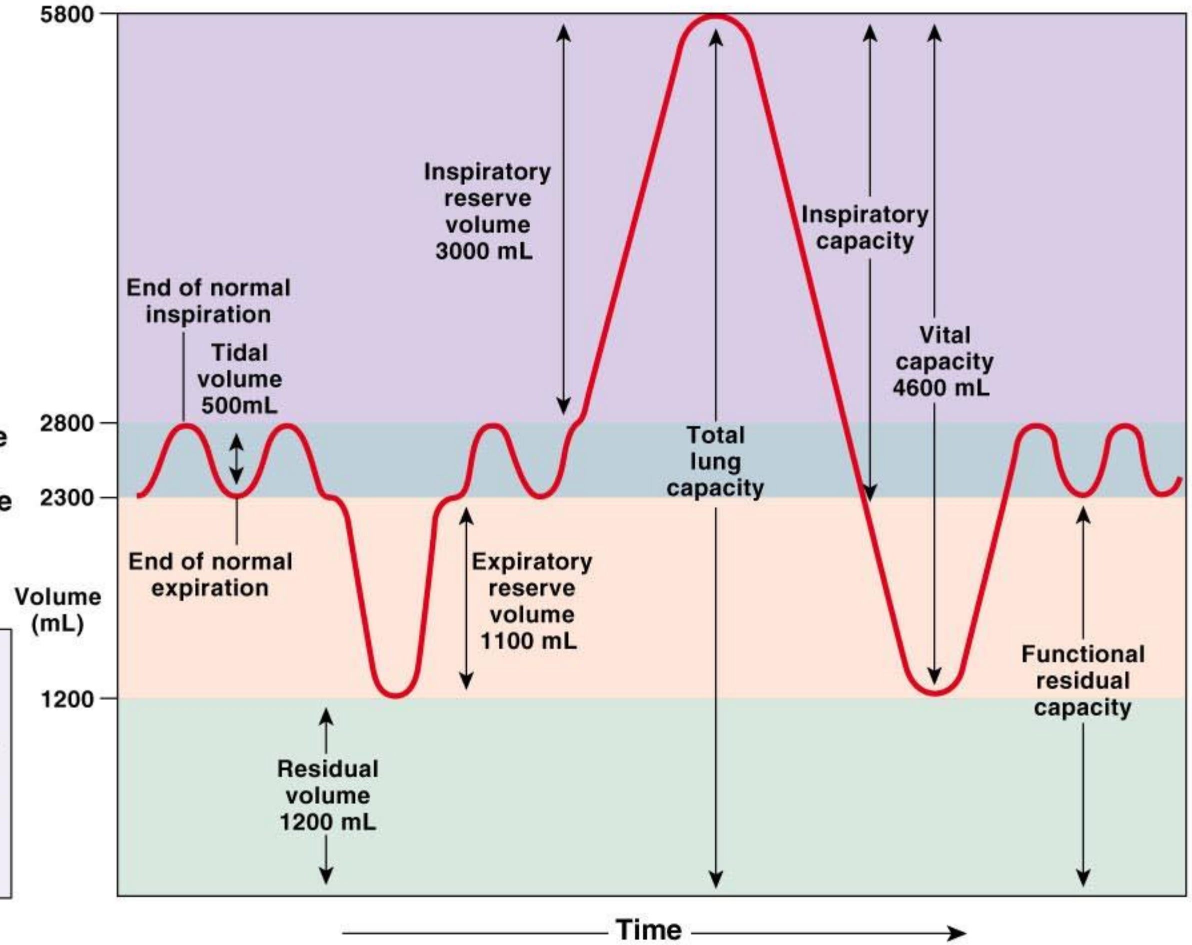


RV = Residual volume
ERV = Expiratory reserve volume
V_T = Tidal volume
IRV = Inspiratory reserve volume

Pulmonary volumes

		Males	Females	
Vital capacity	IRV	3000	1900	Inspiratory capacity
	V_T	500	500	
	ERV	1100	700	Functional residual capacity
Residual volume		1200	1100	
		5800 mL	4200 mL	

A spirometer tracing showing lung volumes and capacities



Capacities are sums of two or more volumes.

Figure 17-7

Respiratory Capacities

- **Inspiratory capacity (IC)** – total amount of air that can be inspired after a tidal expiration (IC = IRV + TV)
- **Functional residual capacity (FRC)** – amount of air remaining in the lungs after a tidal expiration (FRC = RV + ERV)
- **Vital capacity (VC)** – the total amount of exchangeable air (VC = TV + IRV + ERV)
- Total lung capacity (TLC) – sum of all lung volumes (approximately 6000 ml in males)

Dead Space

- Anatomical dead space – volume of the conducting respiratory passages (150 ml)
- Alveolar dead space – alveoli that cease to act in gas exchange due to collapse or obstruction
- Total dead space – sum of alveolar and anatomical dead spaces

Pulmonary Function Tests

- **Spirometer** – an instrument consisting of a hollow bell inverted over water, used to evaluate respiratory function
- Spirometry can distinguish between:
  - Obstructive pulmonary disease – increased airway resistance
  - Restrictive disorders – reduction in total lung capacity from structural or functional lung changes

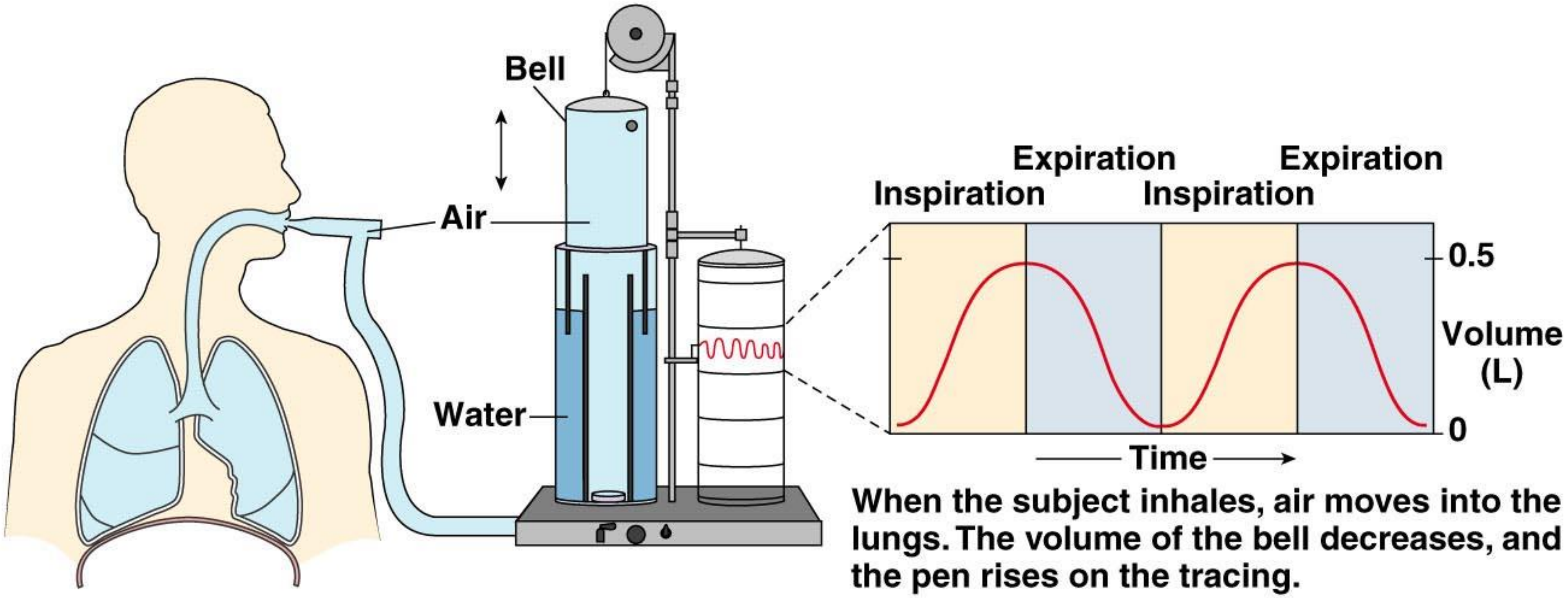

Bell
Air
Water
Expiration
Inspiration
Expiration
Inspiration
0.5
Volume
(L)
0
Time
When the subject inhales, air moves into the lungs. The volume of the bell decreases, and the pen rises on the tracing.

Figure 17-6

Pulmonary Function Tests

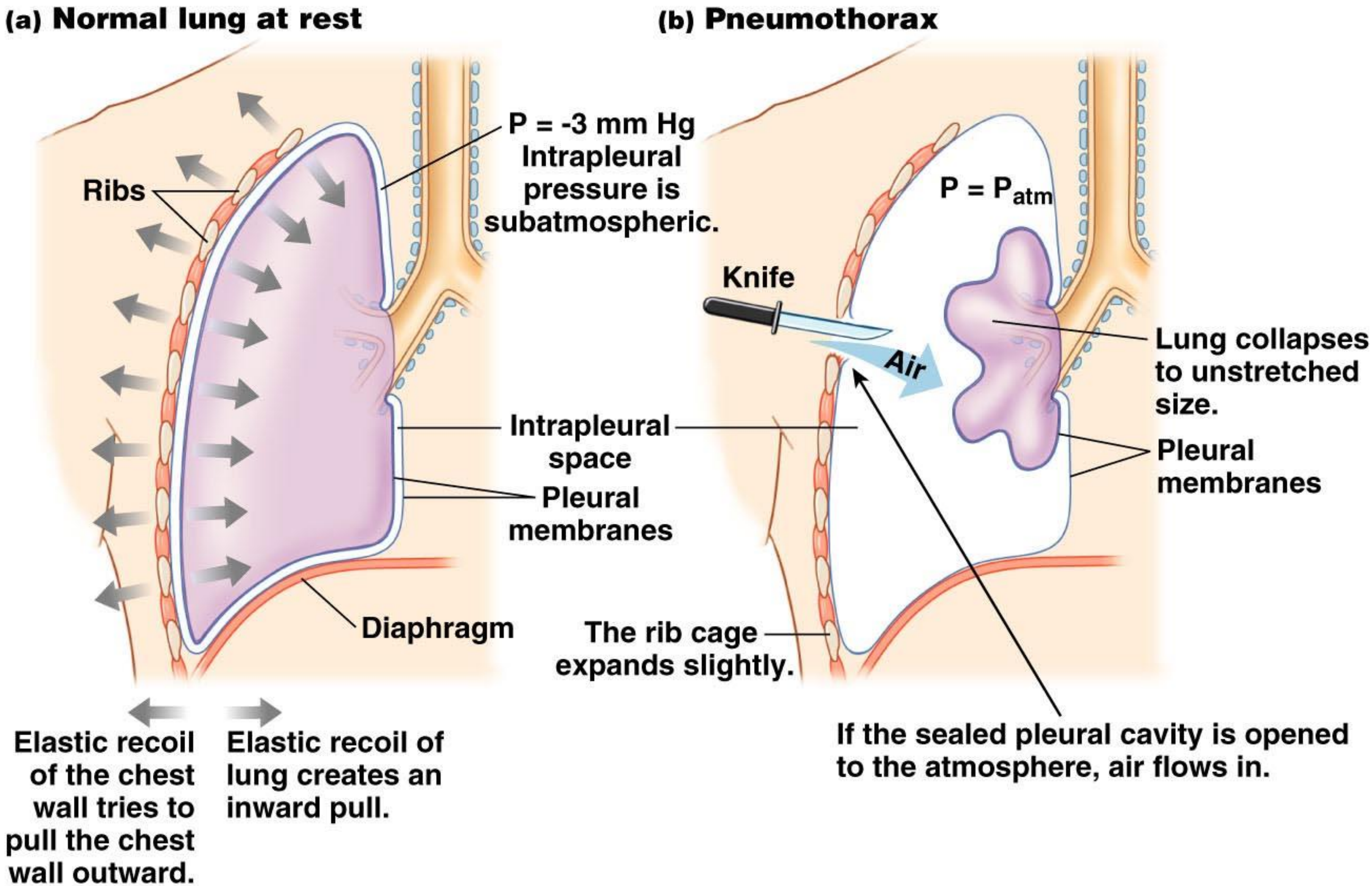
- Total ventilation – total amount of gas flow into or out of the respiratory tract in one minute
- Forced vital capacity (FVC) – gas forcibly expelled after taking a deep breath
- Forced expiratory volume (FEV) – the amount of gas expelled during specific time intervals of the FVC

Pulmonary Function Tests

- Increases in TLC, FRC, and RV may occur as a result of obstructive disease
- Reduction in VC, TLC, FRC, and RV result from restrictive disease

Lung Collapse

- Caused by equalization of the intrapleural pressure with the intrapulmonary pressure
- Transpulmonary pressure keeps the airways open
  - Transpulmonary pressure – difference between the intrapulmonary and intrapleural pressures
    $(P_{pul} – P_{ip})$


(a) Normal lung at rest
(b) Pneumothorax
Ribs
P = -3 mm Hg
Intrapleural
pressure is
subatmospheric.
Intrapleural
space
Pleural
membranes
Diaphragm
Elastic recoil
of the chest
wall tries to
pull the chest
wall outward.
Elastic recoil of
lung creates an
inward pull.
P = P_{atm}
Knife
Air
Lung collapses
to unstretched
size.
Pleural
membranes
The rib cage
expands slightly.
If the sealed pleural cavity is opened
to the atmosphere, air flows in.

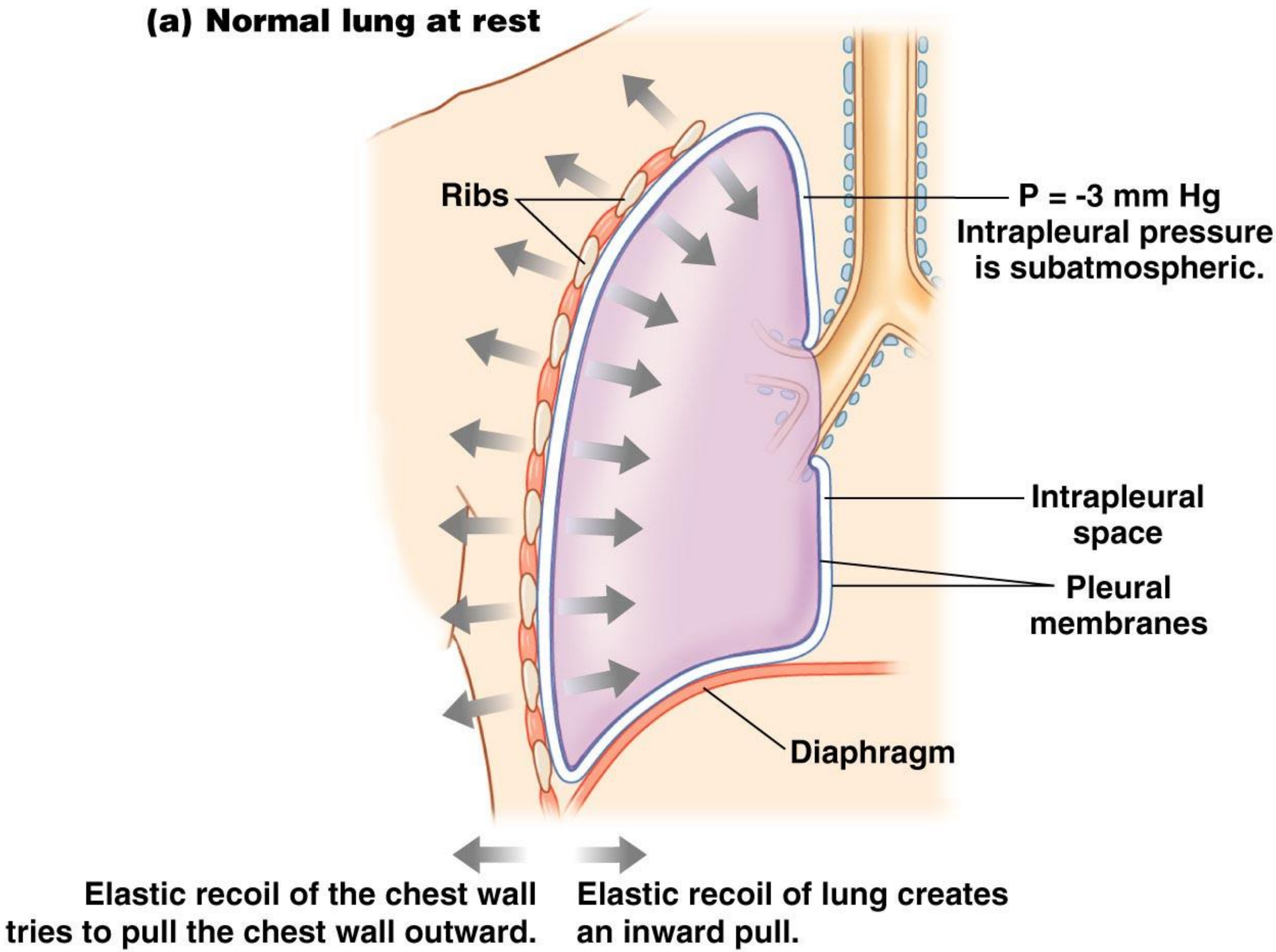


Figure 17-12a

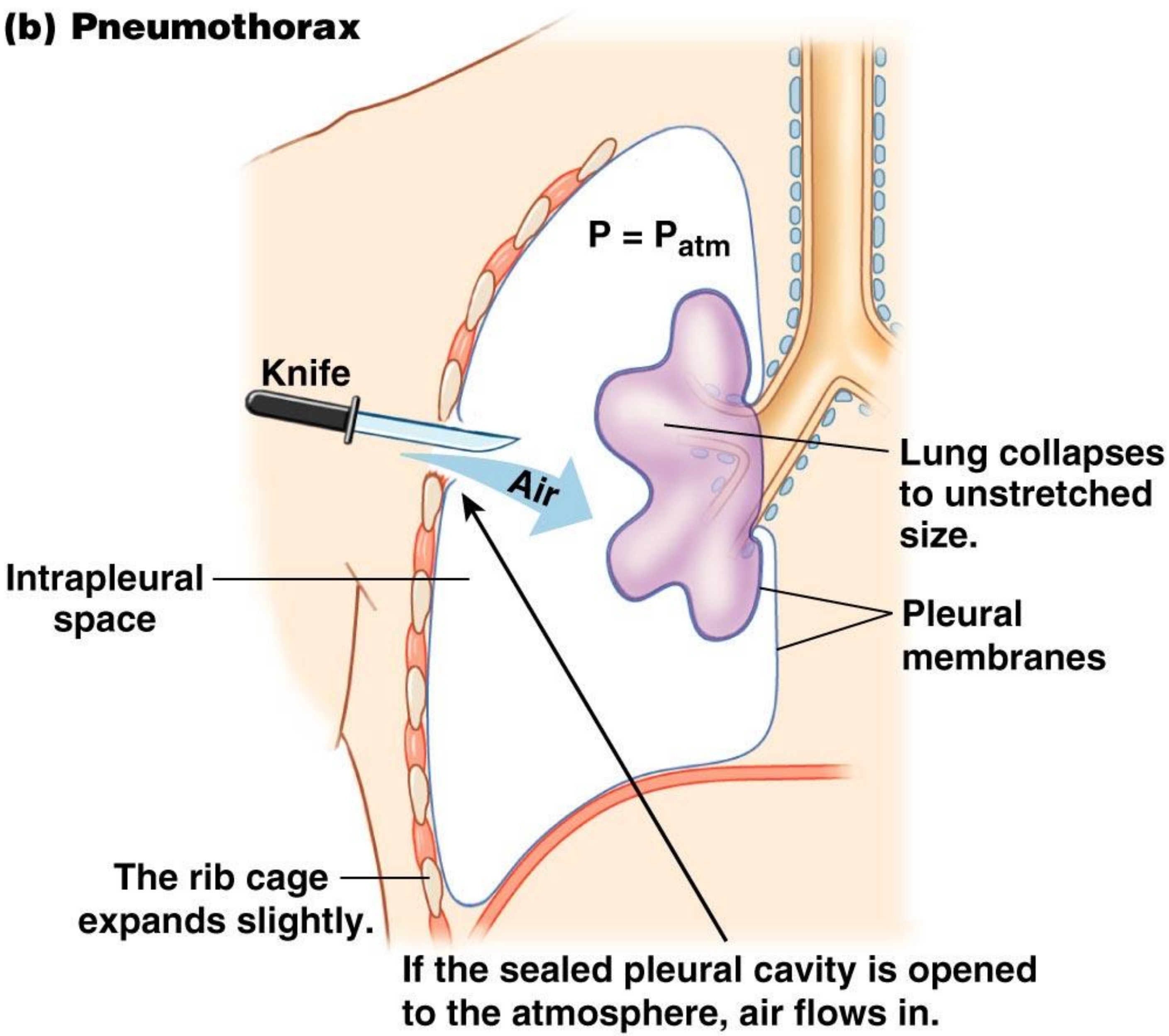


Figure 17-12b

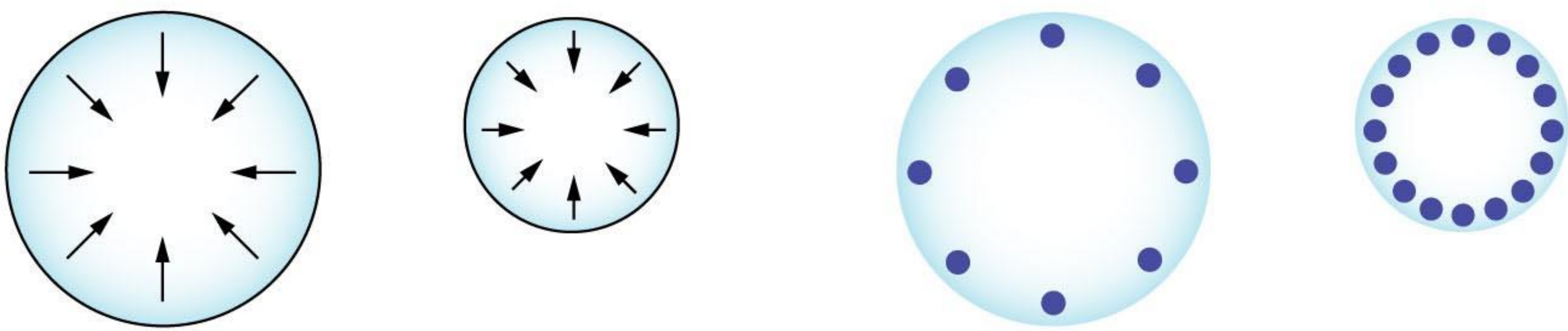
Law of LaPlace: $P = 2T/r$

P = pressure
T = surface tension
r = radius

According to the law of LaPlace, if two bubbles have the same surface tension, the smaller bubble will have higher pressure.

(a) Pressure is greater in the smaller bubble.

(b) Surfactant reduces surface tension (T). Pressure is equalized in the large and small bubbles.



Larger bubble	Smaller bubble		
r = 2	r = 1	r = 2	r = 1
T = 3	T = 3	T = 2	T = 1
P = (2 × 3)/2	P = (2 × 3)/1	P = (2 × 2)/2	P = (2 × 1)/1
P = 3	P = 6	P = 2	P = 2

Figure 17-13 Overview

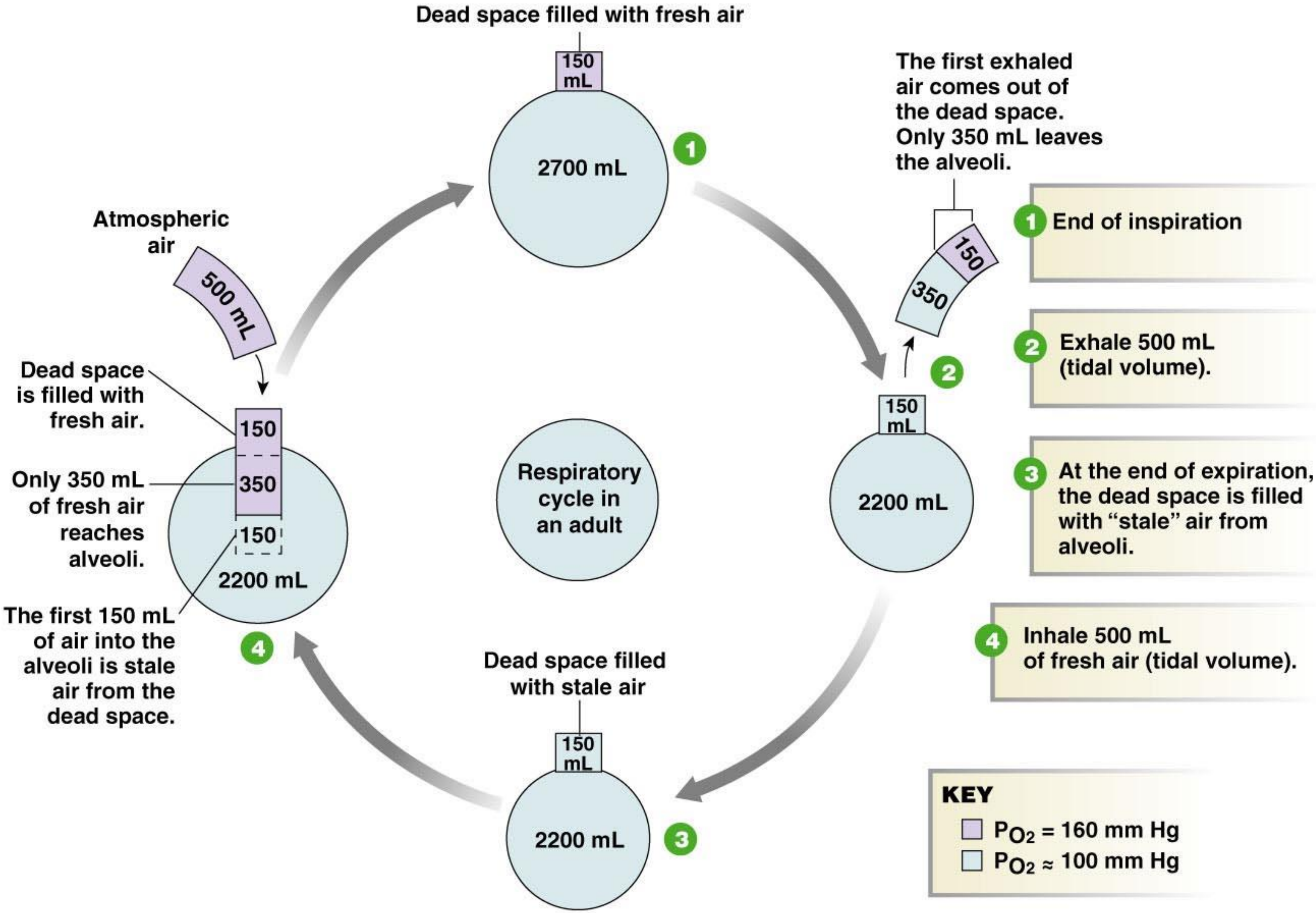

Dead space filled with fresh air
150 mL
2700 mL
1
The first exhaled air comes out of the dead space. Only 350 mL leaves the alveoli.
150
350
2
150 mL
2200 mL
Atmospheric air
500 mL
Dead space is filled with fresh air.
150
Only 350 mL of fresh air reaches alveoli.
350
150
2200 mL
The first 150 mL of air into the alveoli is stale air from the dead space.
4
Respiratory cycle in an adult
Dead space filled with stale air
150 mL
2200 mL
3
1 End of inspiration
2 Exhale 500 mL (tidal volume).
3 At the end of expiration, the dead space is filled with "stale" air from alveoli.
4 Inhale 500 mL of fresh air (tidal volume).
KEY
PO2 = 160 mm Hg
PO2 ≈ 100 mm Hg

Figure 17-14

TABLE 17-6	Normal Ventilation Values in Pulmonary Medicine
Total pulmonary ventilation	6 L/min
Total alveolar ventilation	4.2 L/min
Maximum voluntary ventilation	125–170 L/min
Respiration rate	12–20 breaths/min

Oxygen-hemoglobin dissociation curve

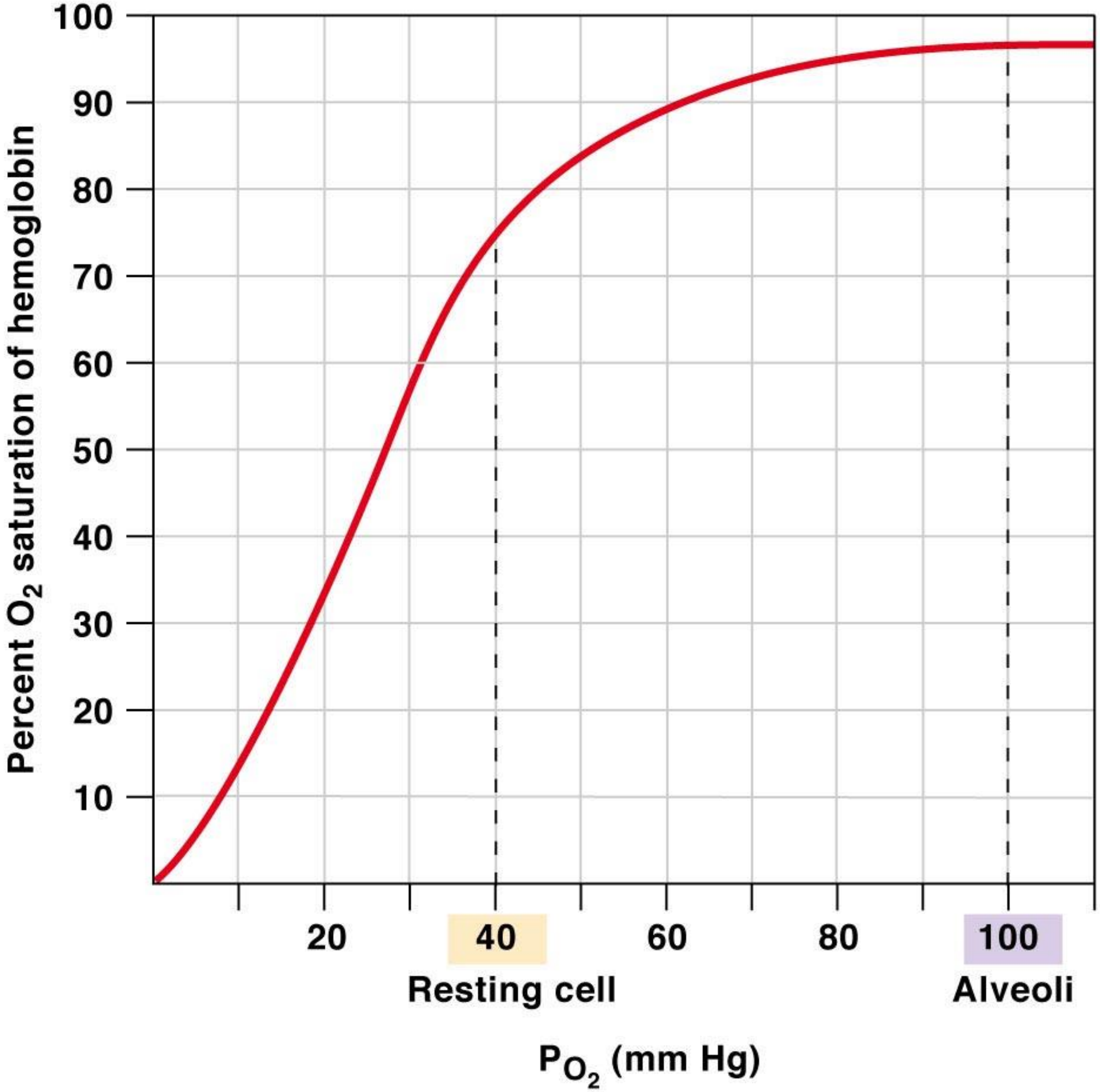


Figure 18-9

Hemoglobin (Hb)

- The oxygen binding protein in RBCs.
- Total blood oxygen content is equal the amount of oxygen dissolved in plasma + the amount of oxygen bound to Hb (~98%).

The amount of O_2 that binds to Hb depends on two factors:

1. The P_{O_2} of plasma
2. The total number of binding sites (how many Hb in the blood).

1 Hb can bind to up to 4 O_2.

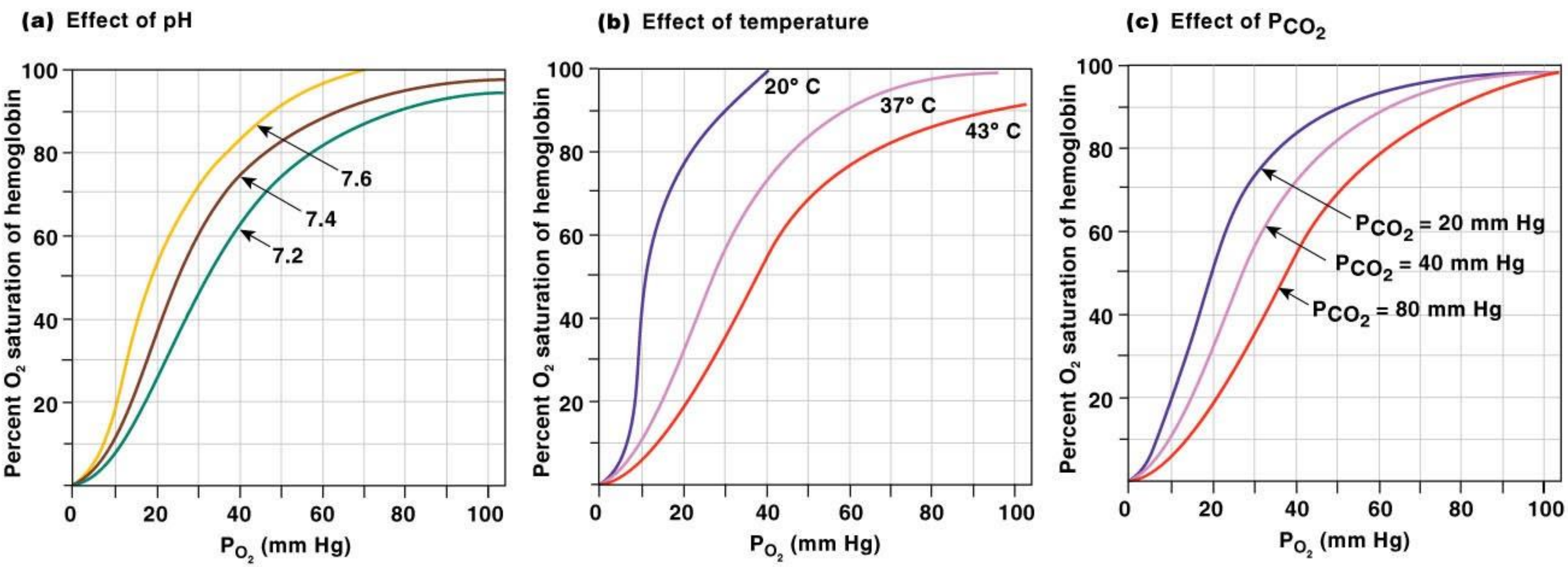


Figure 18-10 Overview

(a) Effect of pH

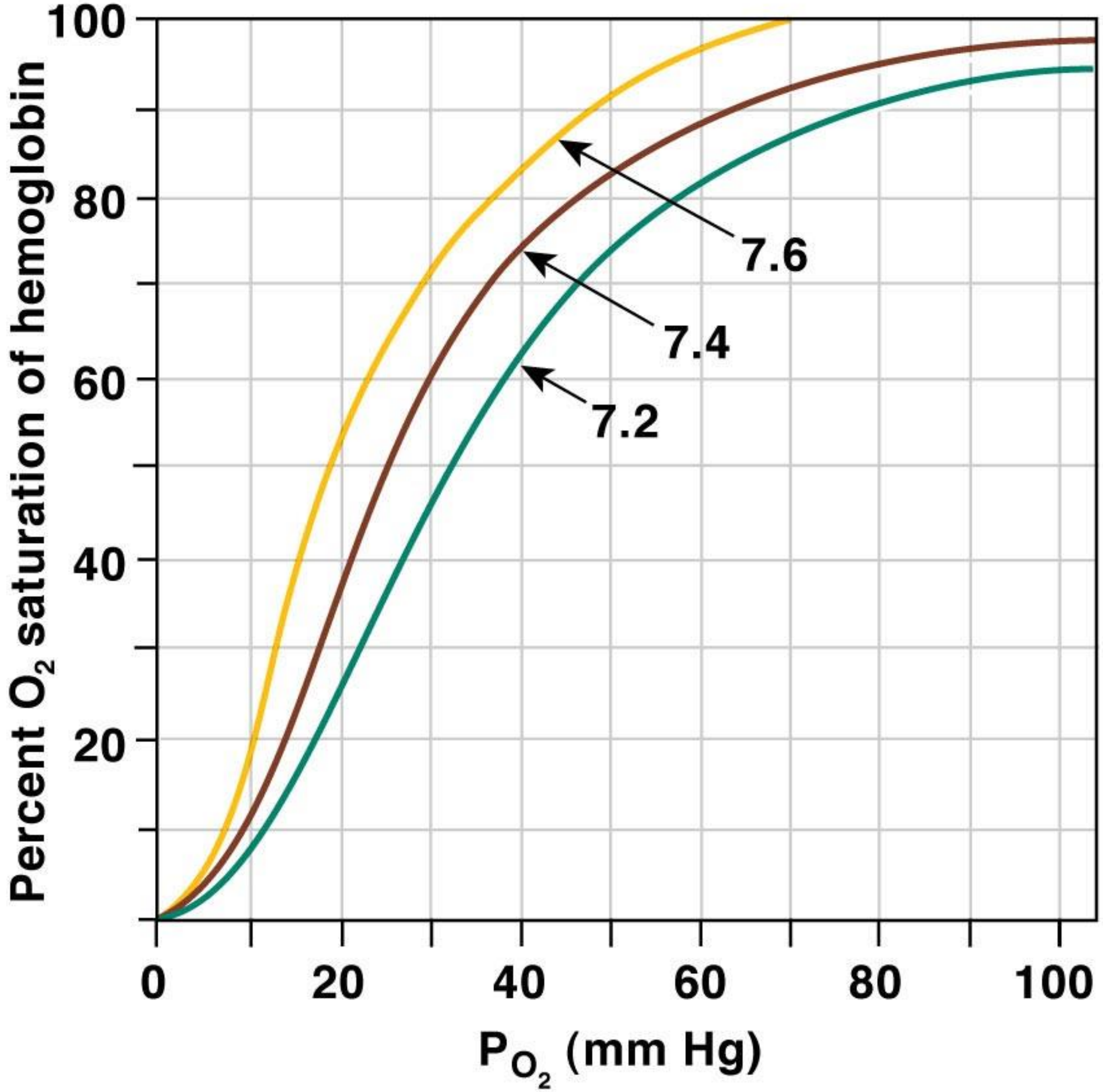


Figure 18-10a

(b) Effect of temperature

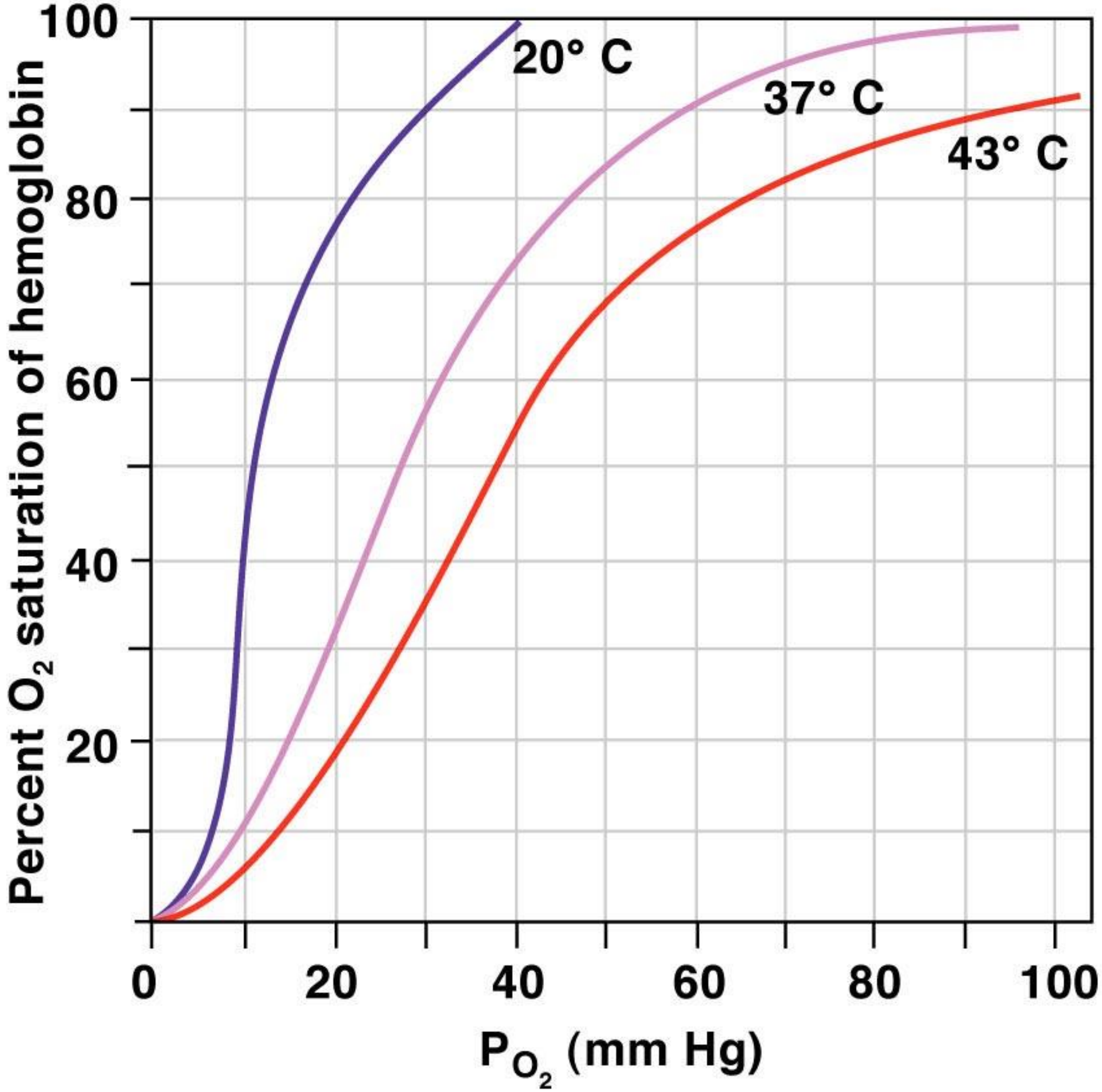


Figure 18-10b

(c) Effect of P_{CO_2}

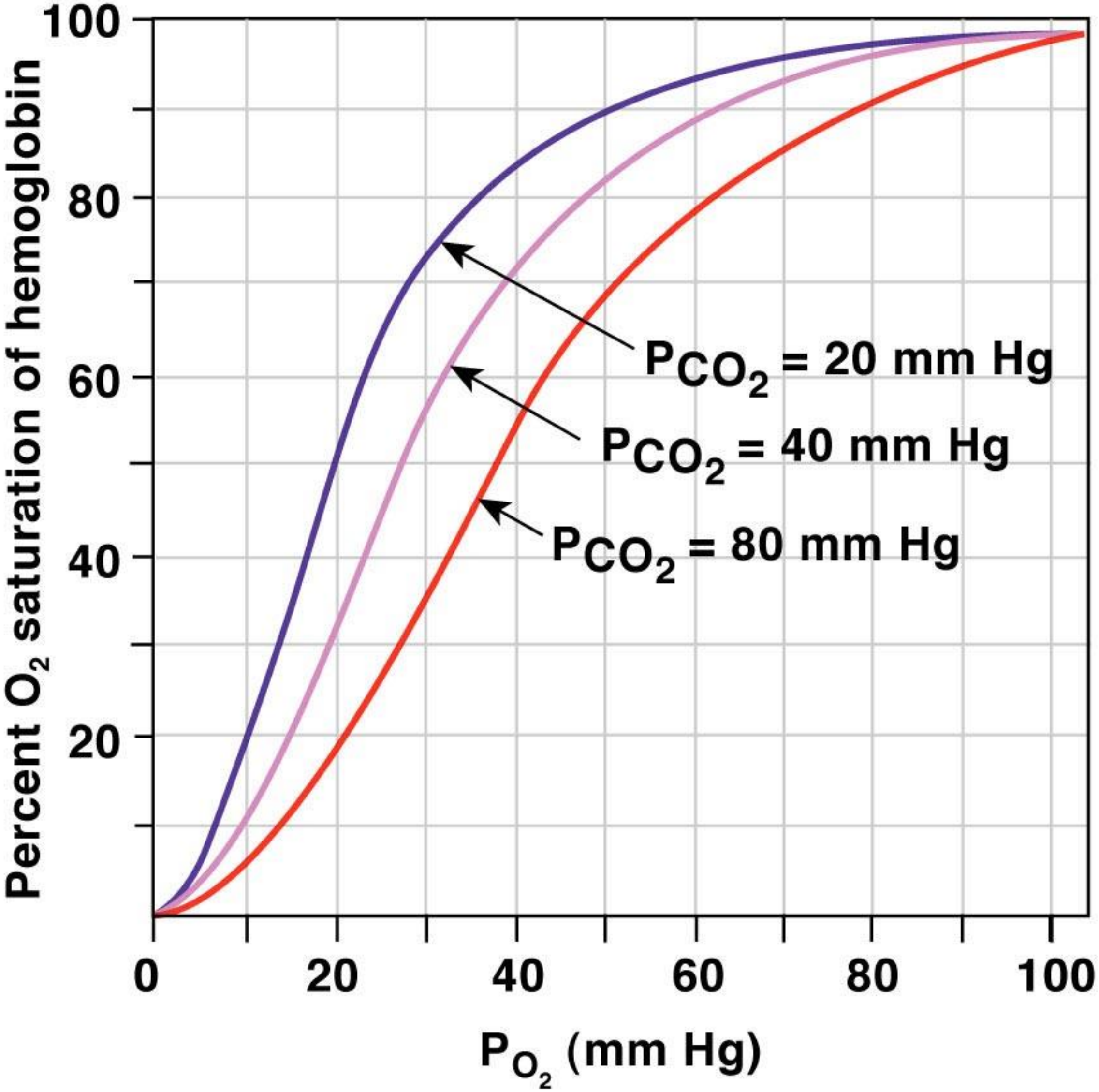


Figure 18-10c

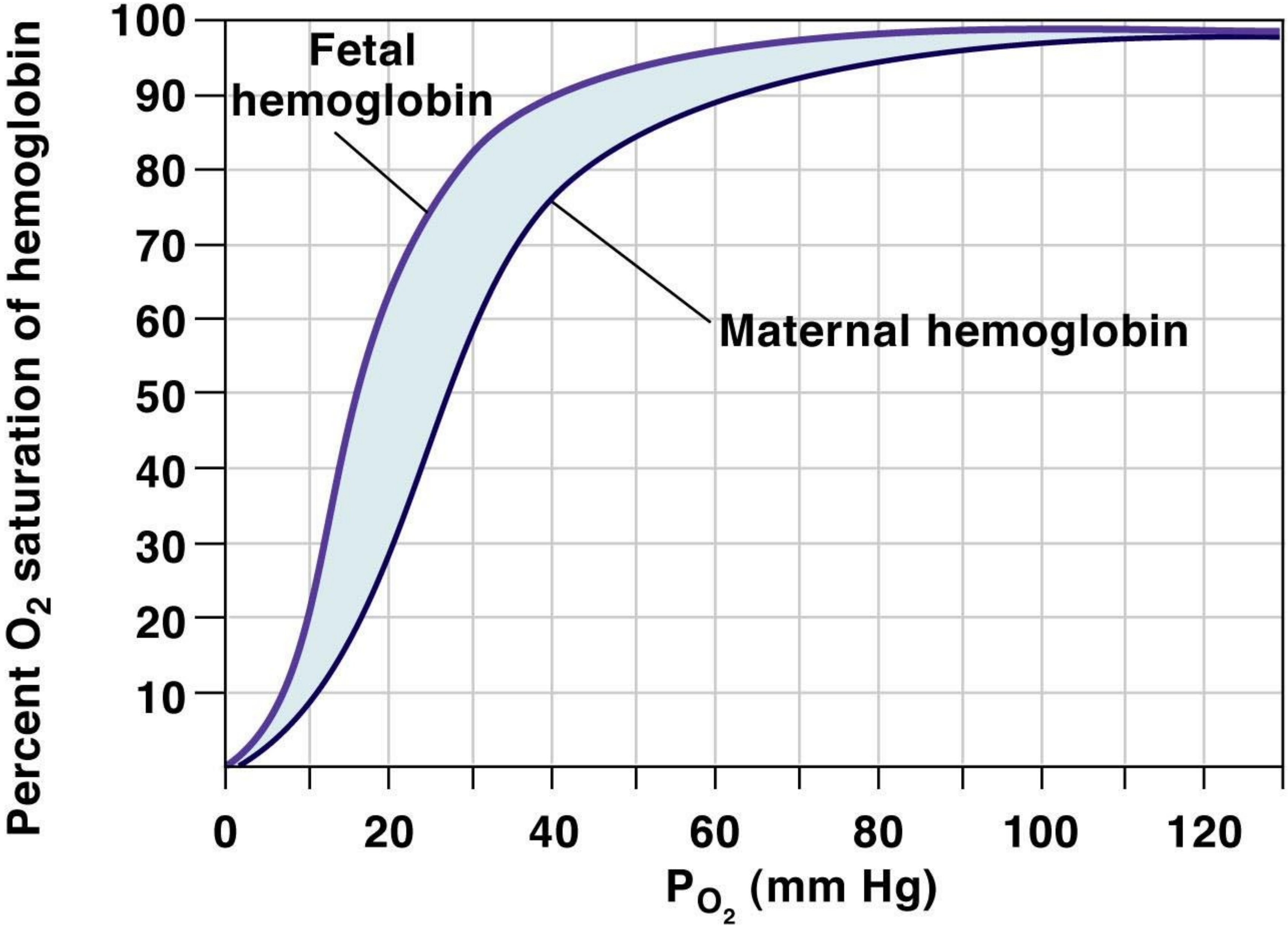

Fetal hemoglobin
Maternal hemoglobin
Percent O_2 saturation of hemoglobin
100
90
80
70
60
50
40
30
20
10
0
20
40
60
80
100
120
P_{O_2} (mm Hg)

Figure 18-12