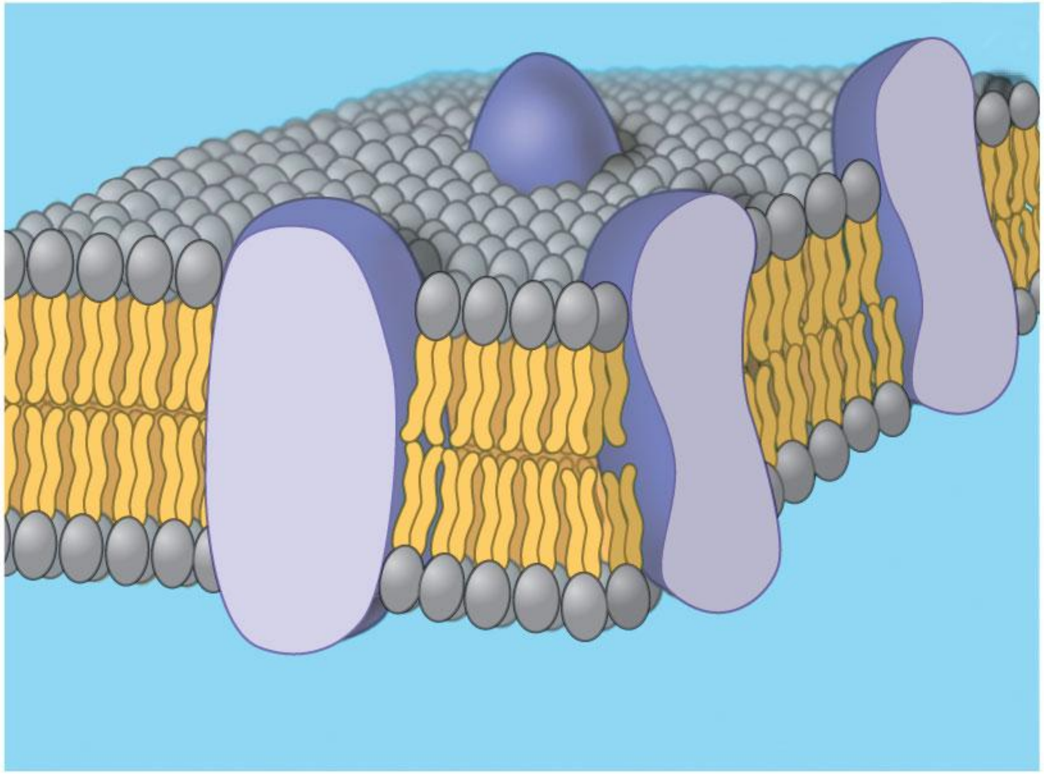
CHAPTER SEVEN
Membrane Structure and Function

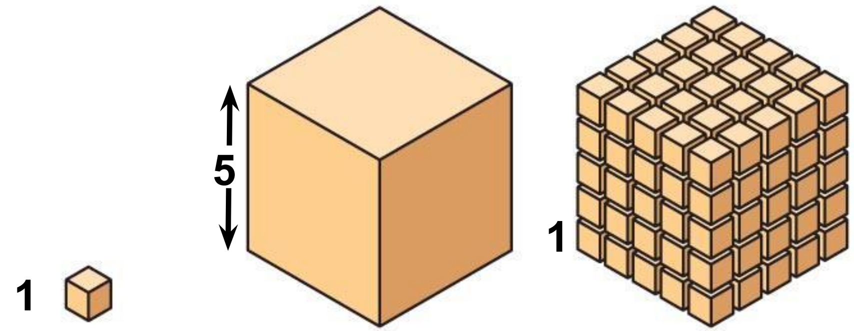


Overview: Life at the Edge

- **The plasma membrane is the boundary that separates the living cell from its surroundings**
- **The plasma membrane exhibits selective permeability, allowing some substances to cross it more easily than others**

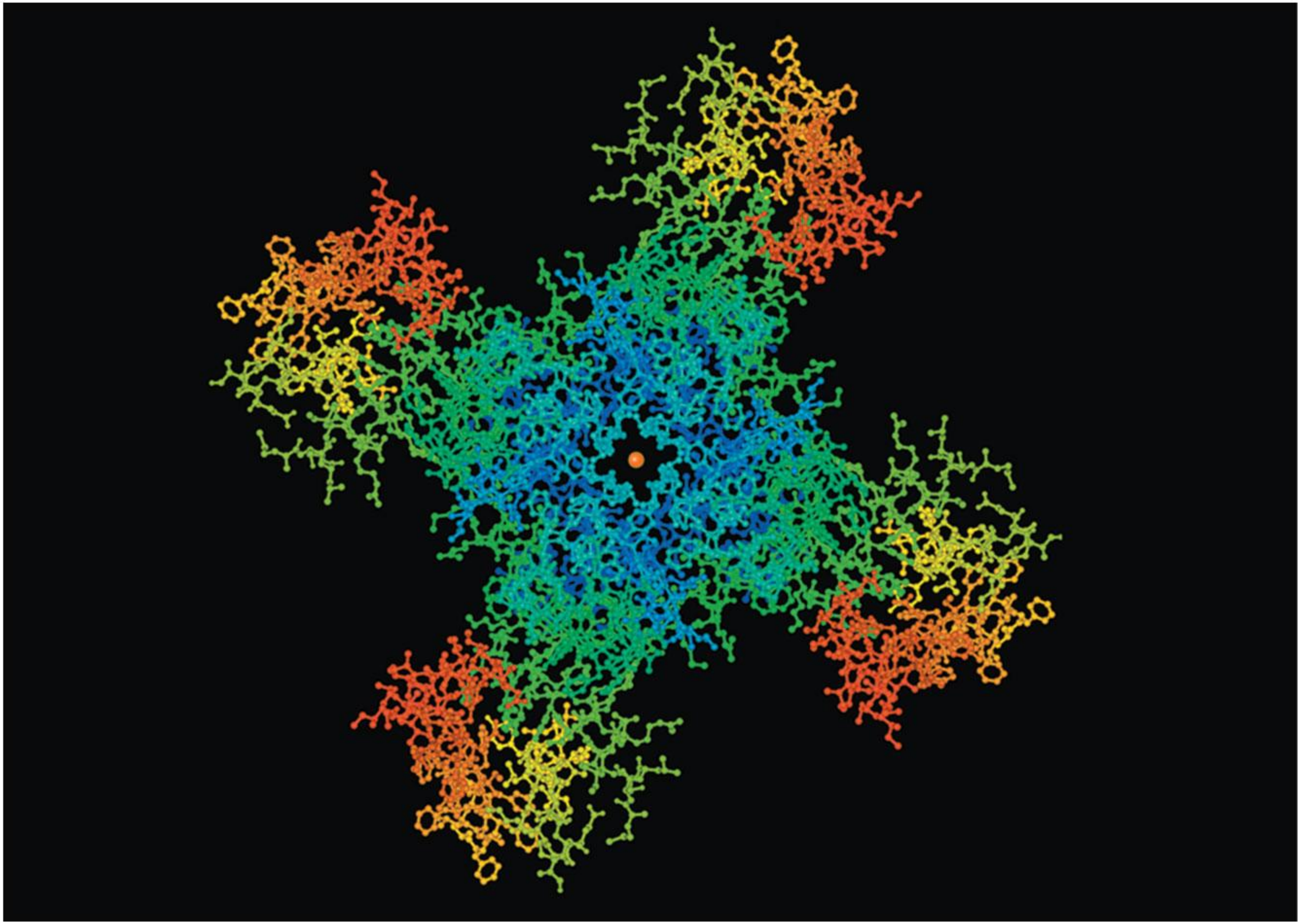
Fig. 6-8

Surface area increases while total volume remains constant



Total surface area [Sum of the surface areas (height × width) of all boxes sides × number of boxes]	6	150	750
Total volume [height × width × length × number of boxes]	1	125	125
Surface-to-volume (S-to-V) ratio [surface area ÷ volume]	6	1.2	6

Figure 7.1



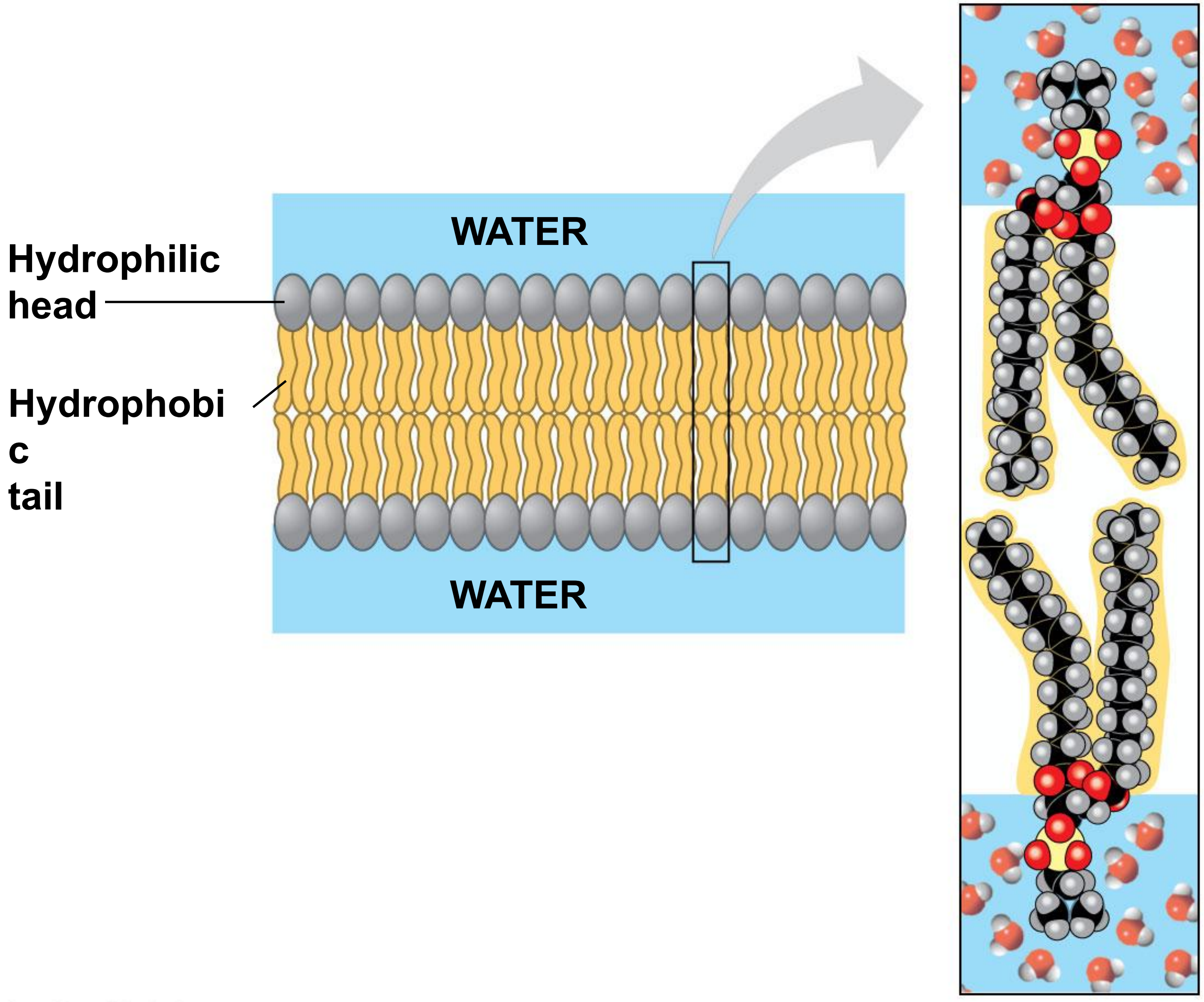
Concept: Cellular membranes are fluid mosaics of lipids and proteins

- **Phospholipids** are the most abundant lipid in the plasma membrane
- Phospholipids are **amphipathic molecules**, containing **hydrophobic** and **hydrophilic** regions
- The **fluid mosaic model** *states that a membrane is a fluid structure with a "mosaic" of various proteins embedded in it*

Membrane Models: *Scientific Inquiry*

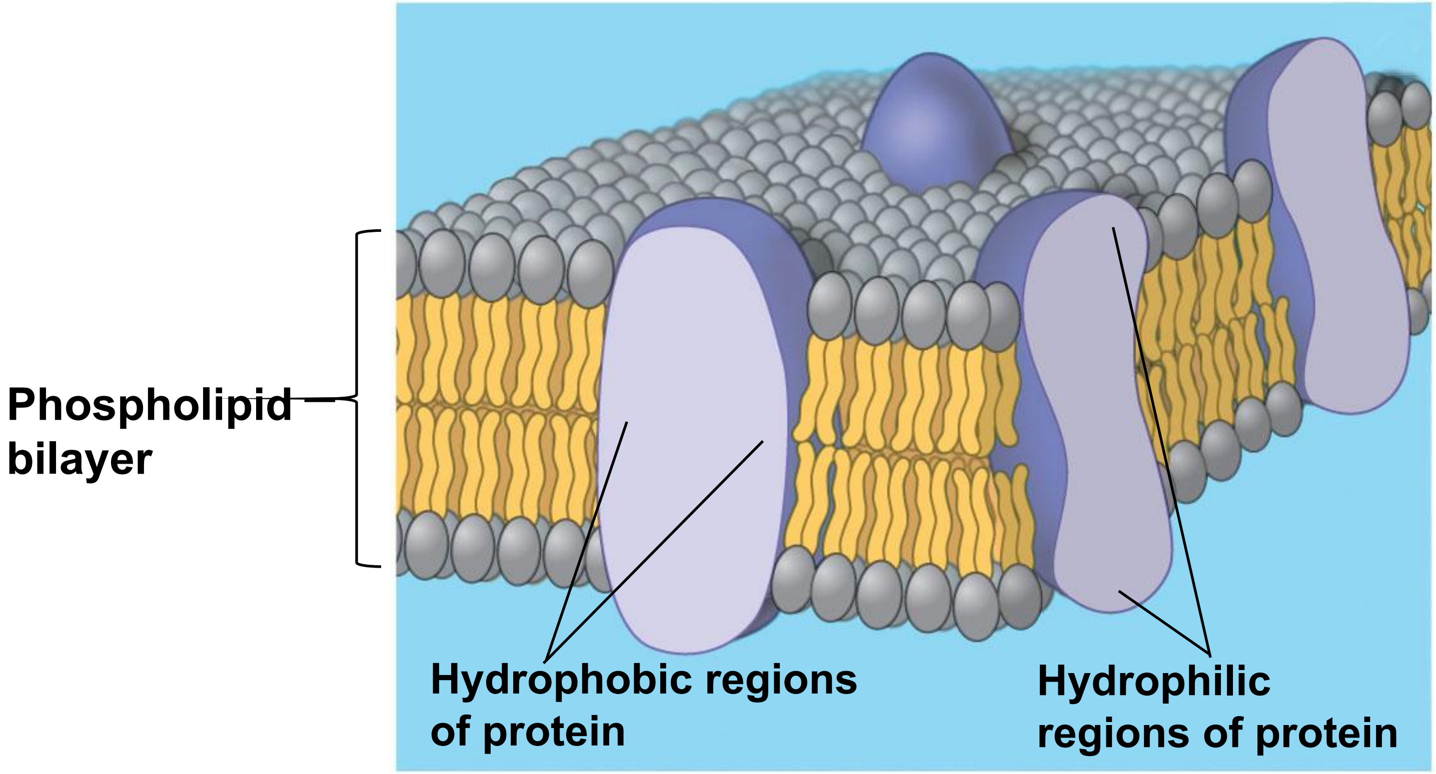
- **Membranes have been chemically analyzed and found to be made of proteins and lipids**
- **Scientists studying the plasma membrane reasoned that it must be a phospholipid bilayer**

Figure 7.2



- In 1972, J. Singer and G. Nicolson proposed the fluid mosaic model which states that the membrane is a *mosaic of proteins dispersed within the bilayer, with only the hydrophilic regions exposed to water*

Figure 7.3

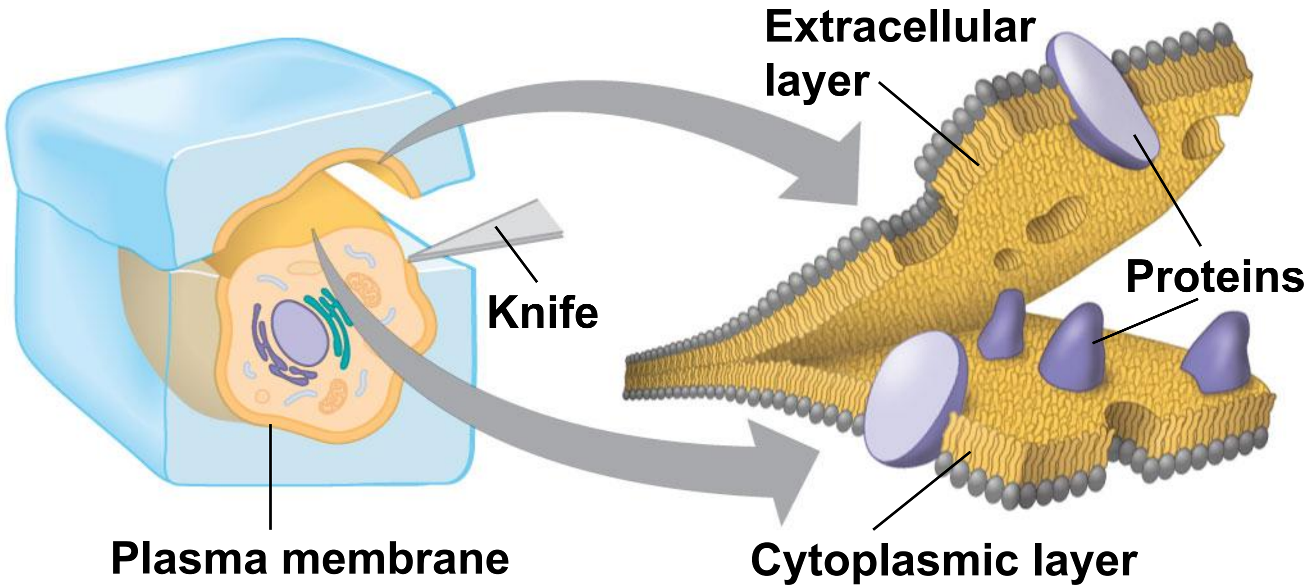


Phospholipid bilayer
Hydrophobic regions of protein
Hydrophilic regions of protein

- **Freeze-fracture studies** of the plasma membrane supported the fluid mosaic model
- Freeze-fracture is a specialized preparation technique that **splits a membrane along the middle of the phospholipid bilayer**

Figure 7.4

TECHNIQUE



RESULTS

Inside of extracellular layer

Inside of cytoplasmic layer

Figure 7.4a

Inside of extracellular layer

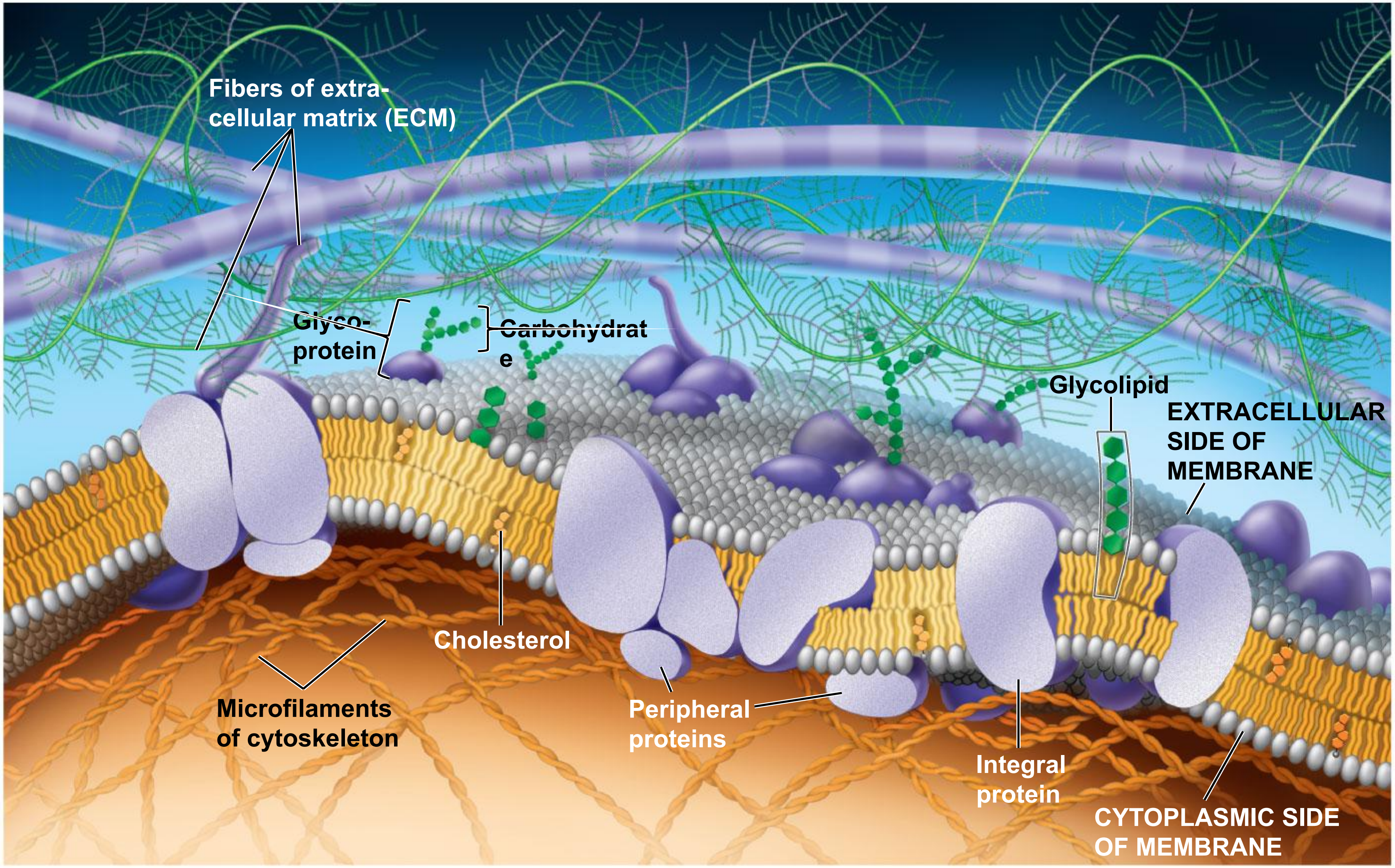
Figure 7.4b

Inside of cytoplasmic layer

The **Fluidity** of Membranes

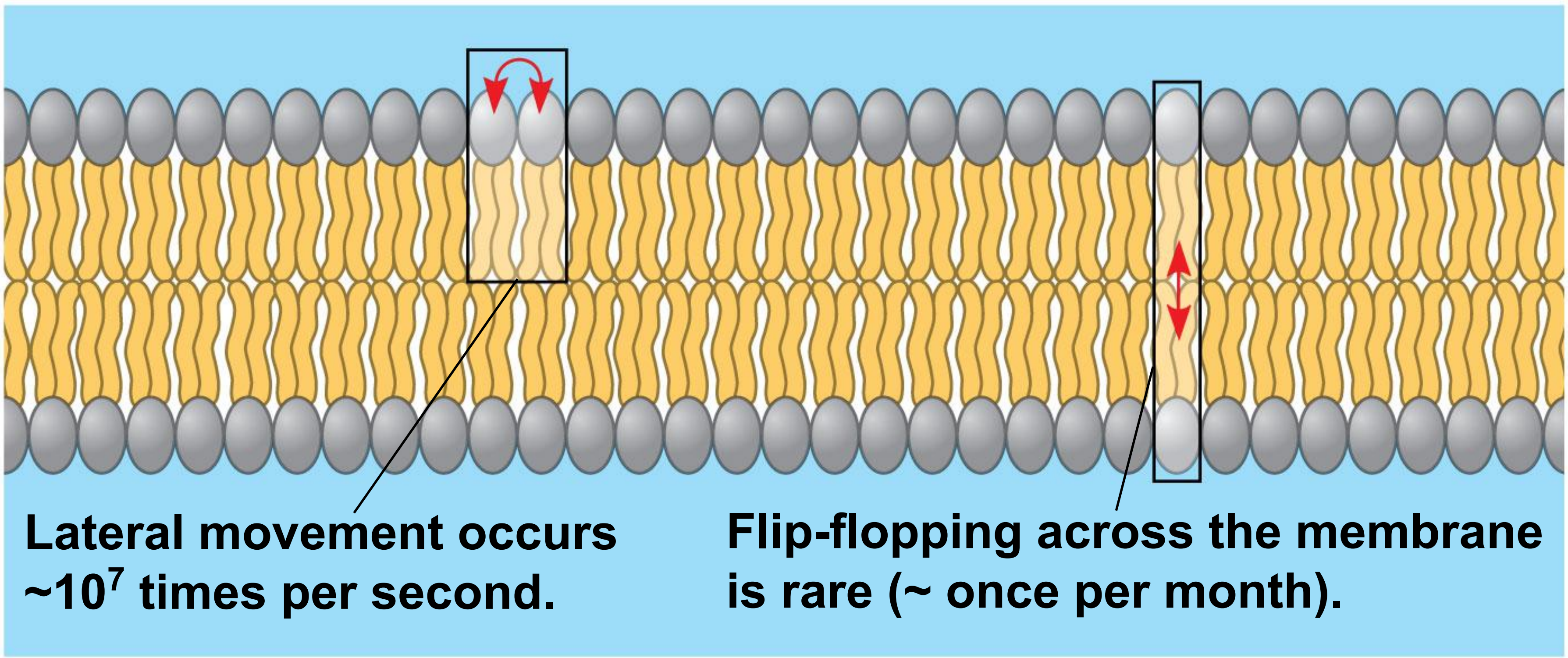
- ***Phospholipids*** **in the plasma membrane *can move within the bilayer***
- **Most of the lipids, and some proteins, drift laterally**
- **Rarely does a molecule flip-flop transversely across the membrane**

Figure 7.5



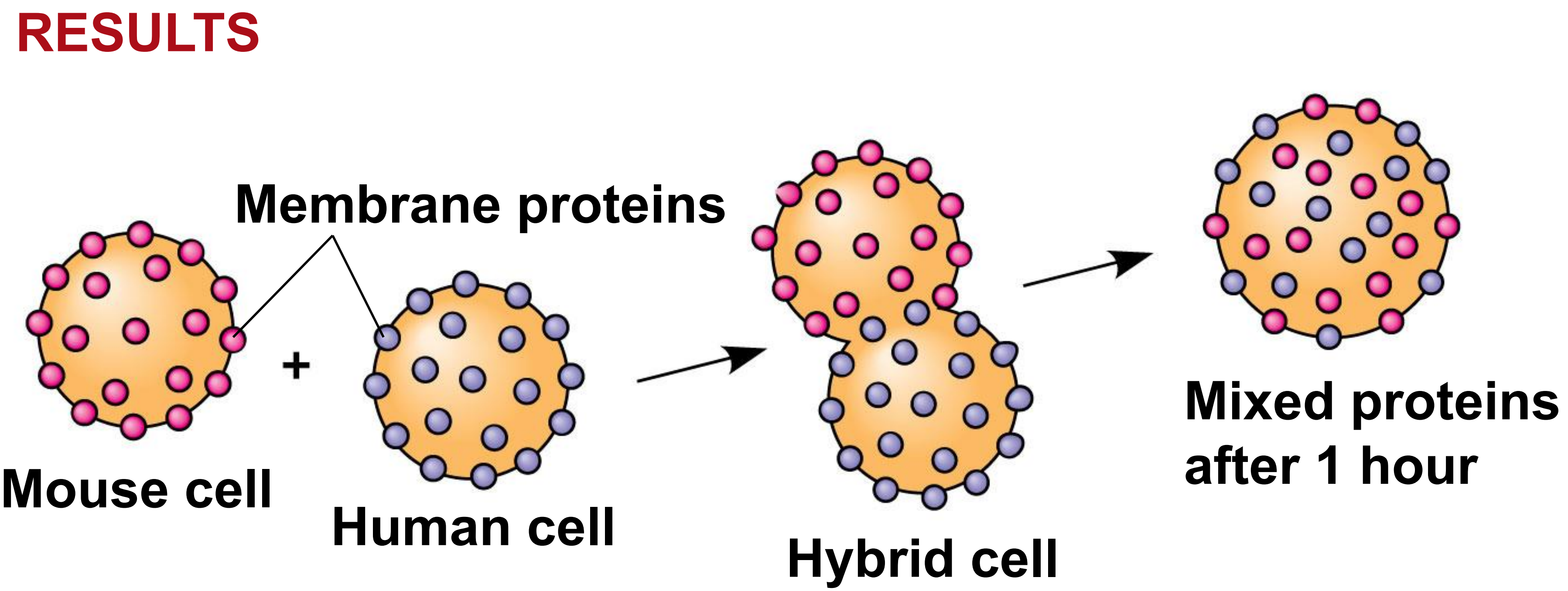
Fibers of extra-cellular matrix (ECM)
Glyco-protein
Carbohydrate
Glycolipid
EXTRACELLULAR SIDE OF MEMBRANE
Cholesterol
Microfilaments of cytoskeleton
Peripheral proteins
Integral protein
CYTOPLASMIC SIDE OF MEMBRANE

Figure 7.6



Lateral movement occurs ~10^7 times per second.
Flip-flopping across the membrane is rare (~ once per month).

Figure 7.7

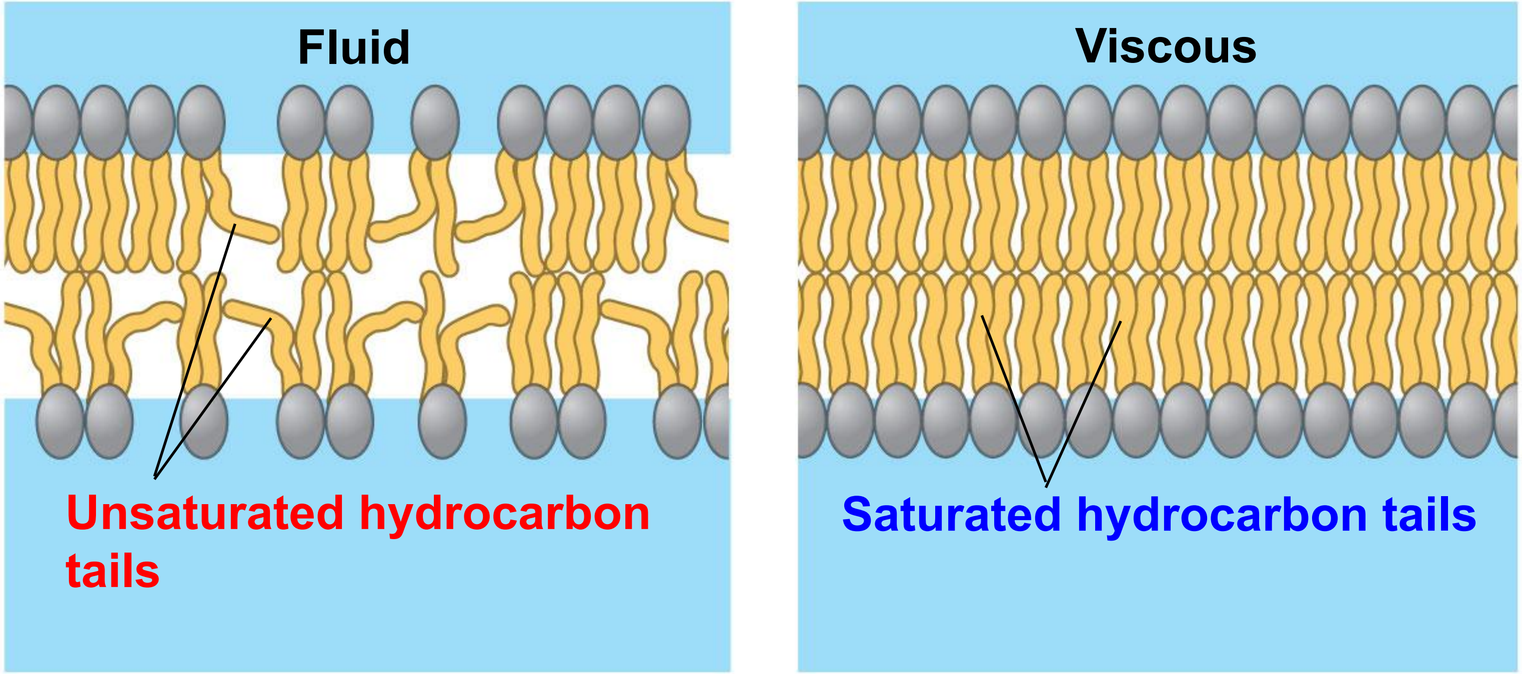


RESULTS
Membrane proteins
Mouse cell
+
Human cell
Hybrid cell
Mixed proteins after 1 hour

- As temperatures cool, *membranes switch from a fluid state to a solid state*
- The temperature at which a membrane solidifies depends on the types of lipids
- Membranes rich in unsaturated fatty acids are more fluid than those rich in saturated fatty acids
- Membranes must be fluid to work properly; they are usually about as fluid as salad oil

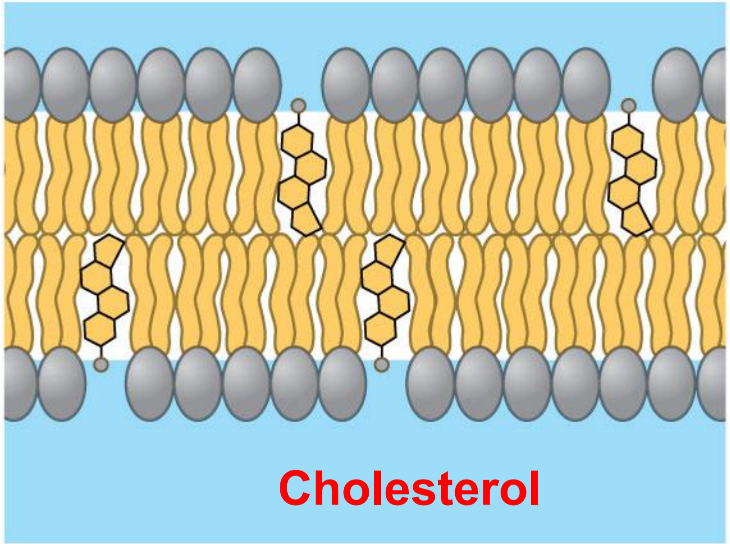
- The steroid cholesterol has different effects on membrane fluidity at different temperatures
- At warm temperatures (such as 37°C), cholesterol restrains movement of phospholipids
- At cool temperatures, it maintains fluidity by preventing tight packing

Figure 7.8



(a) Unsaturated versus saturated hydrocarbon tails

(b) Cholesterol within the animal cell membrane

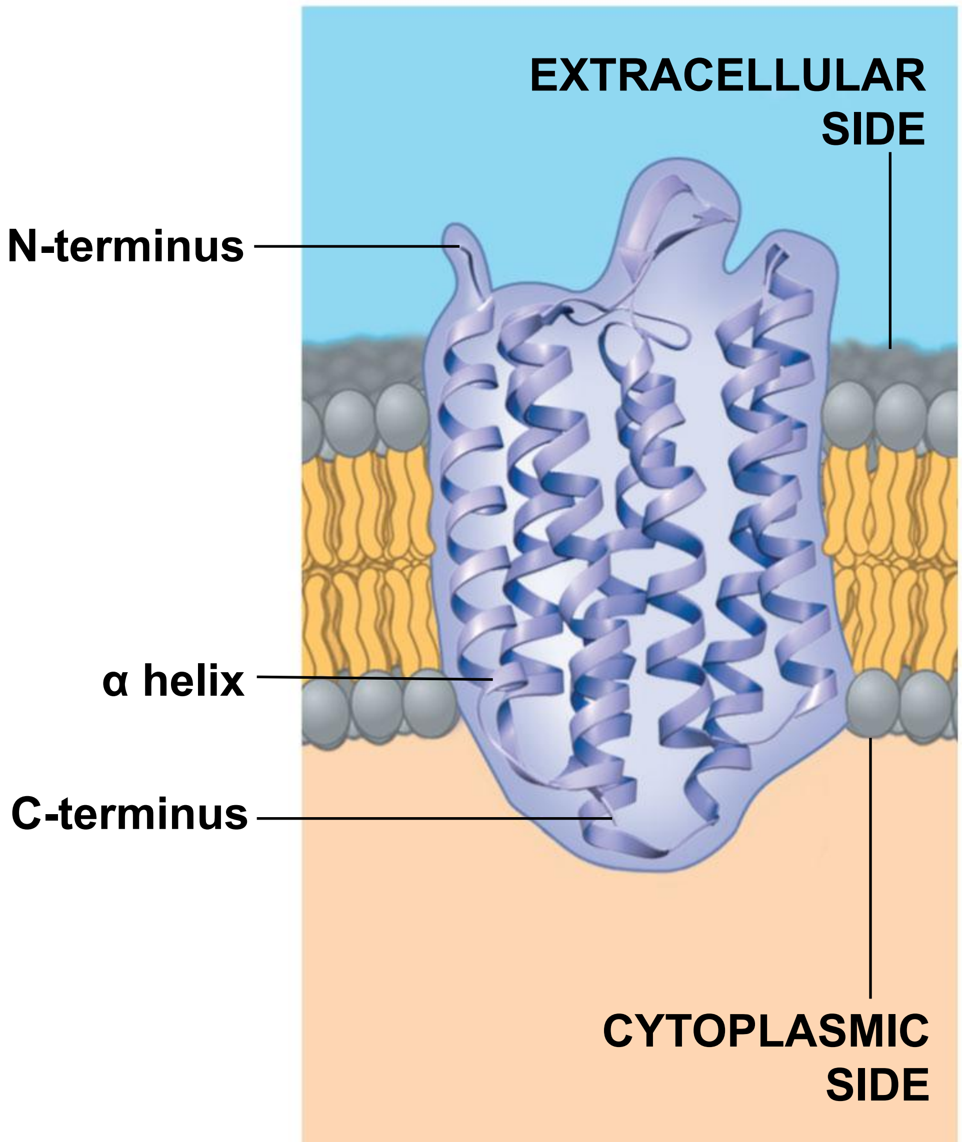


Membrane Proteins and Their Functions

- A membrane is a collage of different proteins embedded in the fluid matrix of the lipid bilayer
- Proteins determine most of the membrane's specific functions

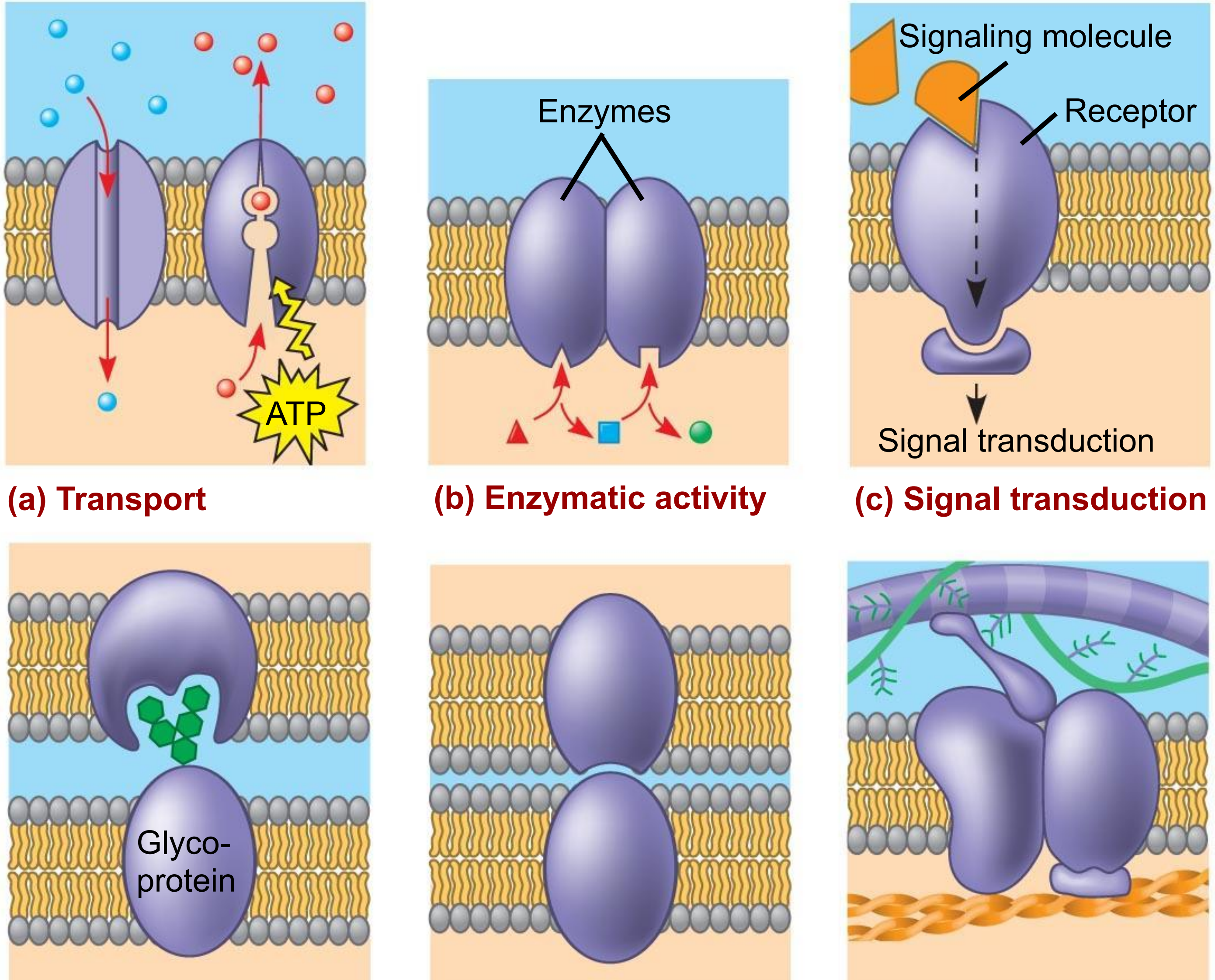
- **Peripheral proteins** are bound to the surface of the membrane
- **Integral proteins** penetrate the hydrophobic core
- Integral proteins that span the membrane are called **transmembrane proteins**
- The hydrophobic regions of an integral protein consist of one or more stretches of nonpolar amino acids, ***often coiled into alpha helices***

Figure 7.9


EXTRACELLULAR SIDE
N-terminus
α helix
C-terminus
CYTOPLASMIC SIDE

- **Six major functions of membrane proteins:**
  - Transport
  - Enzymatic activity
  - Signal transduction
  - Cell-cell recognition
  - Intercellular joining
  - Attachment to the cytoskeleton and extracellular matrix (ECM)

Fig. 7-9



(a) Transport

(b) Enzymatic activity

(c) Signal transduction

(d) Cell-cell recognition

(e) Intercellular joining

(f) Attachment to the cytoskeleton and extracellular matrix (ECM)

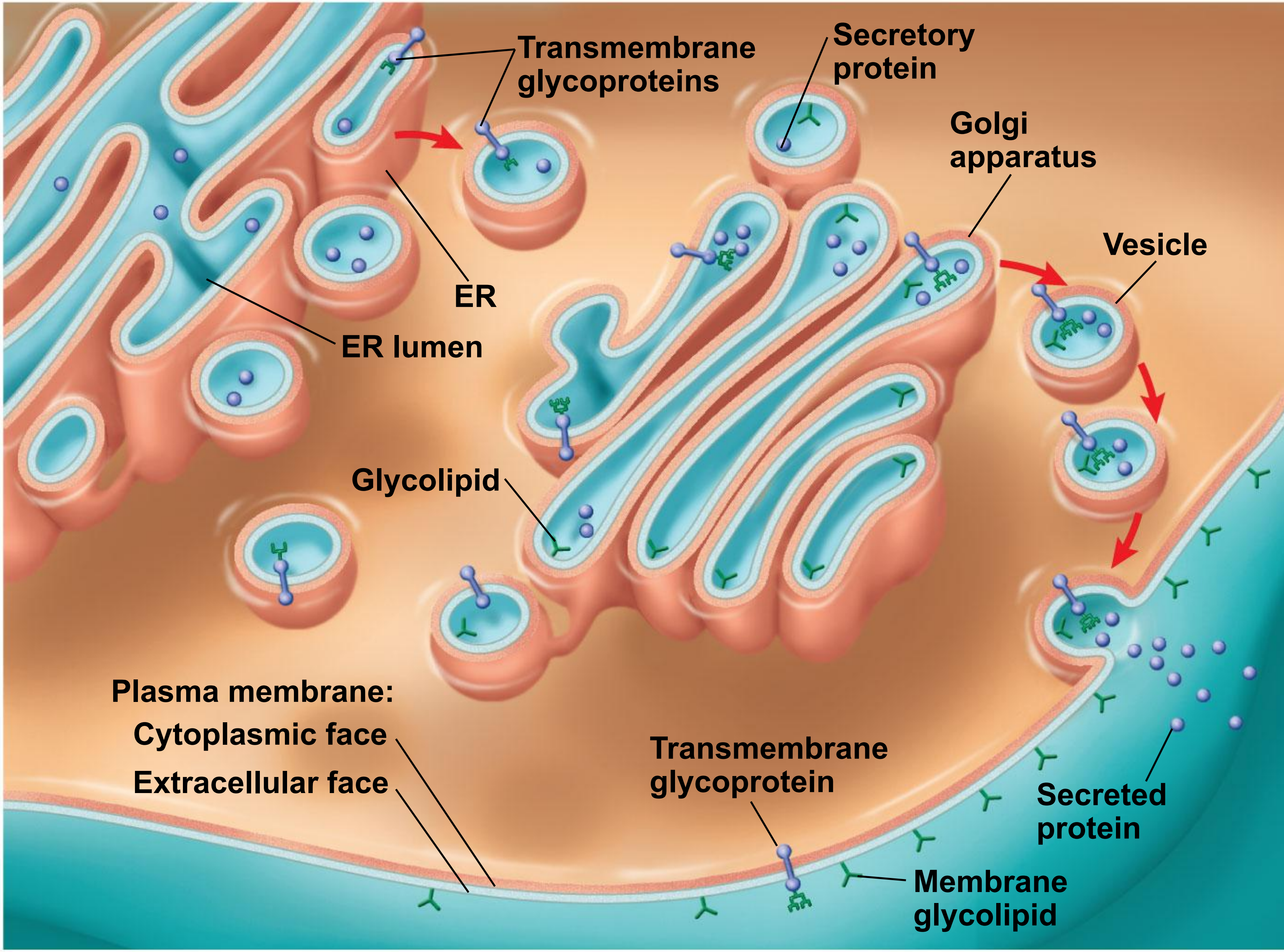
The Role of Membrane Carbohydrates in Cell-Cell Recognition

- Cells recognize each other by binding to surface molecules, often carbohydrates, on the plasma membrane
- Membrane carbohydrates may be covalently bonded to lipids (forming glycolipids) or more commonly to proteins (forming glycoproteins)

Synthesis and Sidedness of Membranes

- Membranes have **distinct inside and outside faces**
- The **asymmetrical distribution** of proteins, lipids, and associated carbohydrates in the plasma membrane is determined when the membrane is built by the ER and Golgi apparatus

Figure 7.12



Transmembrane glycoproteins
Secretory protein
Golgi apparatus
Vesicle
ER
ER lumen
Glycolipid
Plasma membrane:
Cytoplasmic face
Extracellular face
Transmembrane glycoprotein
Secreted protein
Membrane glycolipid

Concept: Membrane structure results in selective permeability

- A cell must exchange materials with its surroundings, a process controlled by the plasma membrane
- Plasma membranes are **selectively permeable**, regulating the cell's molecular traffic

The Permeability of the Lipid Bilayer

- **Hydrophobic (nonpolar) molecules, such as hydrocarbons, can dissolve in the lipid bilayer and pass through the membrane rapidly**
- **Polar molecules, such as sugars, do not cross the membrane easily**

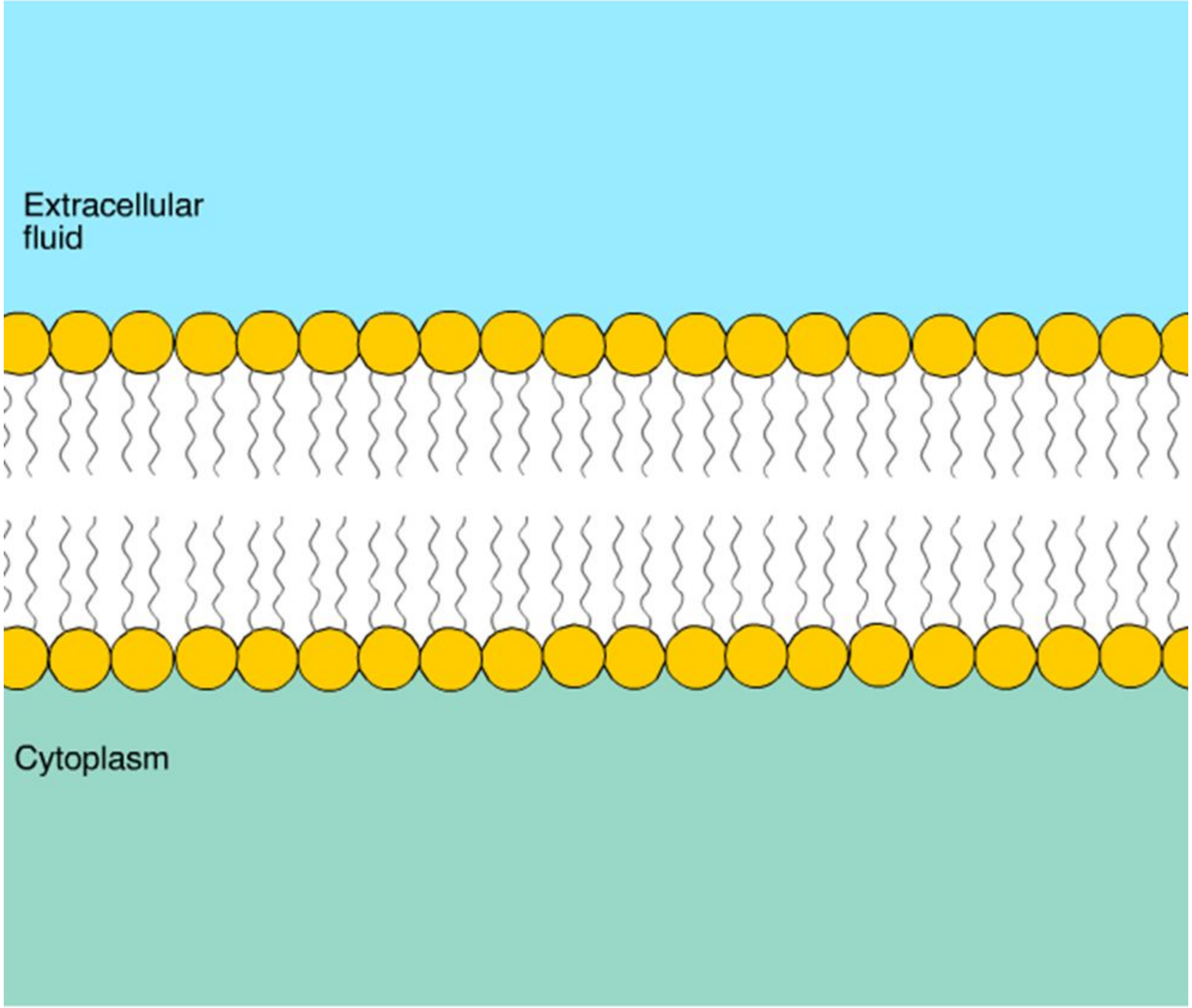
Transport Proteins

- **Transport proteins** allow passage of hydrophilic substances across the membrane
- Some transport proteins, called 1) **channel proteins**, have a hydrophilic channel that certain molecules or ions can use as a tunnel
- Channel proteins called **aquaporins** facilitate the passage of water

- **Other transport proteins, called carrier proteins,** ***bind to molecules and change shape to shuttle them across the membrane***
- **A transport protein is specific for the substance it moves**

Concept: Passive transport is diffusion of a substance across a membrane with no energy investment

- **Diffusion:** the tendency for molecules to spread out evenly into available space
- Although each molecule moves randomly, diffusion of a population of molecules may exhibit a net movement in one direction
- At dynamic equilibrium, as many molecules cross one way as cross in the other direction


Extracellular
fluid
Cytoplasm

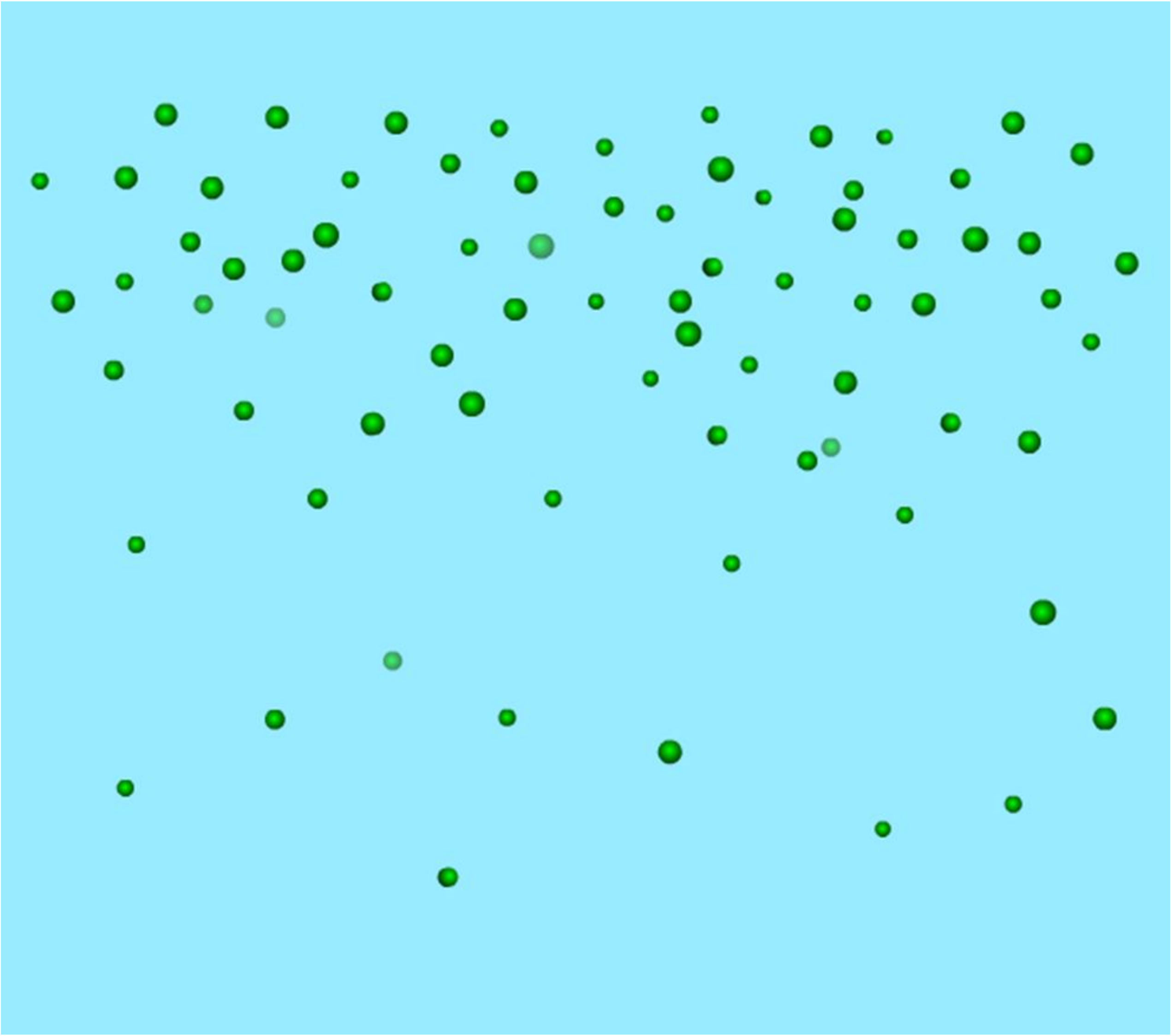
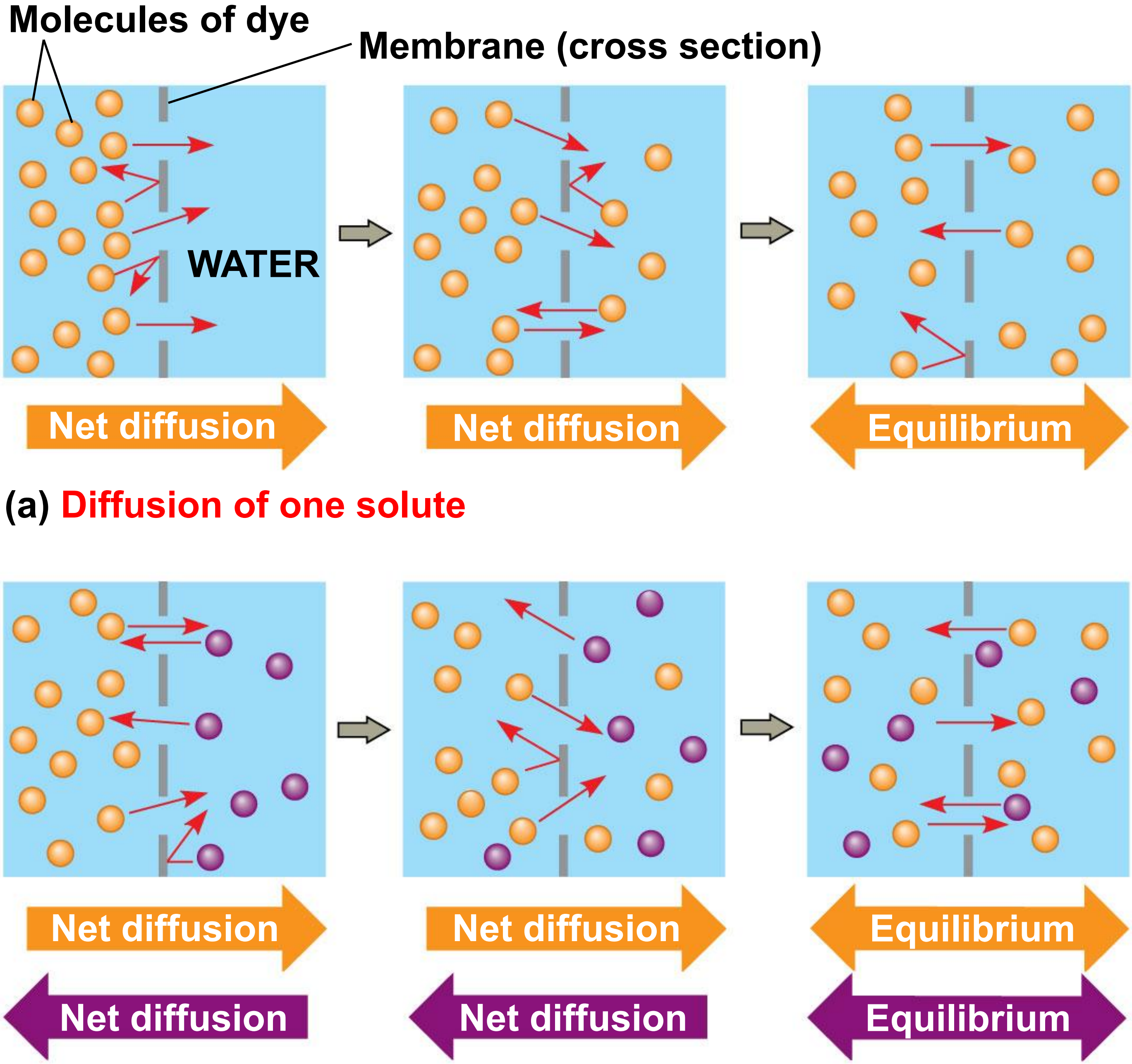


Figure 7.13



(a) Diffusion of one solute

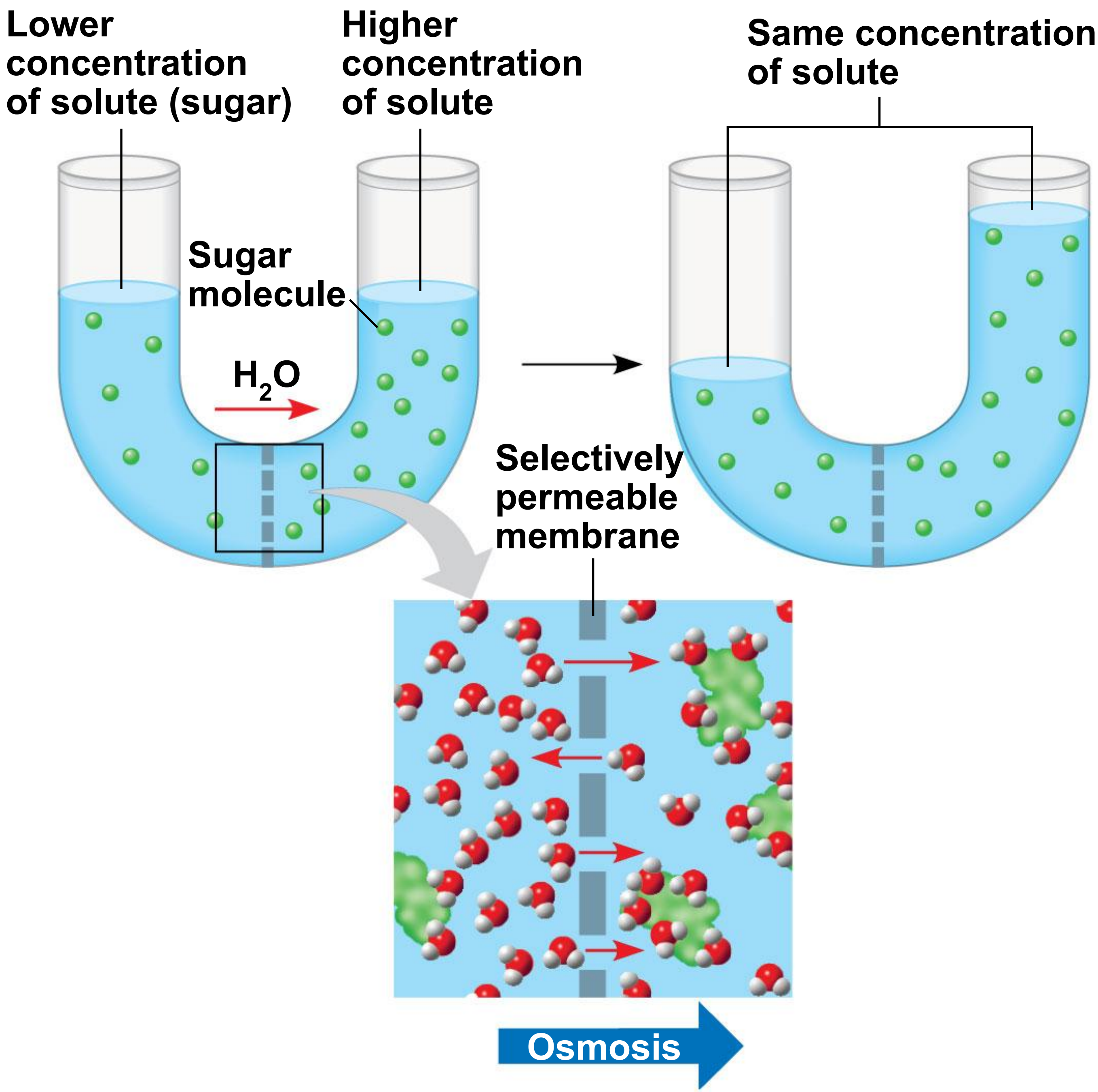
(b) Diffusion of two solutes

- **Substances diffuse down their concentration gradient, the difference in concentration of a substance from one area to another**
- **No work must be done to move substances down the concentration gradient**

Effects of Osmosis on Water Balance

- **Osmosis is the diffusion of water <u>across</u> a selectively permeable membrane**
- **Water diffuses across a membrane from the region of lower solute concentration to the region of higher solute concentration**

Figure 7.14

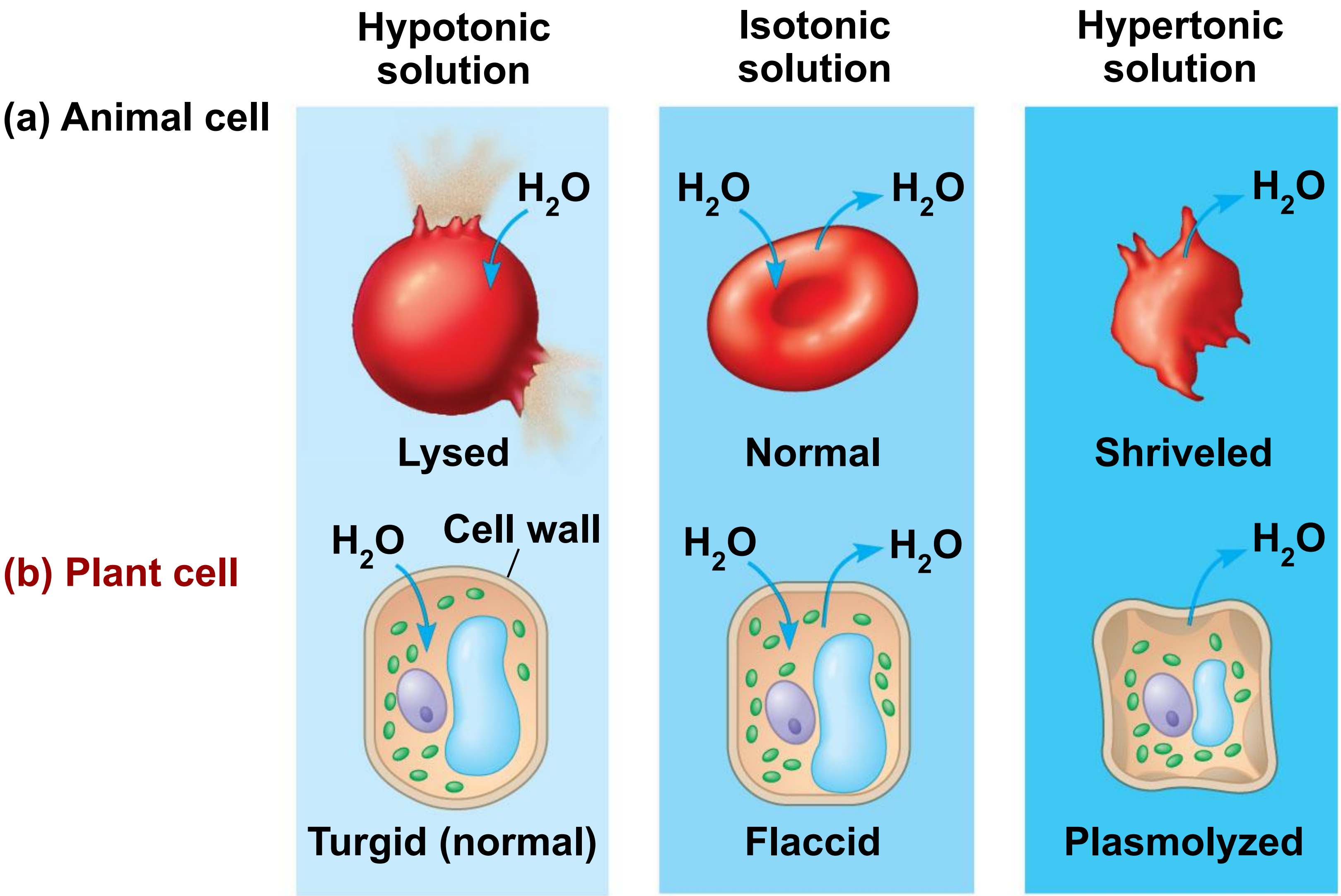


Lower concentration of solute (sugar)
Higher concentration of solute
Same concentration of solute
Sugar molecule
H_2O
Selectively permeable membrane
Osmosis

Water Balance of Cells Without Walls

- **Tonicity** *is the ability of a solution to cause a cell to gain or lose water*
- **Isotonic solution**: Solute concentration is the same as that inside the cell; no net water movement across membrane
- **Hypertonic solution**: Solute concentration is greater than that inside the cell; cell loses water
- **Hypotonic solution**: Solute concentration is less than that inside the cell; cell gains water

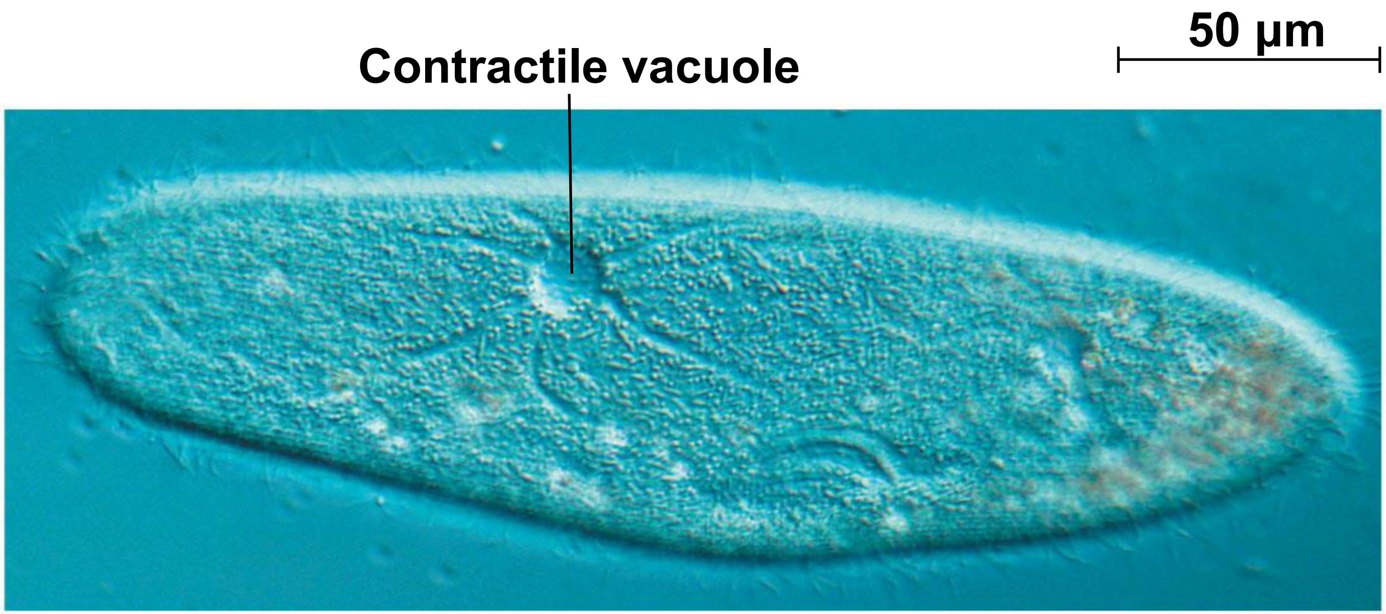
Figure 7.15



Hypotonic solution
Isotonic solution
Hypertonic solution
(a) Animal cell
H_2O
H_2O
H_2O
H_2O
Lysed
Normal
Shriveled
(b) Plant cell
H_2O
Cell wall
H_2O
H_2O
H_2O
Turgid (normal)
Flaccid
Plasmolyzed

- **Hypertonic** or **hypotonic** environments create osmotic problems for organisms
- **Osmoregulation**, the control of water balance, is a necessary adaptation for life in such environments
- The protist *Paramecium,* which is hypertonic to its pond water environment, has a **contractile vacuole** that **acts as a pump**

Figure 7.16



Water Balance of Cells with Walls

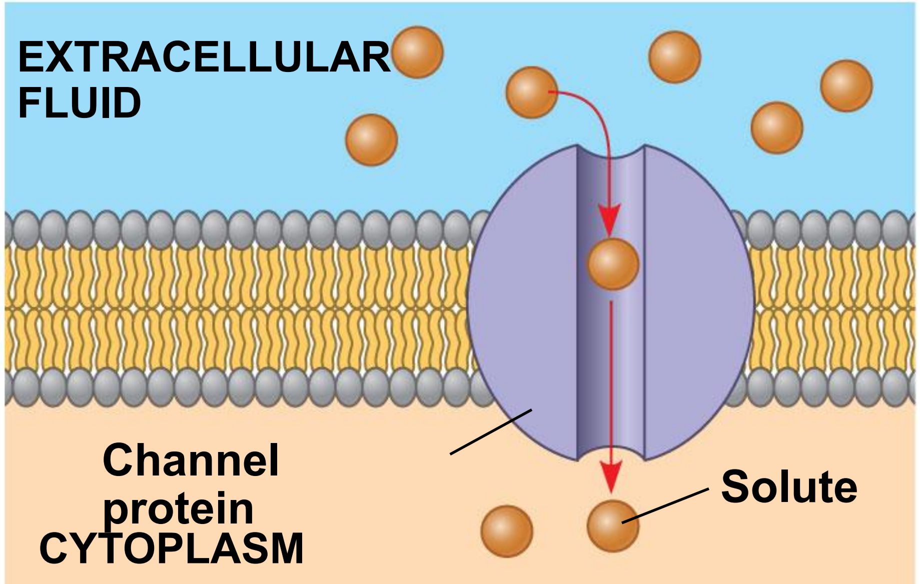
- **Cell walls help maintain water balance**
- **A plant cell in a hypotonic solution swells until the wall opposes uptake; the cell is now turgid (firm)**
- **If a plant cell and its surroundings are isotonic, there is no net movement of water into the cell; the cell becomes flaccid (limp), and the plant may wilt**

- In a **hypertonic environment**, plant **cells lose water**; eventually, the membrane pulls away from the wall, a usually lethal effect called **plasmolysis**

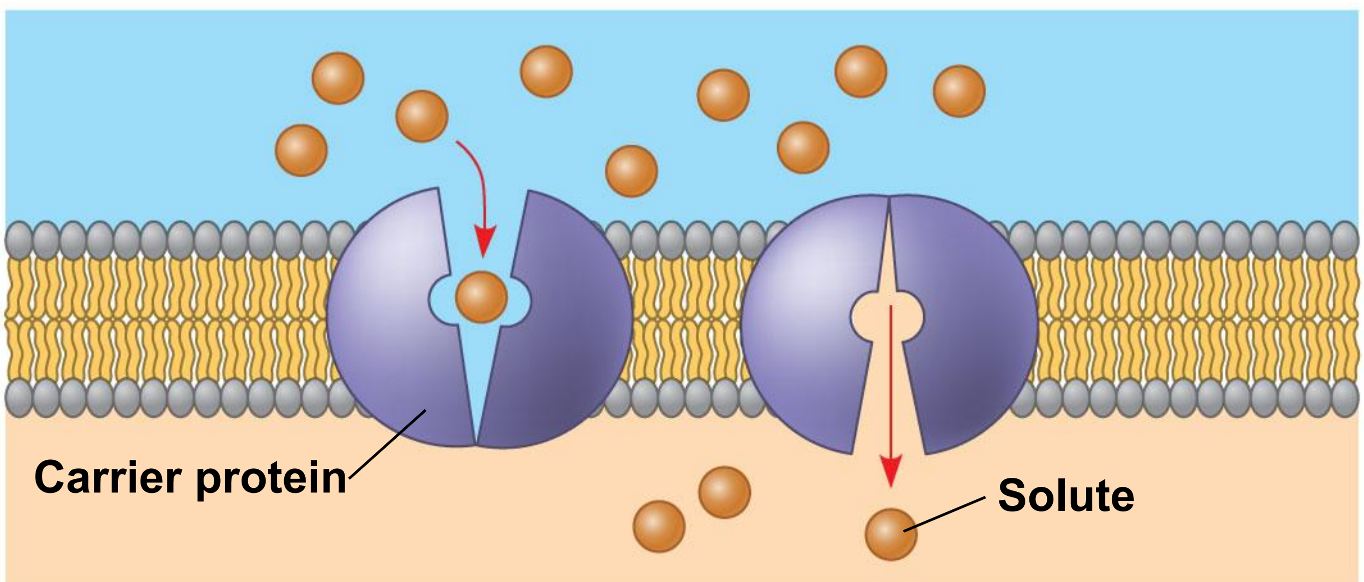
Facilitated Diffusion: Passive Transport Aided by Proteins

- In **facilitated diffusion**, transport proteins speed the passive movement of molecules across the plasma membrane
- **Channel proteins** provide corridors that allow a specific molecule or ion to cross the membrane
- Channel proteins include
  - **Aquaporins**, for facilitated diffusion of water
  - **Ion channels** that open or close in response to a stimulus (**gated channels**)

Figure 7.17



(a) A channel protein

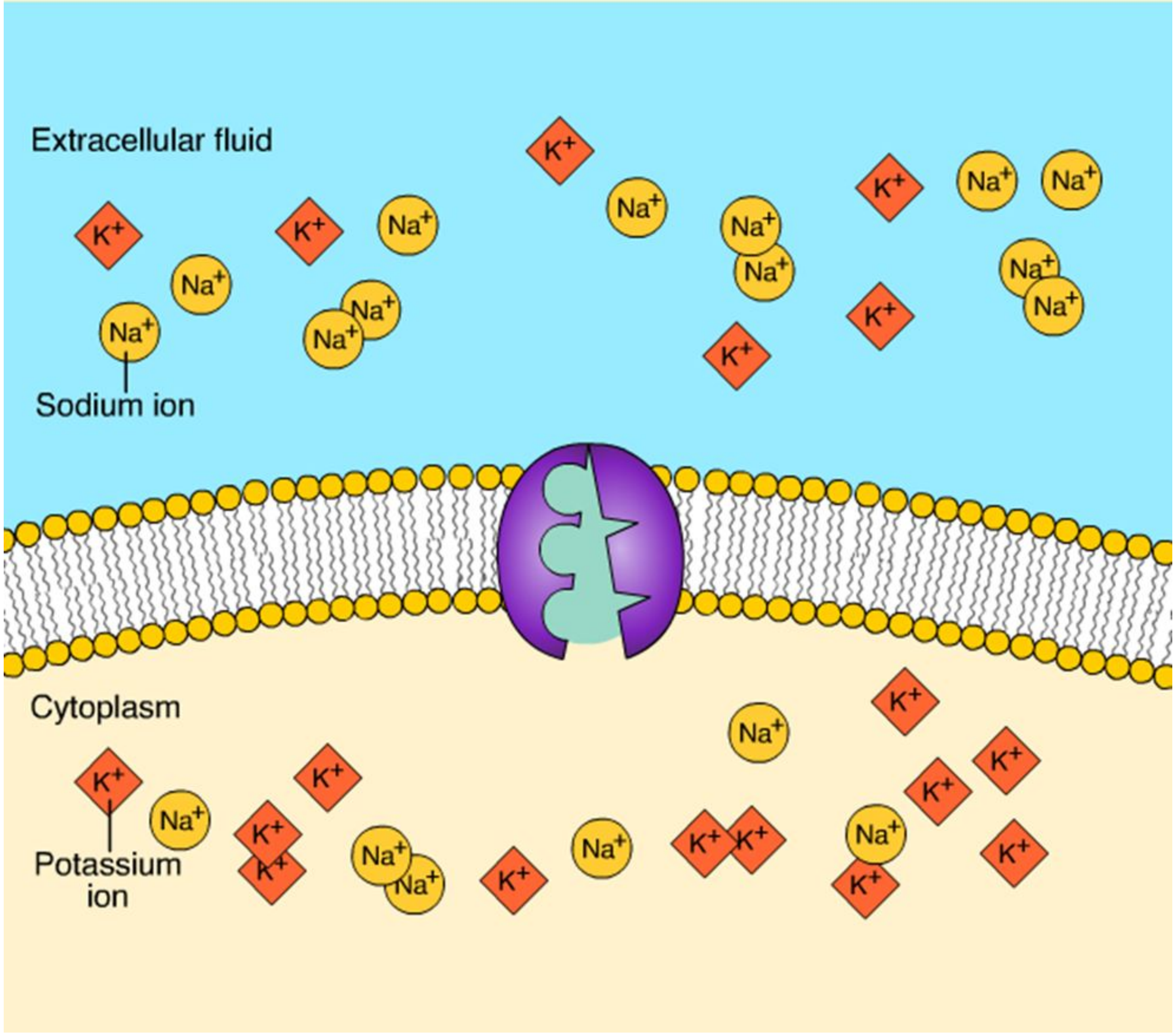


(b) A carrier protein

- **Carrier proteins** undergo a subtle change in shape that translocates the solute-binding site across the membrane

Concept: Active transport uses energy to move solutes <u>against</u> their gradients

- Facilitated diffusion is still passive because the solute moves down its concentration gradient
- Some transport proteins, however, can move solutes against their concentration gradients
- Active transport requires energy, usually in the form of ATP
- Active transport is performed by specific proteins embedded in the membranes



Animation: Active Transport

Right-click slide / select “Play”

- **Active transport** allows cells to maintain concentration gradients that differ from their surroundings
- The **sodium-potassium pump** is one type of active transport system

Figure 7.18-1

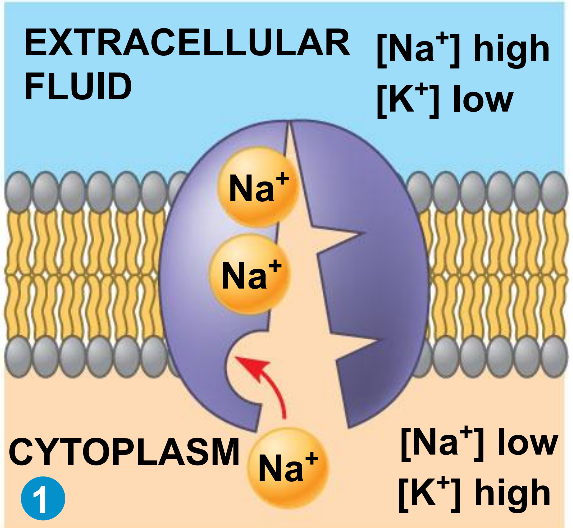
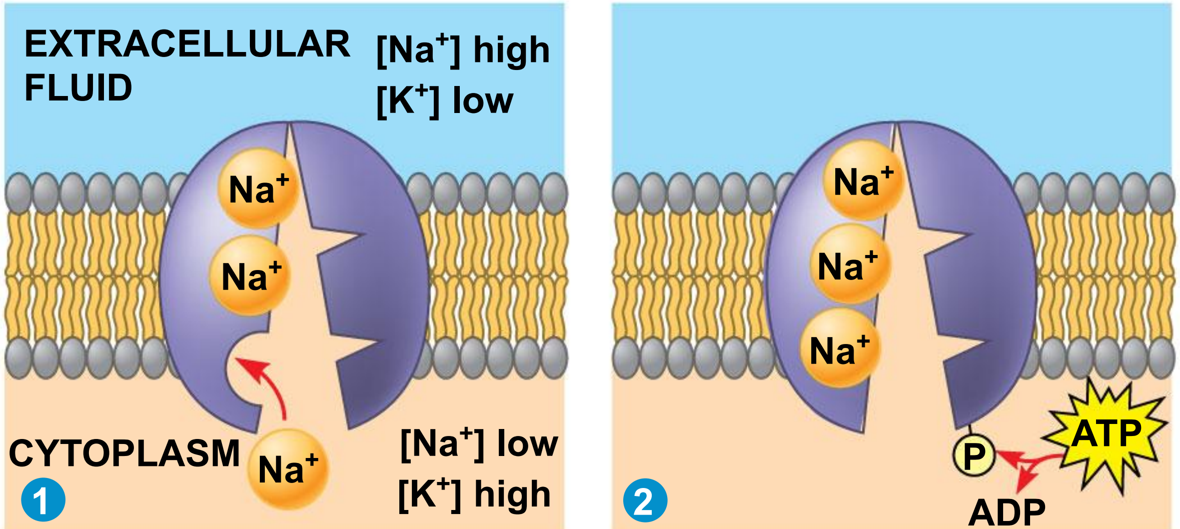
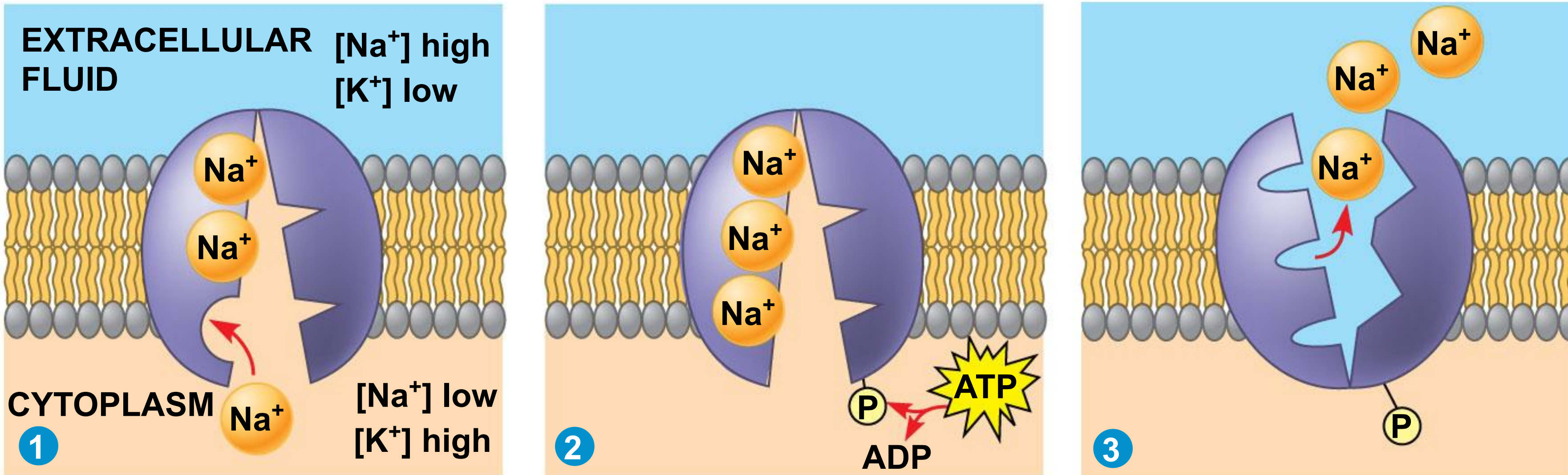

EXTRACELLULAR FLUID
[Na+] high
[K+] low
Na+
Na+
CYTOPLASM
Na+
[Na+] low
[K+] high
1

Figure 7.18-2



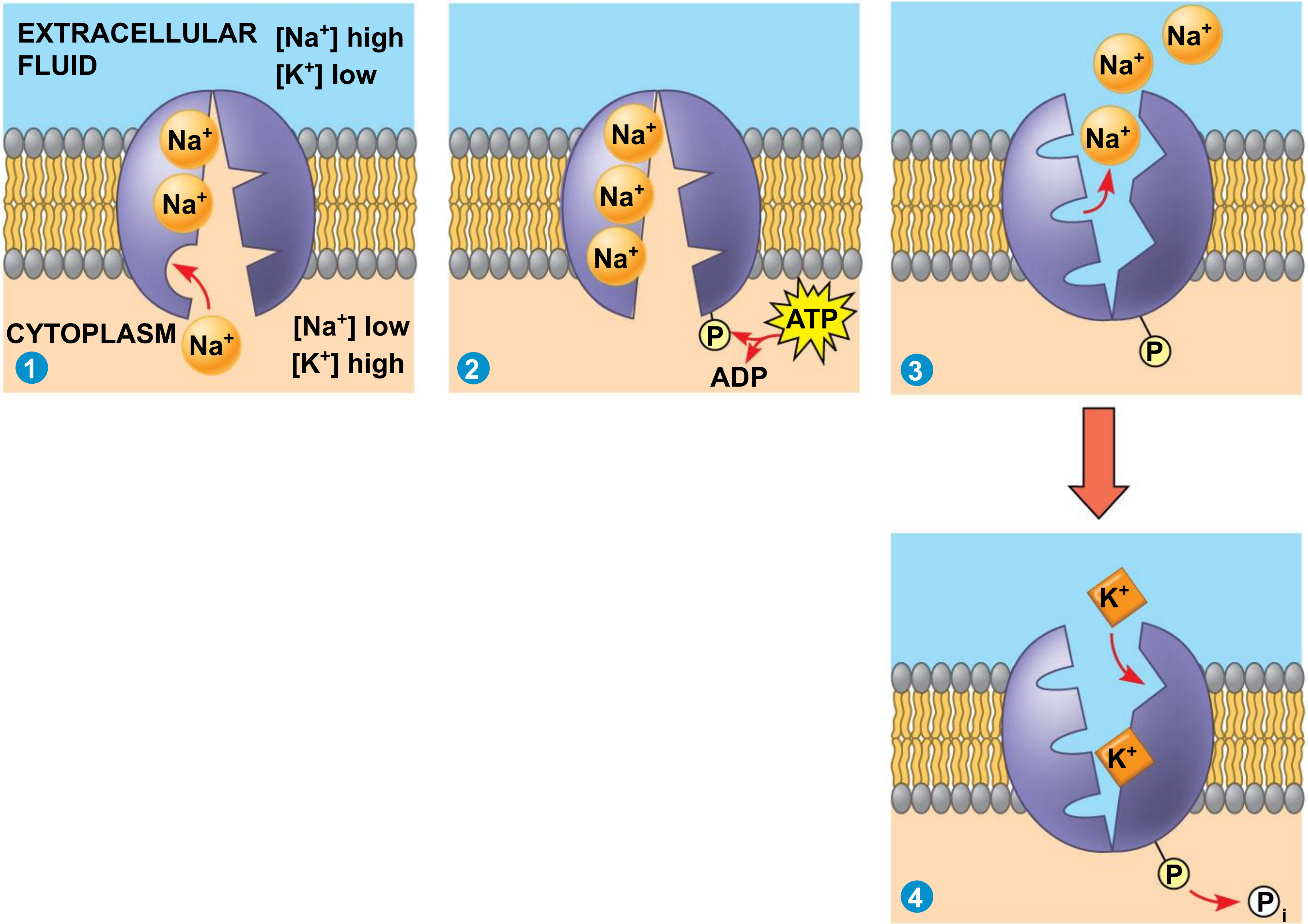
EXTRACELLULAR FLUID
[Na+] high
[K+] low
Na+
Na+
CYTOPLASM
Na+
[Na+] low
[K+] high
1
Na+
Na+
Na+
P
ATP
ADP
2

Figure 7.18-3



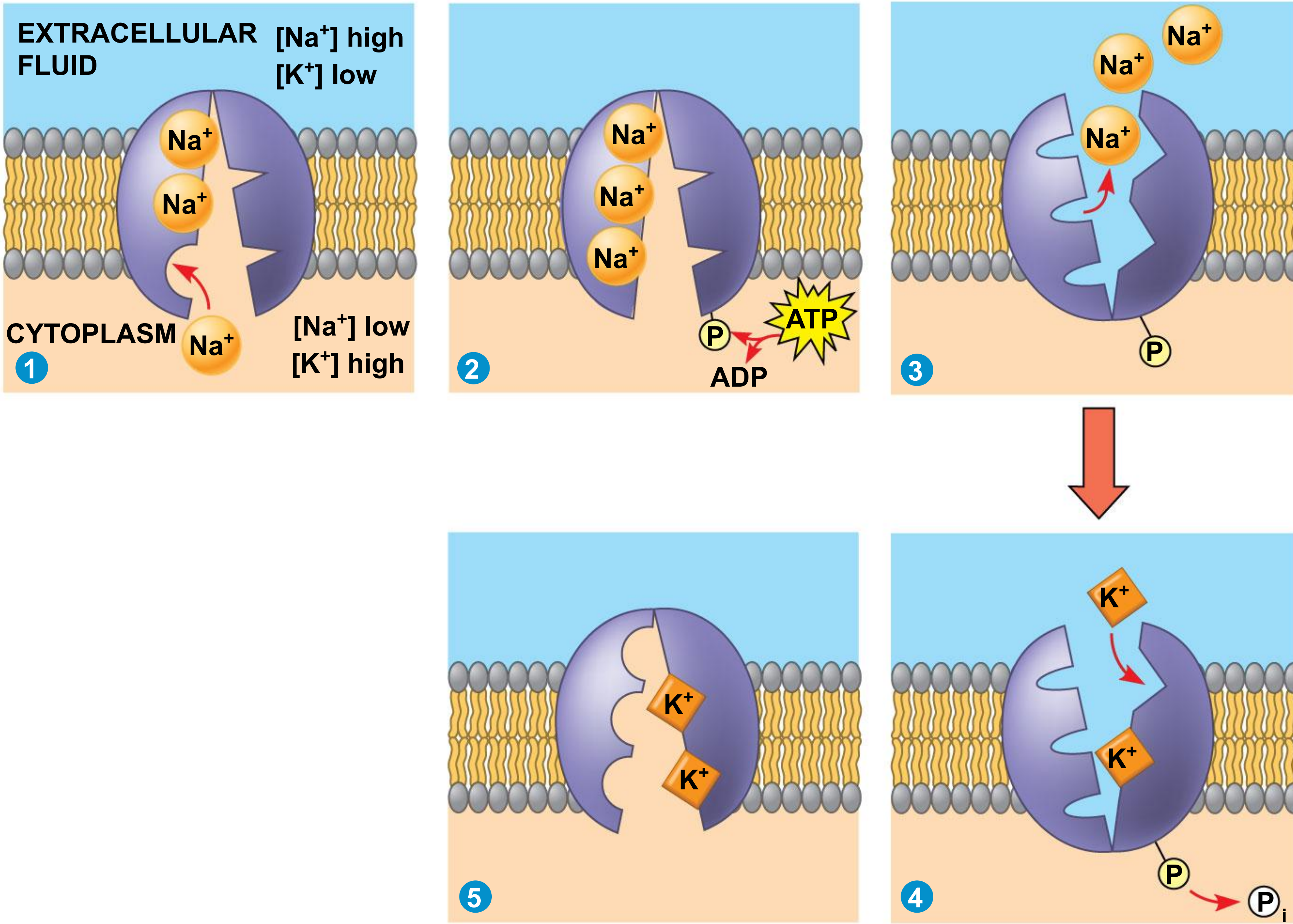
EXTRACELLULAR FLUID
[Na+] high
[K+] low
Na+
Na+
CYTOPLASM
Na+
[Na+] low
[K+] high
1
Na+
Na+
Na+
P
ATP
ADP
2
Na+
Na+
Na+
P
3

Figure 7.18-4



EXTRACELLULAR FLUID
[Na+] high
[K+] low
Na+
Na+
CYTOPLASM
Na+
[Na+] low
[K+] high
1
Na+
Na+
Na+
P
ATP
ADP
2
Na+
Na+
Na+
P
3
K+
K+
P
P i
4

Figure 7.18-5



EXTRACELLULAR FLUID
[Na+] high
[K+] low
Na+
Na+
CYTOPLASM
Na+
[Na+] low
[K+] high
1
Na+
Na+
Na+
P
ATP
ADP
2
Na+
Na+
Na+
P
3
K+
K+
P
P i
4
K+
K+
5

Figure 7.18-6

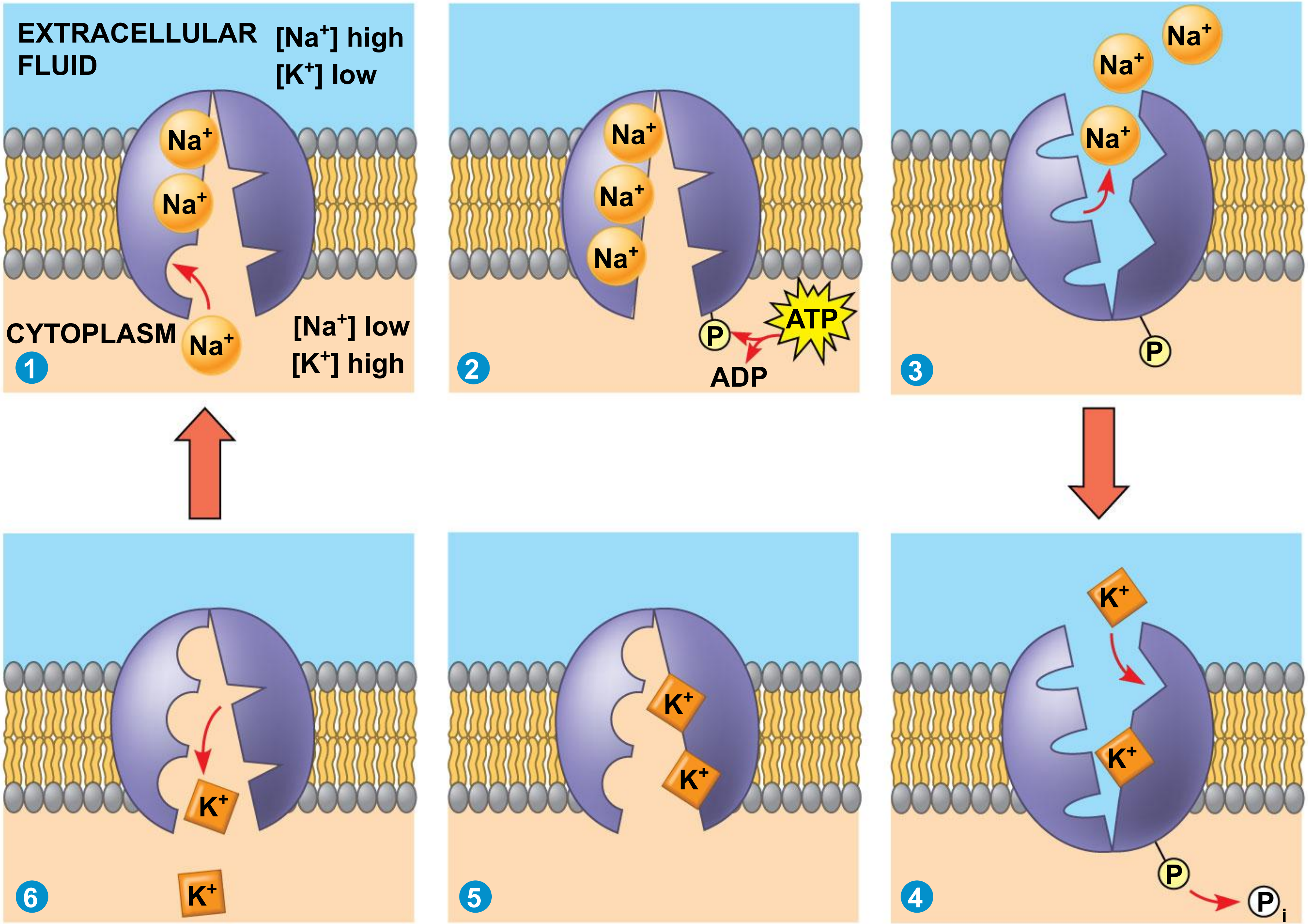
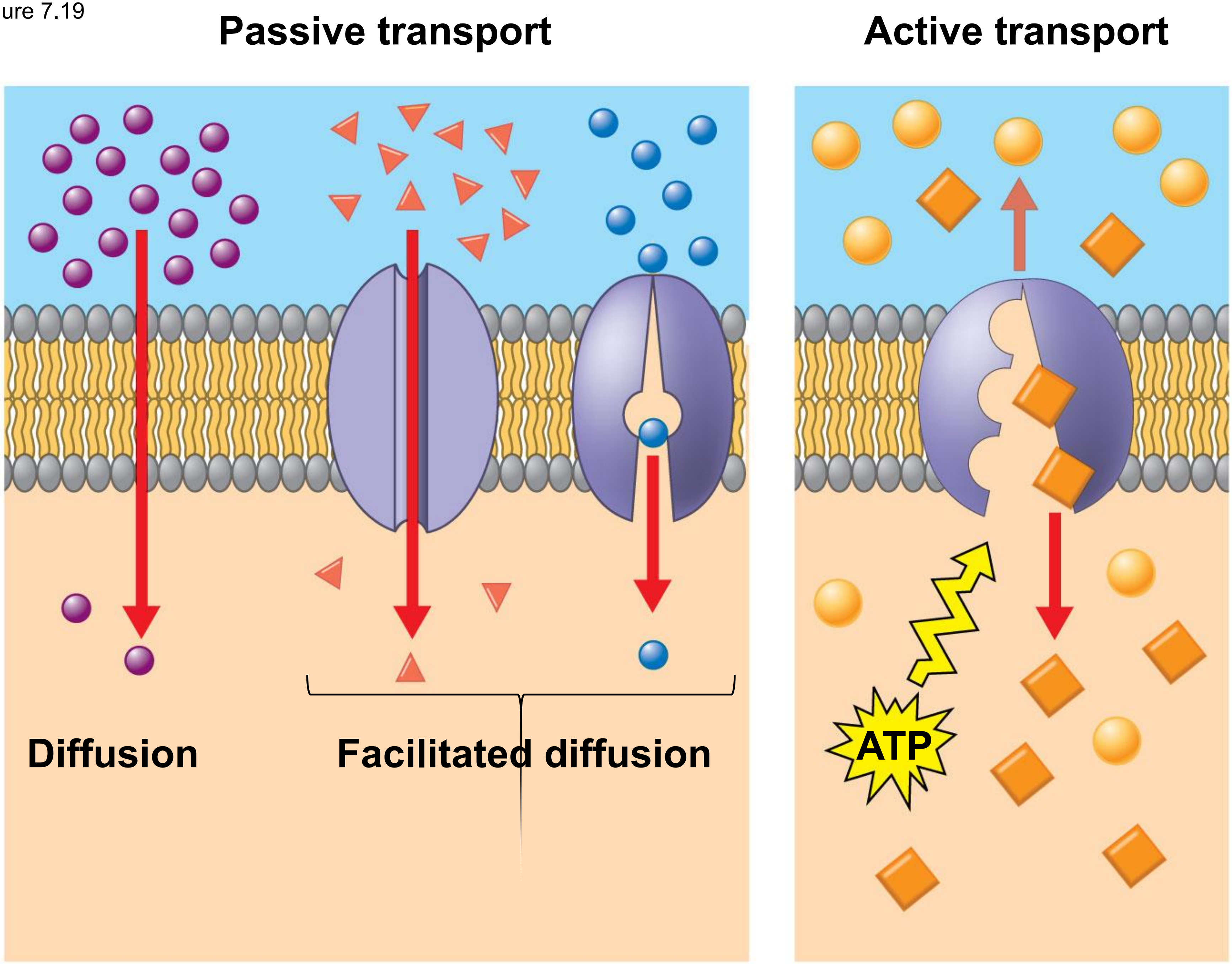

EXTRACELLULAR FLUID
[Na+] high
[K+] low
Na+
Na+
CYTOPLASM
Na+
[Na+] low
[K+] high
1
Na+
Na+
Na+
P
ATP
ADP
2
Na+
Na+
Na+
P
3
K+
K+
P
P i
4
K+
K+
5
K+
K+
6

Figure 7.19


Passive transport
Active transport
Diffusion
Facilitated diffusion
ATP

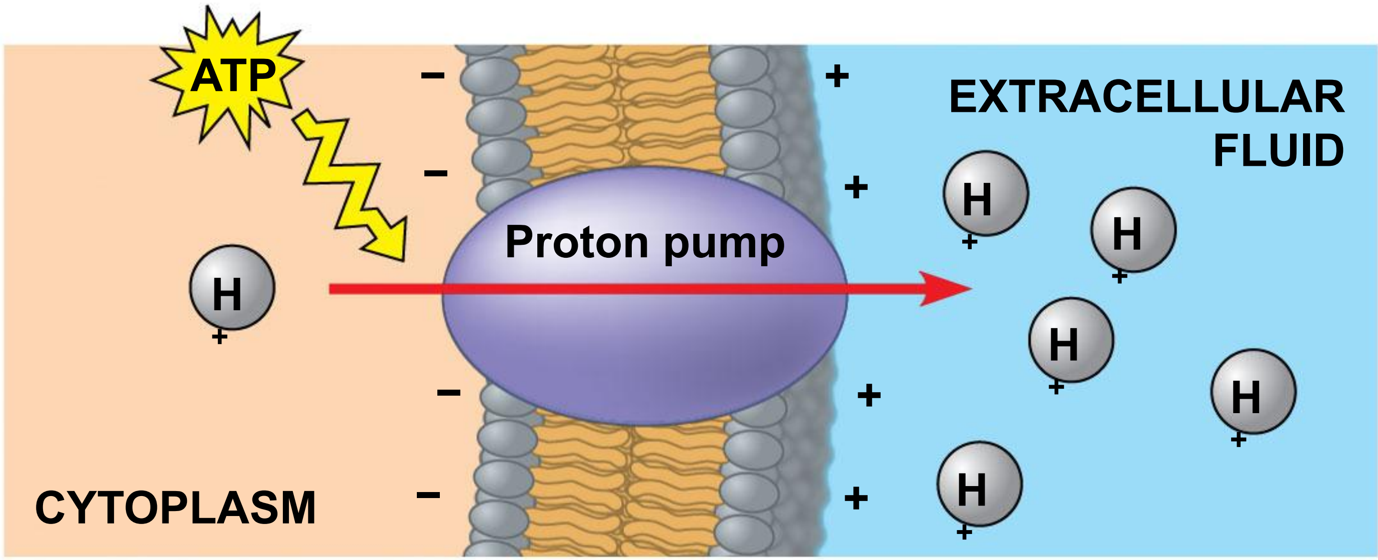
How Ion Pumps Maintain Membrane Potential?

- **Membrane potential** is the voltage difference across a membrane
- Voltage is created by differences in the distribution of **positive and negative ions** across a membrane.

- **Two combined forces, collectively called the electrochemical gradient, drive the diffusion of ions across a membrane:**
  - **A chemical force (the ion’s concentration gradient)**
  - **An electrical force (the effect of the membrane potential on the ion’s movement)**

- An electrogenic pump is a transport protein that generates voltage across a membrane
- The sodium-potassium pump is the major electrogenic pump of animal cells
- The main electrogenic pump of plants, fungi, and bacteria is a proton pump

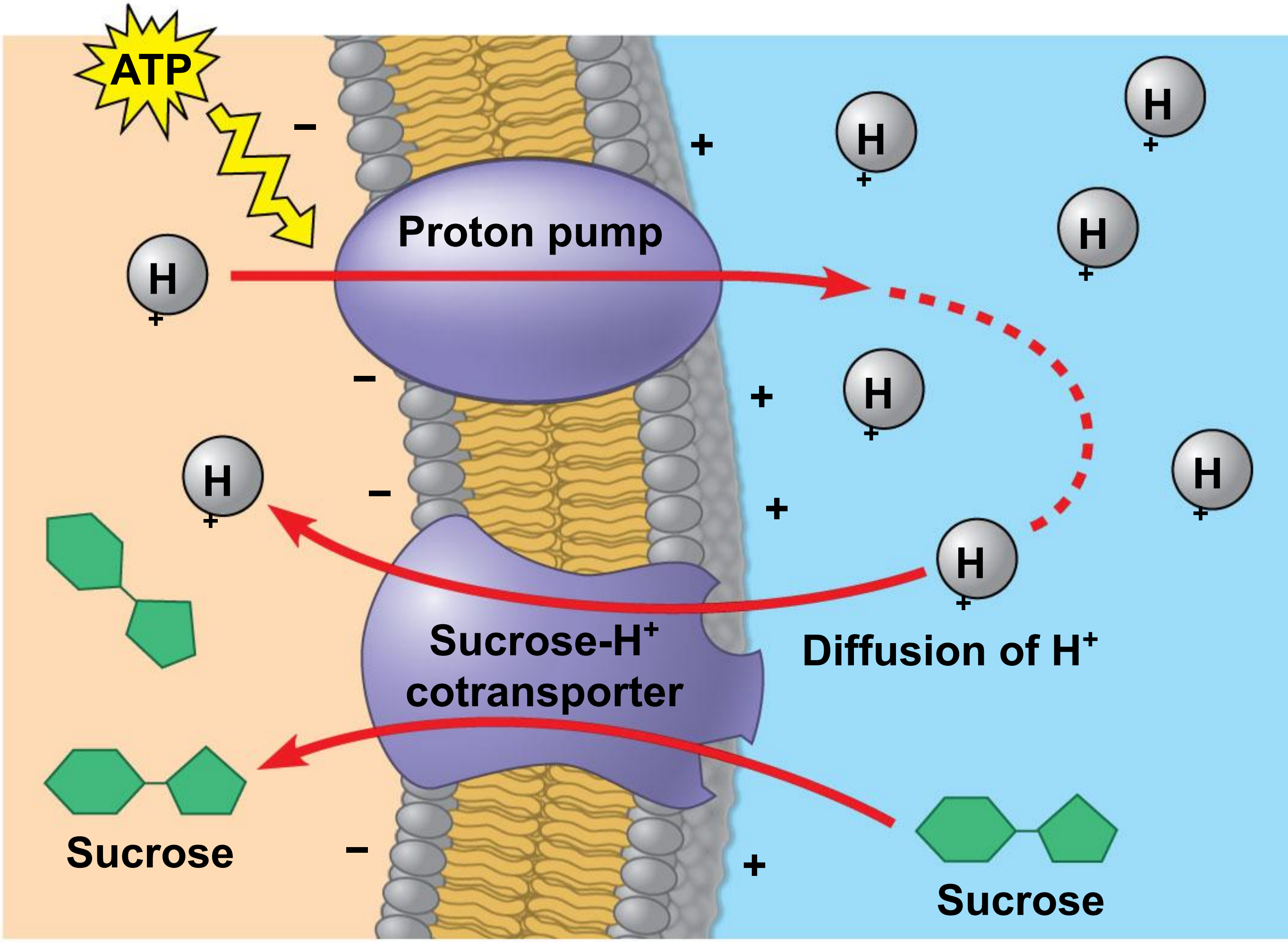
Figure 7.20



Cotransport: Coupled Transport by a Membrane Protein

- **Cotransport** ***occurs when active transport of a solute indirectly drives transport of another solute***
- **Plants commonly use the gradient of hydrogen ions generated by proton pumps to drive active transport of nutrients into the cell**

Figure 7.21



ATP
Proton pump
H
H^+
Sucrose-H^+ cotransporter
Diffusion of H^+
Sucrose
Sucrose

Concept: Bulk transport across the plasma membrane occurs by exocytosis and endocytosis

- Small molecules and water enter or leave the cell through the lipid bilayer or by transport proteins
- Large molecules, such as polysaccharides and proteins, cross the membrane in bulk via vesicles
- Bulk transport requires energy

Exocytosis

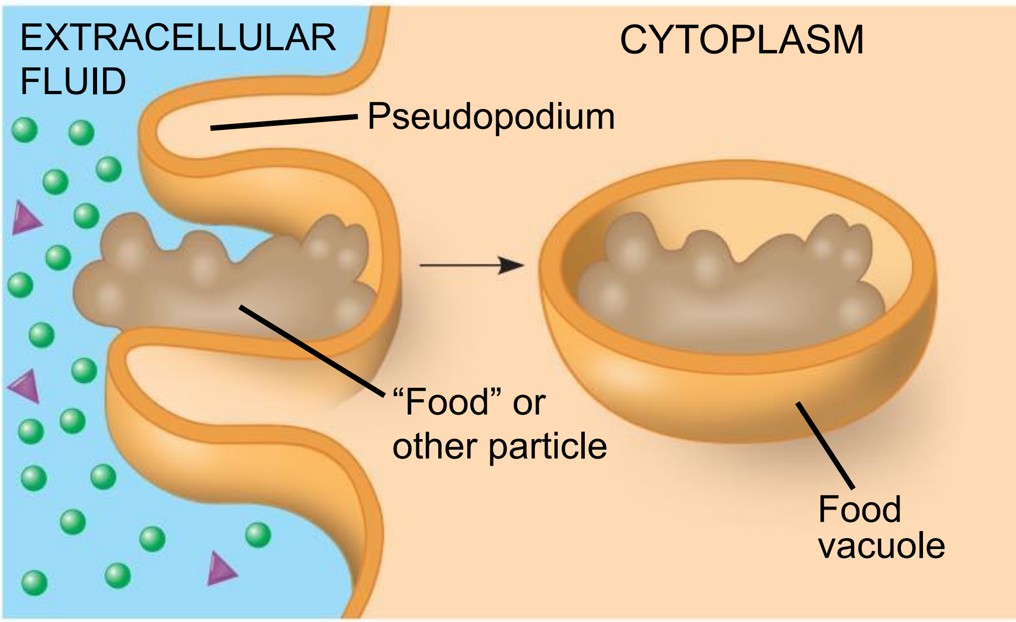
- In **exocytosis**, transport vesicles migrate to the membrane, fuse with it, and release their contents
- Many **secretory cells** use exocytosis to export their products

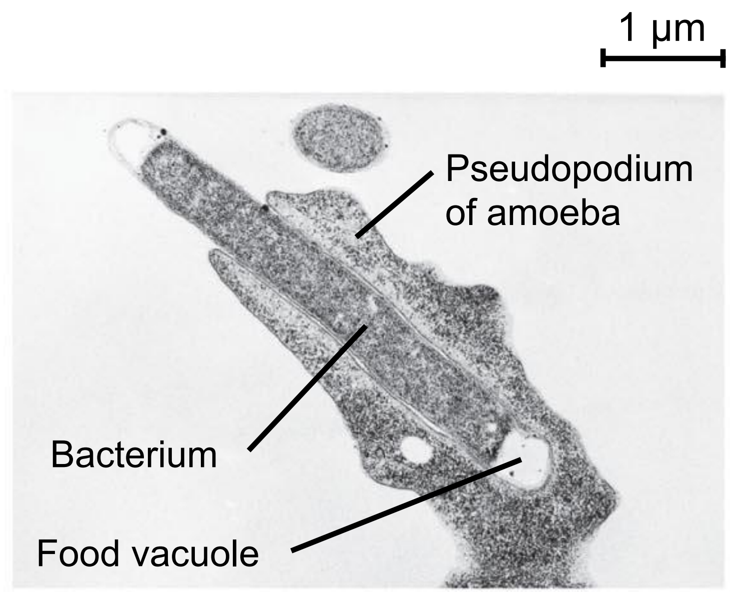
Endocytosis

- In **endocytosis,** the cell takes in macromolecules by forming vesicles from the plasma membrane
- Endocytosis is a reversal of exocytosis, involving different proteins
- There are **three types of endocytosis**:
  - **Phagocytosis** (“cellular eating”)
  - **Pinocytosis** (“cellular drinking”)
  - **Receptor-mediated endocytosis**

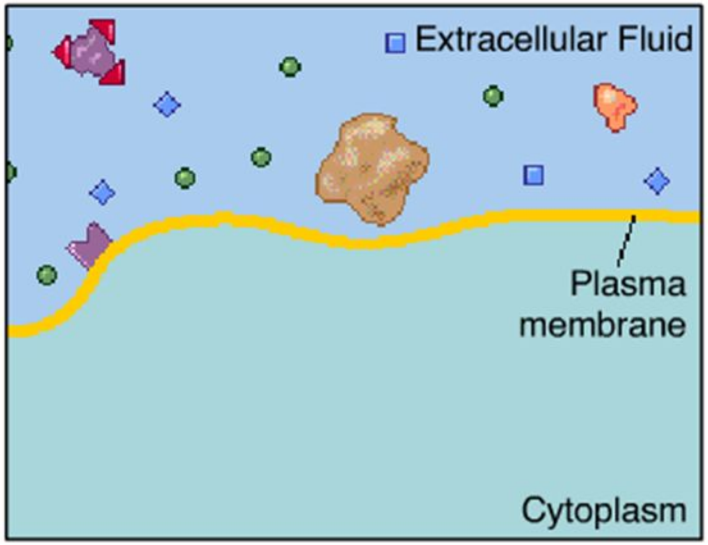
- In **phagocytosis** a cell engulfs a particle in a vacuole
- The vacuole **fuses with a lysosome** to digest the particle

PHAGOCYTOSIS





An amoeba engulfing a bacterium via phagocytosis (TEM)



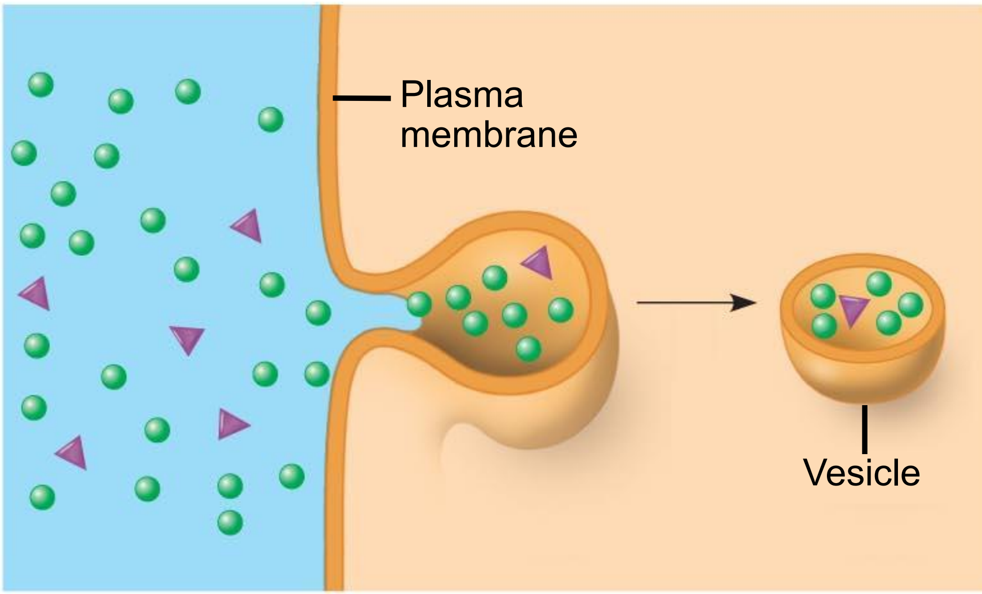
Animation: Phagocytosis

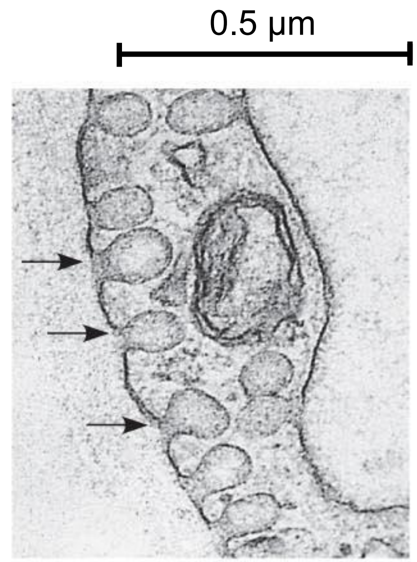
Right-click slide / select “Play”

- In pinocytosis, molecules are taken up when extracellular fluid is “gulped” into tiny vesicles

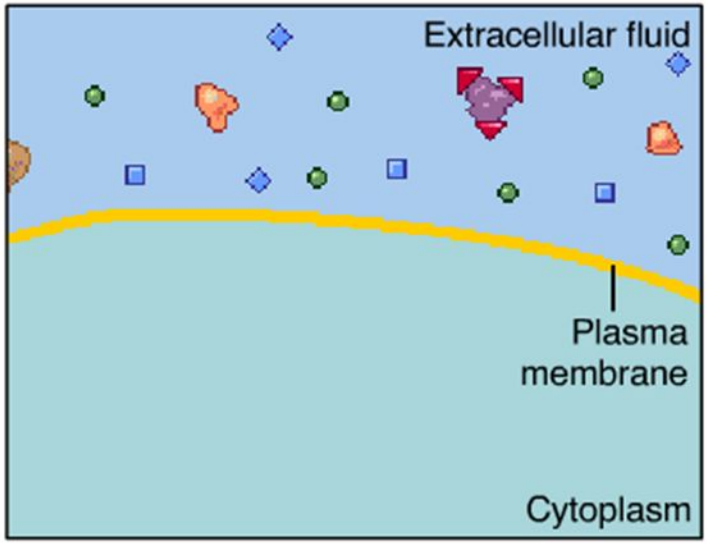
Fig. 7-20b

PINOCYTOSIS





Pinocytosis vesicles forming (arrows) in a cell lining a small blood vessel (TEM)


Extracellular fluid
Plasma membrane
Cytoplasm

- In **receptor-mediated endocytosis**, **binding of ligands to receptors** triggers vesicle formation
- A **ligand** is any molecule that **binds specifically** to a **receptor site** of another molecule

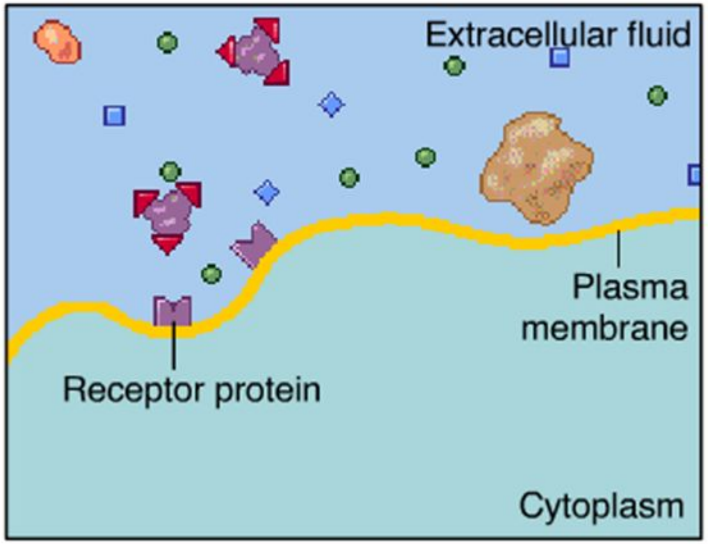
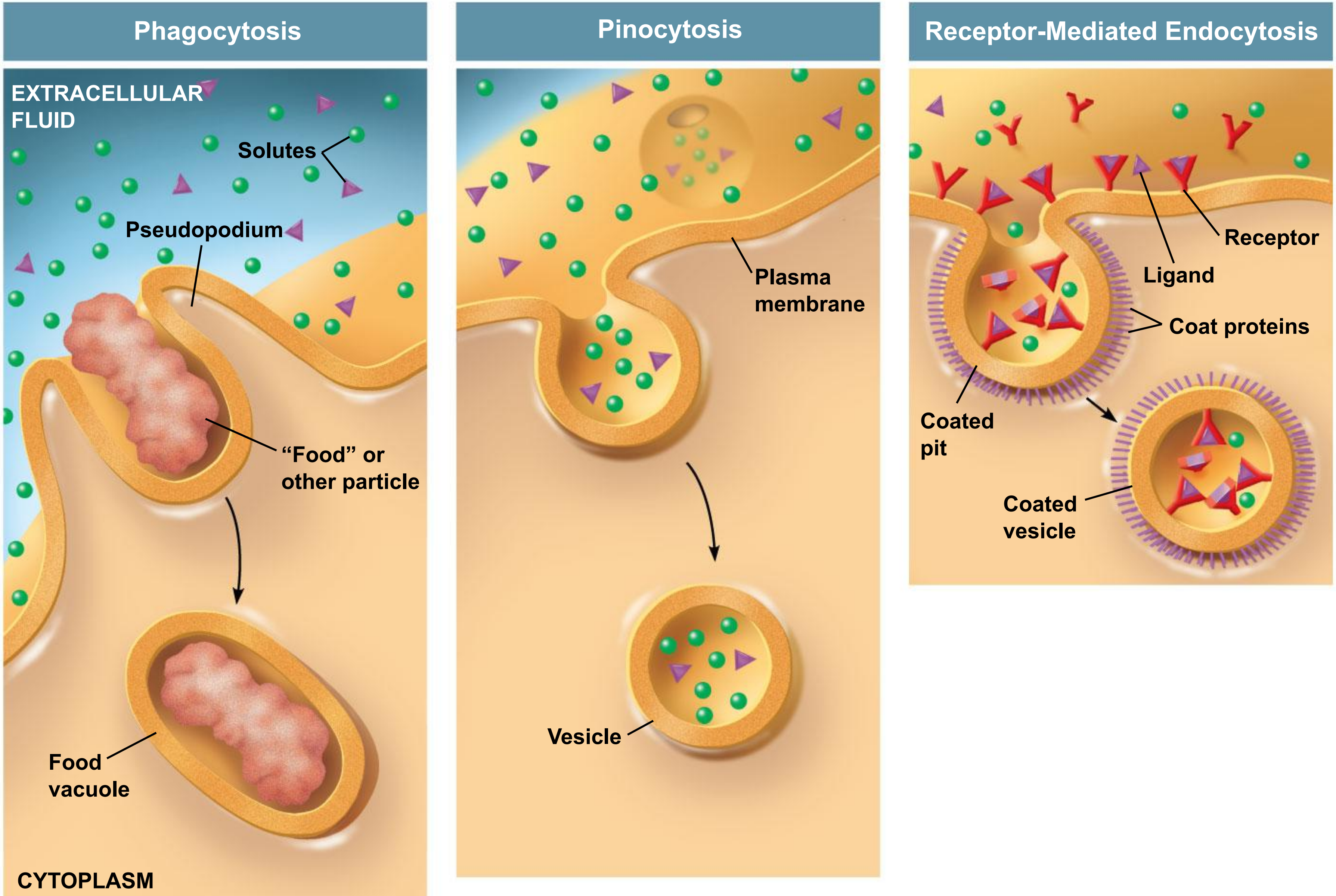

Extracellular fluid
Plasma
membrane
Receptor protein
Cytoplasm

Figure 7.22



Phagocytosis
EXTRACELLULAR FLUID
Solutes
Pseudopodium
"Food" or other particle
Food vacuole
CYTOPLASM
Pinocytosis
Plasma membrane
Vesicle
Receptor-Mediated Endocytosis
Receptor
Ligand
Coat proteins
Coated pit
Coated vesicle

Familial *hypercholersterolemia* (FH)

- Cholesterol is transported in blood in particles called LDL
- LDL binds to receptors on plasma membranes & enter cells by receptor-mediated endocytosis
- In FH, LDL receptors are defective or missing >> cholesterol accumulates in blood vessels and lead to athersclerosis