Chapter 7

Membrane Structure and Function

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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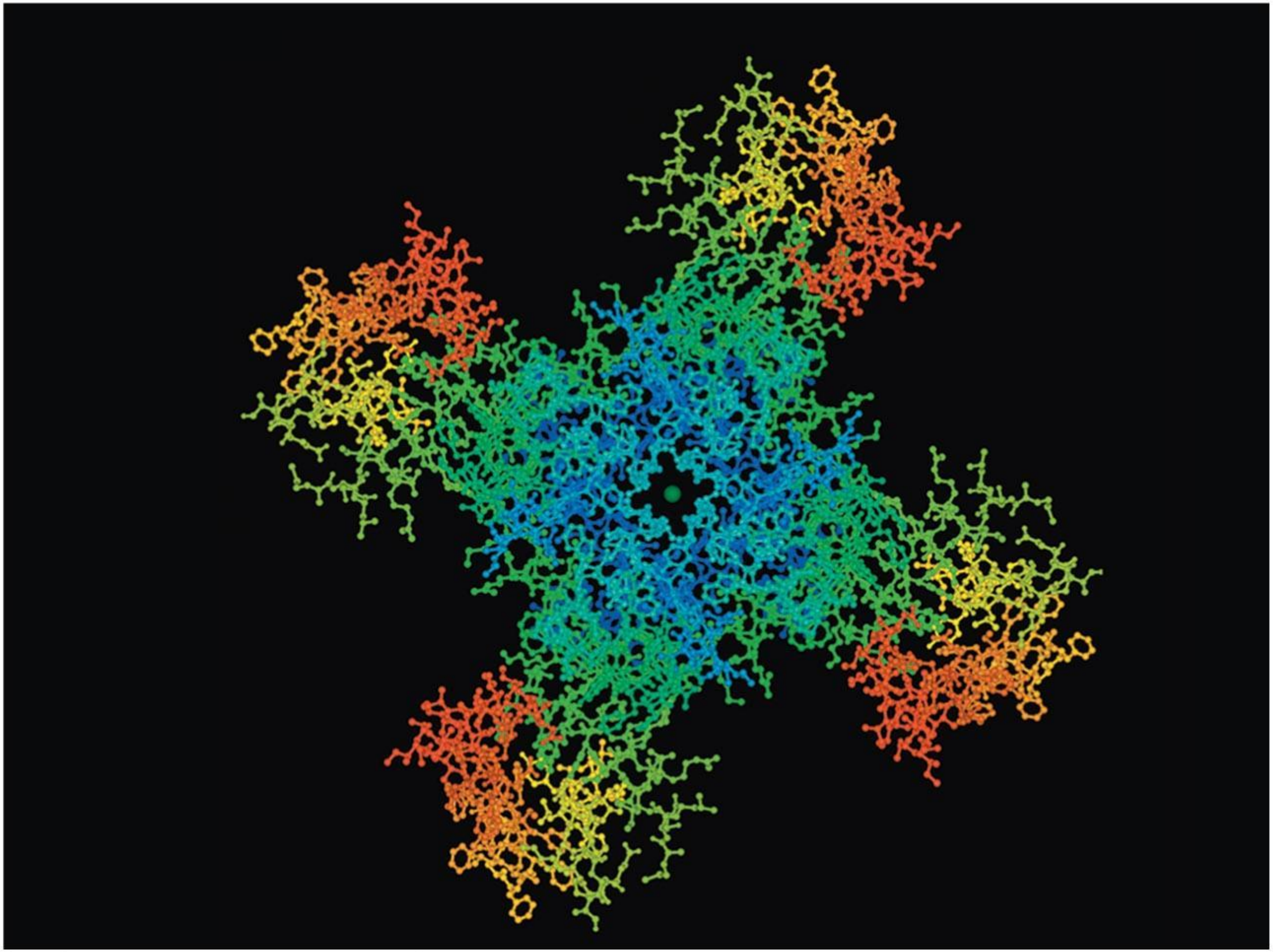
Overview: Life at the Edge

- 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. 7-1



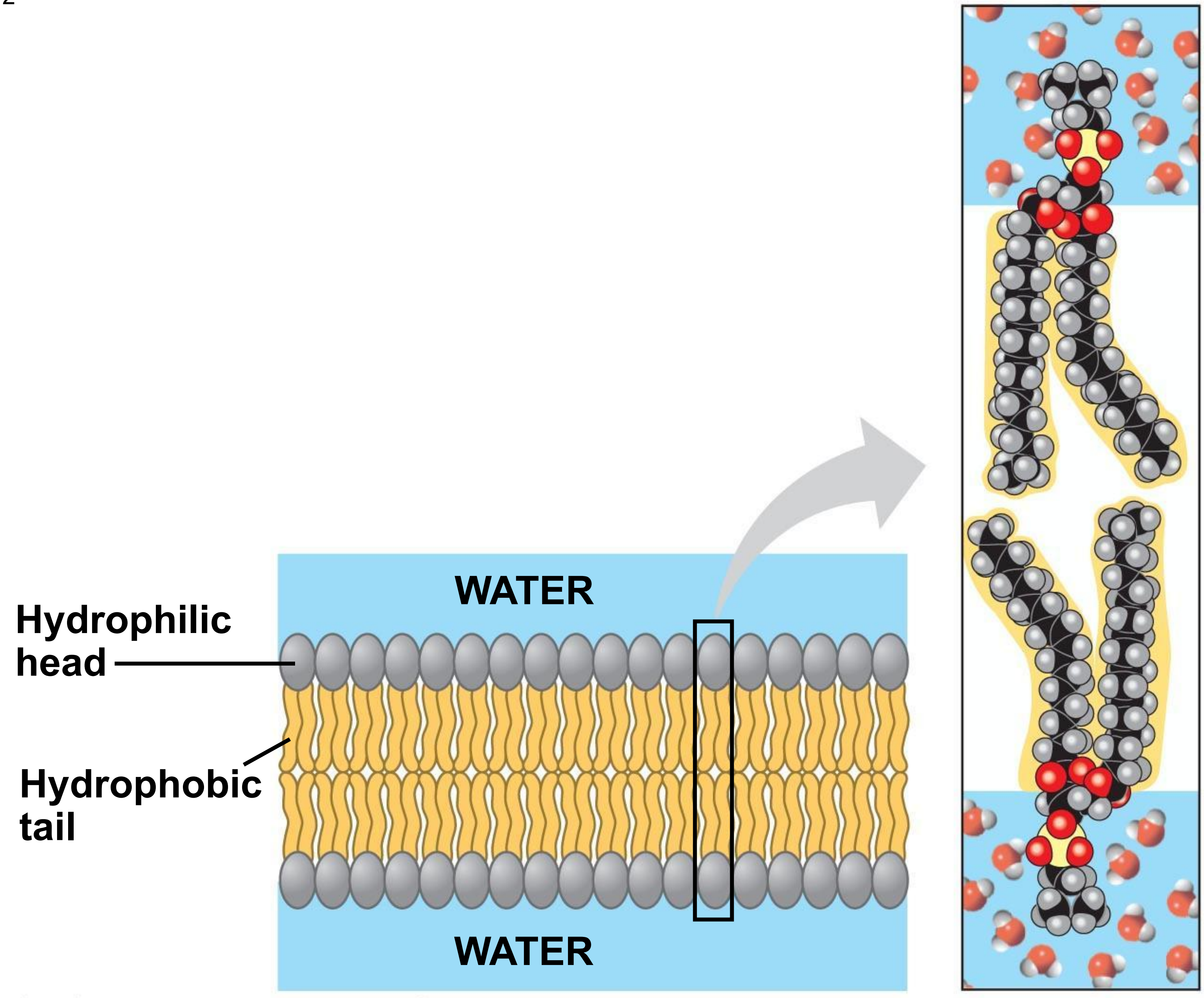
Concept 7.1: Cellular membranes are fluid mosaics of lipids and proteins

- 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*

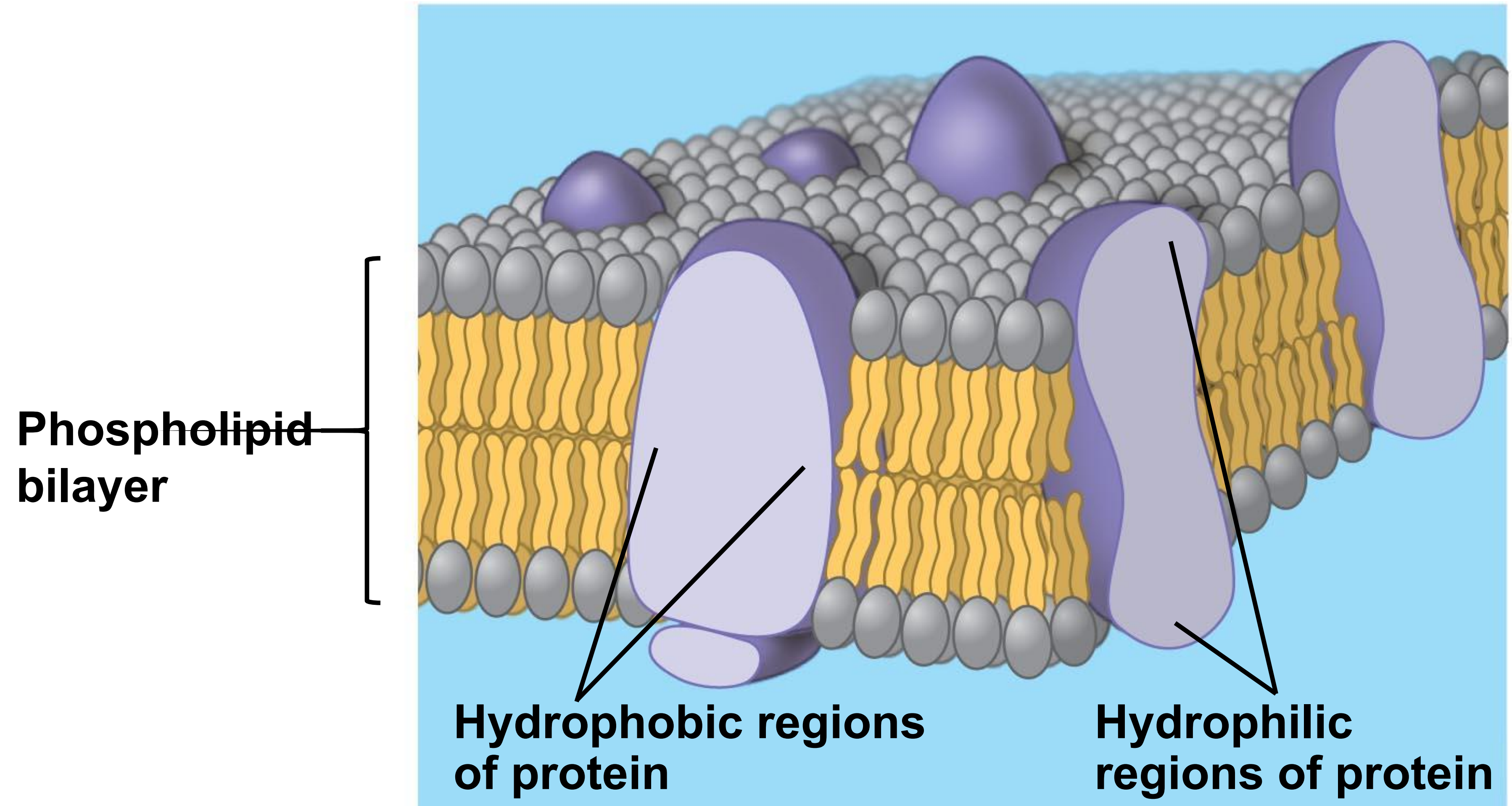
- Membranes have been chemically analyzed and found to be made of proteins and lipids
- Scientists studying the plasma membrane reasoned that it must be a phospholipid bilayer

Fig. 7-2



- In 1935, Hugh Davson and James Danielli proposed a sandwich model in which the phospholipid bilayer lies between two layers of globular proteins
- Later studies found problems with this model, particularly the placement of membrane proteins, which have hydrophilic and hydrophobic regions
- In 1972, J. Singer and G. Nicolson proposed that the membrane is a mosaic of proteins dispersed within the bilayer, with only the hydrophilic regions exposed to water

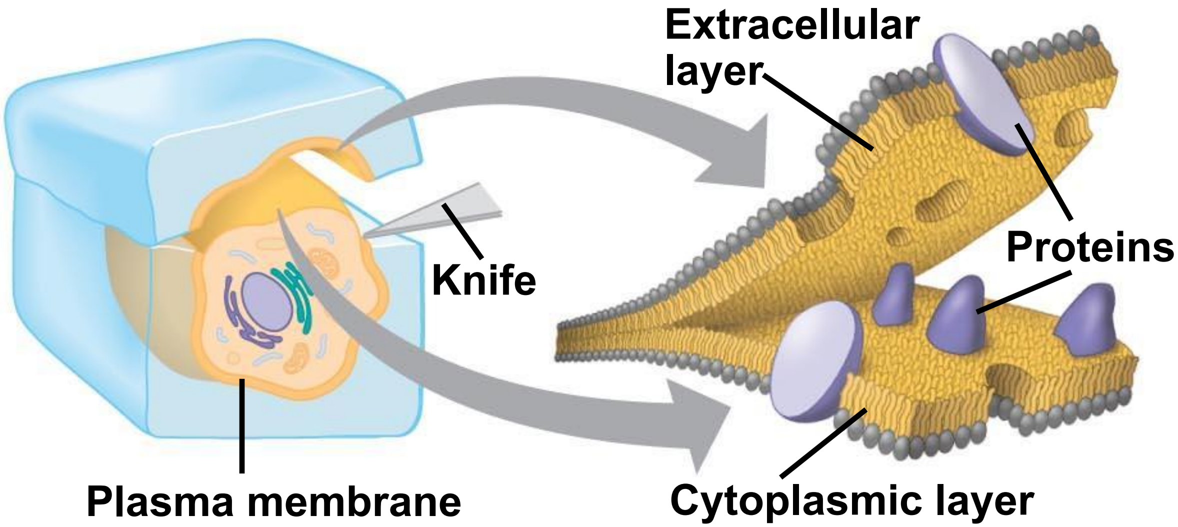
Fig. 7-3


Phospholipid
bilayer
Hydrophobic regions
of protein
Hydrophilic
regions of protein

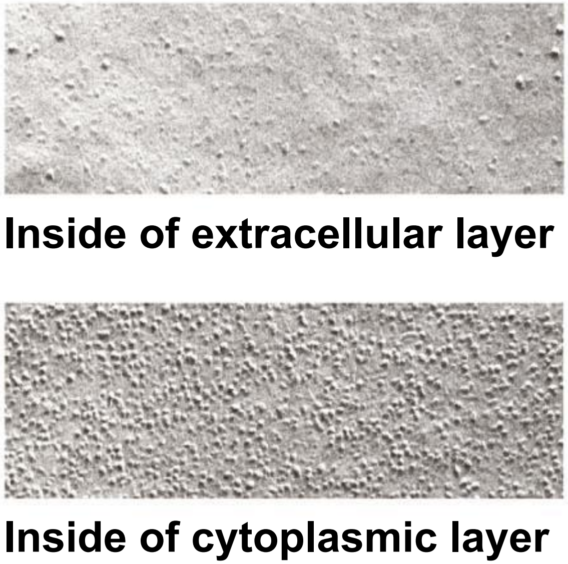
- Freeze-fracture studies of the plasma membrane supported the fluid mosaic model
- Freeze-fracture is a specialized preparation technique that splits a membrane along the middle of the phospholipid bilayer

Fig. 7-4

TECHNIQUE



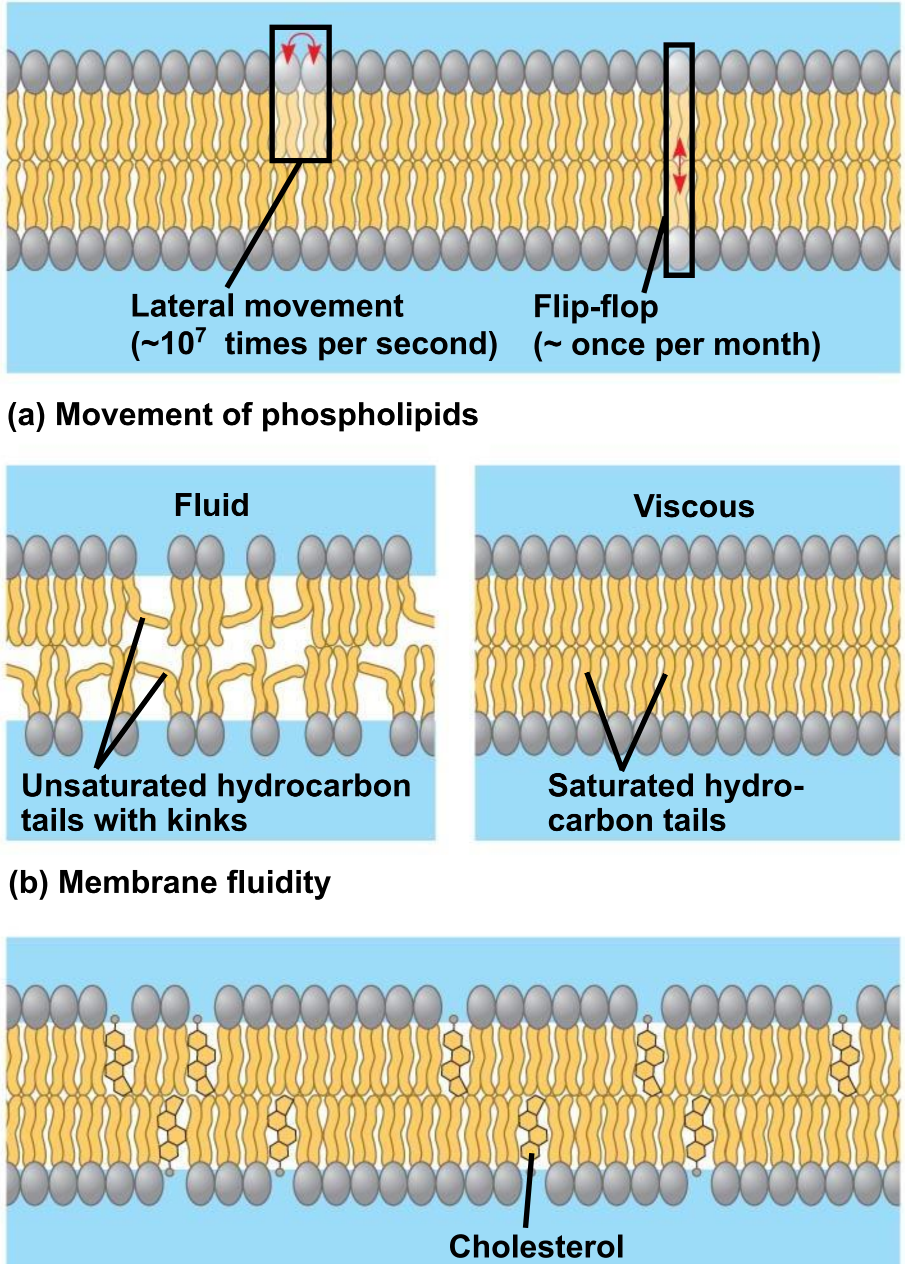
RESULTS



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

Fig. 7-5

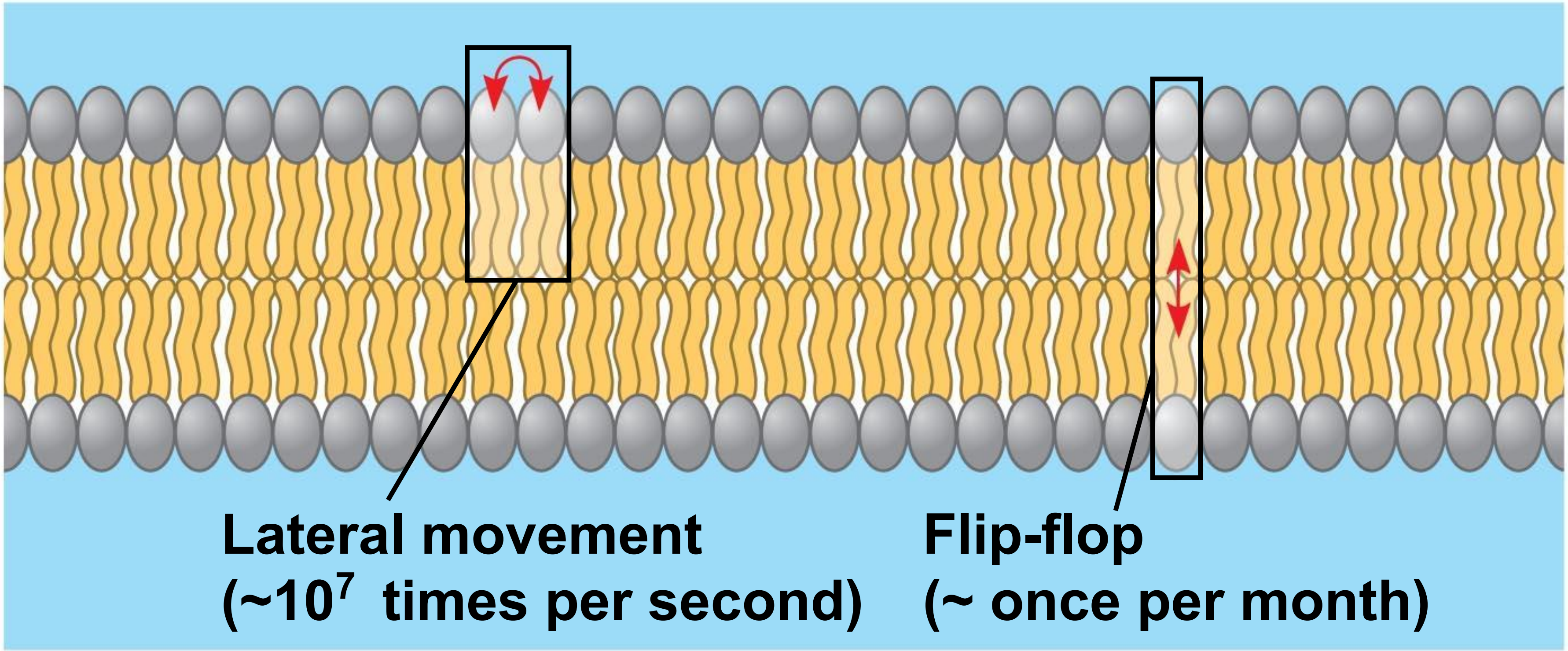


(a) Movement of phospholipids

(b) Membrane fluidity

(c) Cholesterol within the animal cell membrane

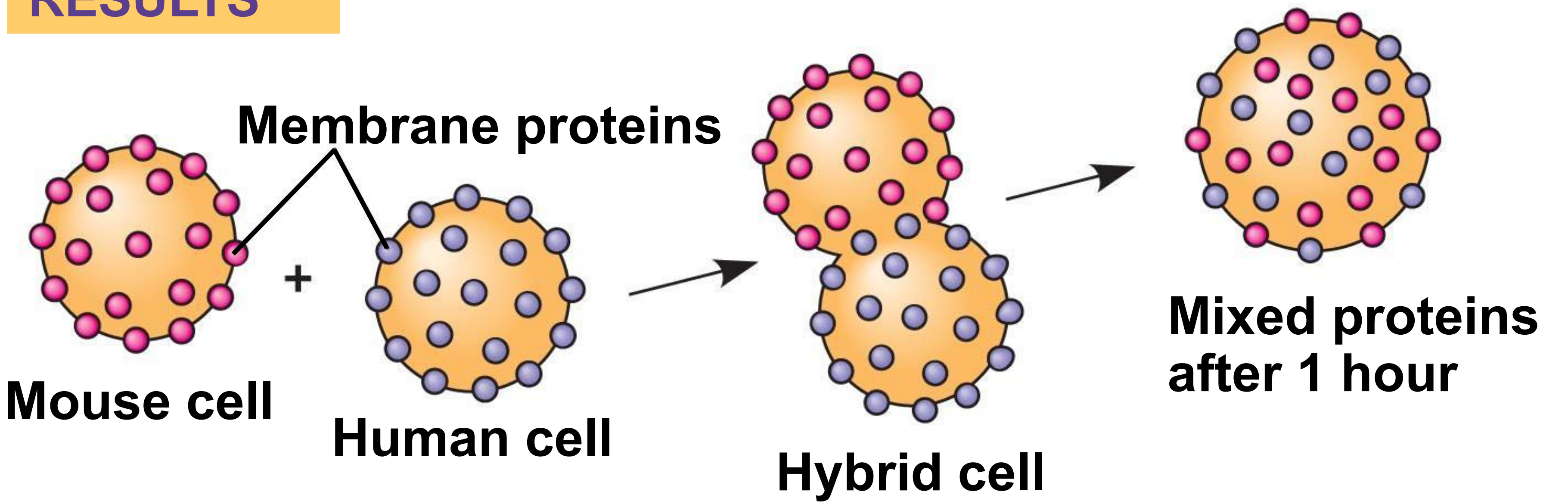
Fig. 7-5a



(a) Movement of phospholipids

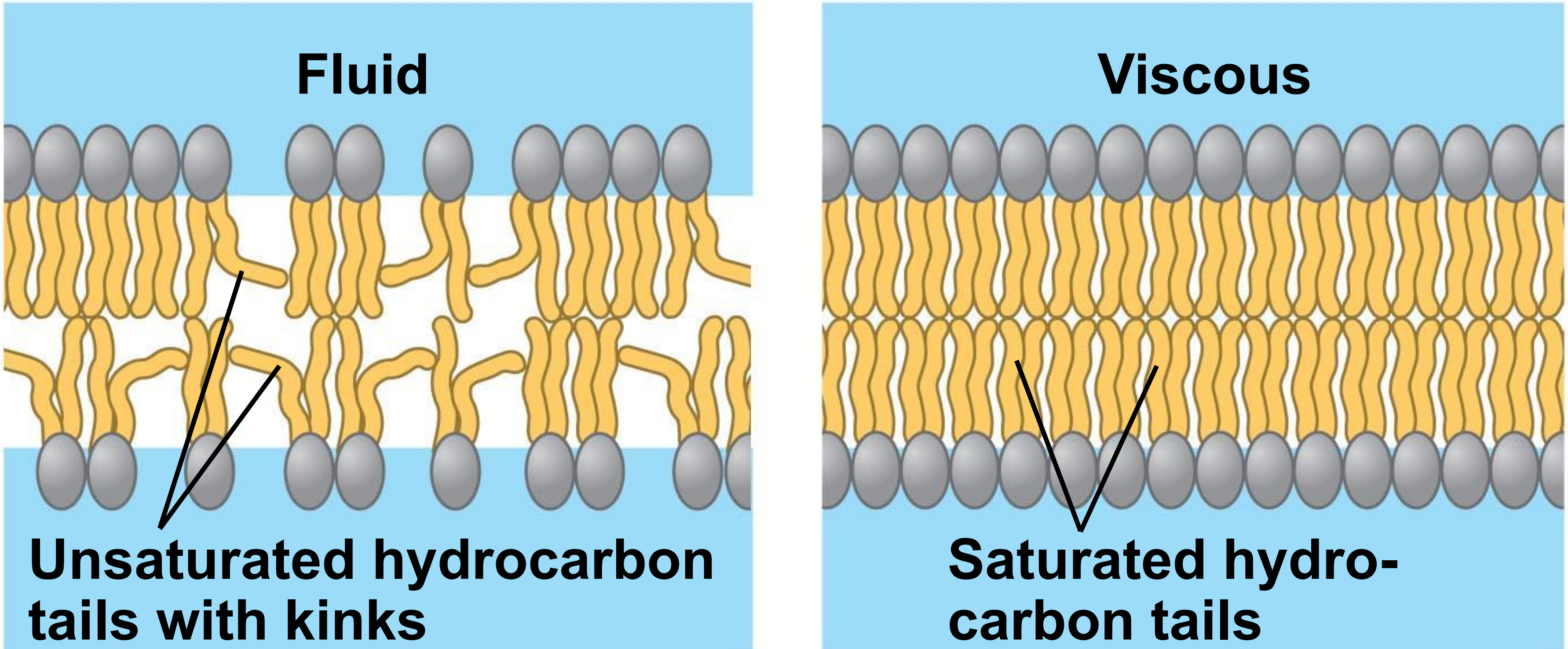
Fig. 7-6

RESULTS



- 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 that those rich in saturated fatty acids
- Membranes must be fluid to work properly; they are usually about as fluid as salad oil

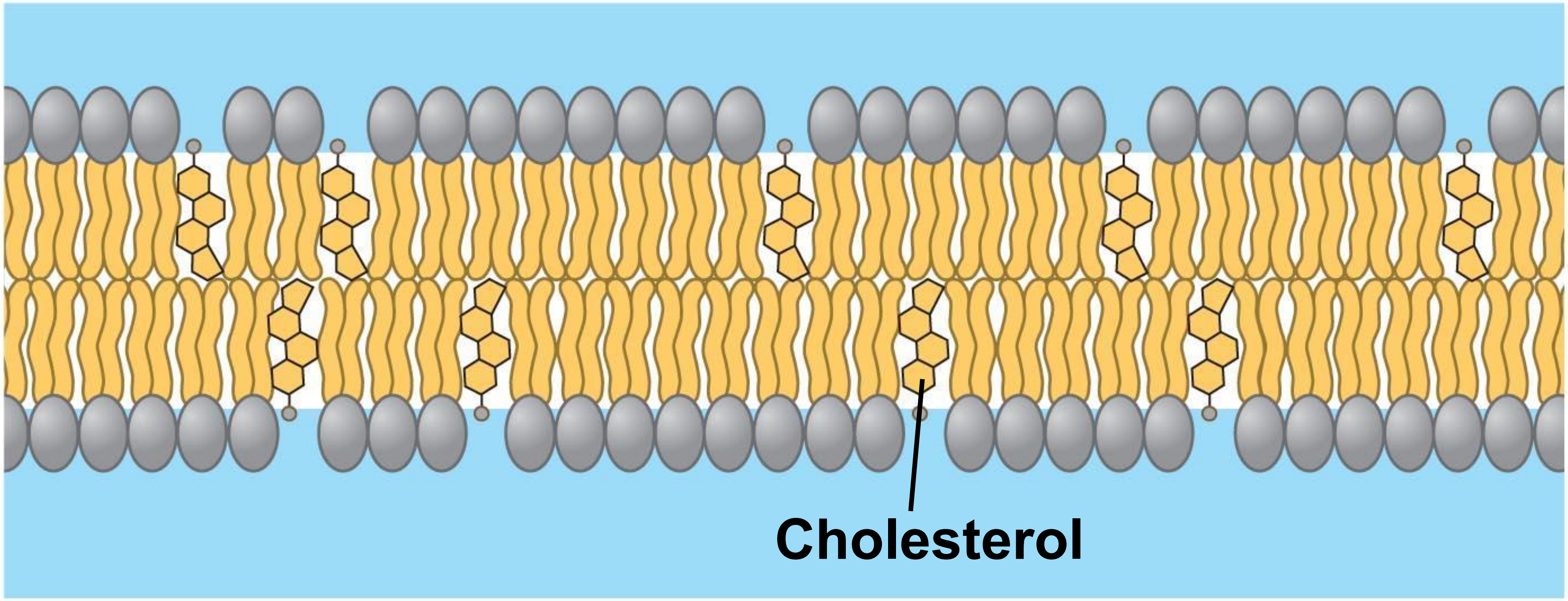
Fig. 7-5b



(b) Membrane fluidity

- 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

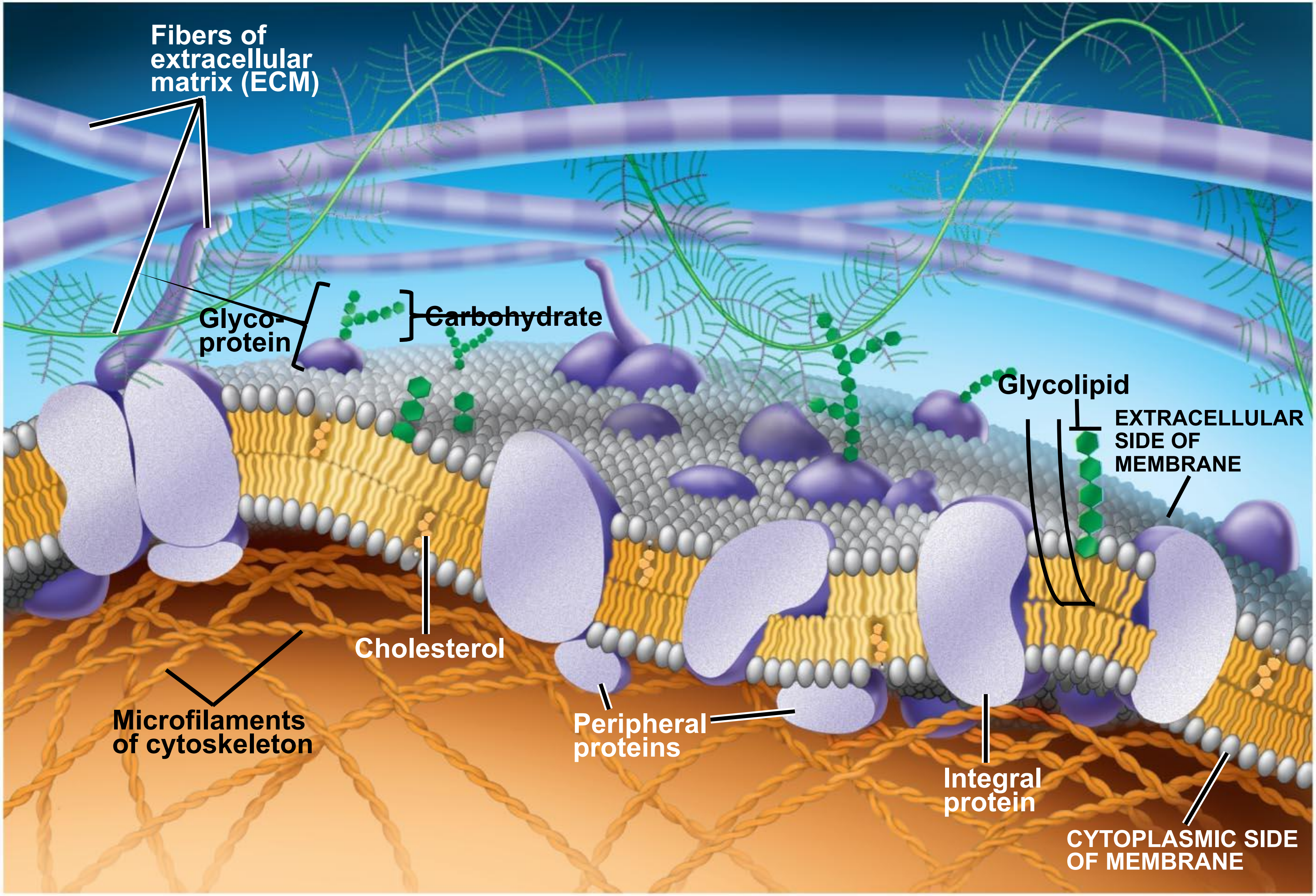
Fig. 7-5c



(c) Cholesterol within the animal cell membrane

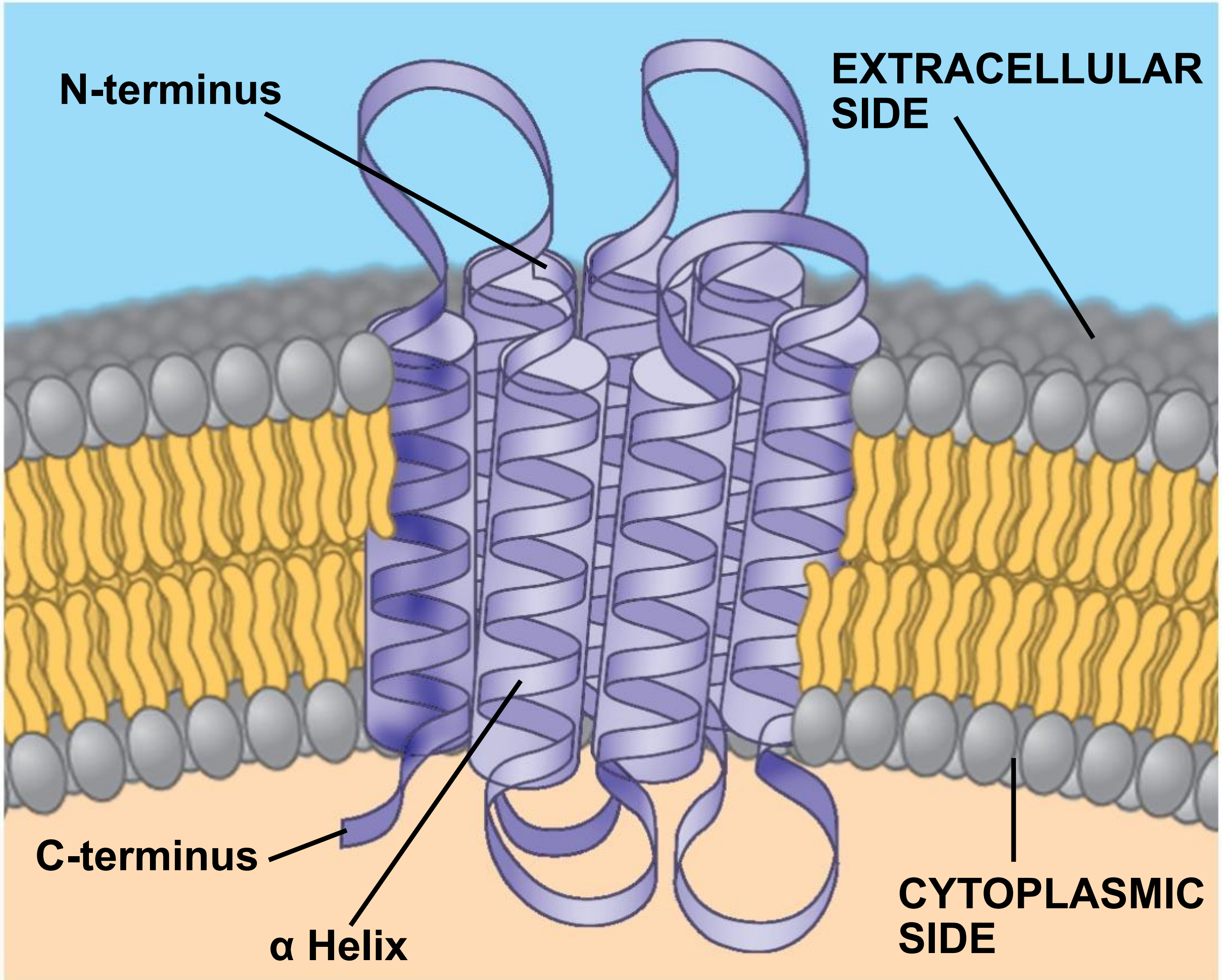
Membrane Proteins and Their Functions

- 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


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

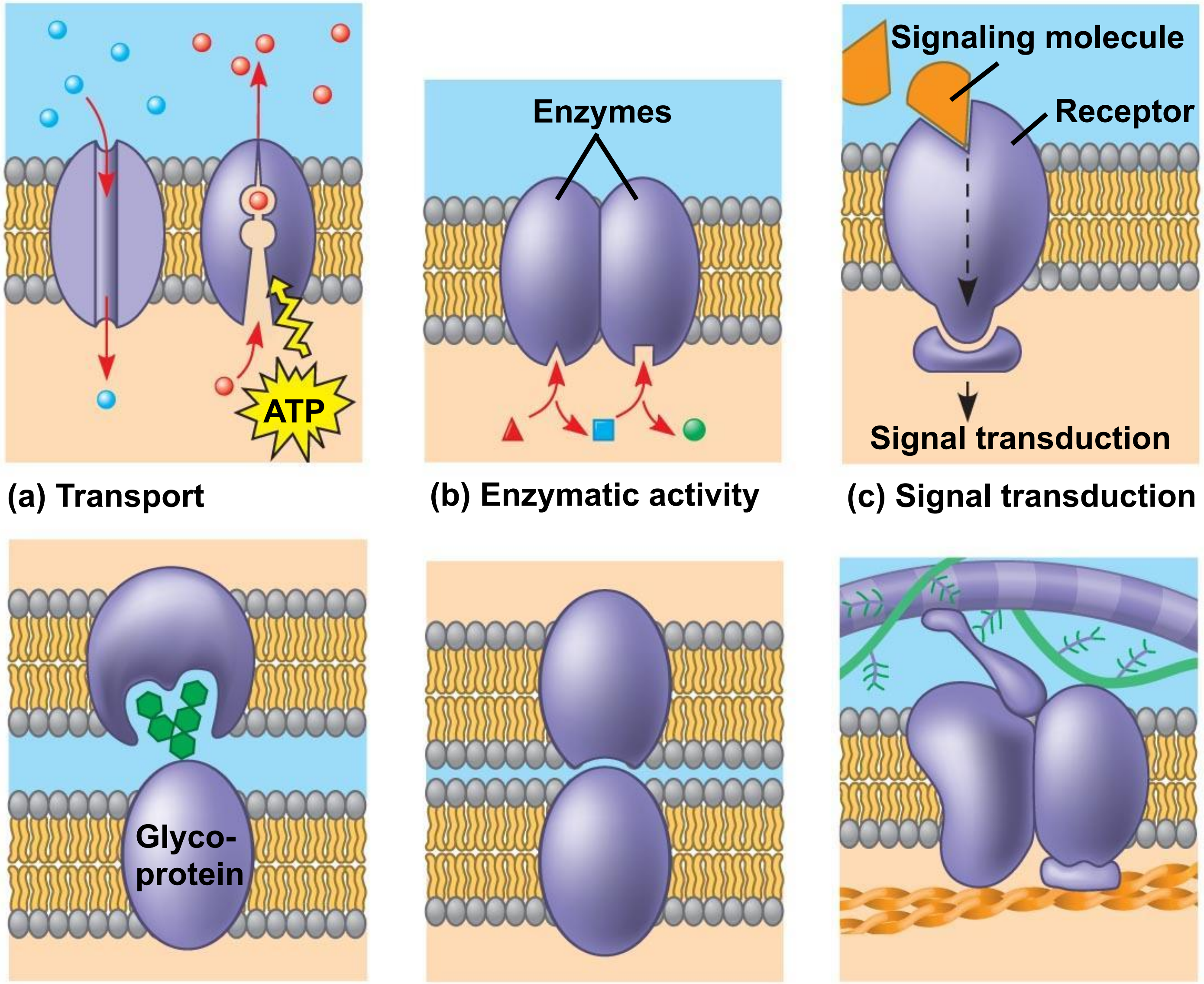
- **Peripheral proteins** are bound to the surface of the membrane
- **Integral proteins** penetrate the hydrophobic core
- Integral proteins that span the membrane are called transmembrane proteins
- The hydrophobic regions of an integral protein consist of one or more stretches of nonpolar amino acids,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

Fig. 7-8


N-terminus
EXTRACELLULAR SIDE
C-terminus
α Helix
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

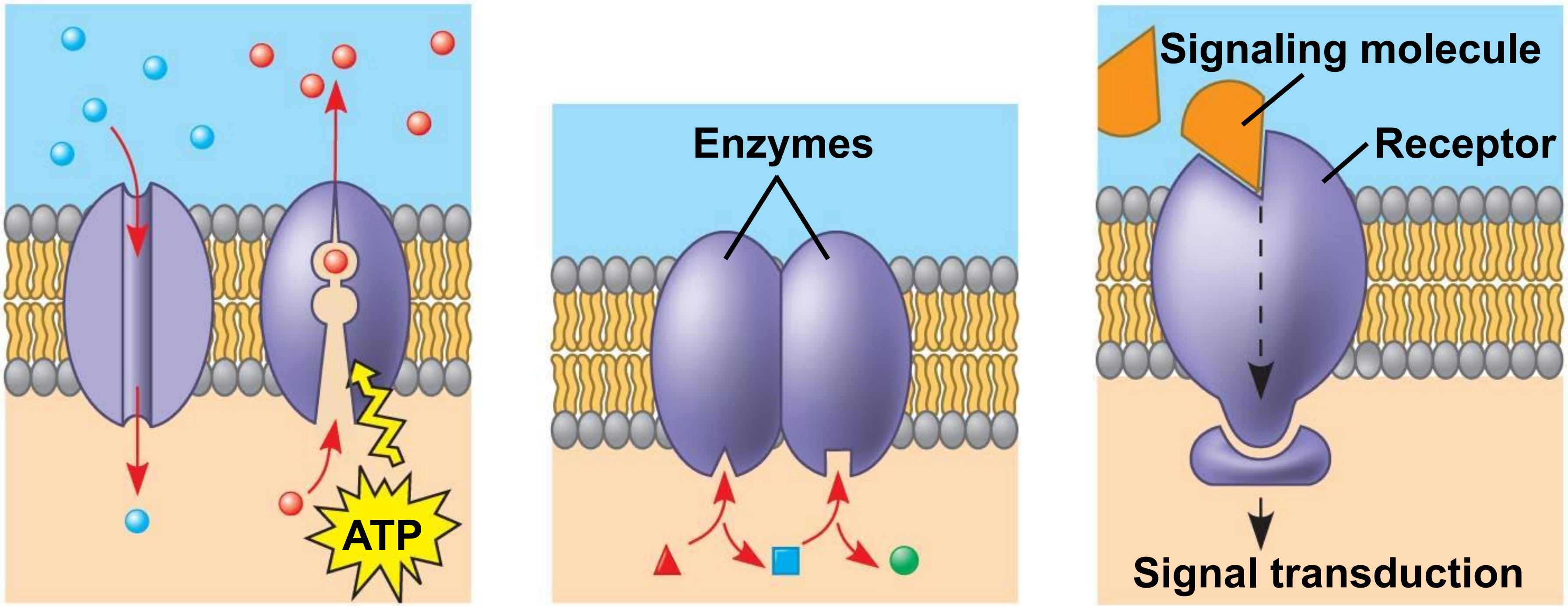
(c) Signal transduction

(d) Cell-cell recognition

(e) Intercellular joining

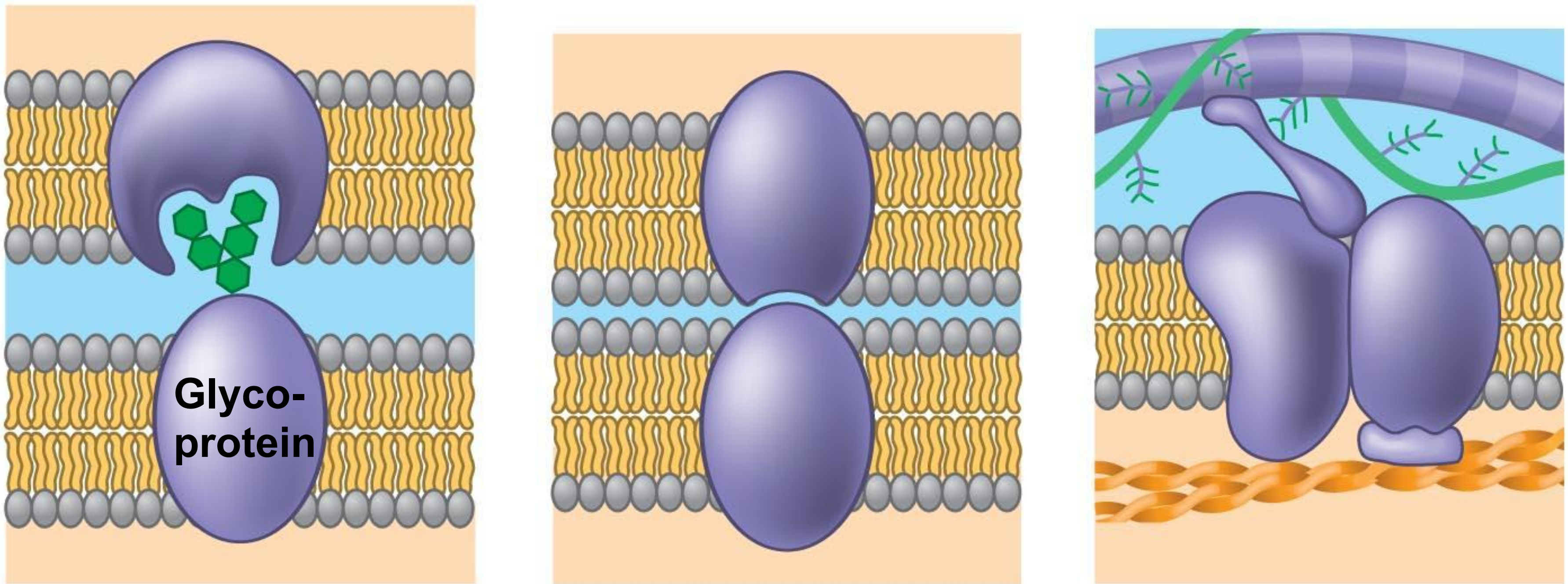
(f) Attachment to the cytoskeleton and extracellular matrix (ECM)

Fig. 7-9ac



(a) Transport (b) Enzymatic activity (c) Signal transduction

Fig. 7-9df



(d) Cell-cell recognition

(e) Intercellular joining

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

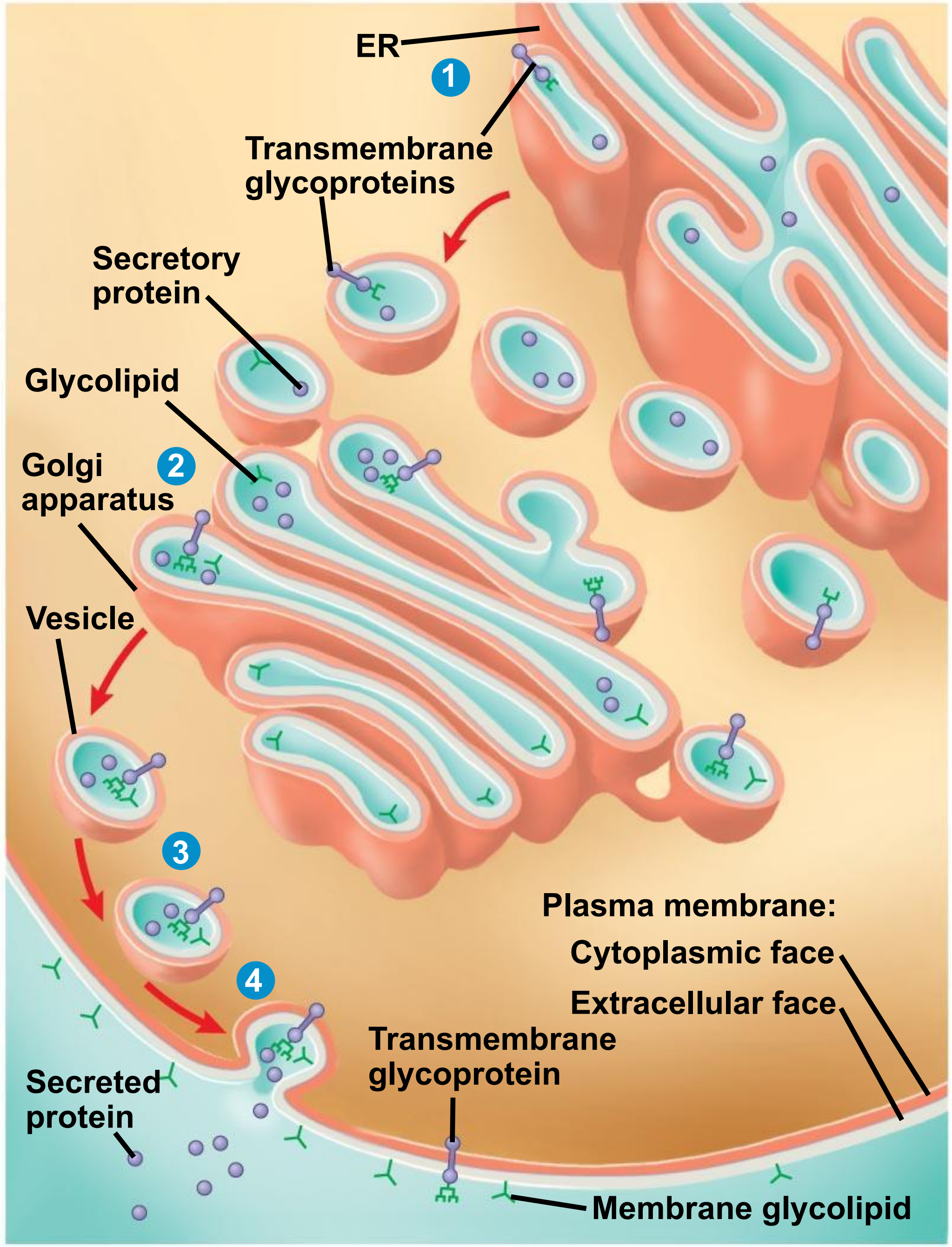
The Role of Membrane Carbohydrates in Cell-Cell Recognition

- 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**)
- Carbohydrates on the external side of the plasma membrane vary among species, individuals, and even cell types in an individual

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

Fig. 7-10


ER
1
Transmembrane glycoproteins
Secretory protein
Glycolipid
Golgi apparatus
2
Vesicle
3
4
Plasma membrane:
Cytoplasmic face
Extracellular face
Transmembrane glycoprotein
Secreted protein
Membrane glycolipid

Concept 7.2: 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 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

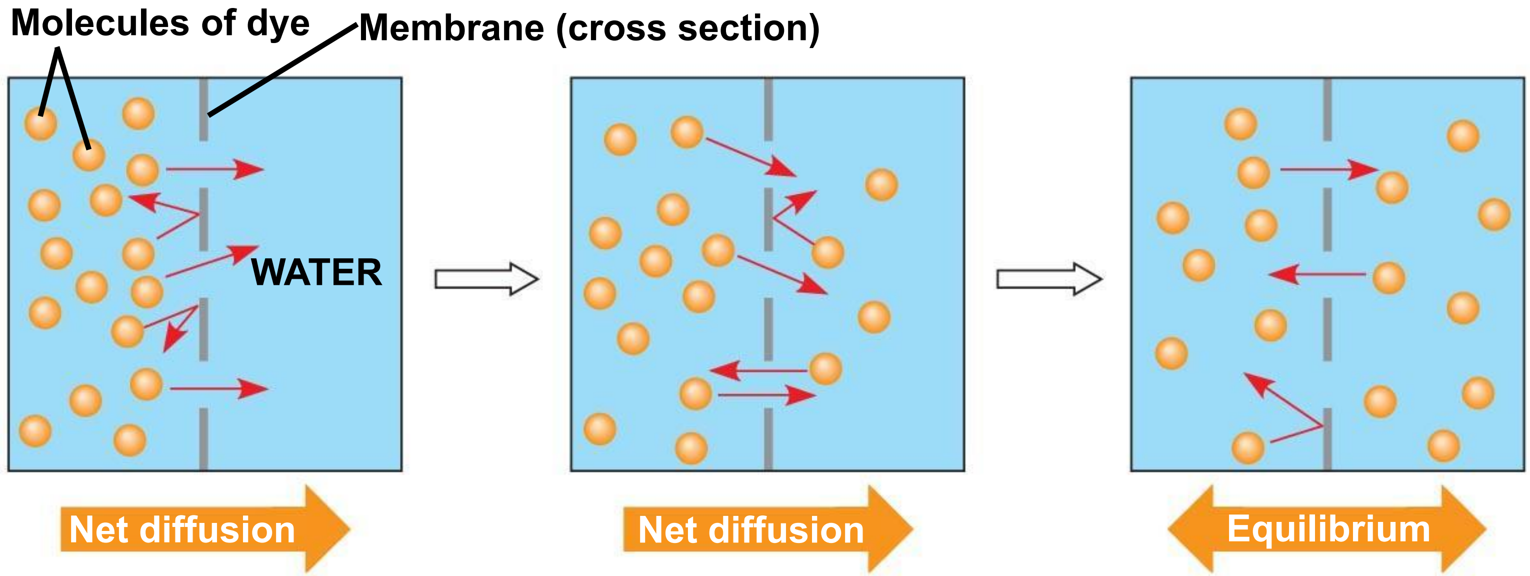
Concept 7.3: Passive transport is diffusion of a substance across a membrane with no energy investment

- **Diffusion** is the tendency for molecules to spread out evenly into the 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

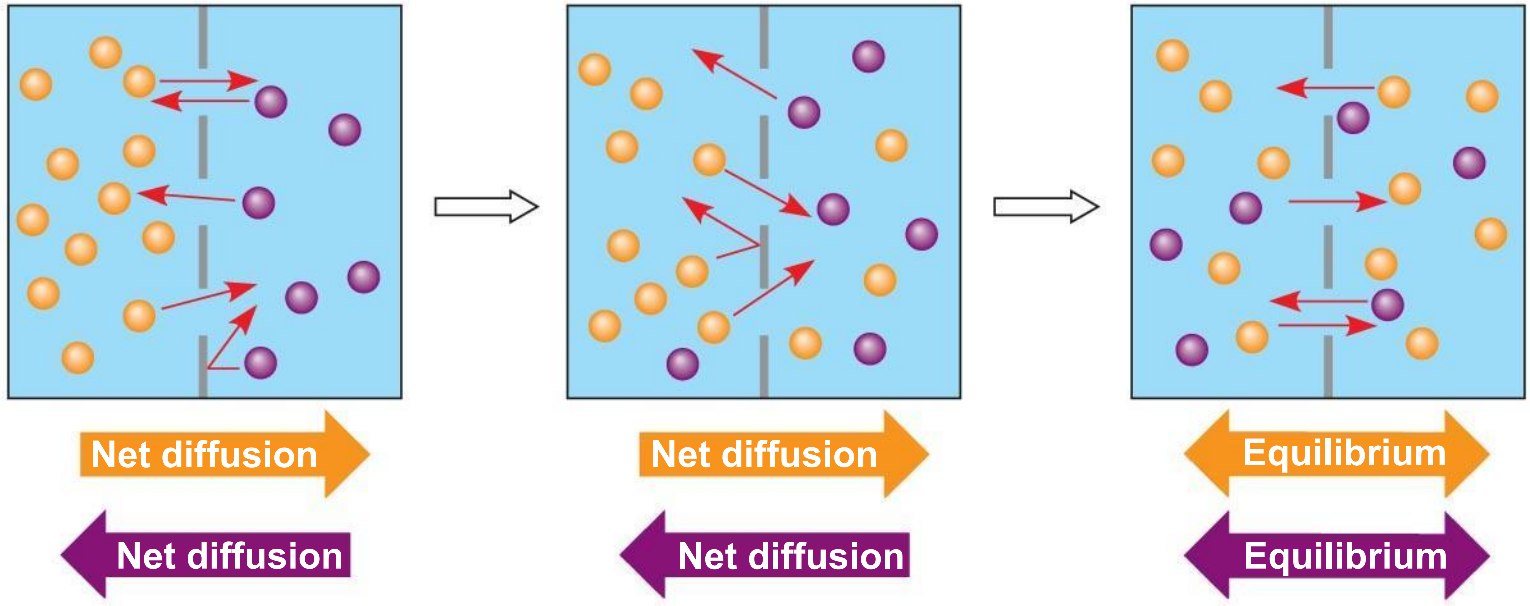
PLAY Animation: Membrane Selectivity

PLAY Animation: Diffusion

Fig. 7-11

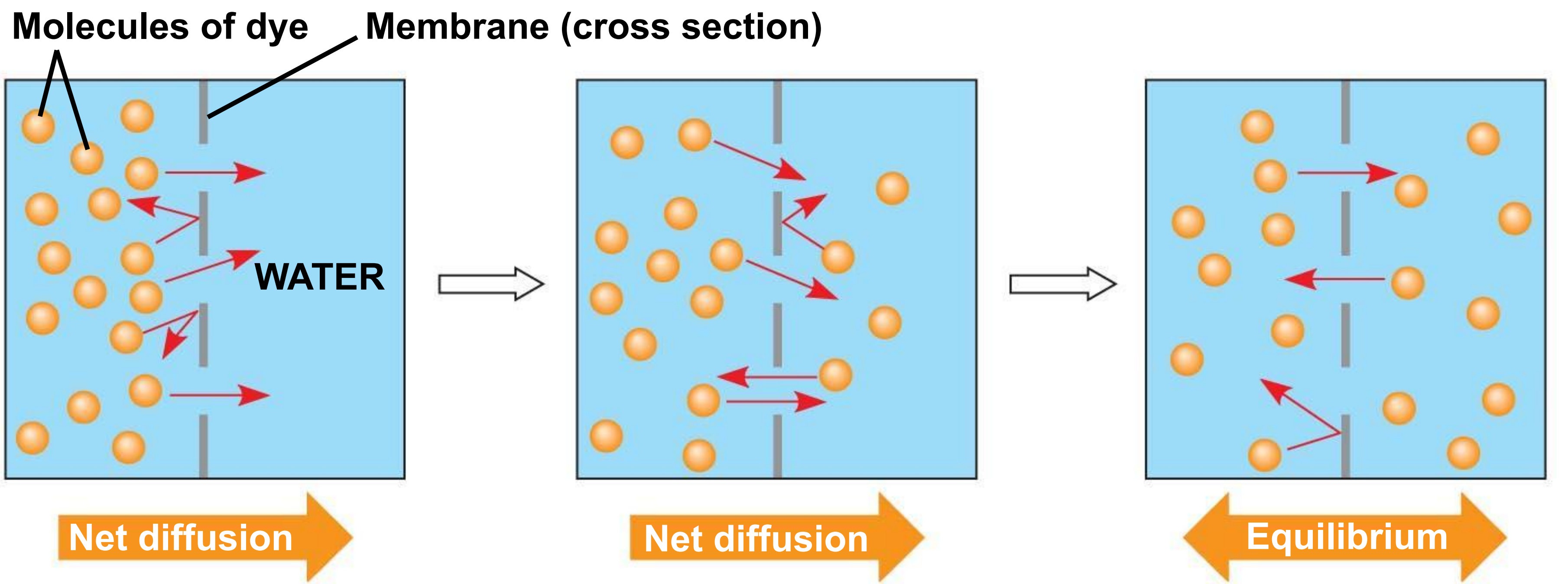


(a) Diffusion of one solute



(b) Diffusion of two solutes

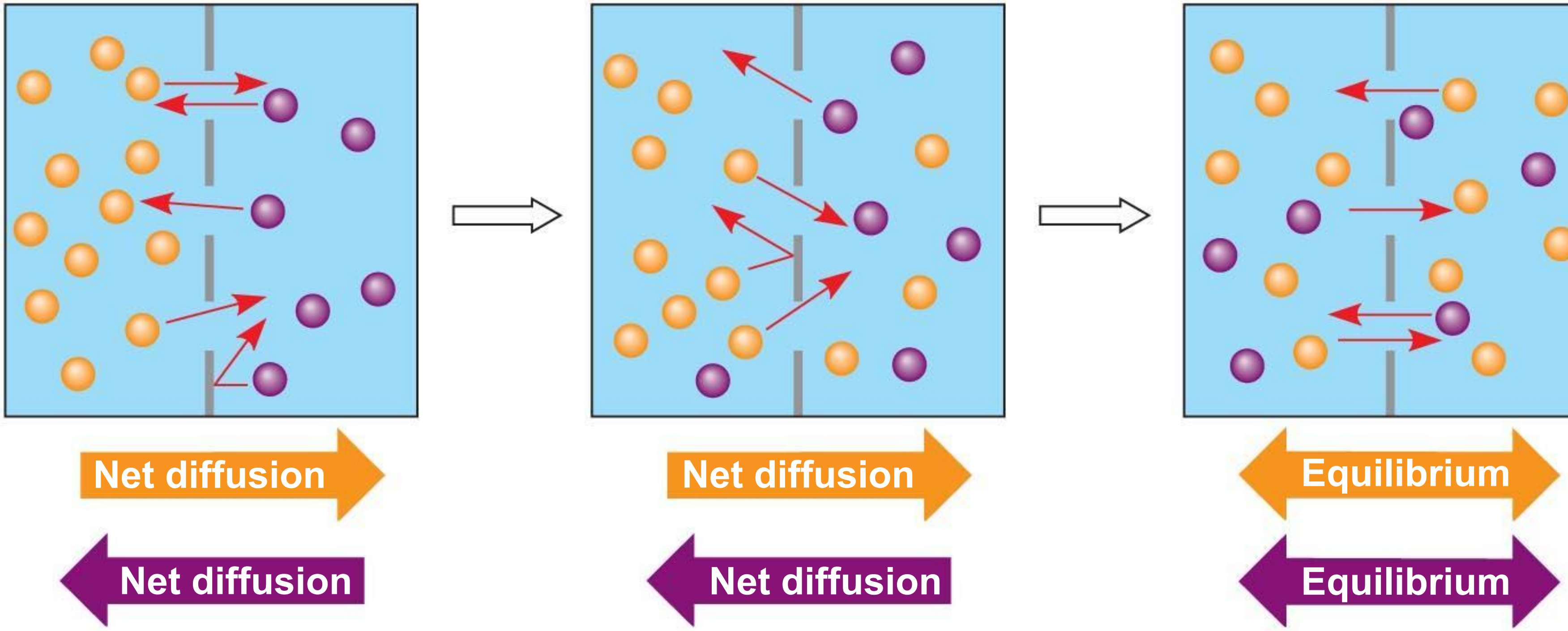
Fig. 7-11a



(a) Diffusion of one solute

- 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
- The diffusion of a substance across a biological membrane is **passive transport** because it requires no energy from the cell to make it happen

Fig. 7-11b

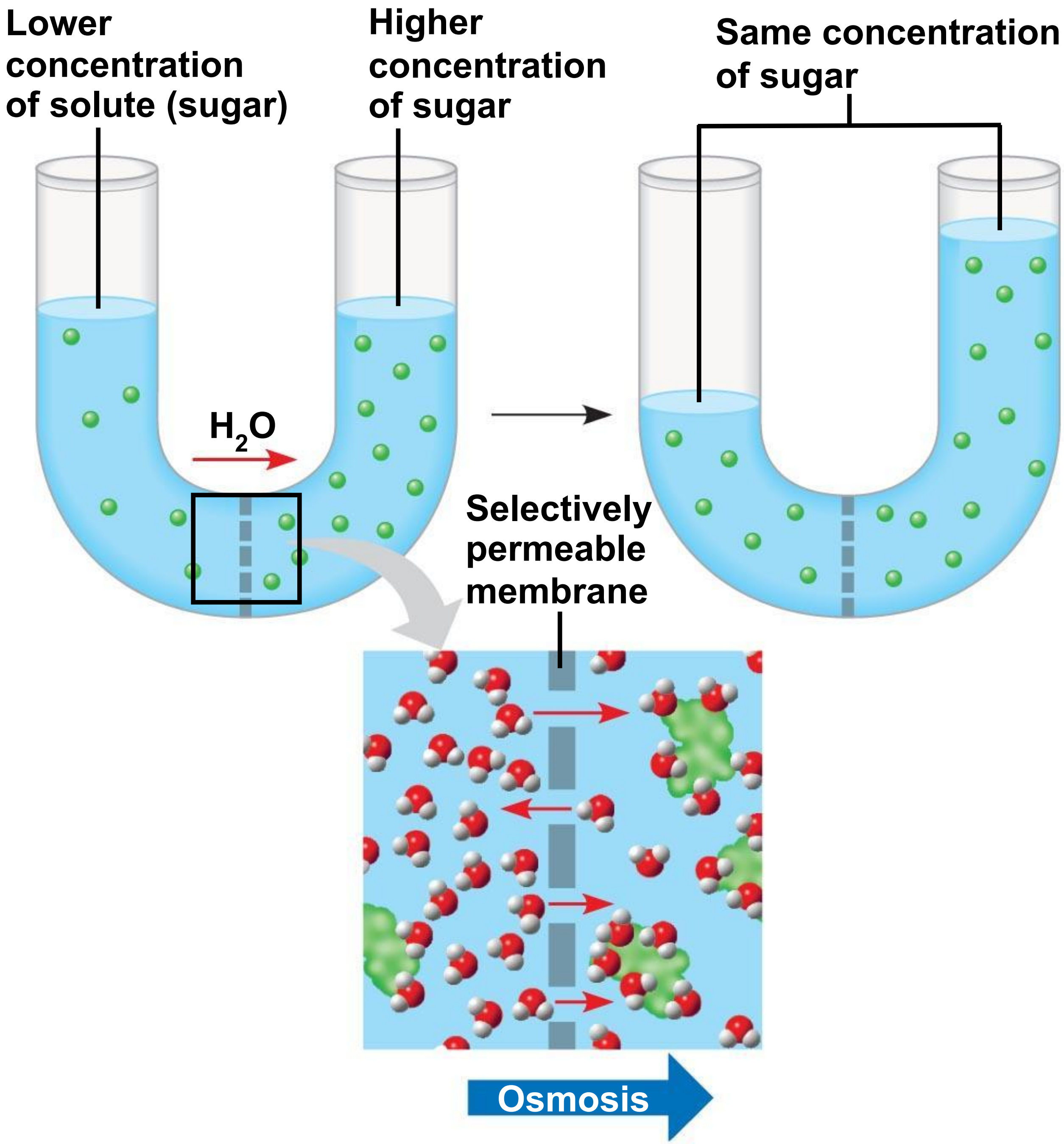


(b) Diffusion of two solutes

Effects of Osmosis on Water Balance

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

Fig. 7-12

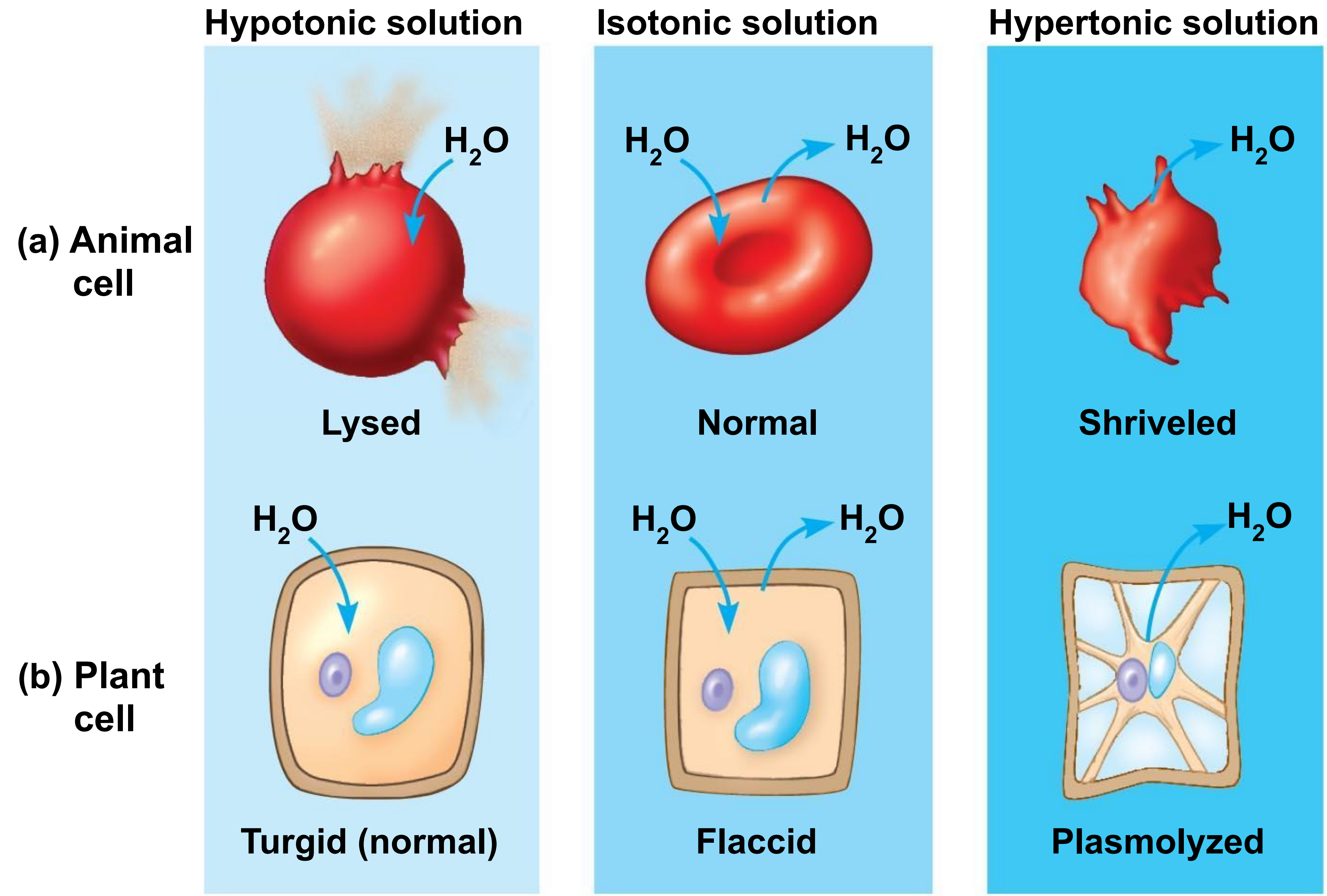


Lower concentration of solute (sugar)
Higher concentration of sugar
Same concentration of sugar
H2O
Selectively permeable membrane
Osmosis

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 the plasma 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

Fig. 7-13

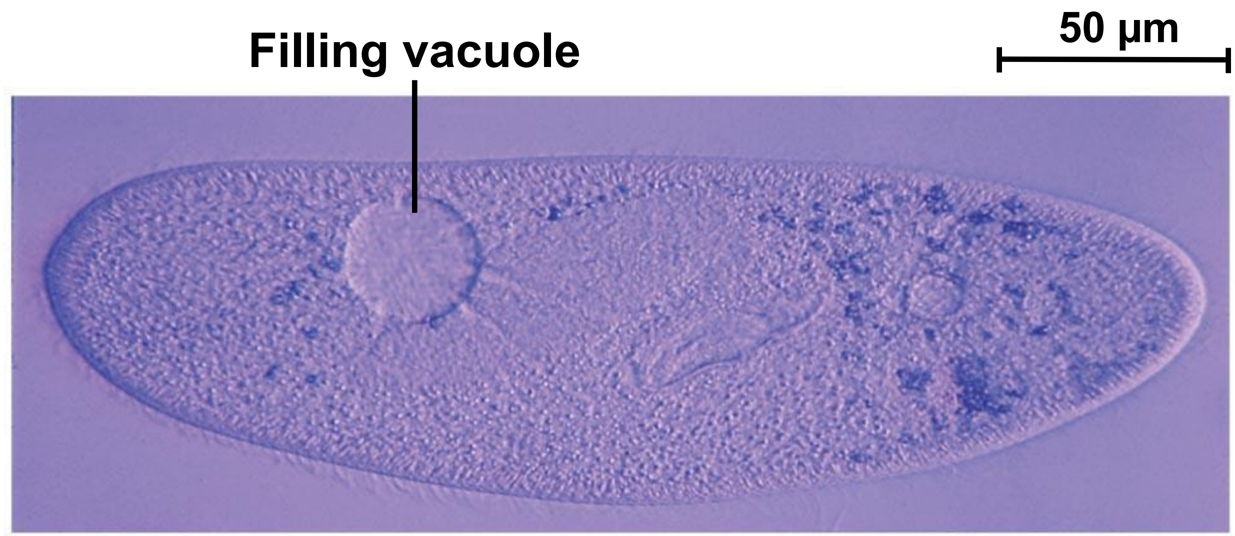

Hypotonic solution
Isotonic solution
Hypertonic solution
(a) Animal cell
H_2O
H_2O
H_2O
H_2O
Lysed
Normal
Shriveled
(b) Plant cell
H_2O
H_2O
H_2O
H_2O
Turgid (normal)
Flaccid
Plasmolyzed

- 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

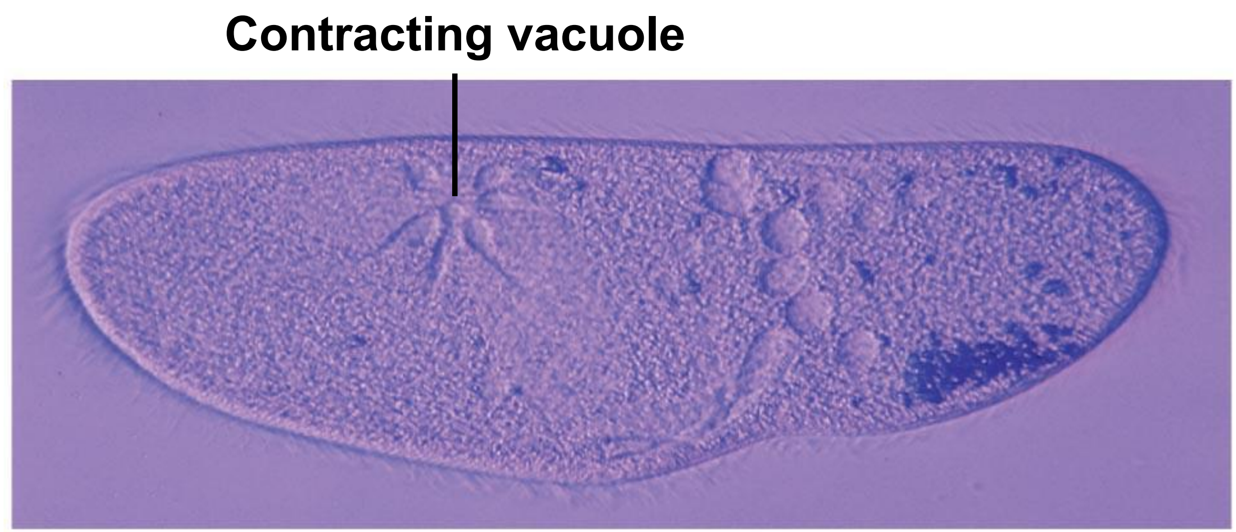
PLAY Video: *Chlamydomonas*

PLAY Video: *Paramecium* Vacuole

Fig. 7-14



(a) A contractile vacuole fills with fluid that enters from a system of canals radiating throughout the cytoplasm.



(b) When full, the vacuole and canals contract, expelling fluid from the cell.

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**

PLAY Video: Plasmolysis

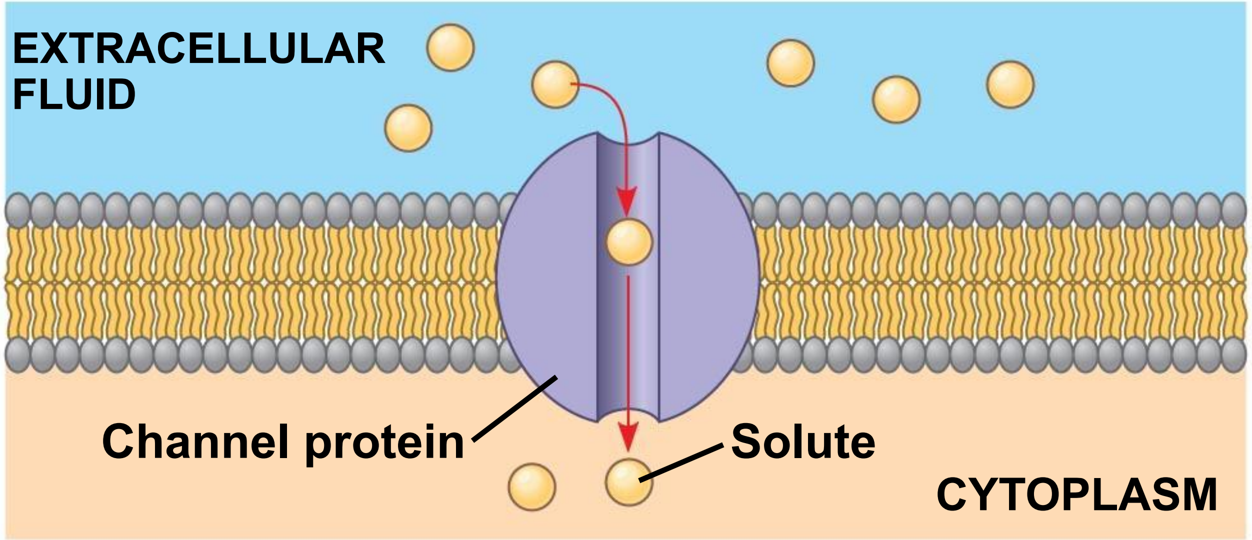
PLAY Video: Turgid *Elodea*

PLAY Animation: Osmosis

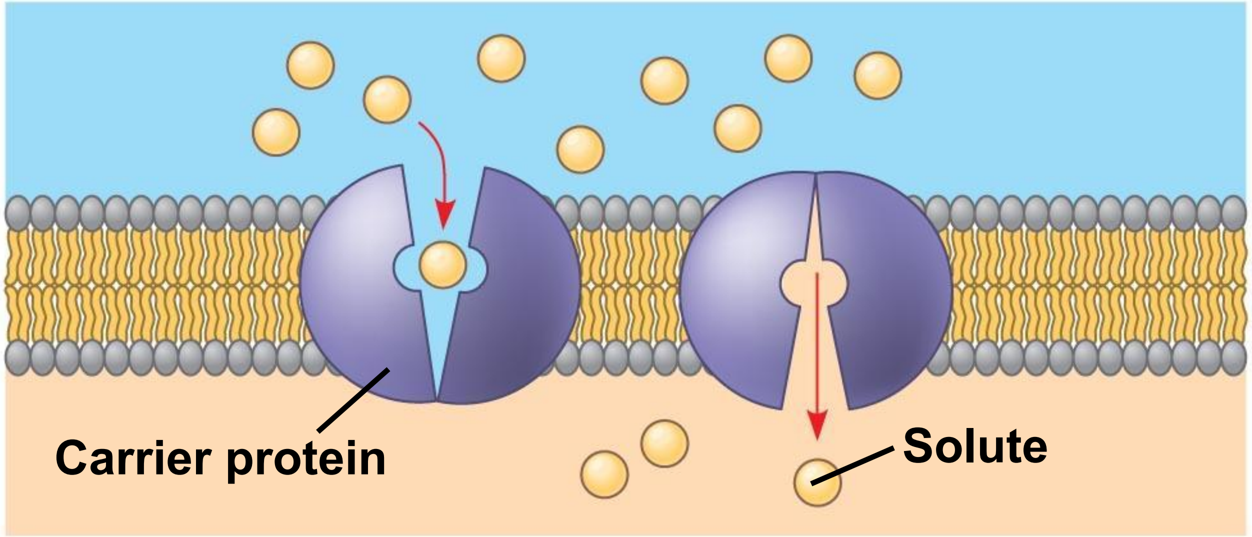
Facilitated Diffusion: Passive Transport Aided by Proteins

- 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**)

Fig. 7-15



(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

- Some diseases are caused by malfunctions in specific transport systems, for example the kidney disease cystinuria

Concept 7.4: Active transport uses energy to move solutes against their gradients

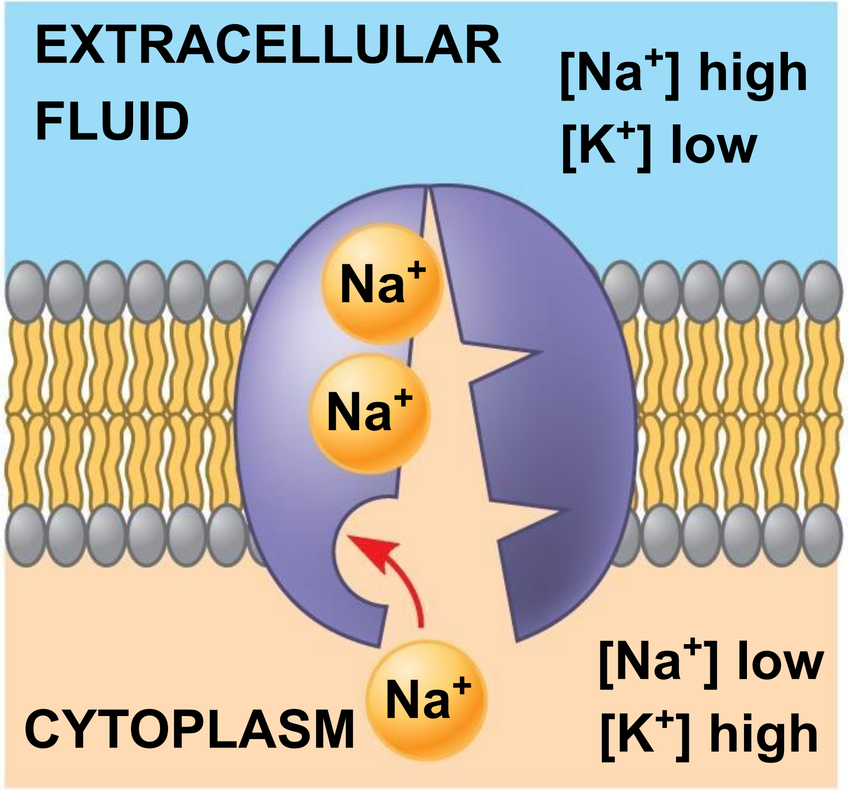
- Facilitated diffusion is still passive because the solute moves down its concentration gradient
- Some transport proteins, however, can move solutes against their concentration gradients

The Need for Energy in Active Transport

- **Active transport** moves substances against their concentration gradient
- Active transport requires energy, usually in the form of ATP
- Active transport is performed by specific proteins embedded in the membranes

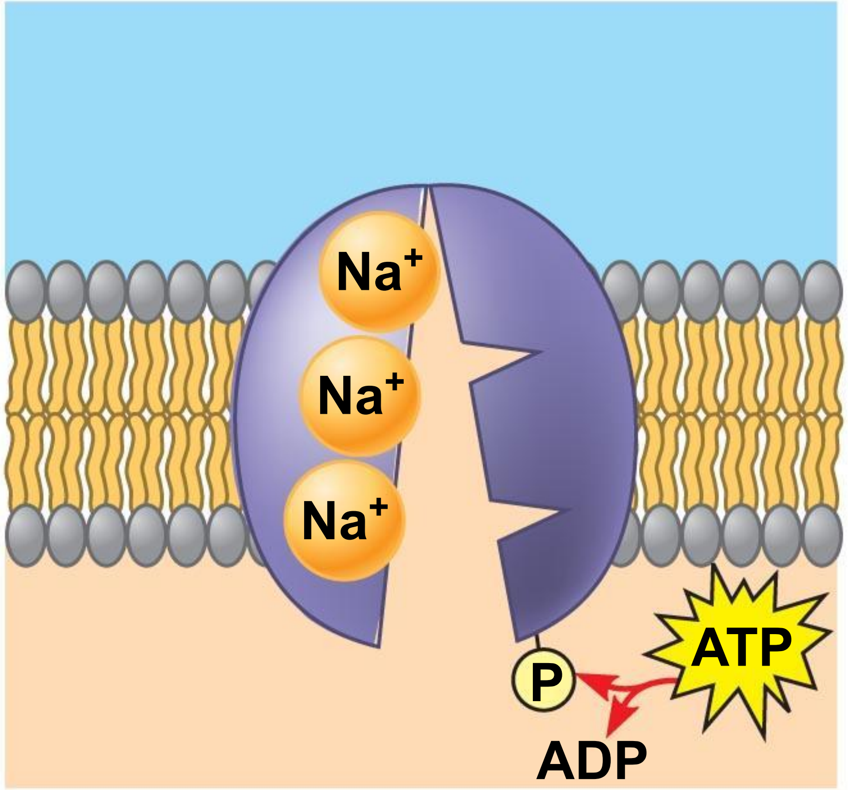
PLAY Animation: Active Transport

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



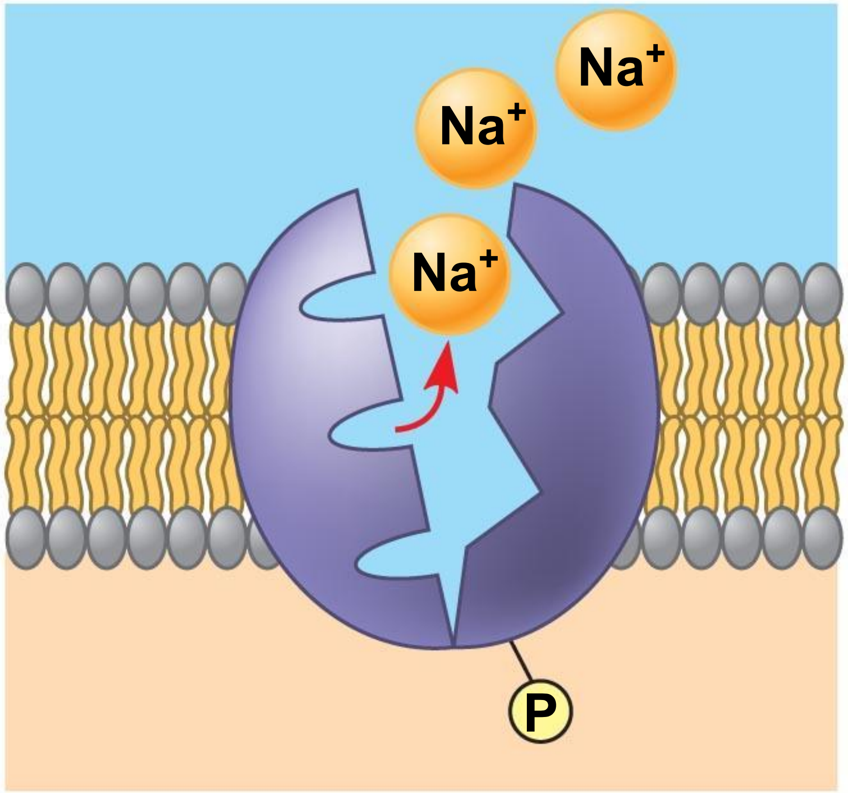
1 Cytoplasmic Na^+ binds to the sodium-potassium pump.

Fig. 7-16-2



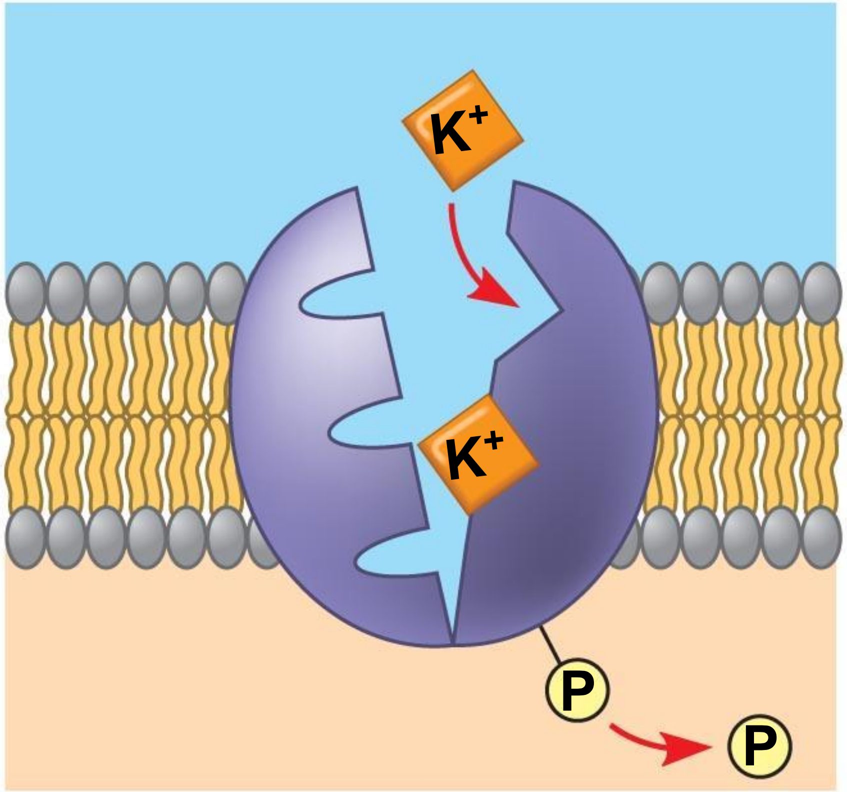
2 Na^+ binding stimulates phosphorylation by ATP.

Fig. 7-16-3



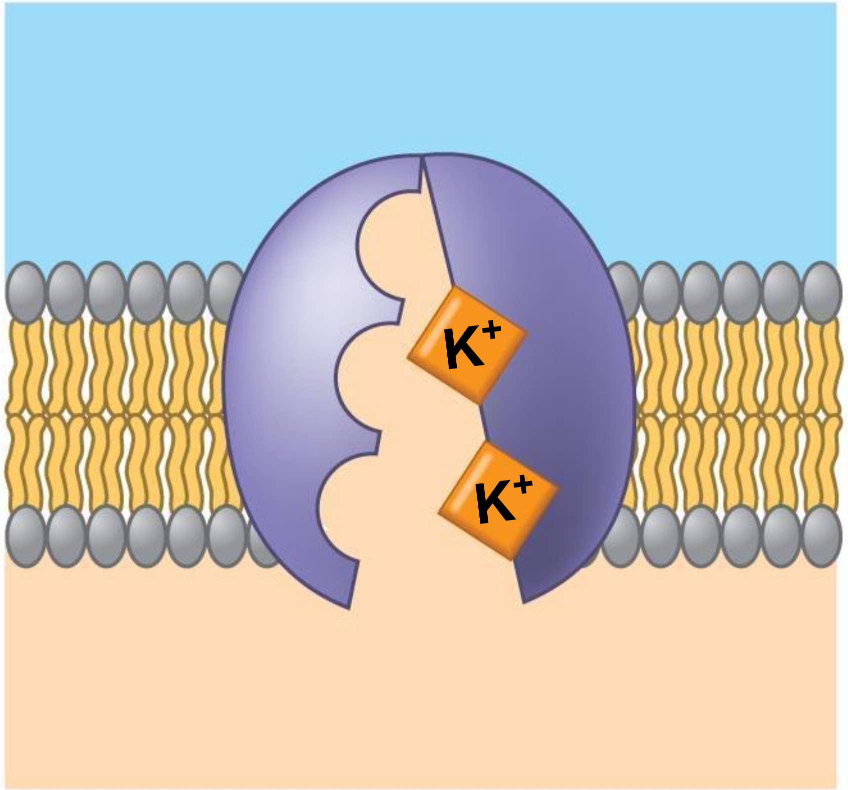
3 **Phosphorylation causes the protein to change its shape. Na^+ is expelled to the outside.**

Fig. 7-16-4



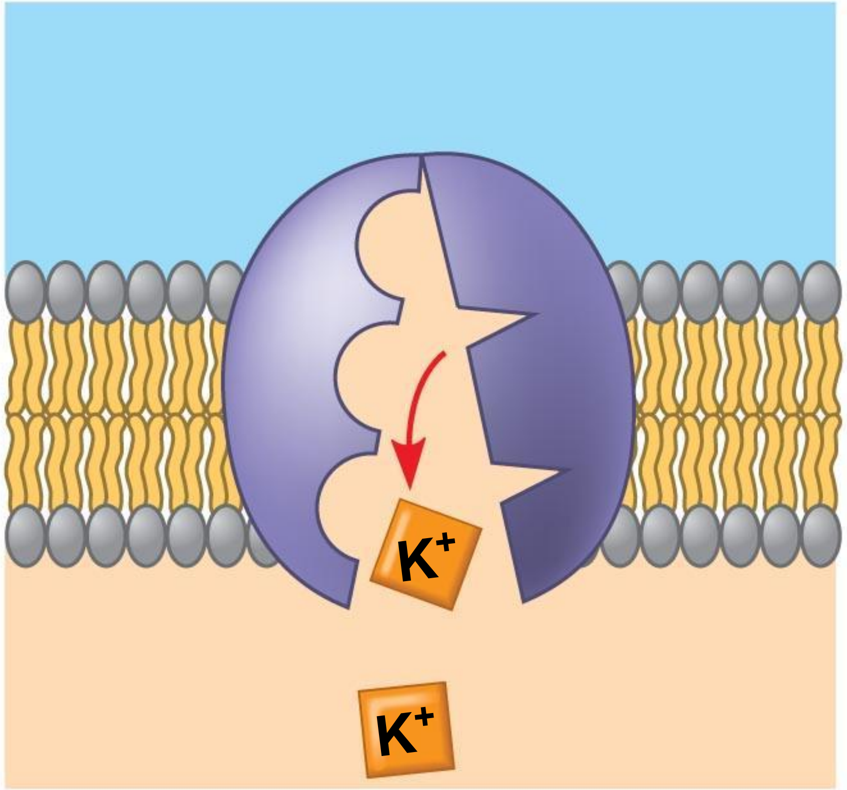
4 K^+ binds on the extracellular side and triggers release of the phosphate group.

Fig. 7-16-5



5 **Loss of the phosphate restores the protein’s original shape.**

Fig. 7-16-6



6 K^+ is released, and the cycle repeats.

Fig. 7-16-7

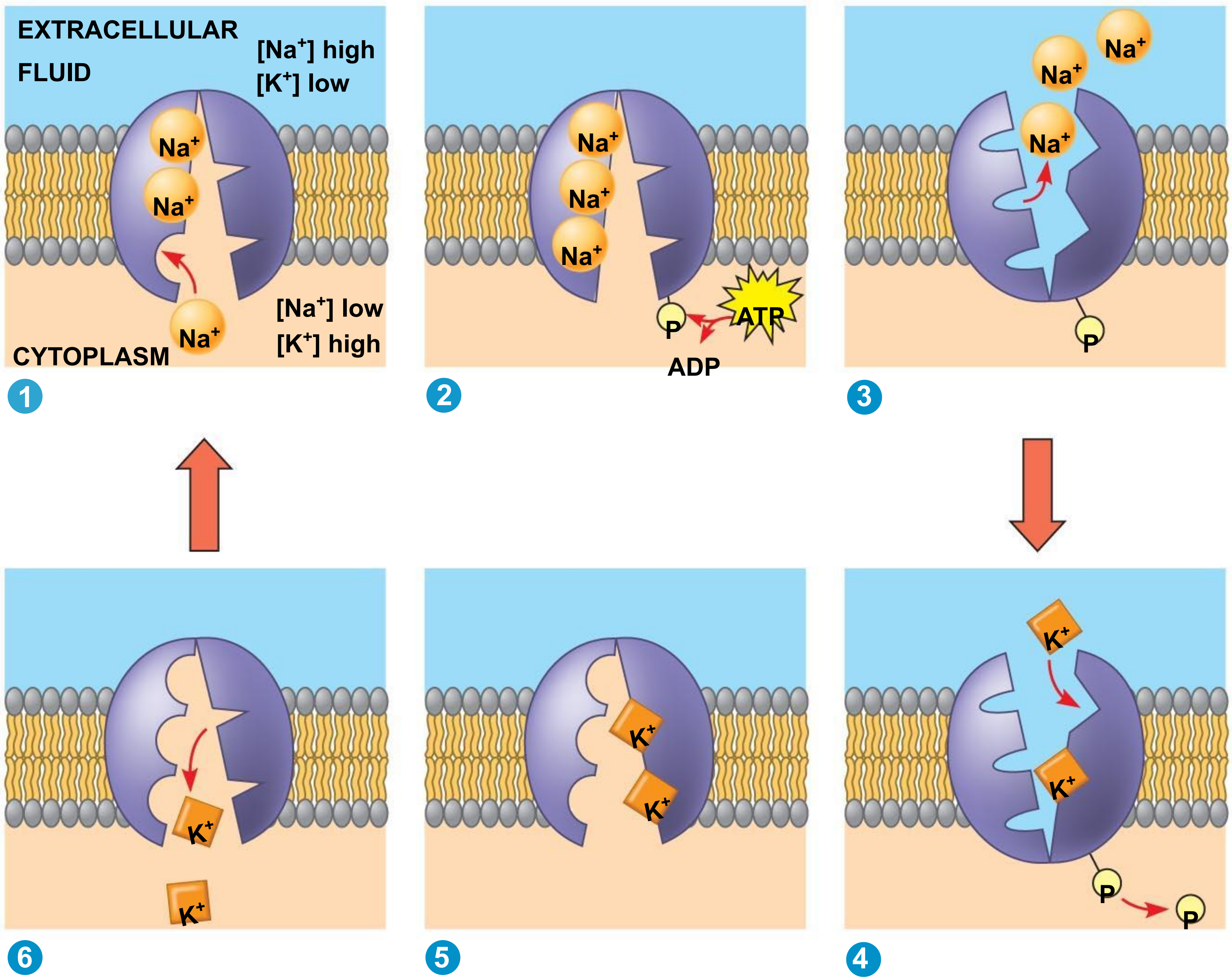
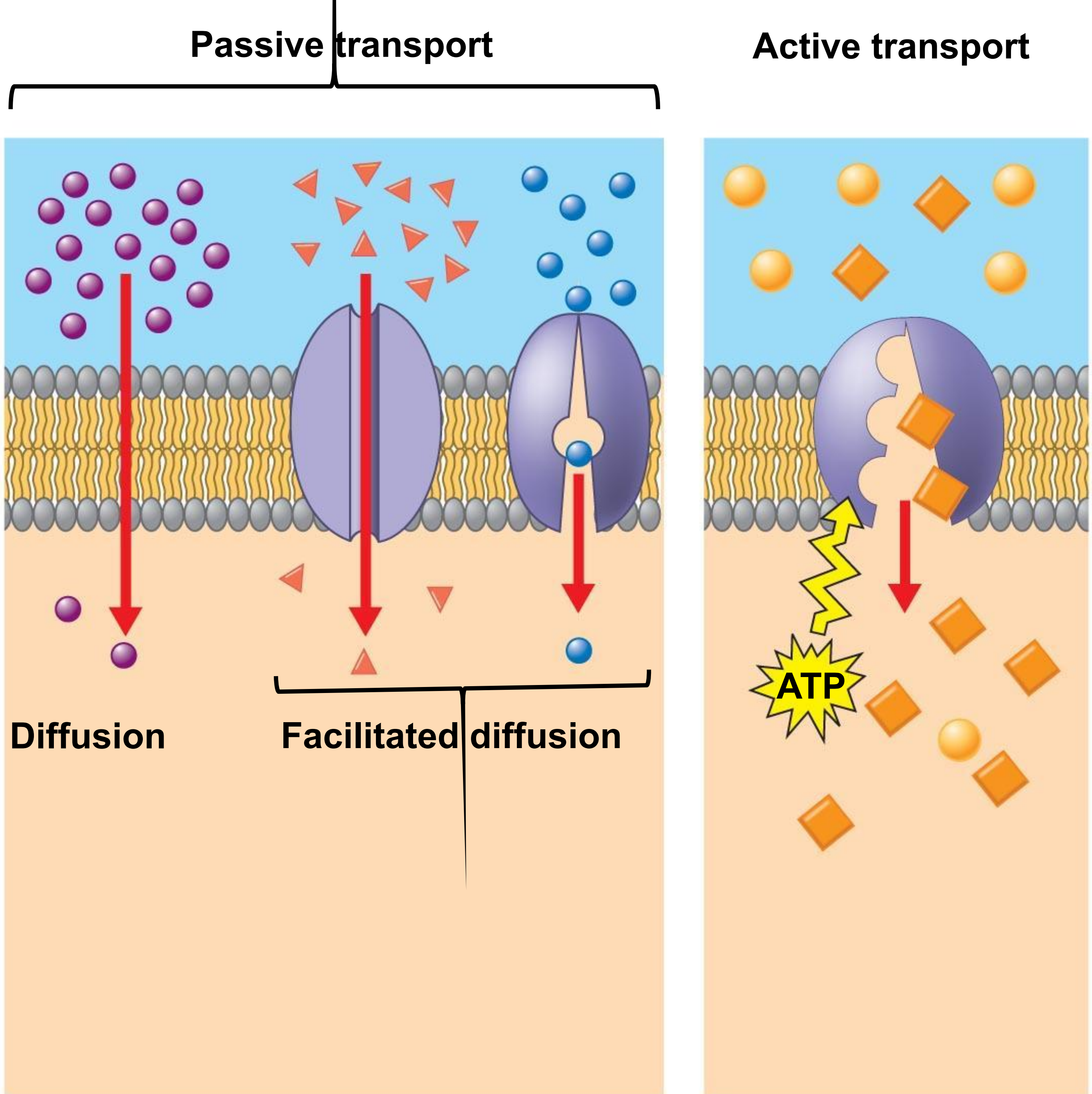

EXTRACELLULAR
FLUID
[Na+] high
[K+] low
Na+
Na+
Na+
[Na+] low
[K+] high
CYTOPLASM
1
Na+
Na+
Na+
P
ATP
ADP
2
Na+
Na+
Na+
P
3
K+
K+
P
P
4
K+
K+
5
K+
K+
6

Fig. 7-17



Passive transport
Active transport
ATP
Diffusion
Facilitated diffusion

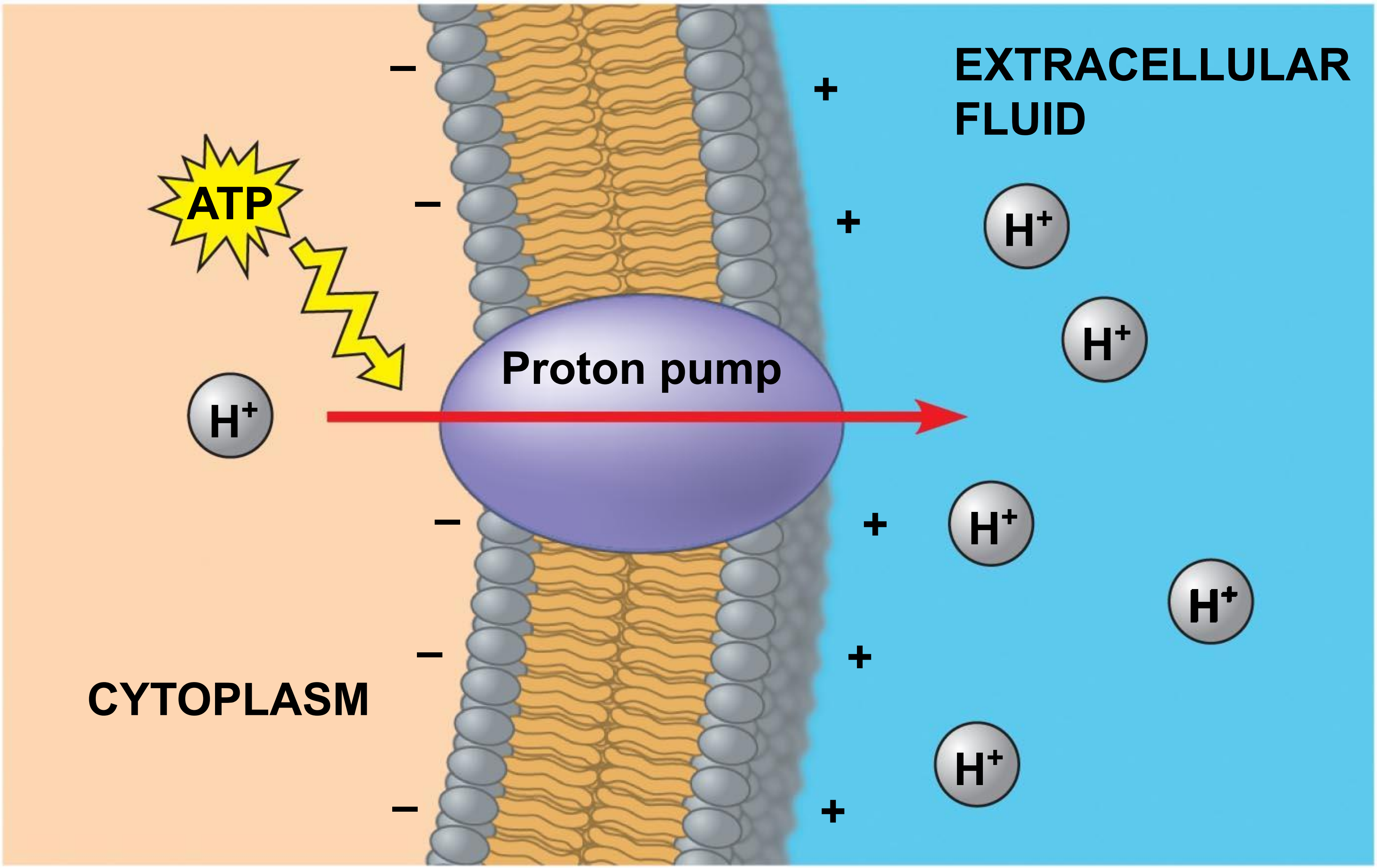
How Ion Pumps Maintain Membrane Potential

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

- 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**

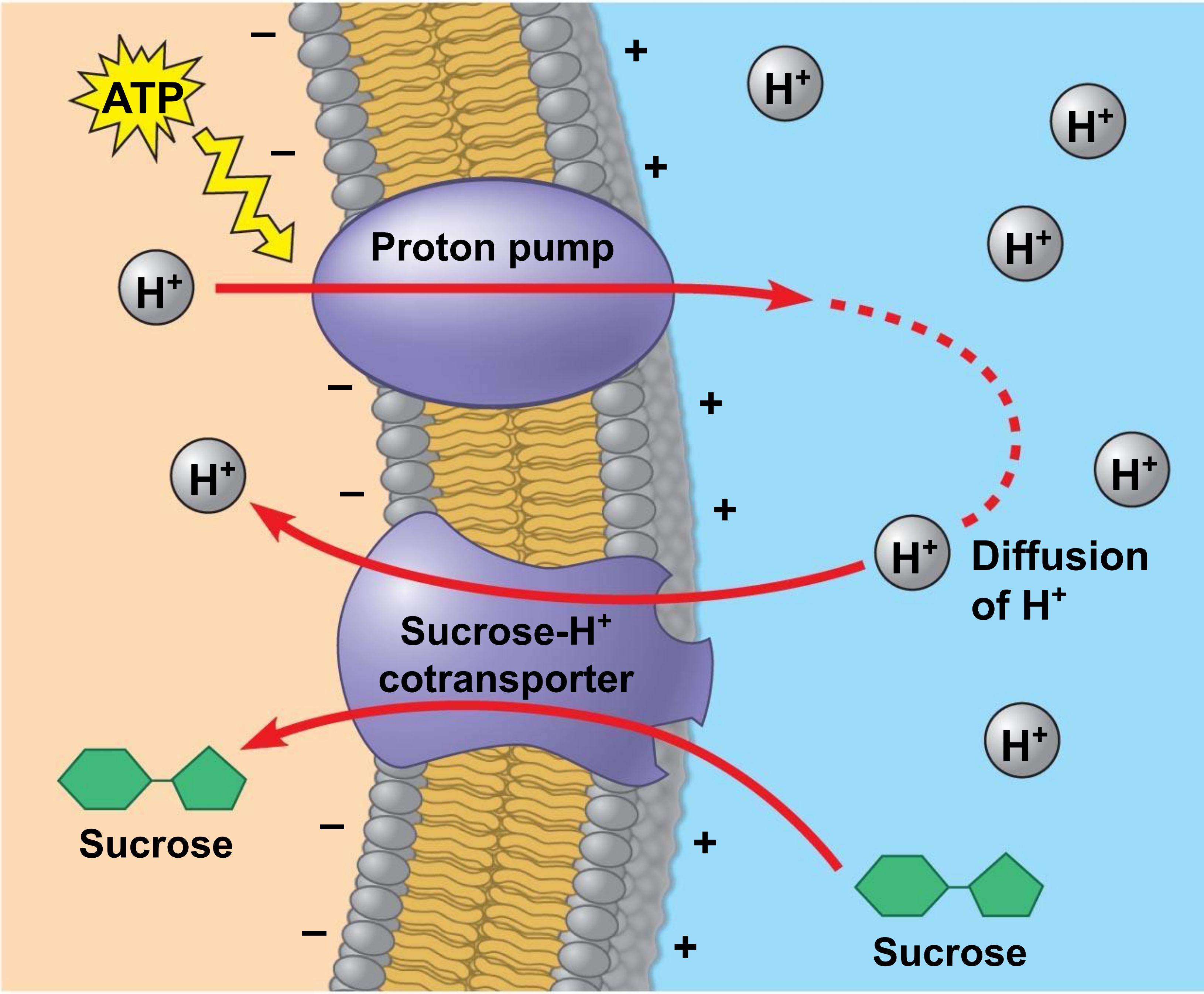
Fig. 7-18



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

Fig. 7-19


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

Concept 7.5: 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

PLAY Animation: Exocytosis

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

PLAY Animation: Exocytosis and Endocytosis Introduction

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

PLAY **Animation: Phagocytosis**

Fig. 7-20

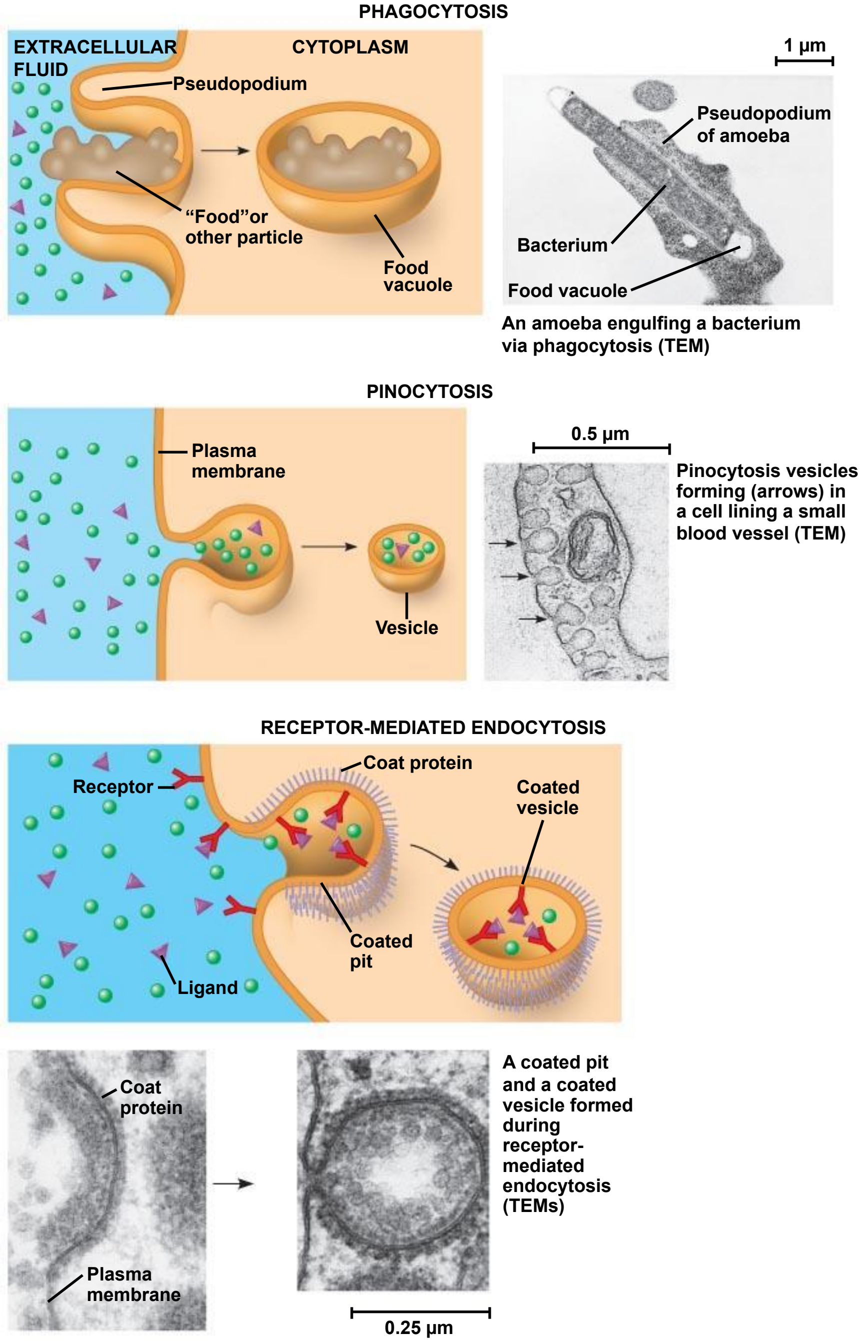
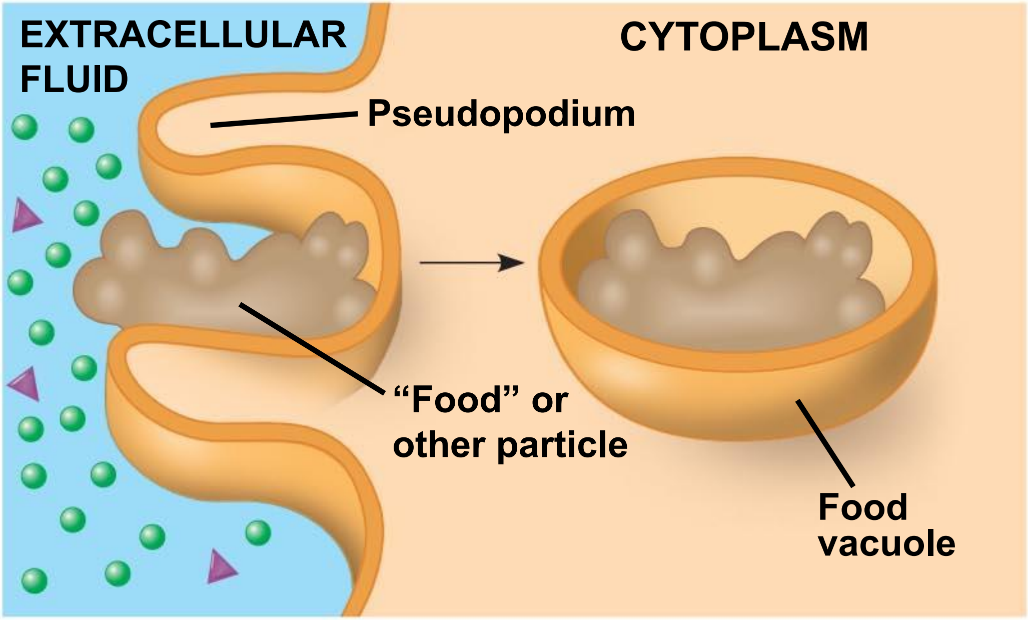
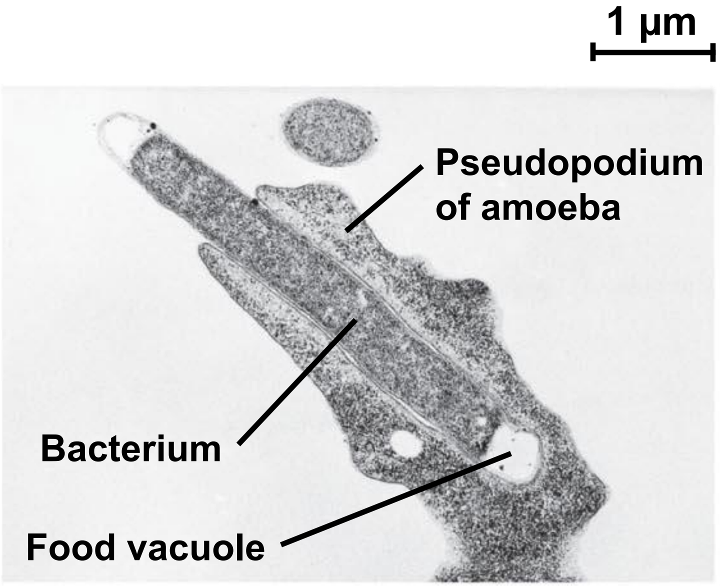

PHAGOCYTOSIS
EXTRACELLULAR FLUID
CYTOPLASM
Pseudopodium
"Food"or other particle
Food vacuole
1 µm
Pseudopodium of amoeba
Bacterium
Food vacuole
An amoeba engulfing a bacterium via phagocytosis (TEM)
PINOCYTOSIS
Plasma membrane
Vesicle
0.5 µm
Pinocytosis vesicles forming (arrows) in a cell lining a small blood vessel (TEM)
RECEPTOR-MEDIATED ENDOCYTOSIS
Receptor
Coat protein
Coated vesicle
Coated pit
Ligand
Coat protein
Plasma membrane
0.25 µm
A coated pit and a coated vesicle formed during receptor-mediated endocytosis (TEMs)

Fig. 7-20a

PHAGOCYTOSIS





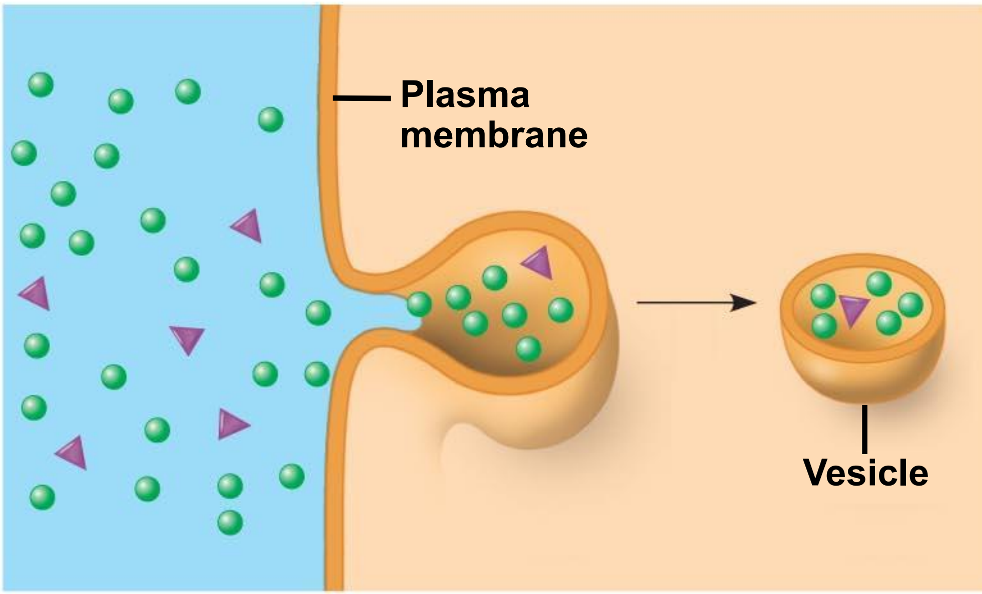
An amoeba engulfing a bacterium via phagocytosis (TEM)

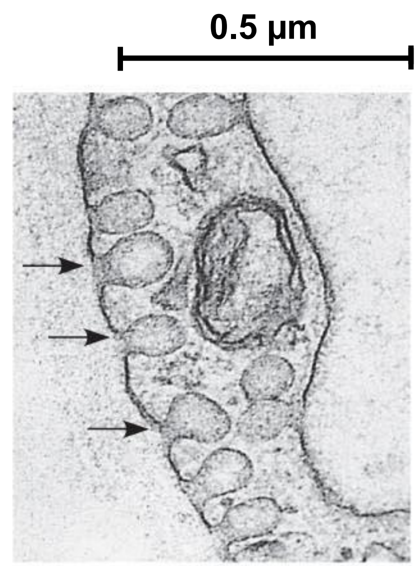
- In **pinocytosis**, molecules are taken up when extracellular fluid is “gulped” into tiny vesicles

PLAY Animation: Pinocytosis

Fig. 7-20b

PINOCYTOSIS



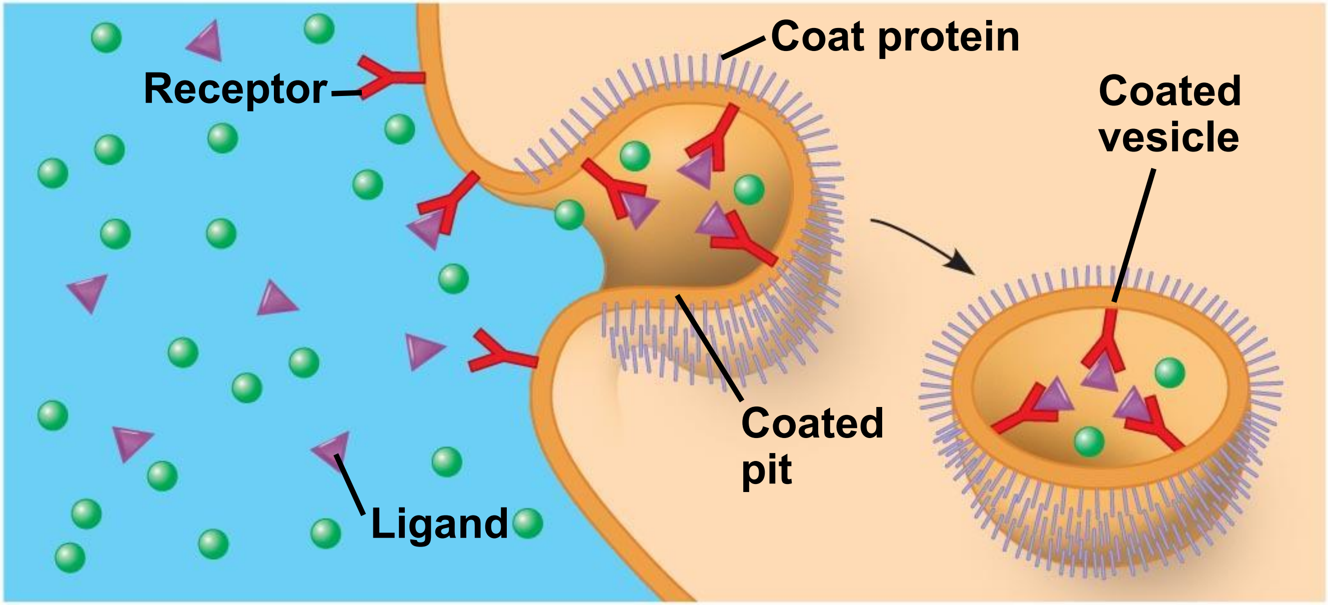


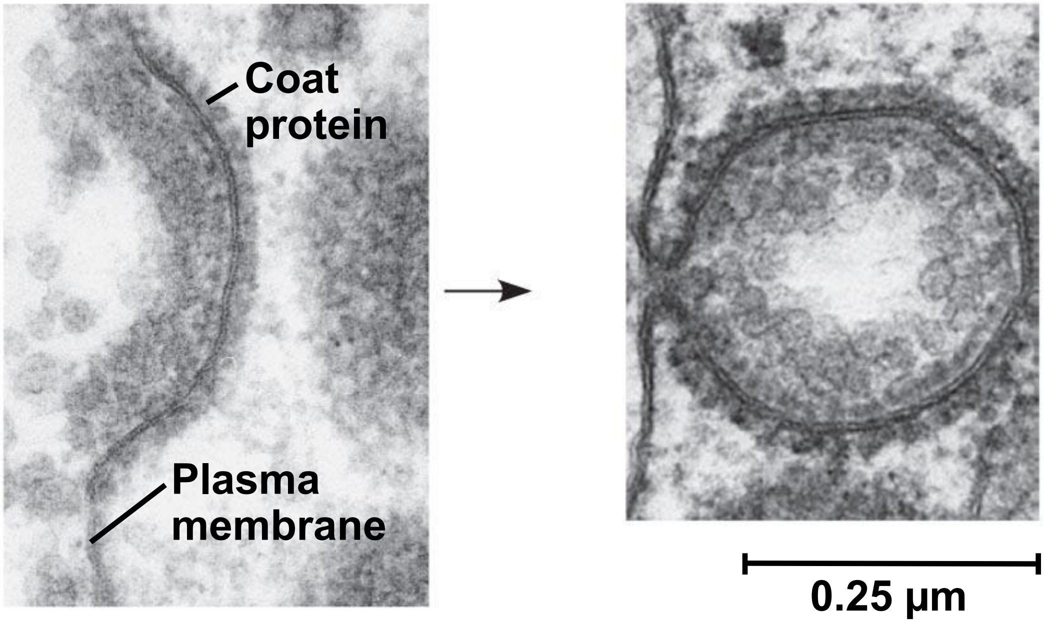
Pinocytosis vesicles forming (arrows) in a cell lining a small blood vessel (TEM)

- 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

PLAY **Animation: Receptor-Mediated Endocytosis**

RECEPTOR-MEDIATED ENDOCYTOSIS





A coated pit and a coated vesicle formed during receptor-mediated endocytosis (TEMs)

Fig. 7-UN1

Passive transport: Facilitated diffusion

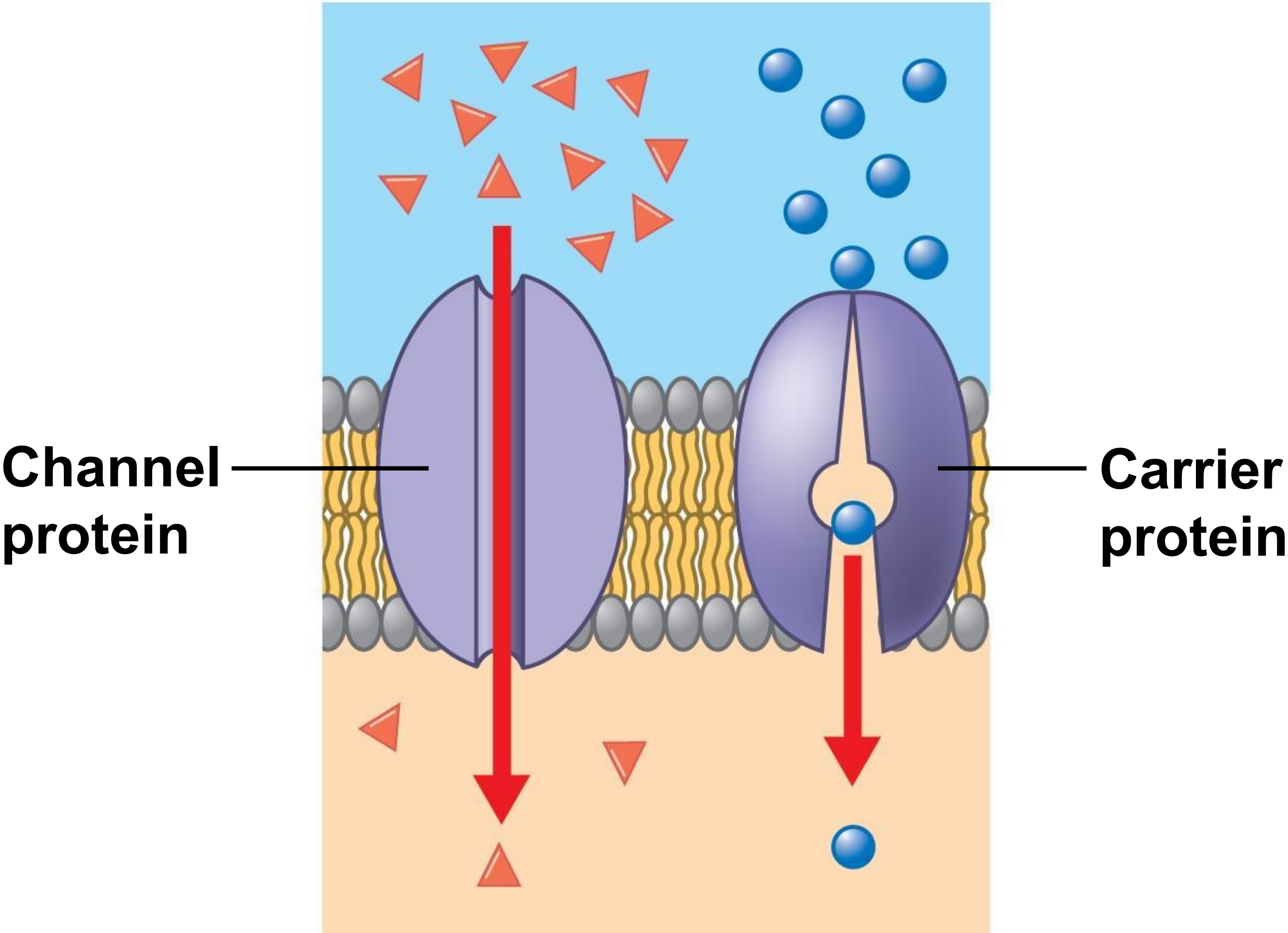


Fig. 7-UN2

Active transport:

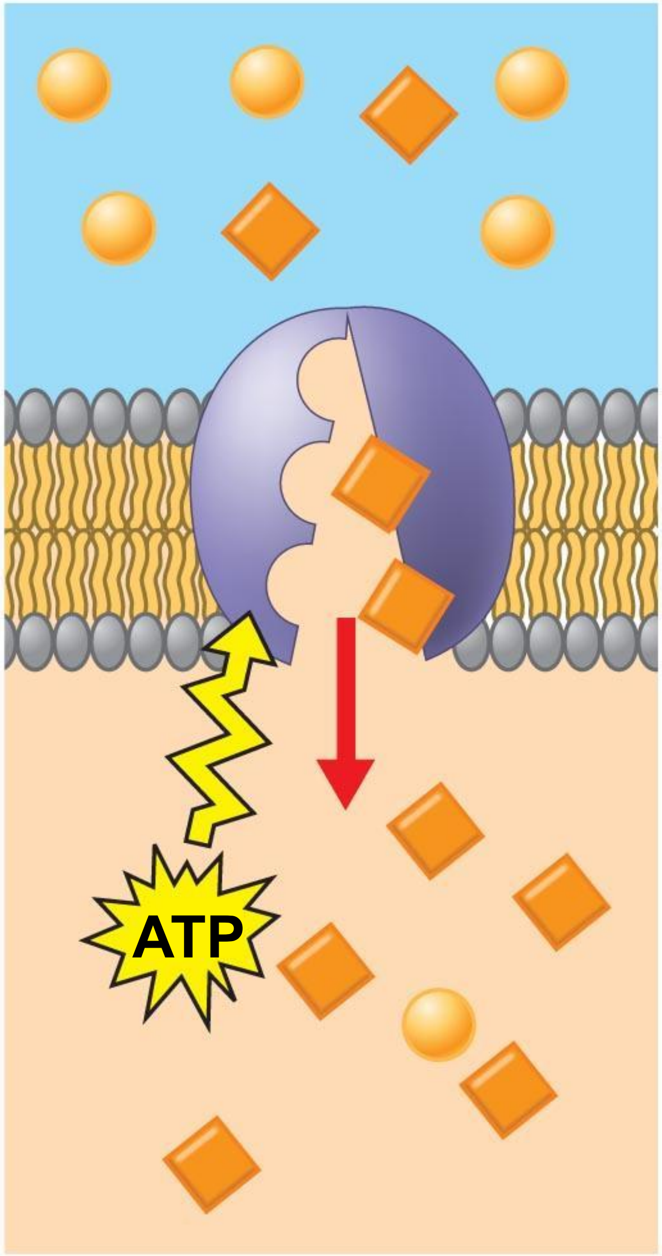
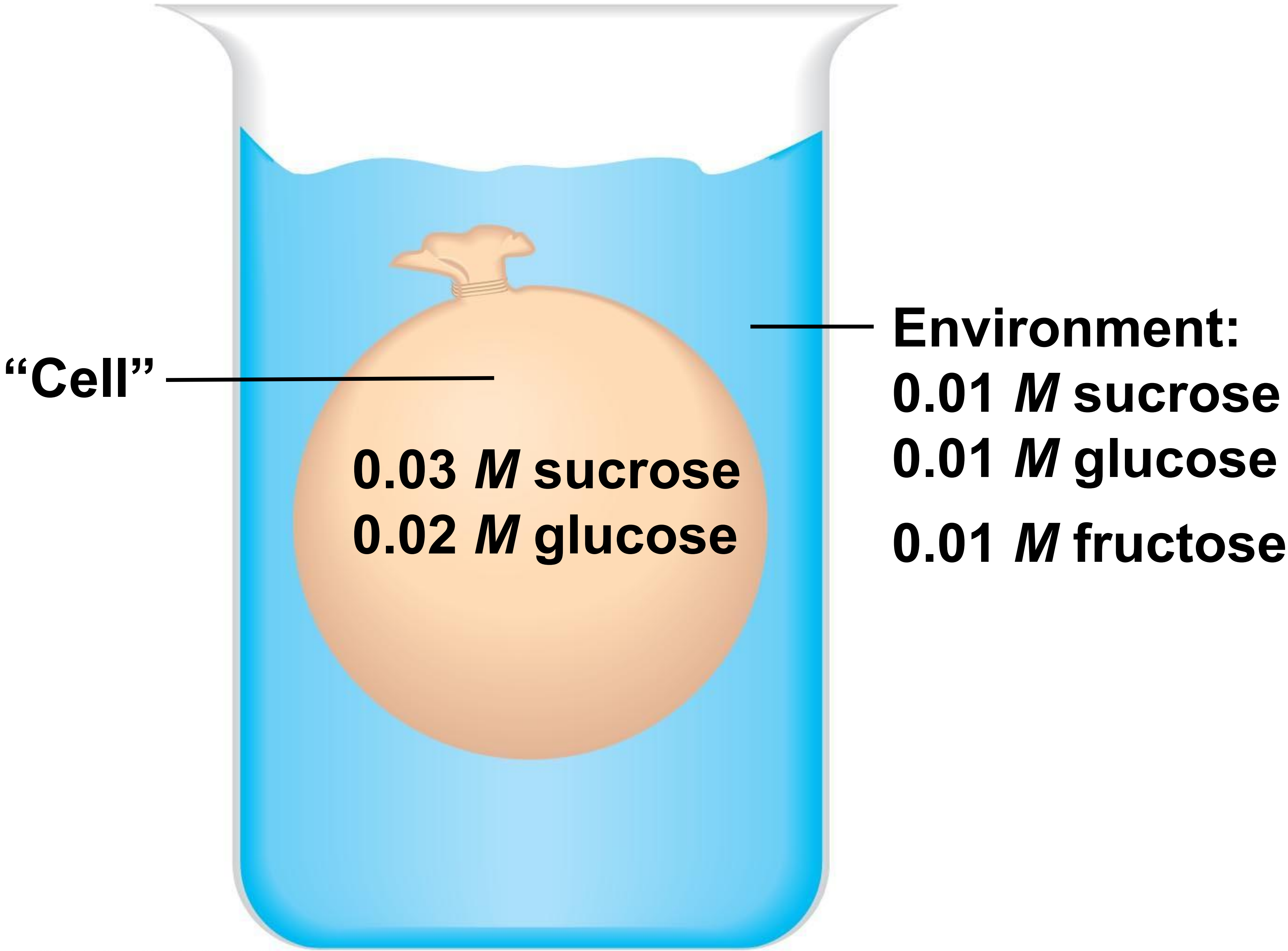
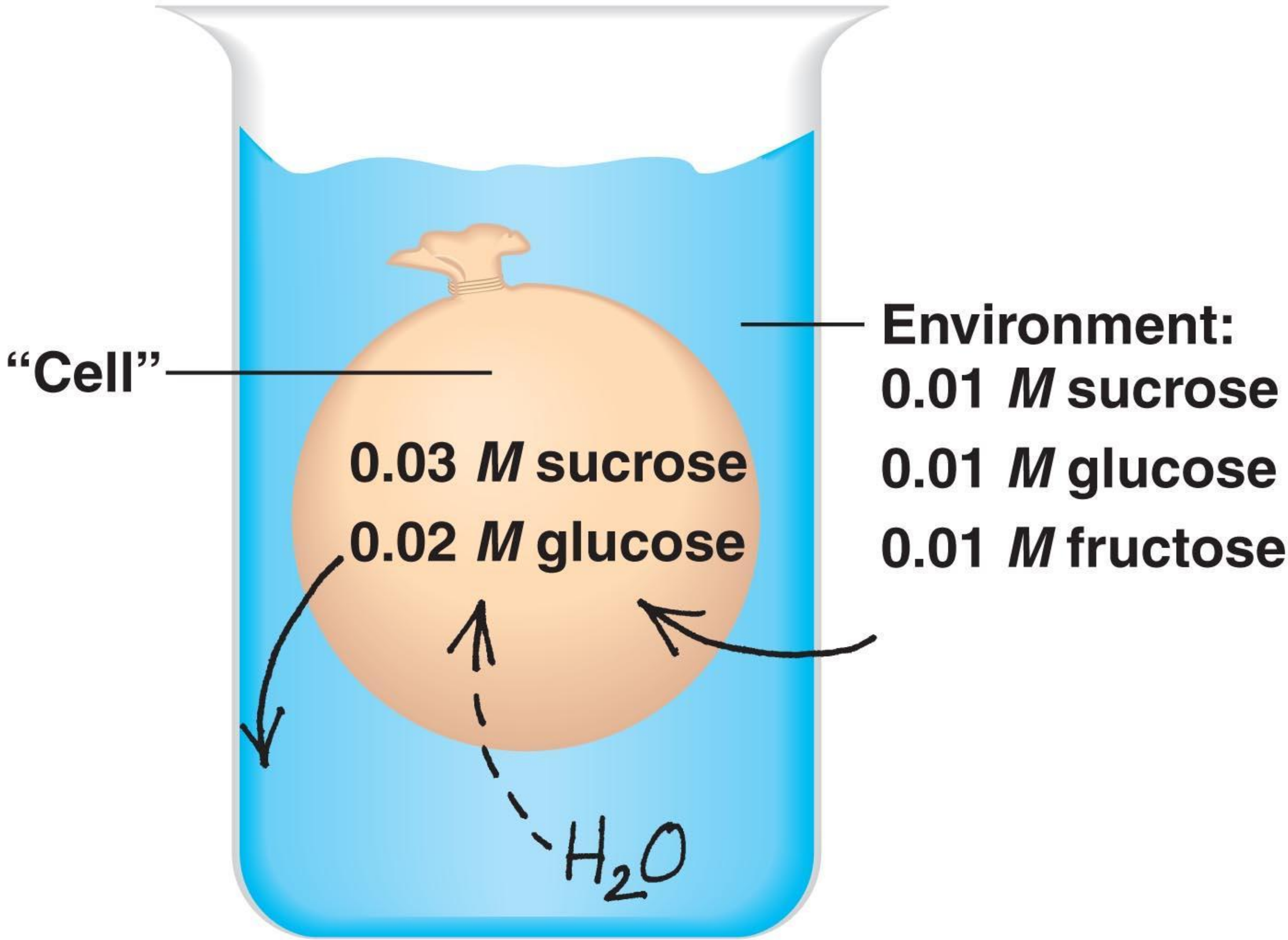


Fig. 7-UN3



"Cell"
0.03 *M* sucrose
0.02 *M* glucose
Environment:
0.01 *M* sucrose
0.01 *M* glucose
0.01 *M* fructose

Fig. 7-UN4


"Cell"
0.03 *M* sucrose
0.02 *M* glucose
Environment:
0.01 *M* sucrose
0.01 *M* glucose
0.01 *M* fructose
H_2O

You should now be able to:

1. Define the following terms: amphipathic molecules, aquaporins, diffusion
2. Explain how membrane fluidity is influenced by temperature and membrane composition
3. Distinguish between the following pairs or sets of terms: peripheral and integral membrane proteins; channel and carrier proteins; osmosis, facilitated diffusion, and active transport; hypertonic, hypotonic, and isotonic solutions

4. Explain how transport proteins facilitate diffusion
5. Explain how an electrogenic pump creates voltage across a membrane, and name two electrogenic pumps
6. Explain how large molecules are transported across a cell membrane