Chapter 7

Membrane Structure and Function

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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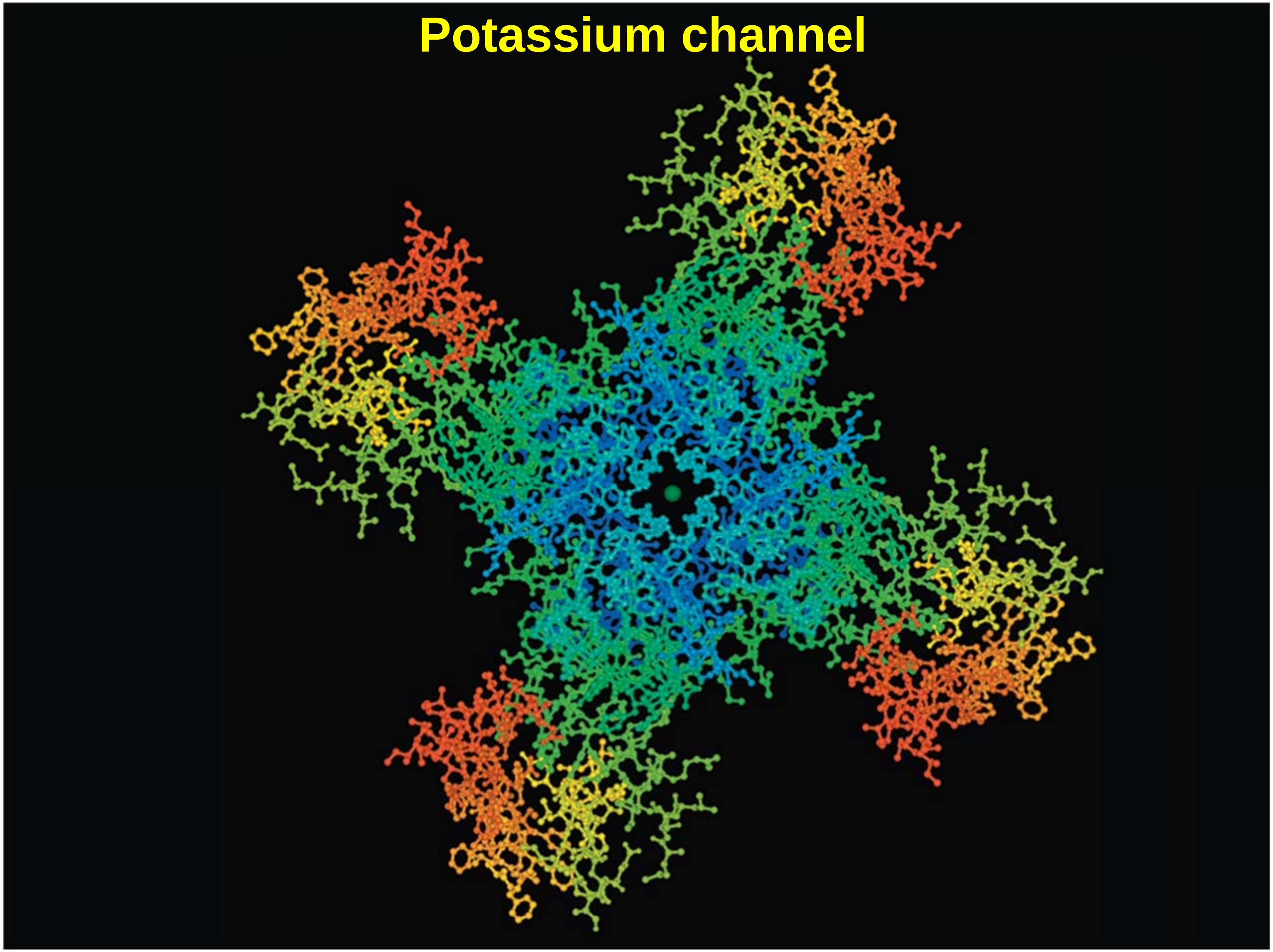
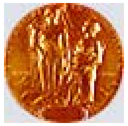
Overview: Life at the Edge

- 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

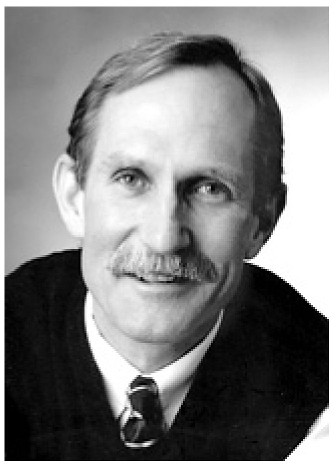
Fig. 7-1





The Nobel Prize in Chemistry 2003

"for discoveries concerning channels in cell membranes"



Peter Agre

"for the discovery of water channels"

Roderick MacKinnon

"for structural and mechanistic studies of ion channels"

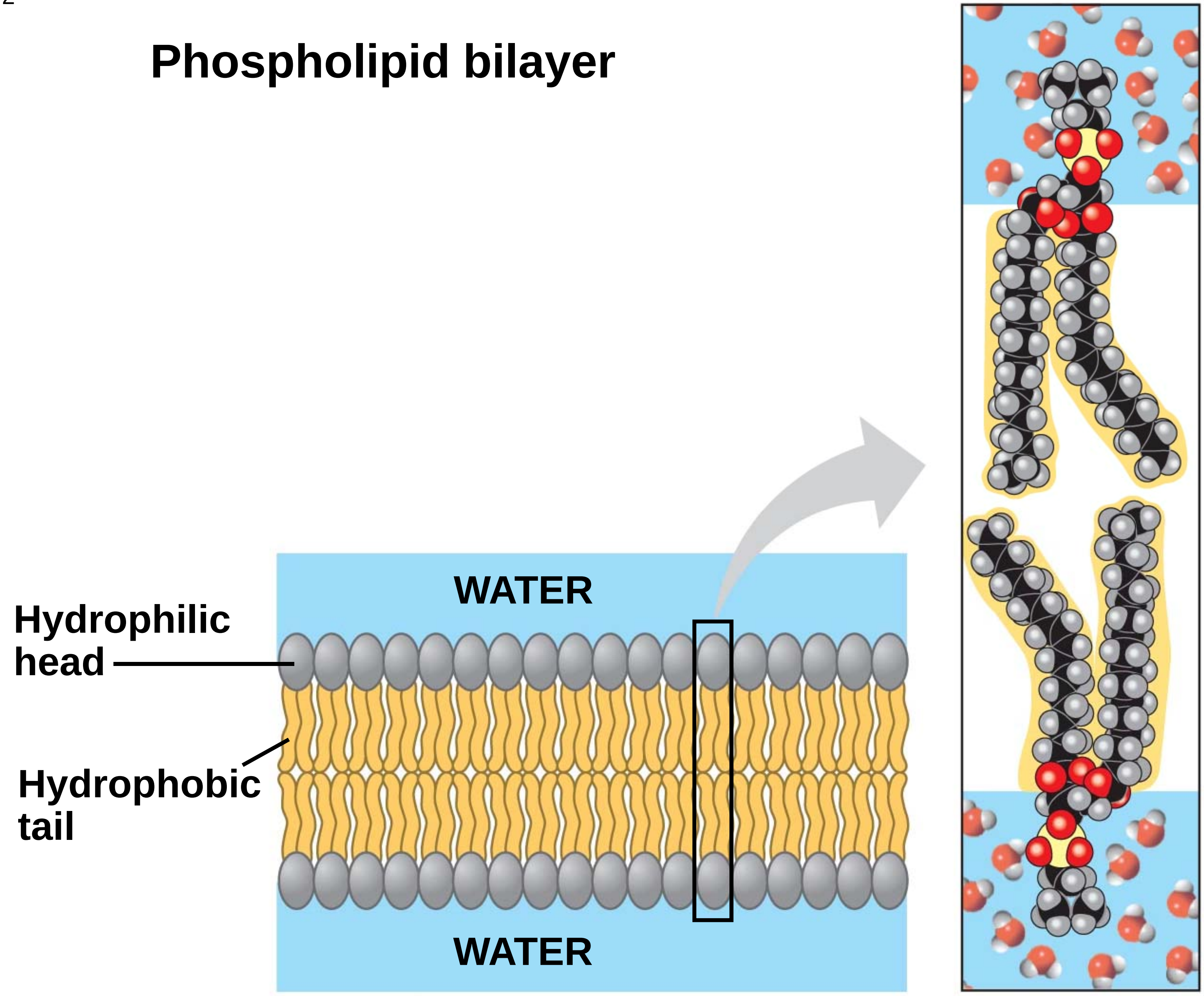
Concept 7.1: Cellular membranes are fluid mosaics of lipids and proteins

- 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

Phospholipid bilayer



- 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

The fluid mosaic model for membranes

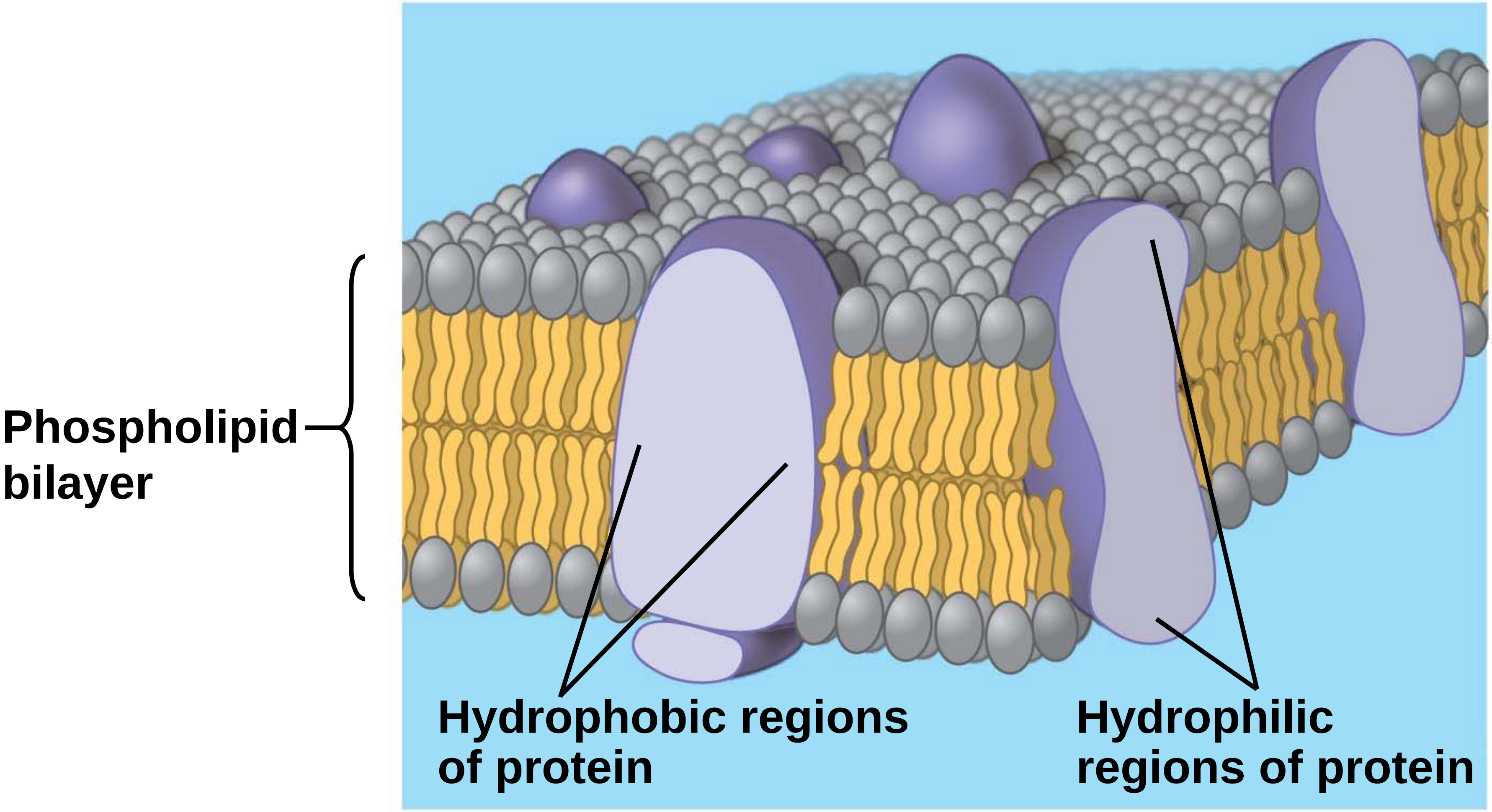
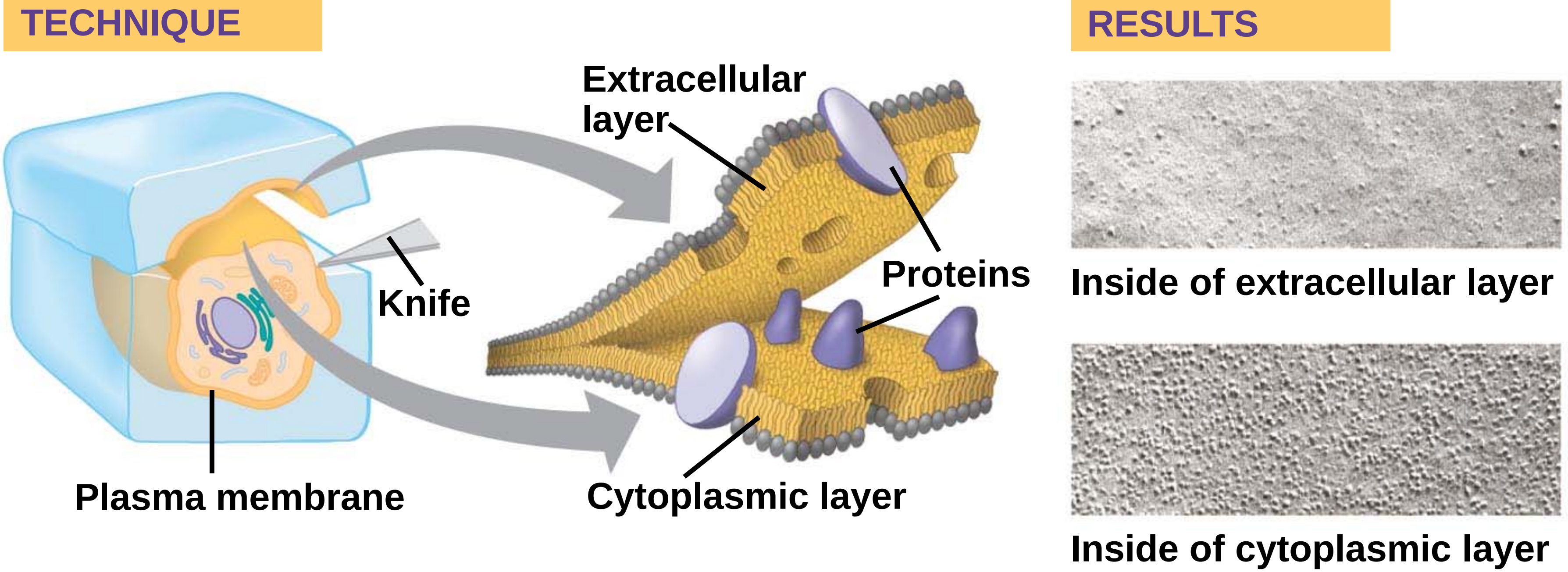


Fig. 7-4

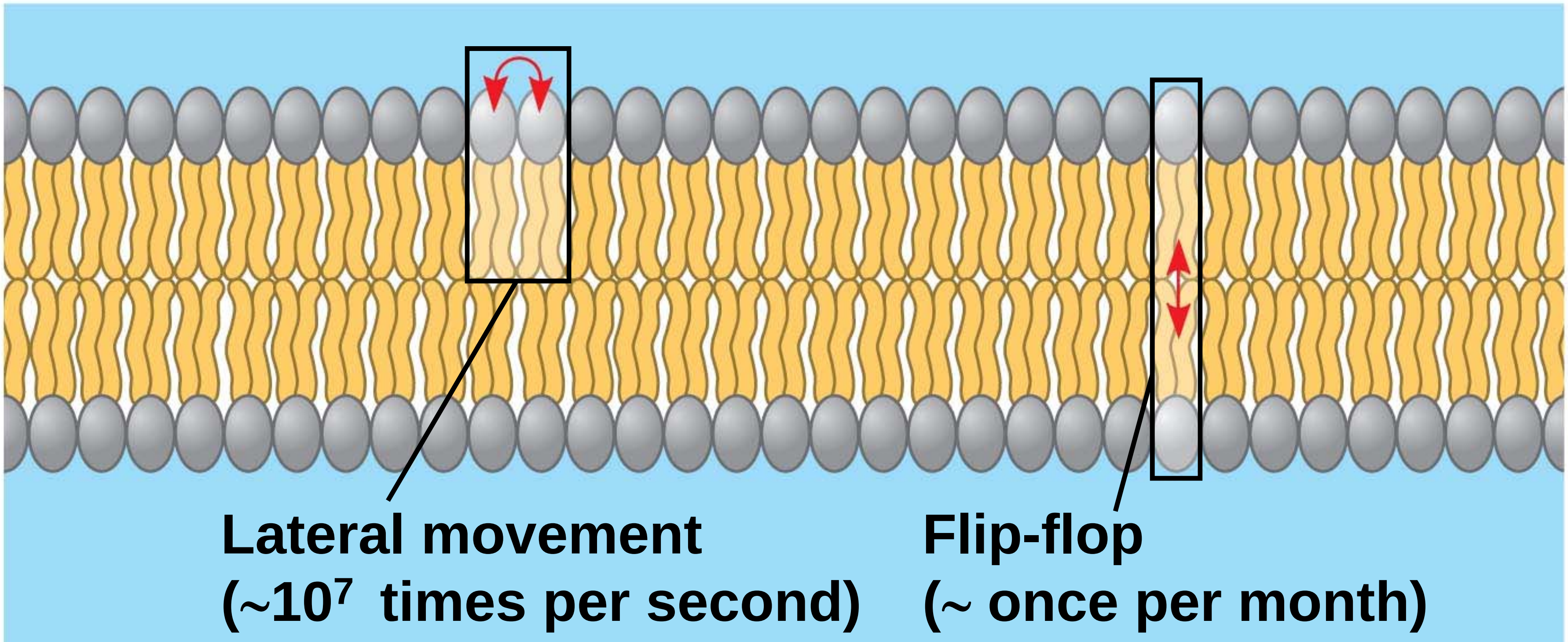
- Freeze-fracture studies of the plasma membrane supported the fluid mosaic model
- Freeze-fracture is a specialized preparation technique that splits a membrane along the middle of the phospholipid bilayer



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. 7-5a

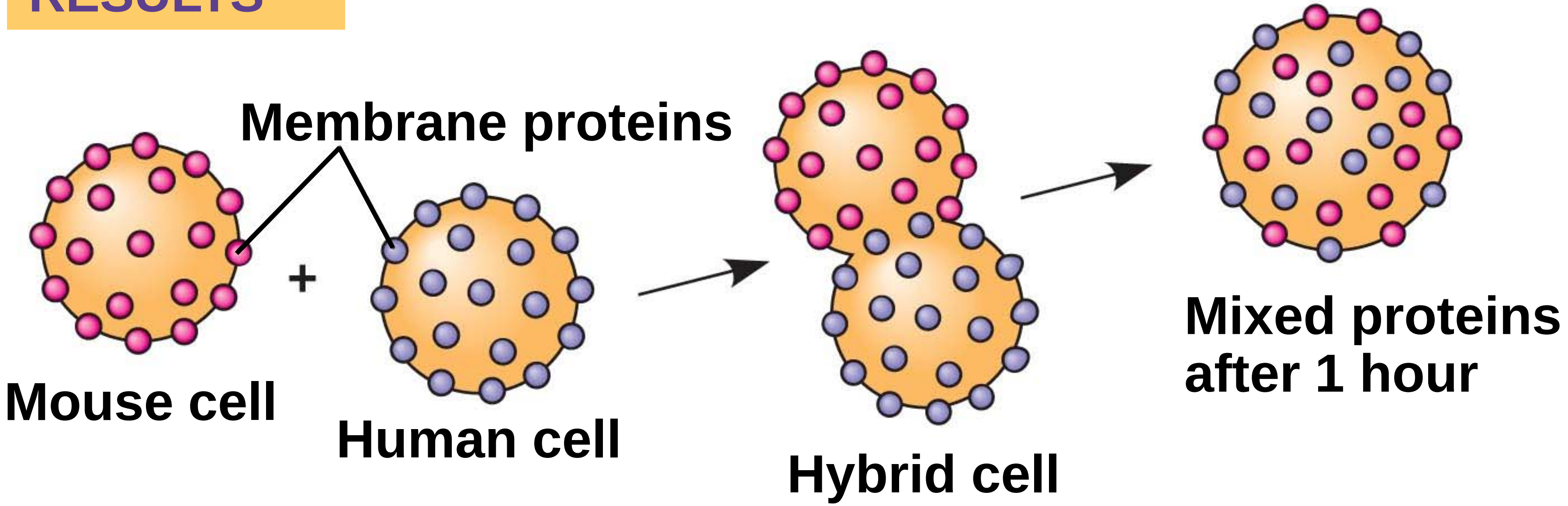


(a) Movement of phospholipids

Fig. 7-6

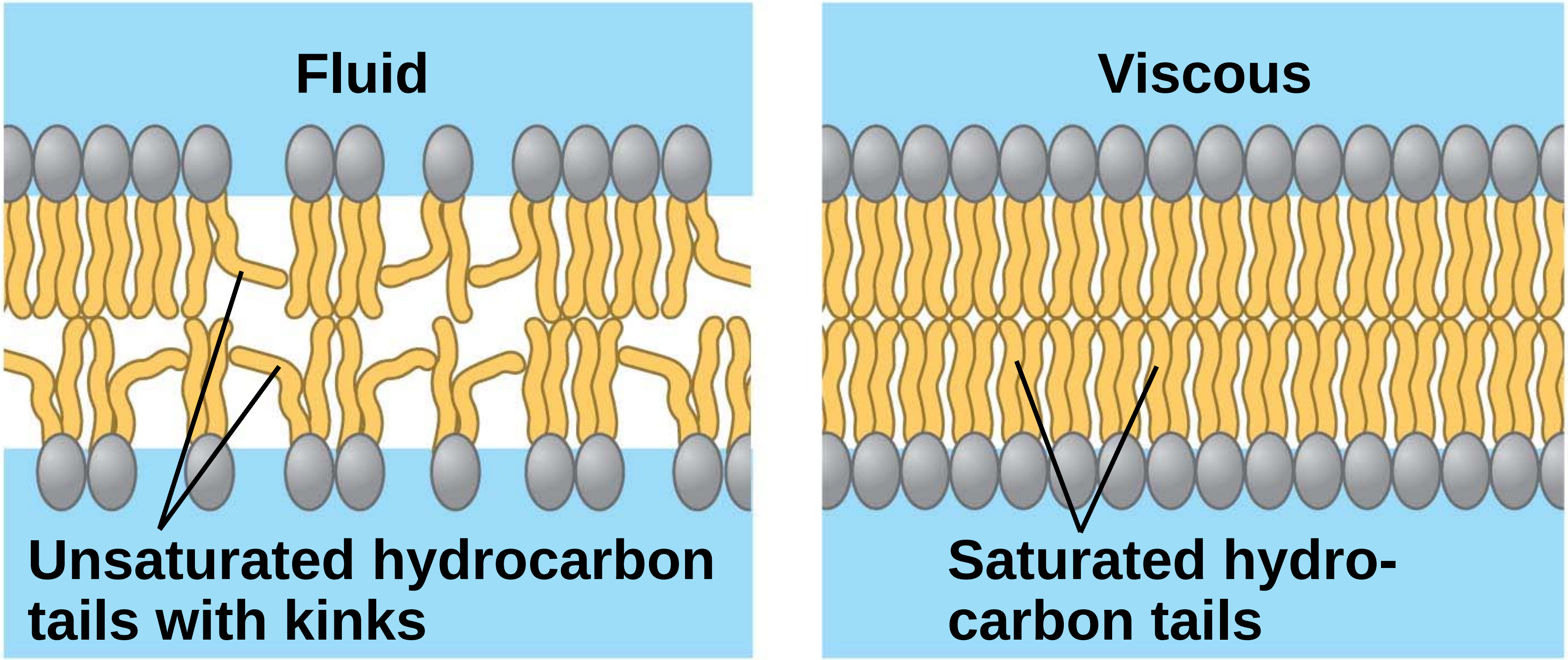
Do membrane proteins move?

RESULTS



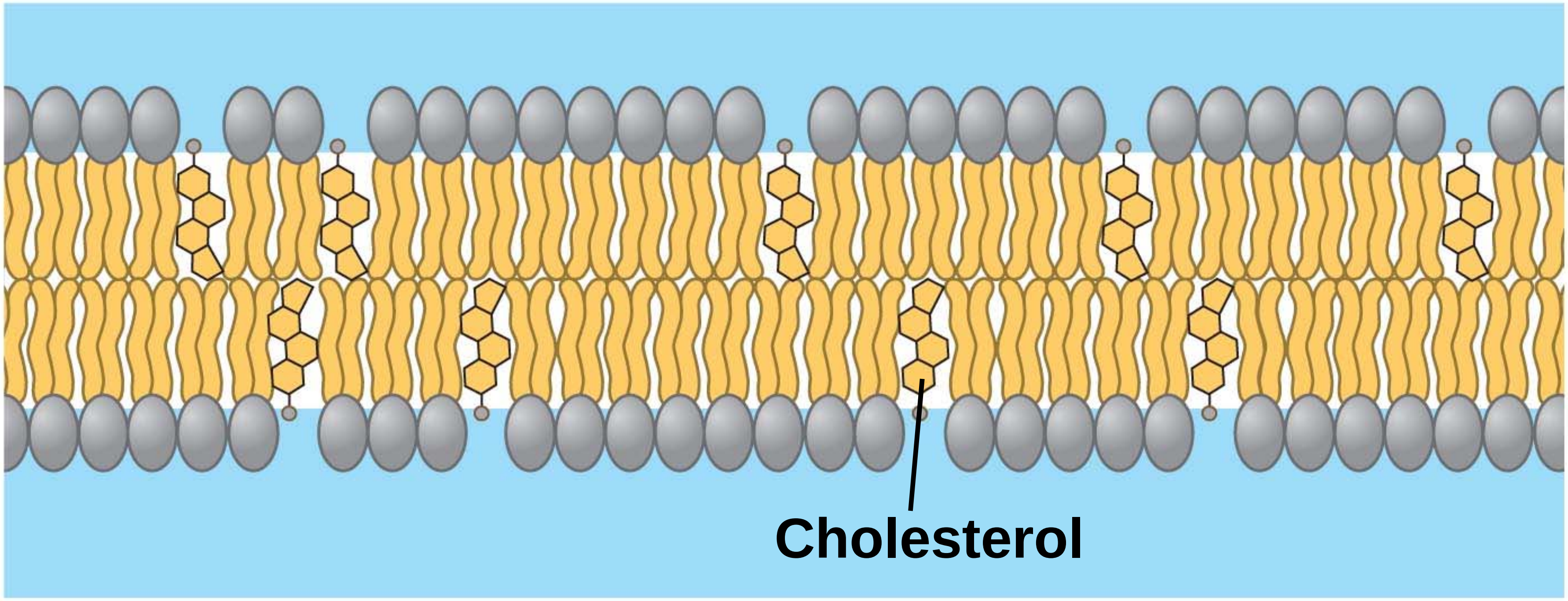
- As temperatures cool, membranes switch from a fluid state to a solid state
- The temperature at which a membrane solidifies depends on the types of lipids
- Membranes rich in unsaturated fatty acids are more fluid that those rich in saturated fatty acids
- Membranes must be fluid to work properly;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

Fig. 7-5b



(b) Membrane fluidity

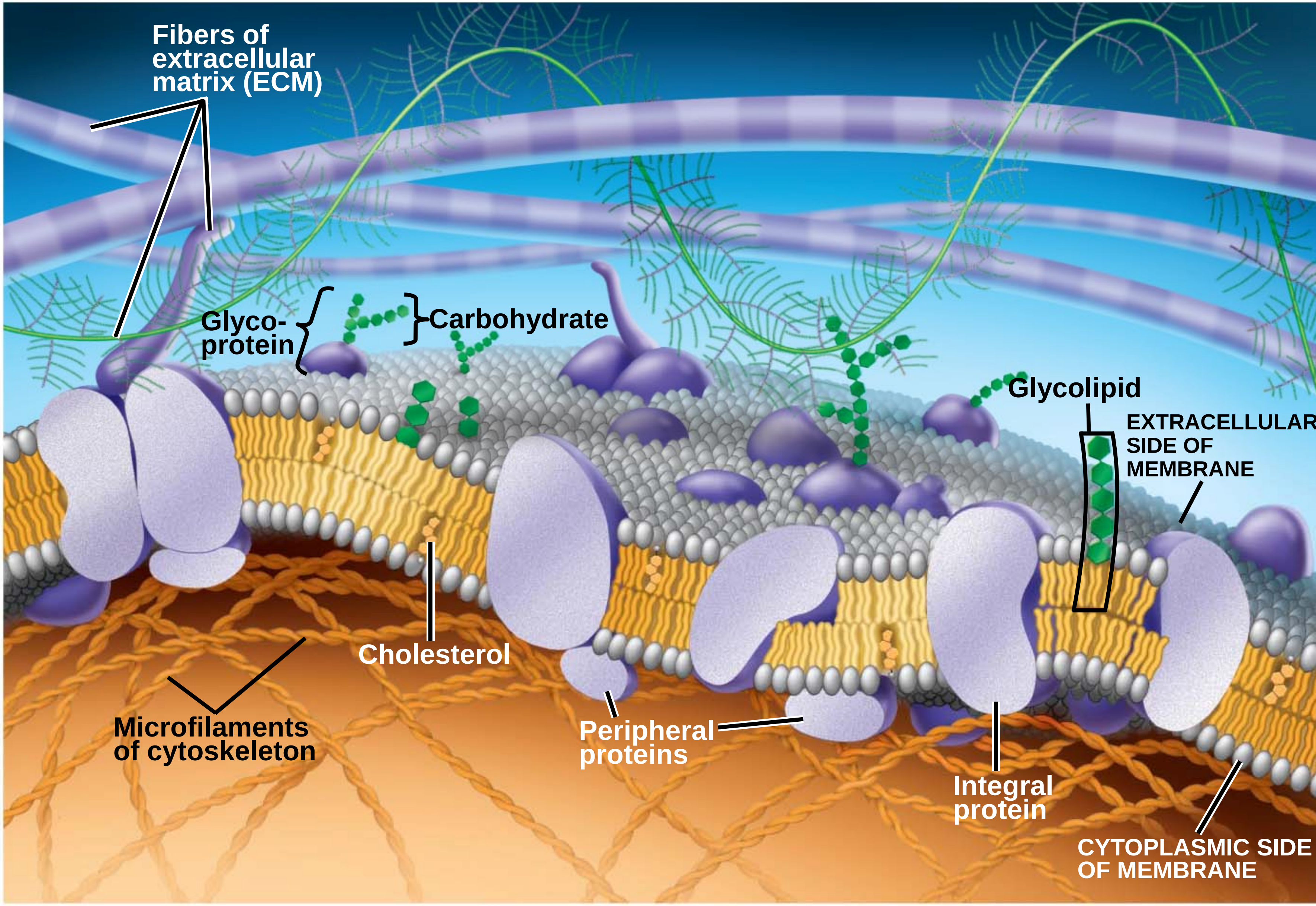
- The steroid cholesterol has different effects on membrane fluidity at different temperatures
- At warm temperatures (such as 37°C), cholesterol restrains movement of phospholipids
- At cool temperatures, it maintains fluidity by preventing tight packing



(c) Cholesterol within the animal cell membrane

Membrane Proteins and Their Functions

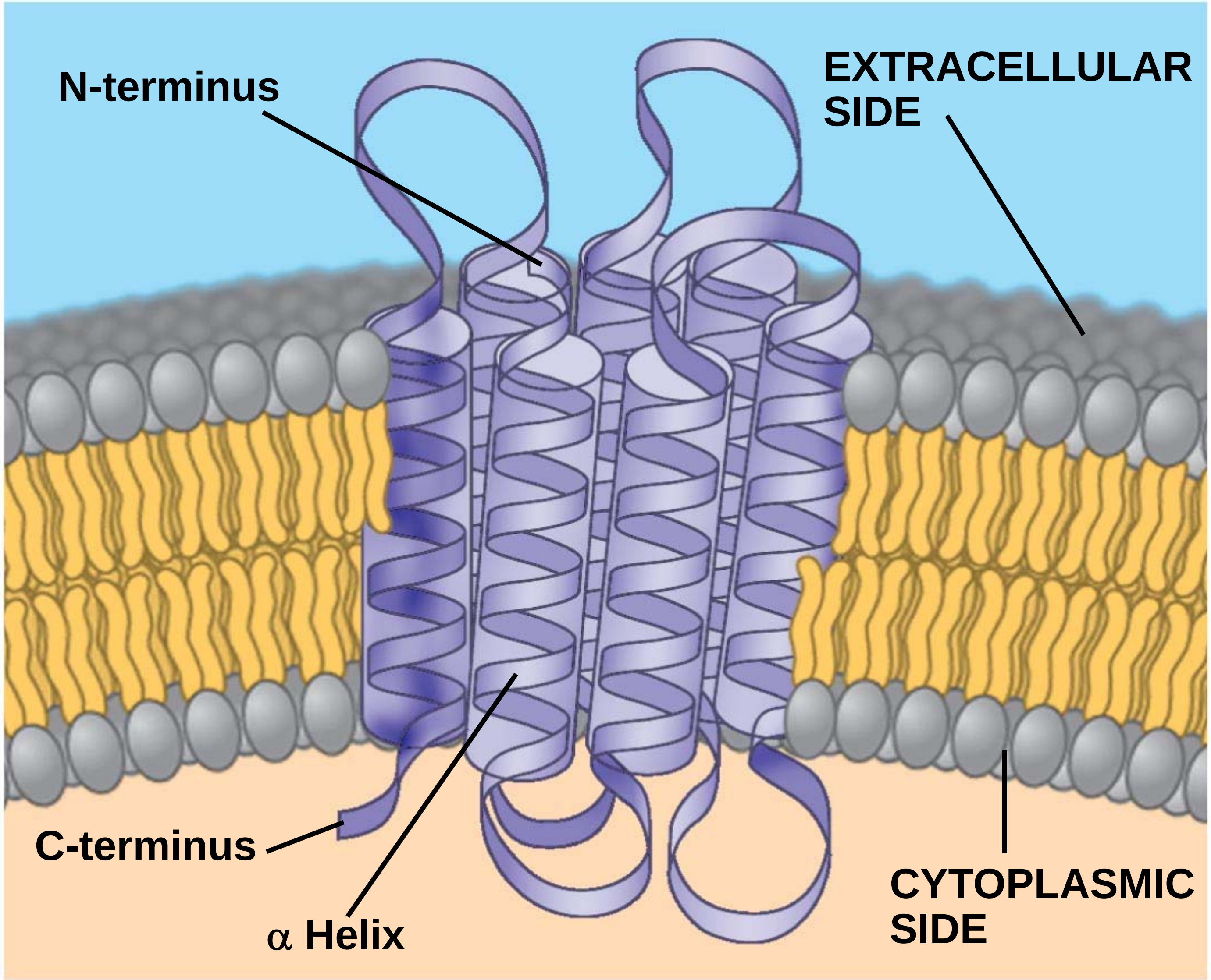
- A membrane is a collage of different proteins embedded in the fluid matrix of the lipid bilayer
- Proteins determine most of the membrane's specific functions


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

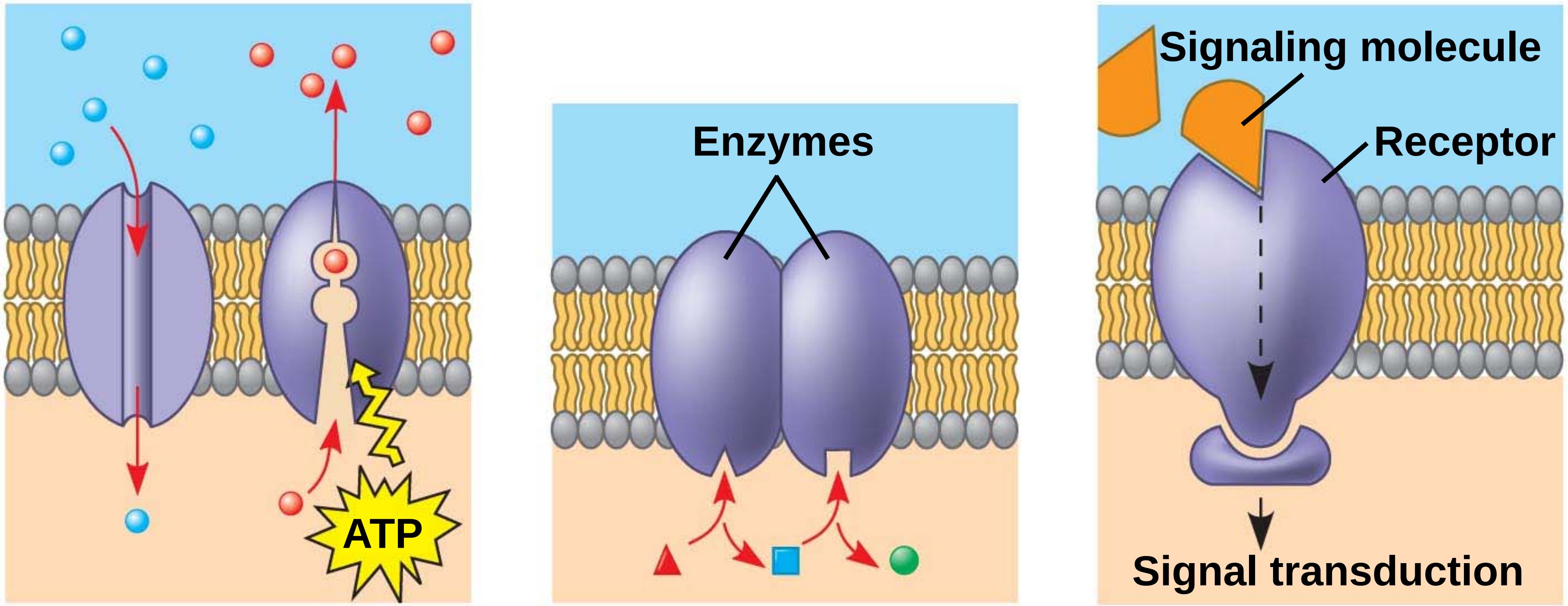
Fig. 7-8

The structure of a transmembrane protein



- 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. 7-9ac

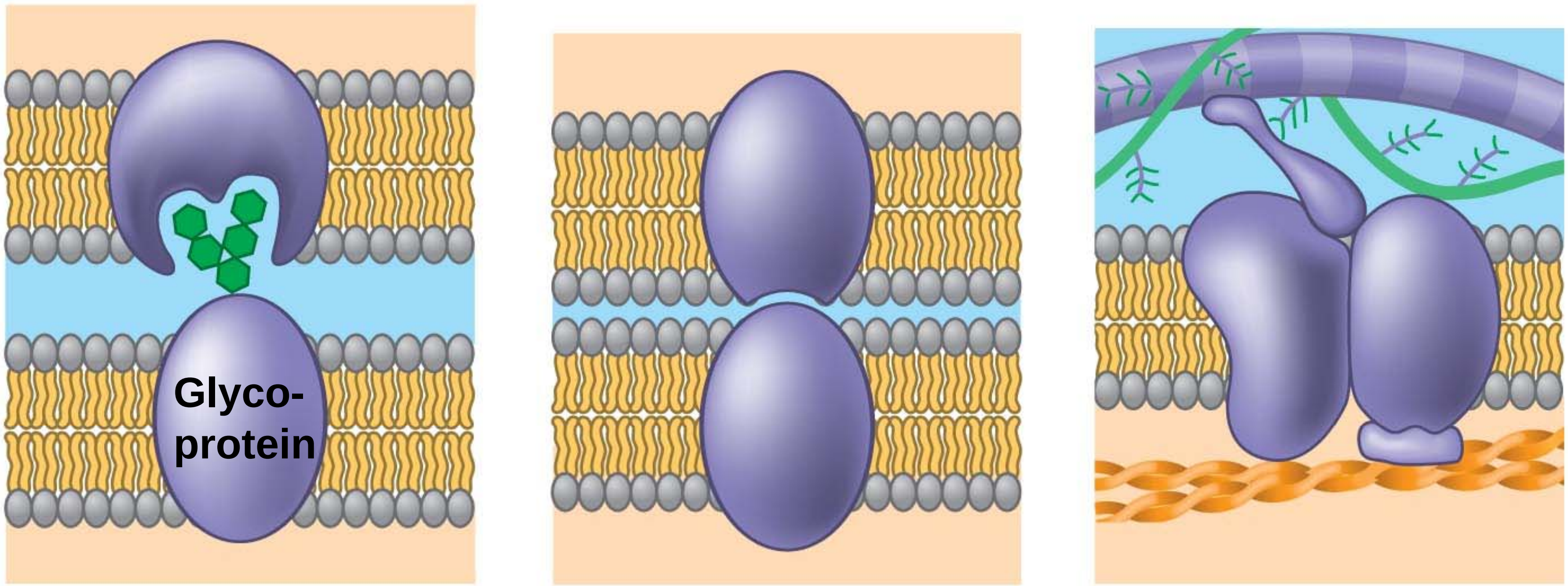


(a) Transport

(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)

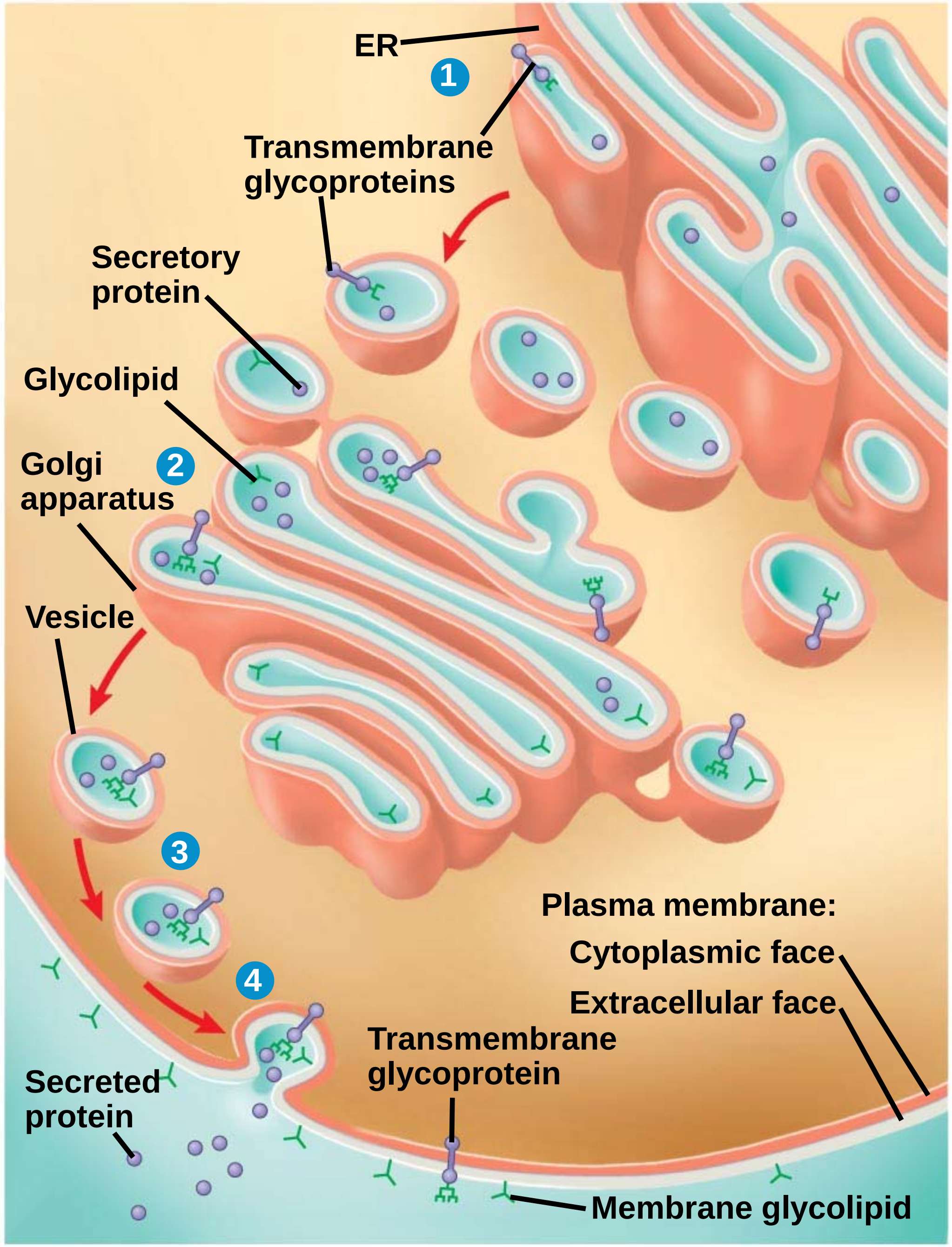
The Role of Membrane Carbohydrates in Cell-Cell Recognition

- 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

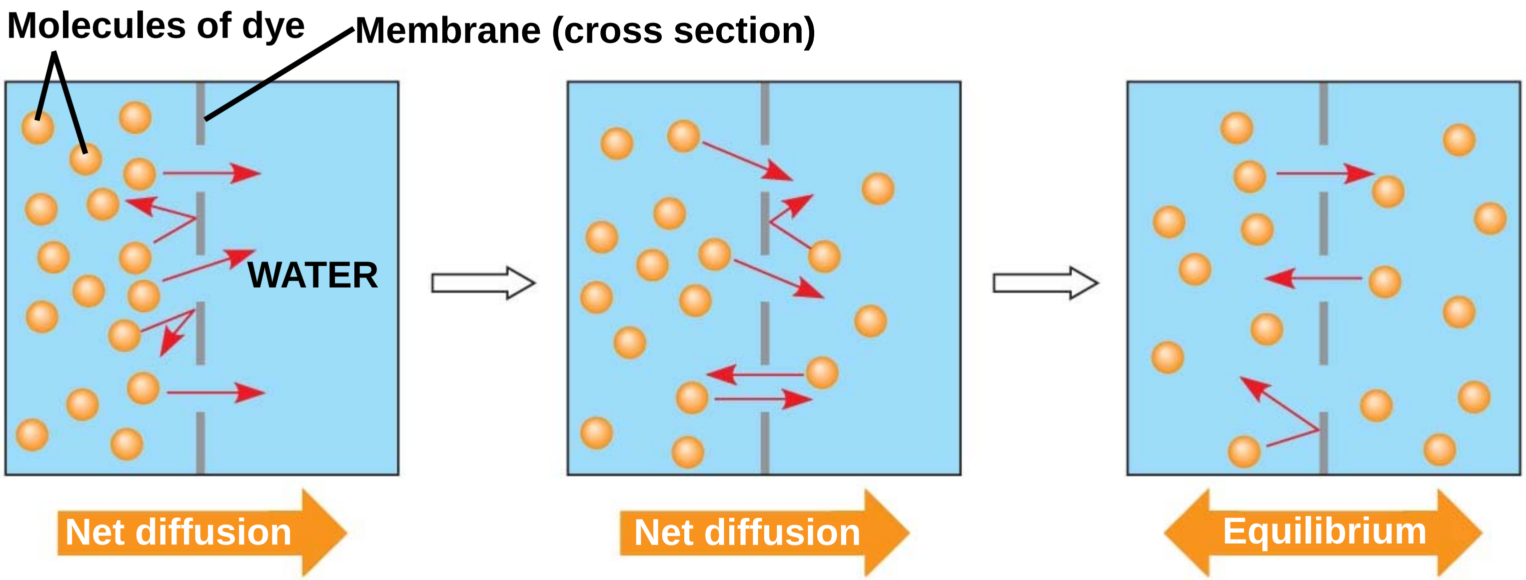
- **Transport proteins** allow passage of hydrophilic substances across the membrane
- Some transport proteins, called channel proteins, have a hydrophilic channel that certain molecules or ions can use as a tunnel
- Channel proteins called **aquaporins** facilitate the passage of water

- 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

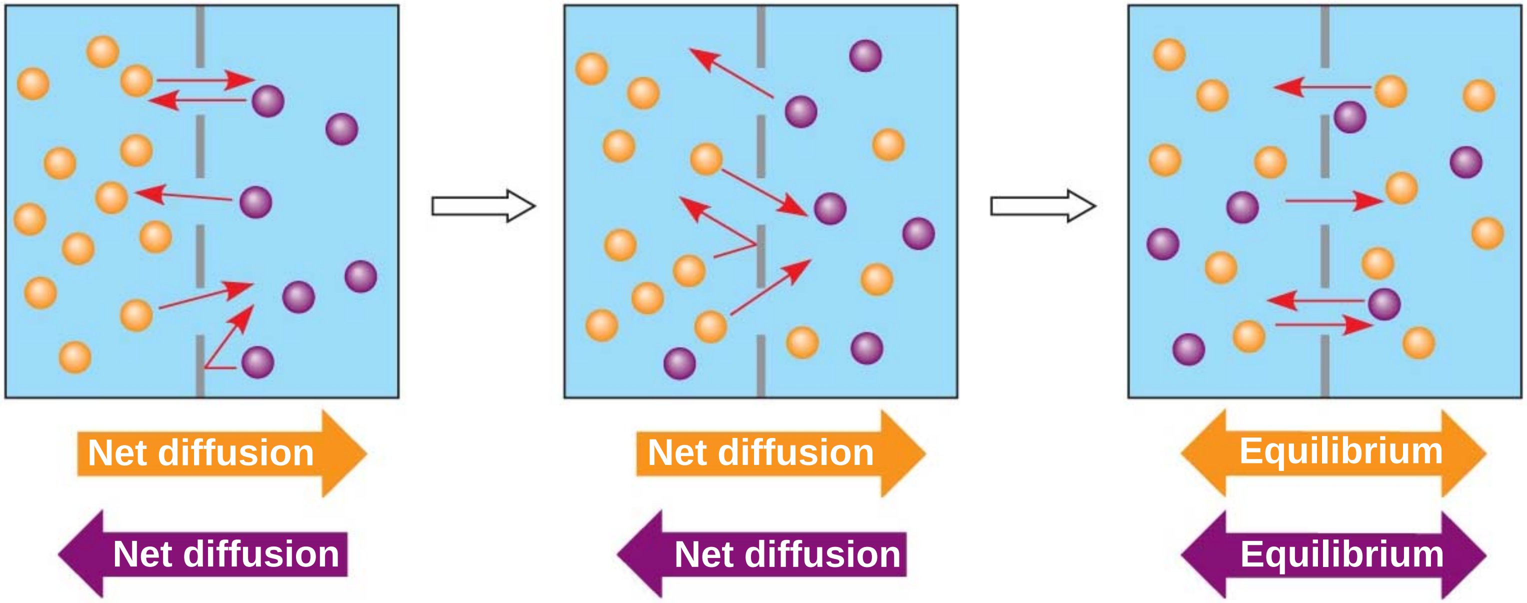
Concept 7.3: Passive transport is diffusion of a substance across a membrane with no energy investment

- **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

Fig. 7-11



(a) Diffusion of one solute



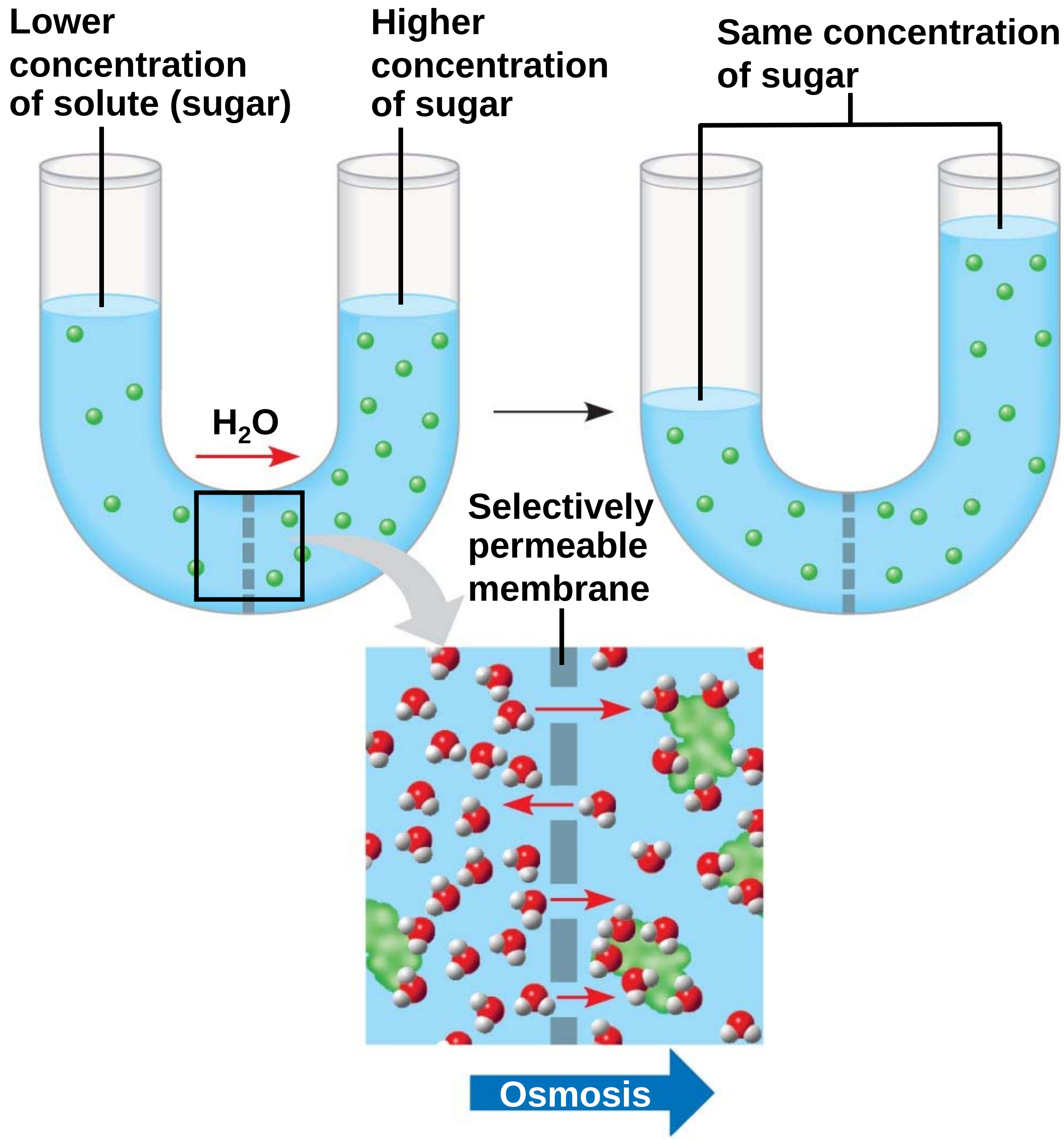
(b) Diffusion of two solutes

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

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

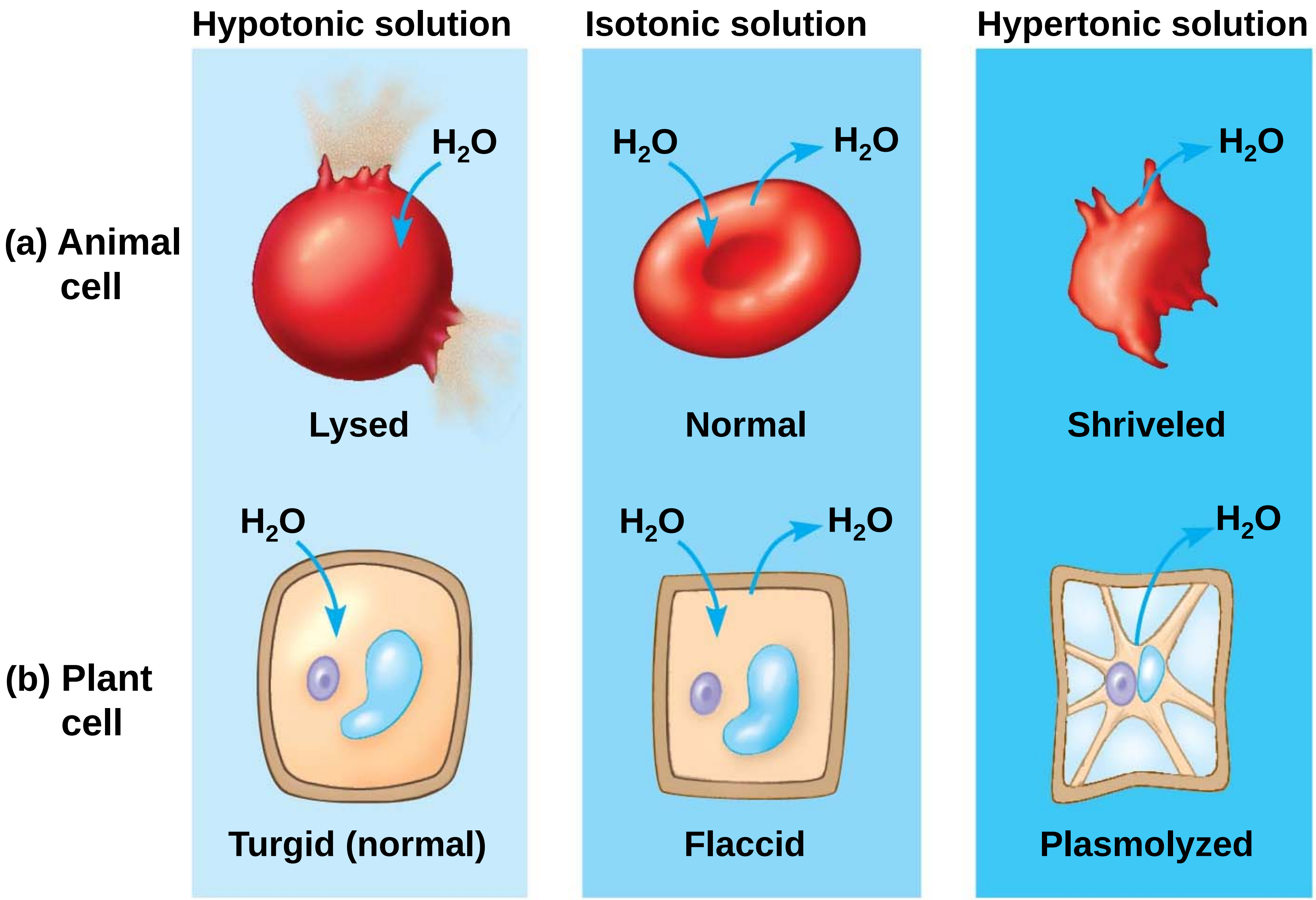


Lower concentration of solute (sugar)
Higher concentration of sugar
Same concentration of sugar
H_2O
Selectively permeable membrane
Osmosis

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 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

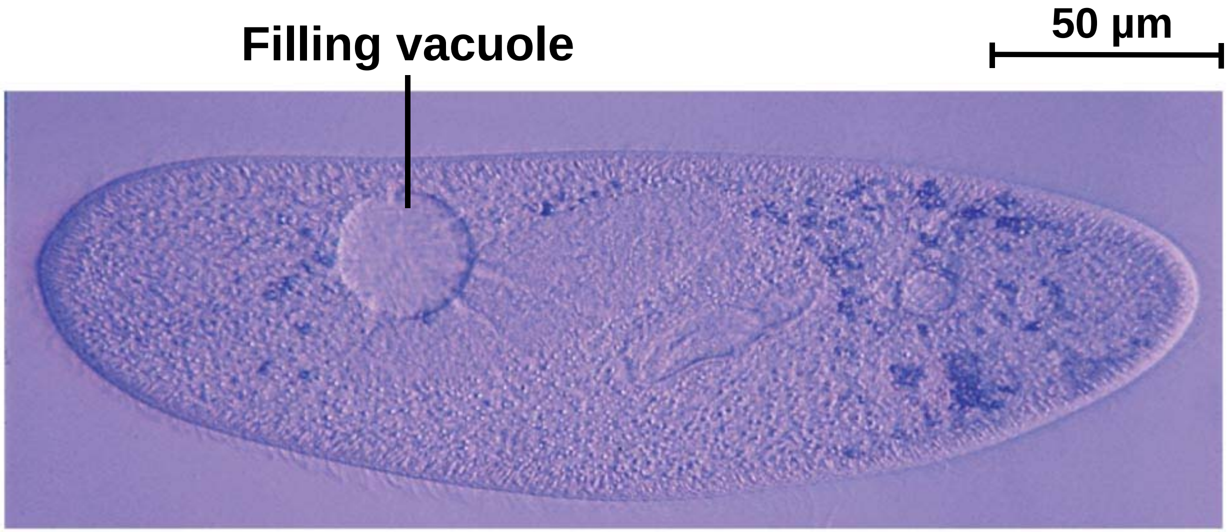
Fig. 7-13



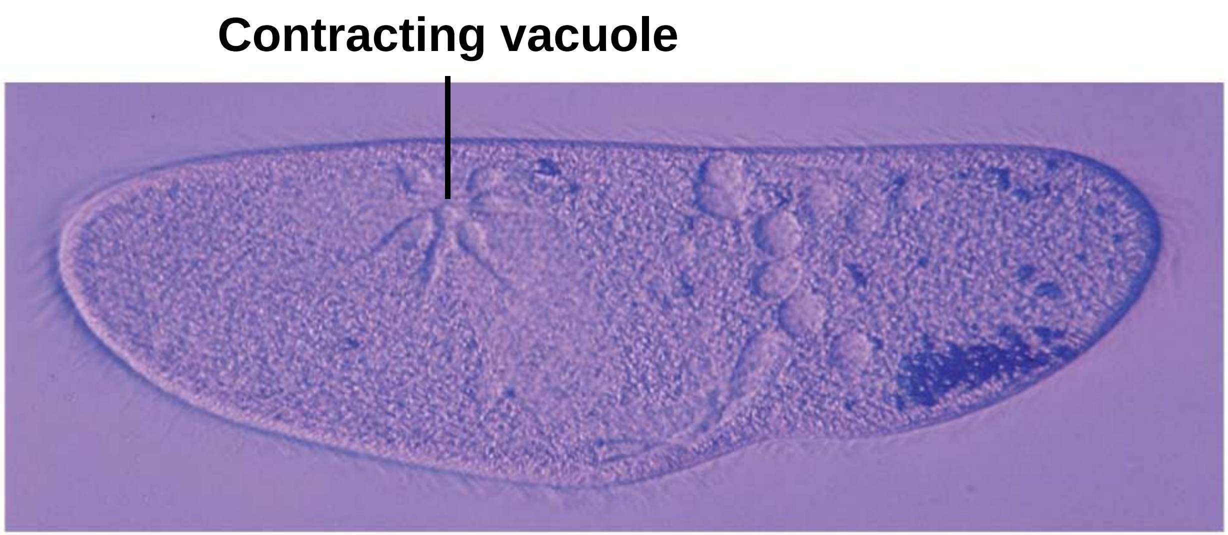
Hypotonic solution
Isotonic solution
Hypertonic solution
(a) Animal cell
H_2O
H_2O
H_2O
H_2O
Lysed
Normal
Shriveled
(b) Plant cell
H_2O
H_2O
H_2O
H_2O
Turgid (normal)
Flaccid
Plasmolyzed

- 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

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

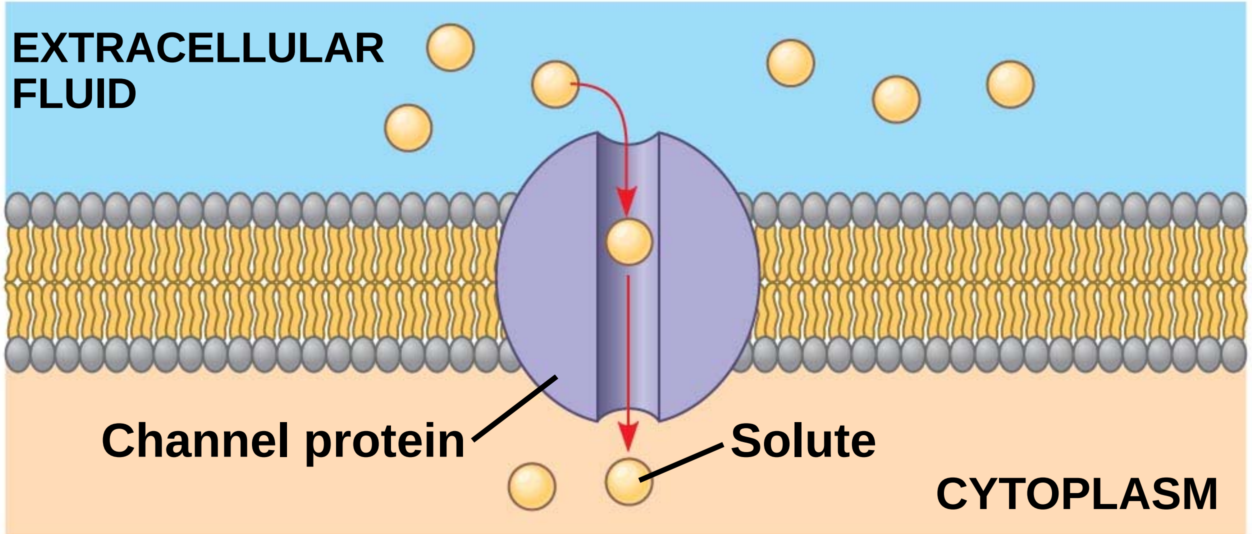
- Cell walls help maintain water balance
- A plant cell in a hypotonic solution swells until the wall opposes uptake; the cell is now **turgid** (firm)
- If a plant cell and its surroundings are isotonic, there is no net movement of water into the cell; the cell becomes **flaccid** (limp), and the plant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

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

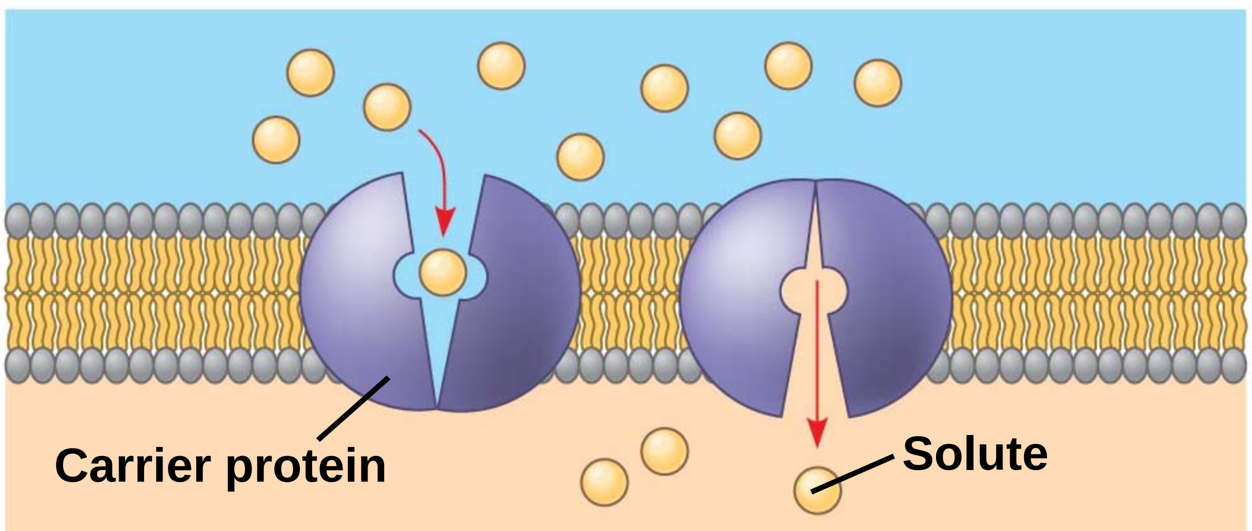
Facilitated Diffusion: Passive Transport Aided by Proteins

- 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

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

Fig. 7-16-7

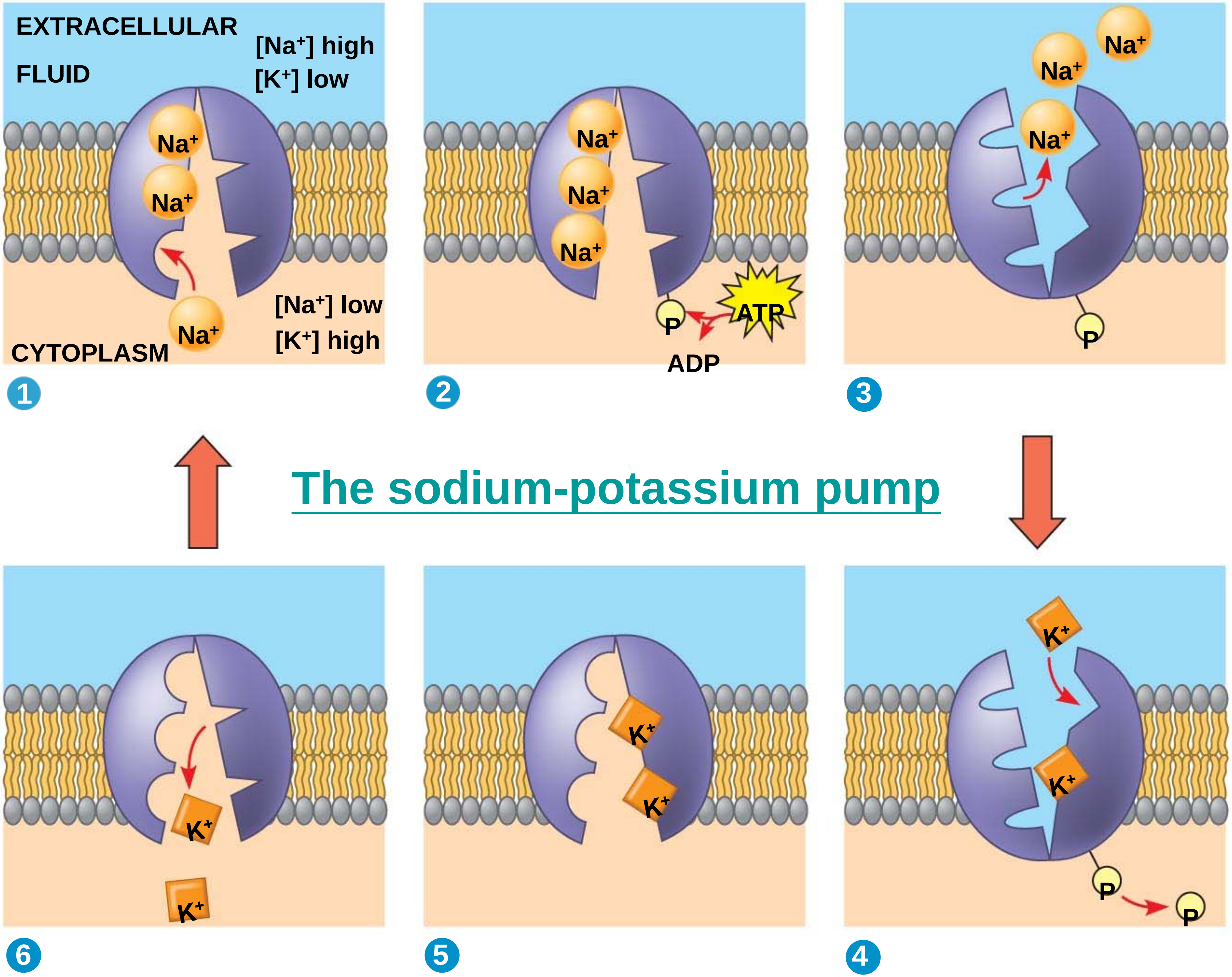
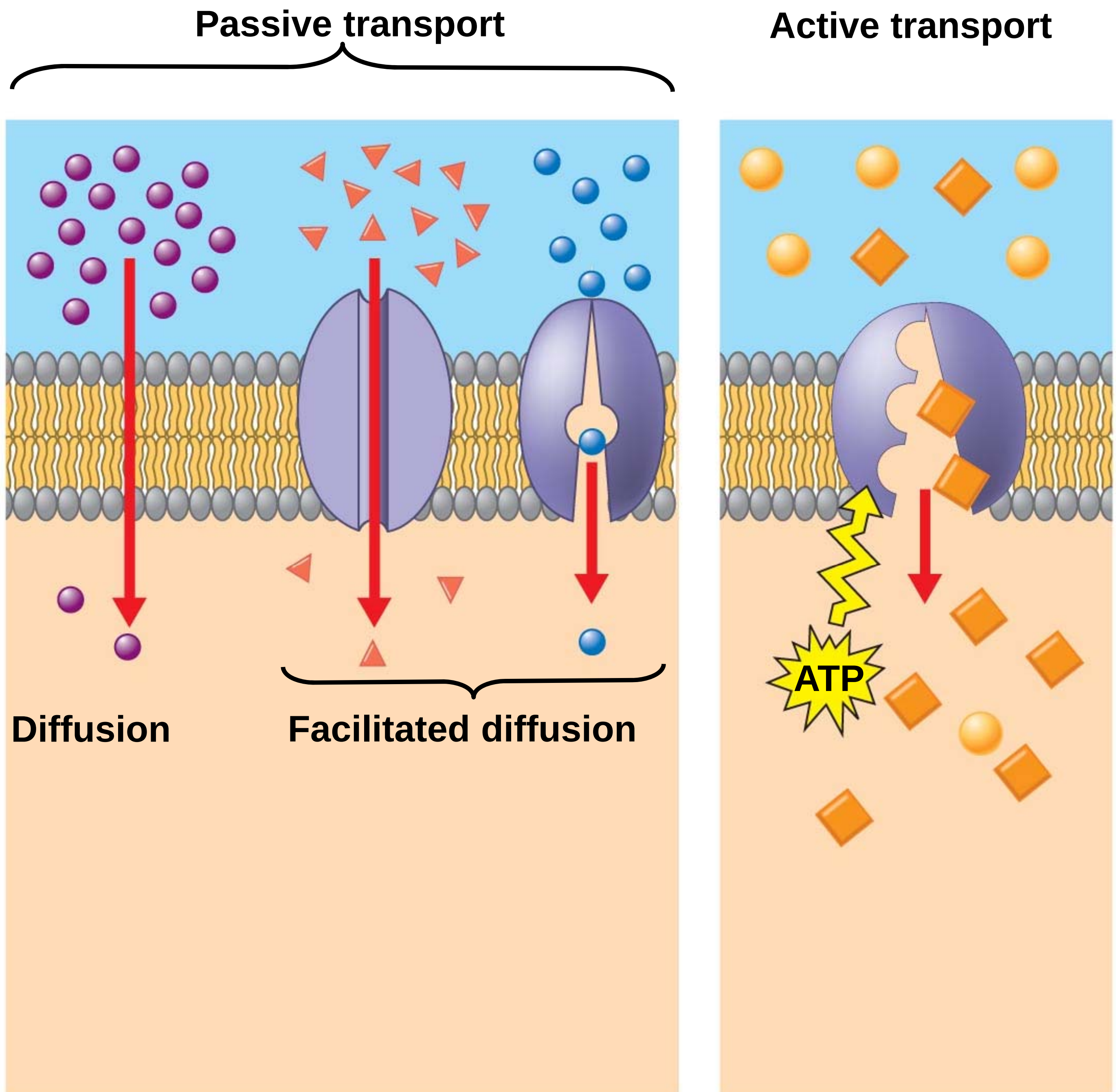

EXTRACELLULAR
FLUID
[Na+] high
[K+] low
Na+
Na+
Na+
[Na+] low
[K+] high
CYTOPLASM
1
Na+
Na+
Na+
P
ATP
ADP
2
Na+
Na+
Na+
P
3
The sodium-potassium pump
K+
K+
P
P
4
K+
K+
5
K+
K+
6

Fig. 7-17


Passive transport
Active transport
ATP
Diffusion
Facilitated diffusion

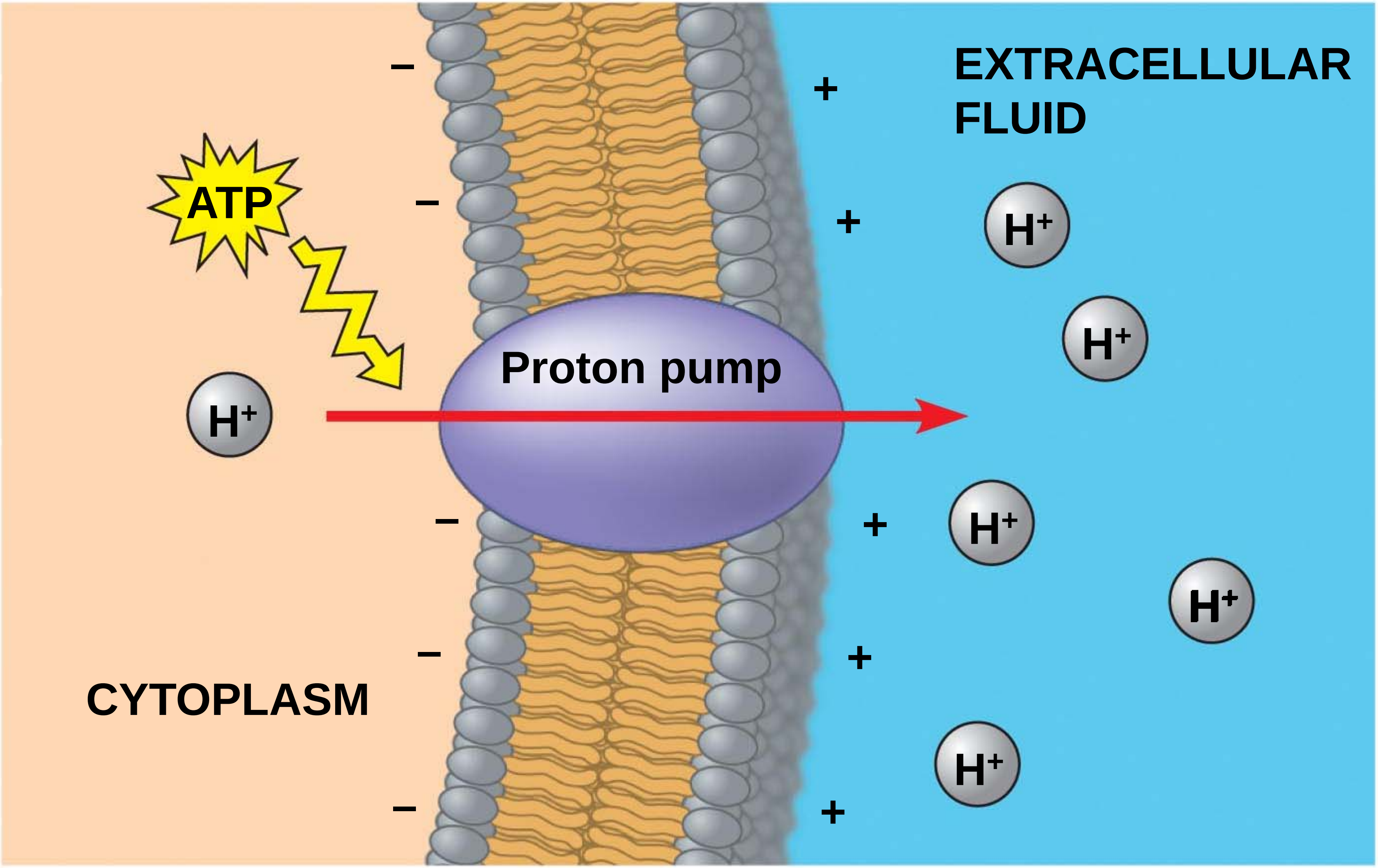
How Ion Pumps Maintain Membrane Potential

- **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**

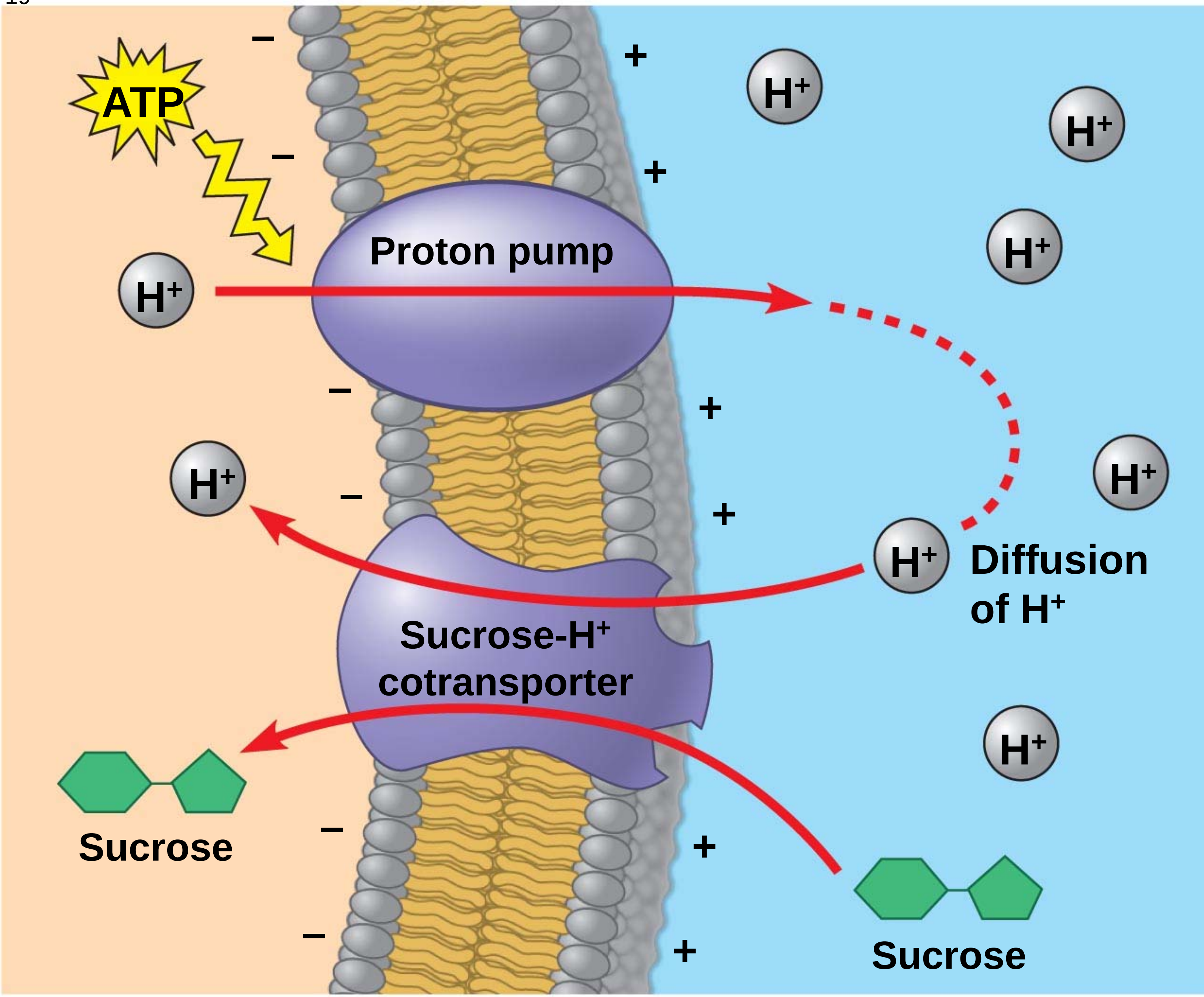
Fig. 7-18



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+
Sucrose-H+
cotransporter
Diffusion
of H+
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

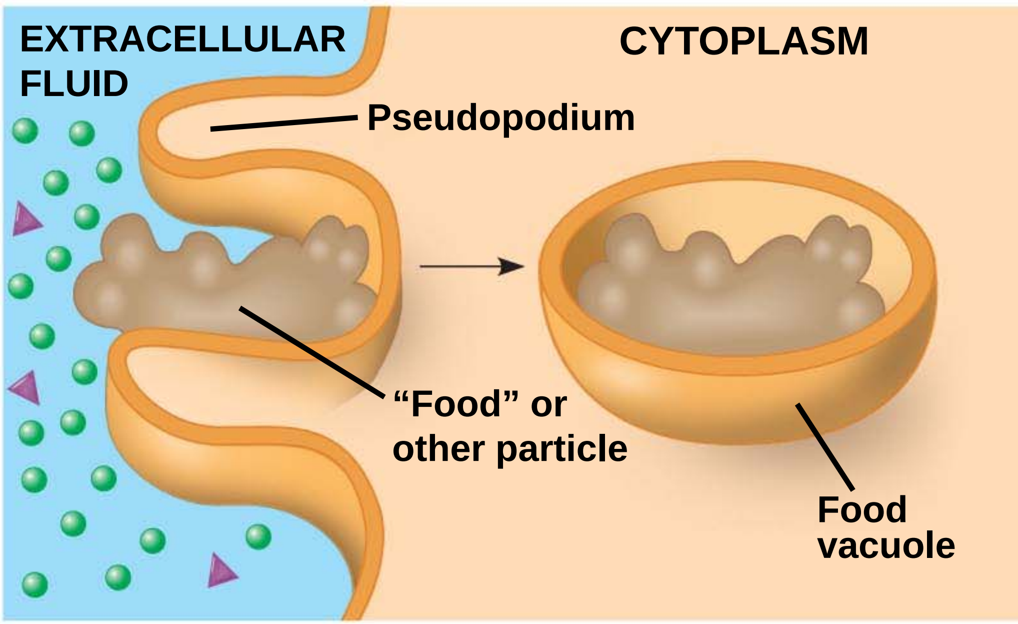
Endocytosis

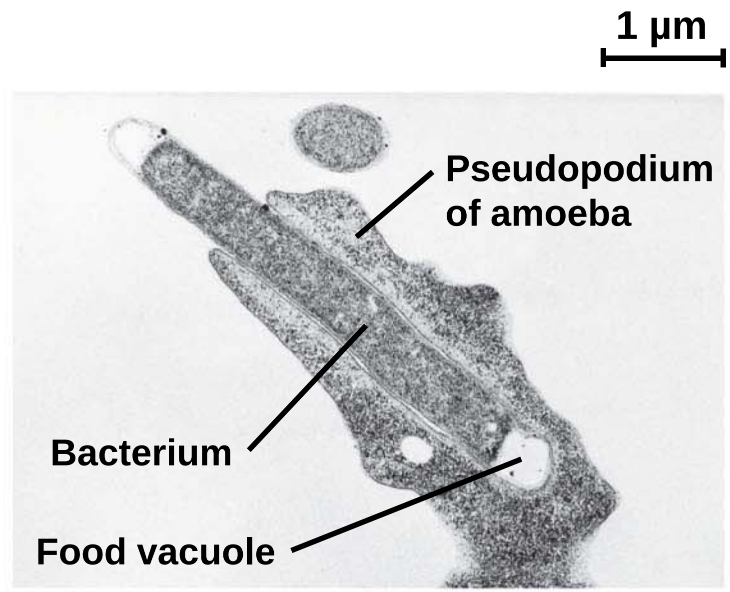
- In **endocytosis**, the cell takes in macromolecules by forming vesicles from the plasma membrane
- Endocytosis is a reversal of exocytosis, involving different proteins
- There are three types of endocytosis:
  - Phagocytosis ("cellular eating")
  - Pinocytosis ("cellular drinking")
  - Receptor-mediated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

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

Fig. 7-20a

PHAGOCYTOSIS



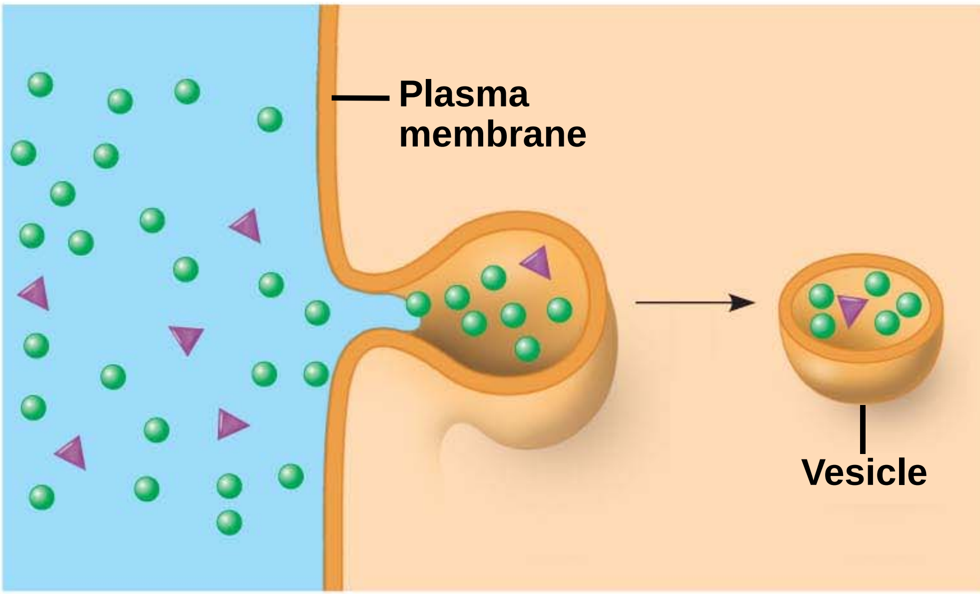


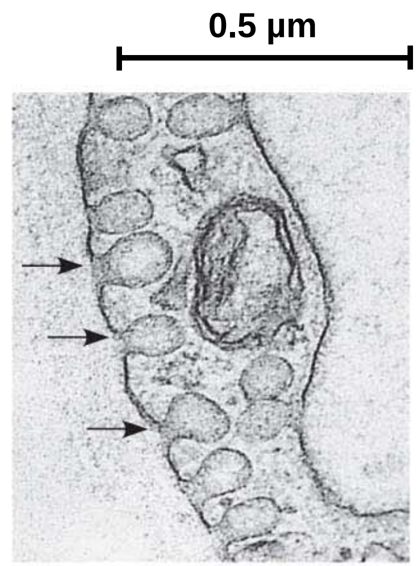
An amoeba engulfing a bacterium via phagocytosis (TEM)

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

Fig. 7-20b

PINOCYTOSIS



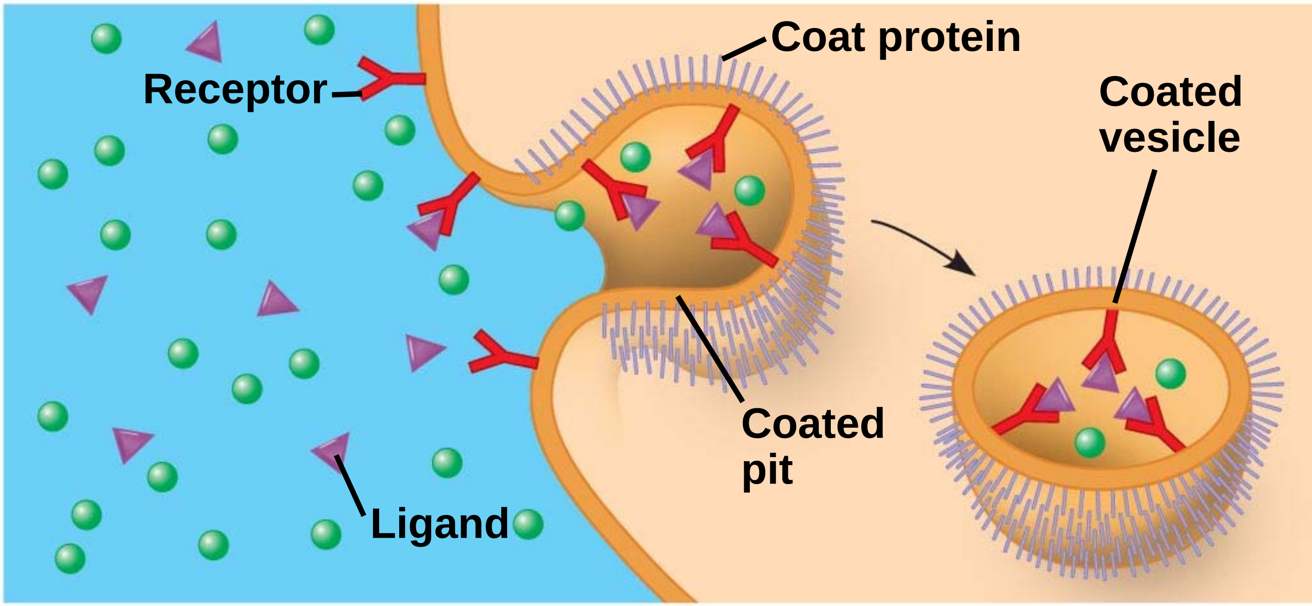


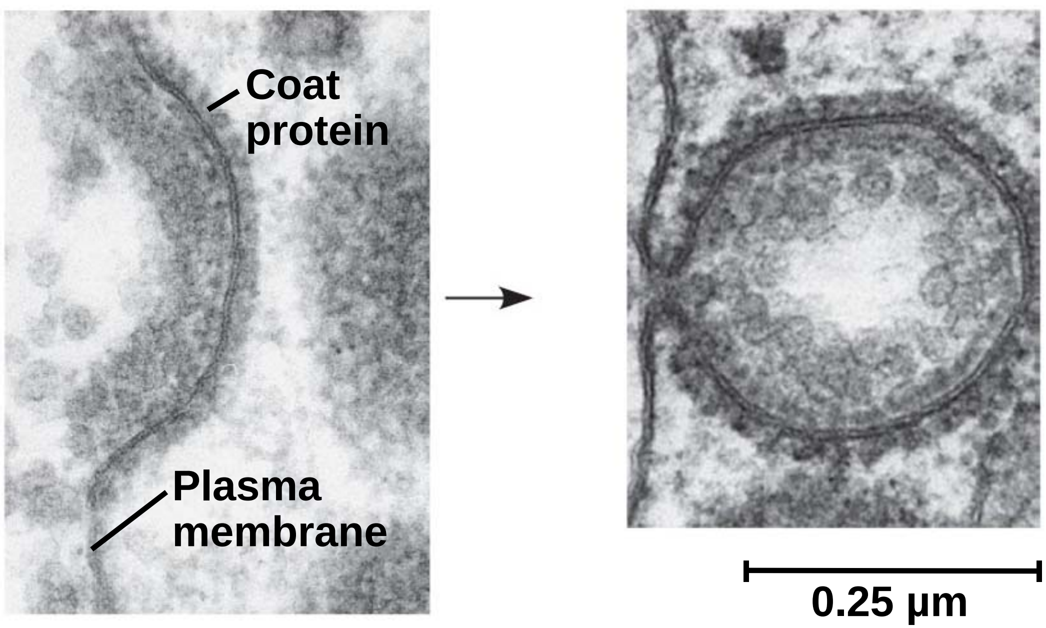
Pinocytosis vesicles forming (arrows) in a cell lining a small blood vessel (TEM)

- 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

Fig. 7-20c

RECEPTOR-MEDIATED ENDOCYTOSIS





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

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