Chapter 7

Membrane Structure and Function

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

Neil Campbell and Jane Reece

Lectures by Chris Romero, updated by Erin Barley with contributions from Joan Sharp

Overview: Life at the Edge

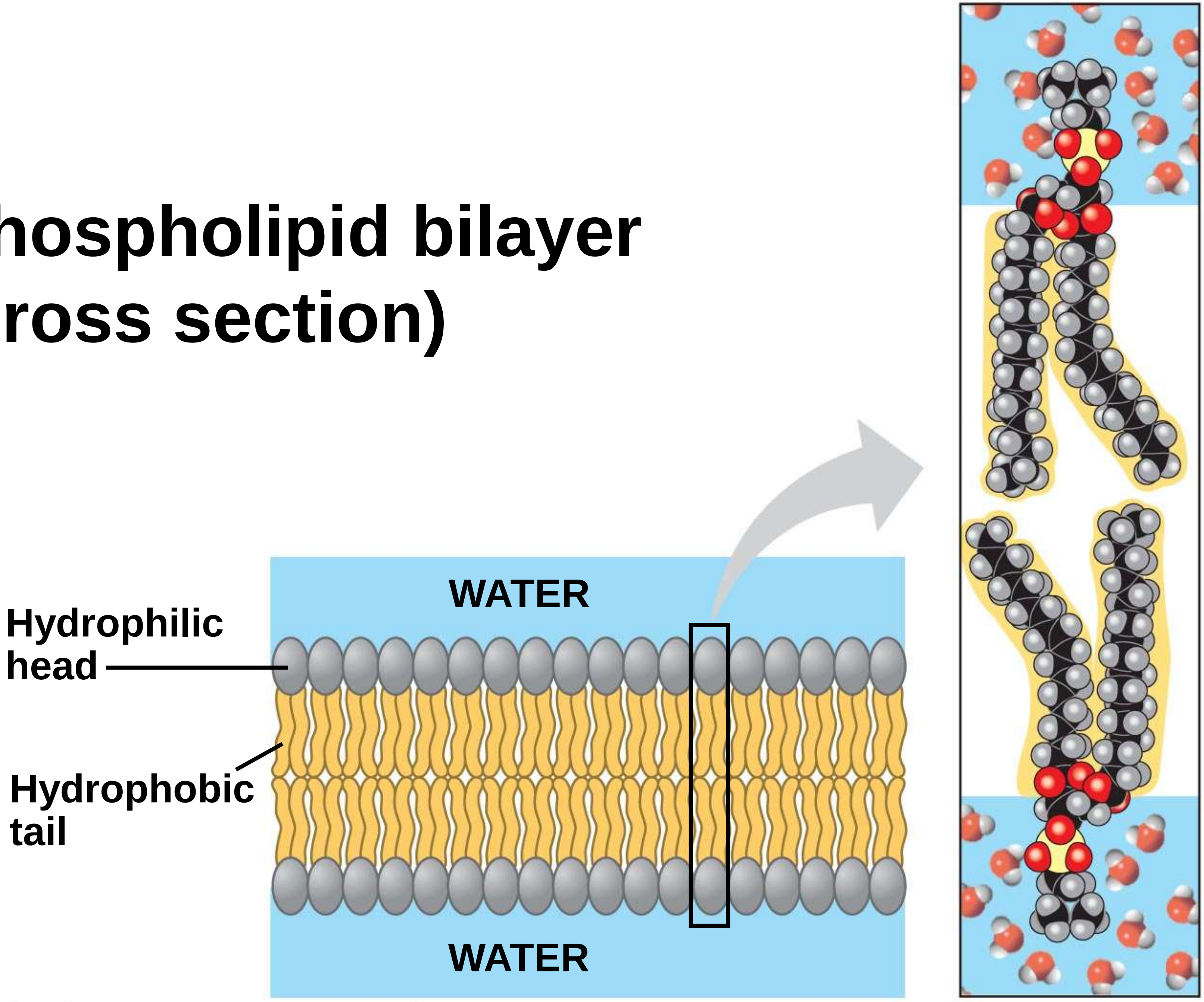
- The plasma membrane is the **boundary** that separates the living cell from its surroundings

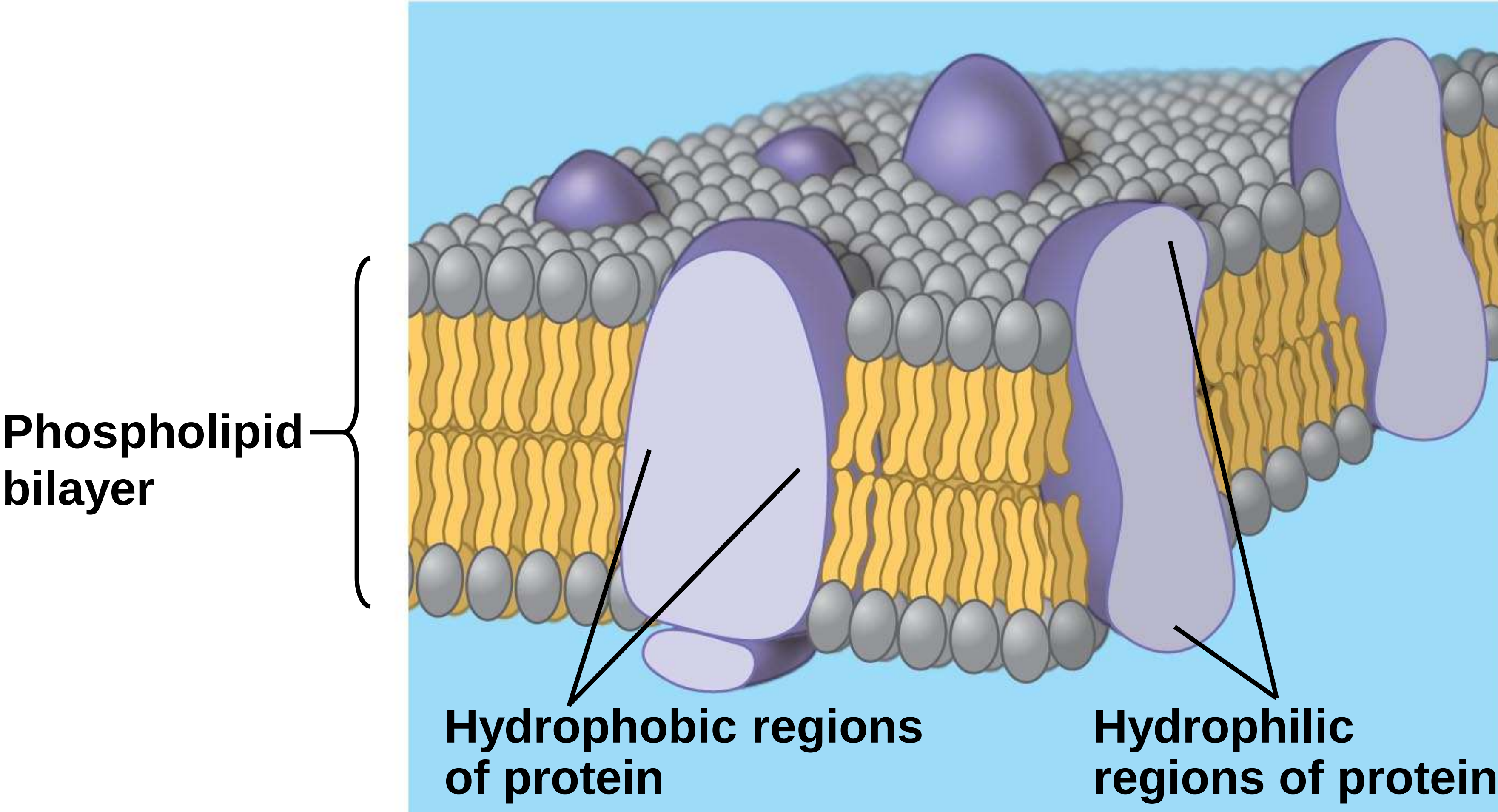
- The plasma membrane exhibits **selective permeability**, allowing some substances to cross it more easily than others

Cellular membranes are fluid mosaics of lipids and proteins

- Phospholipids are the most abundant lipid in the plasma membrane
- Phospholipids contain 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**
- 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 (cross section)





In 1972, J. Singer and G. Nicolson proposed that the membrane is a <u>mosaic of proteins dispersed within the bilayer</u>, with only the hydrophilic regions exposed to water

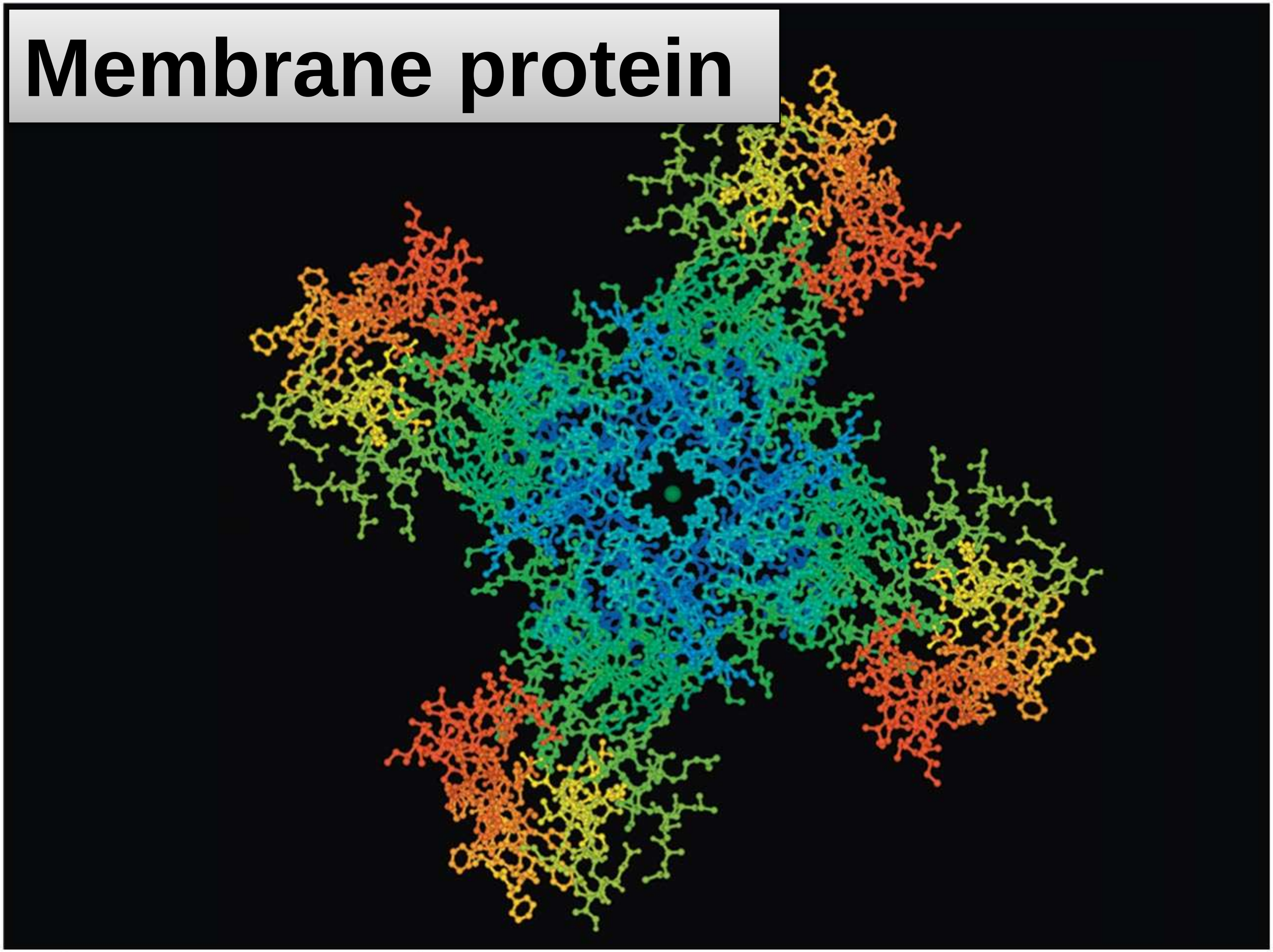
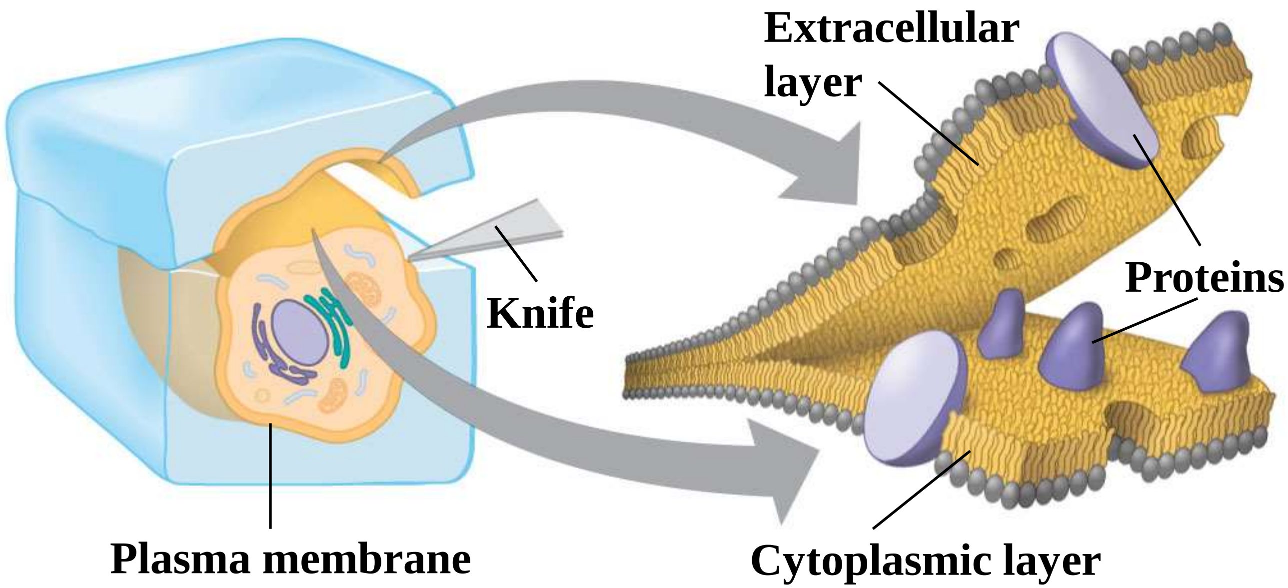

Membrane protein

Figure 7.4

RESEARCH METHOD: Freeze-fracture

TECHNIQUE

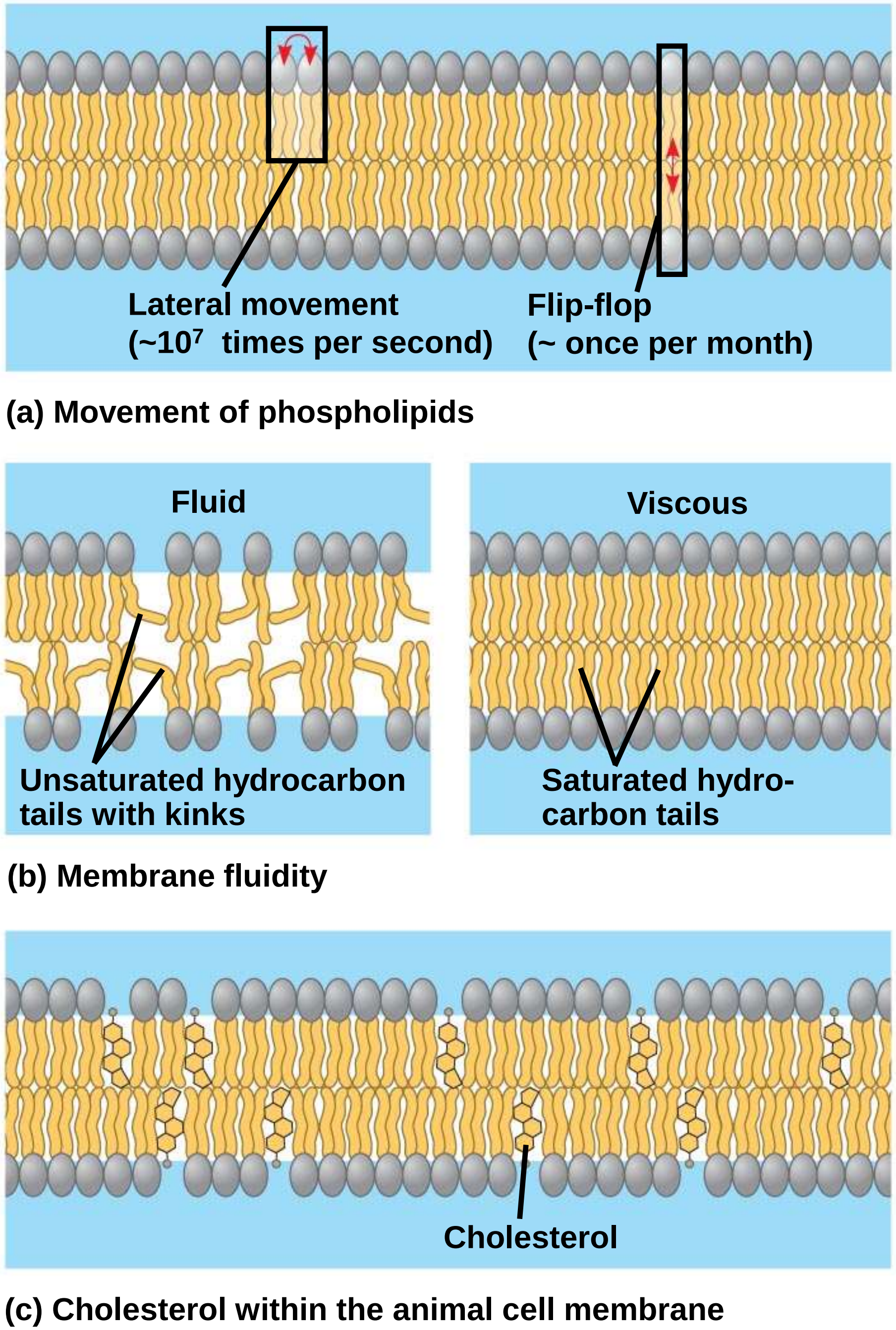


RESULTS

Inside of extracellular layer

Inside of cytoplasmic layer

The fluidity of membranes



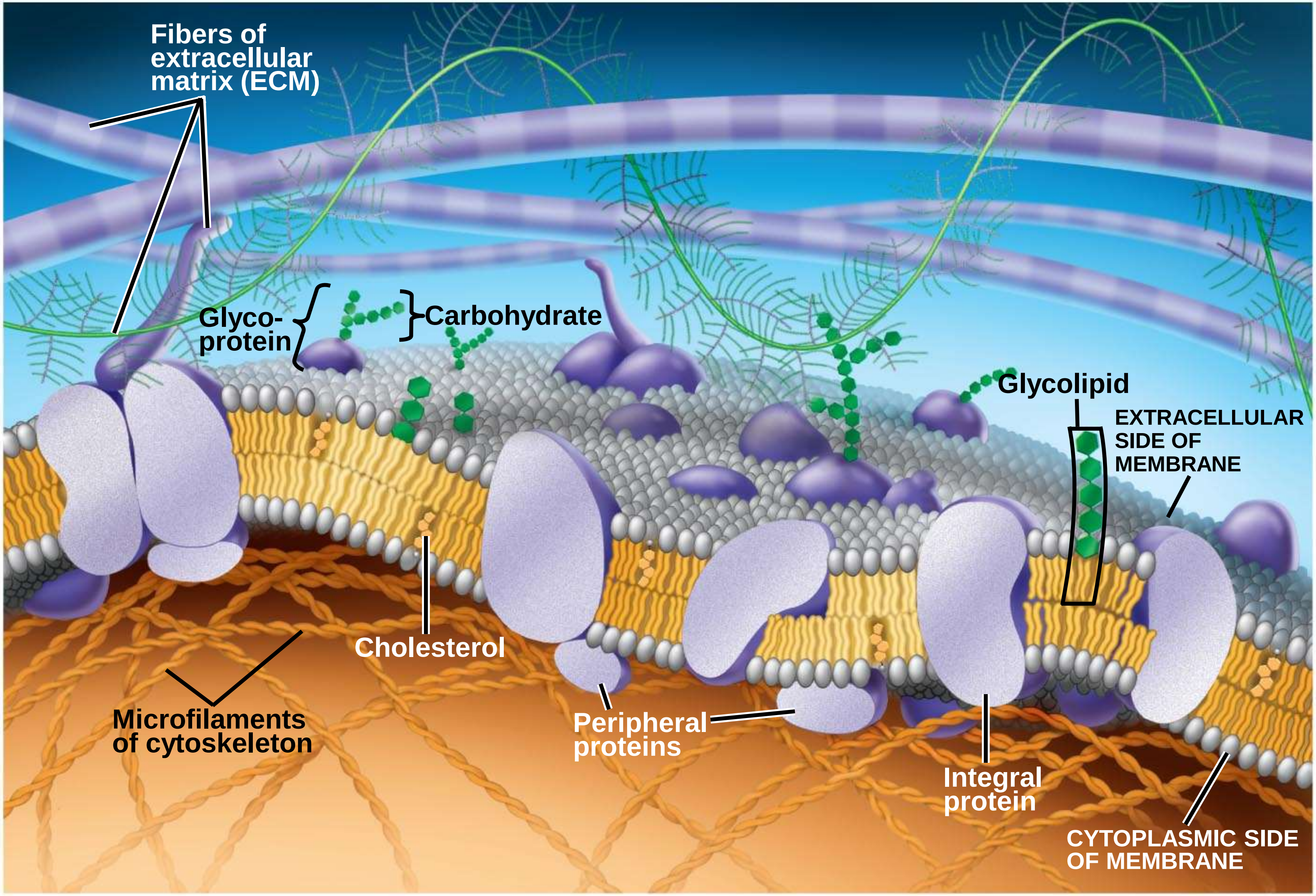
- **As temperatures cool**, **membranes switch from a fluid state to a solid state**
- The temperature at which a membrane solidifies depends on the types of lipids
- Membranes rich in **unsaturated fatty acids** **are more fluid** that those rich in ***saturated fatty acids***
- Membranes **must be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

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

Membrane Proteins and Their Functions

- A membrane is a collage of different proteins **embedded** in the fluid matrix of the lipid bilayer

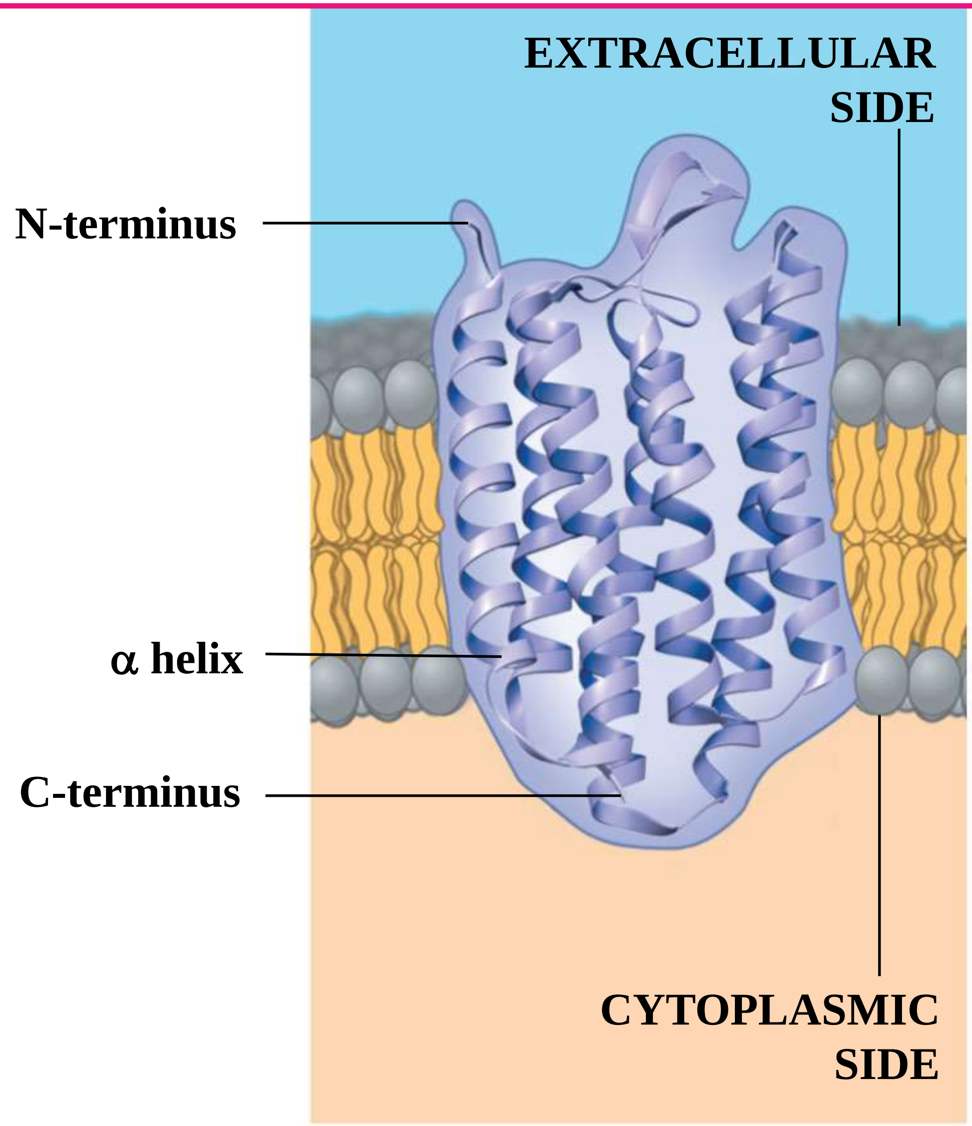
- Proteins **determine** most of the membrane's specific functions


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

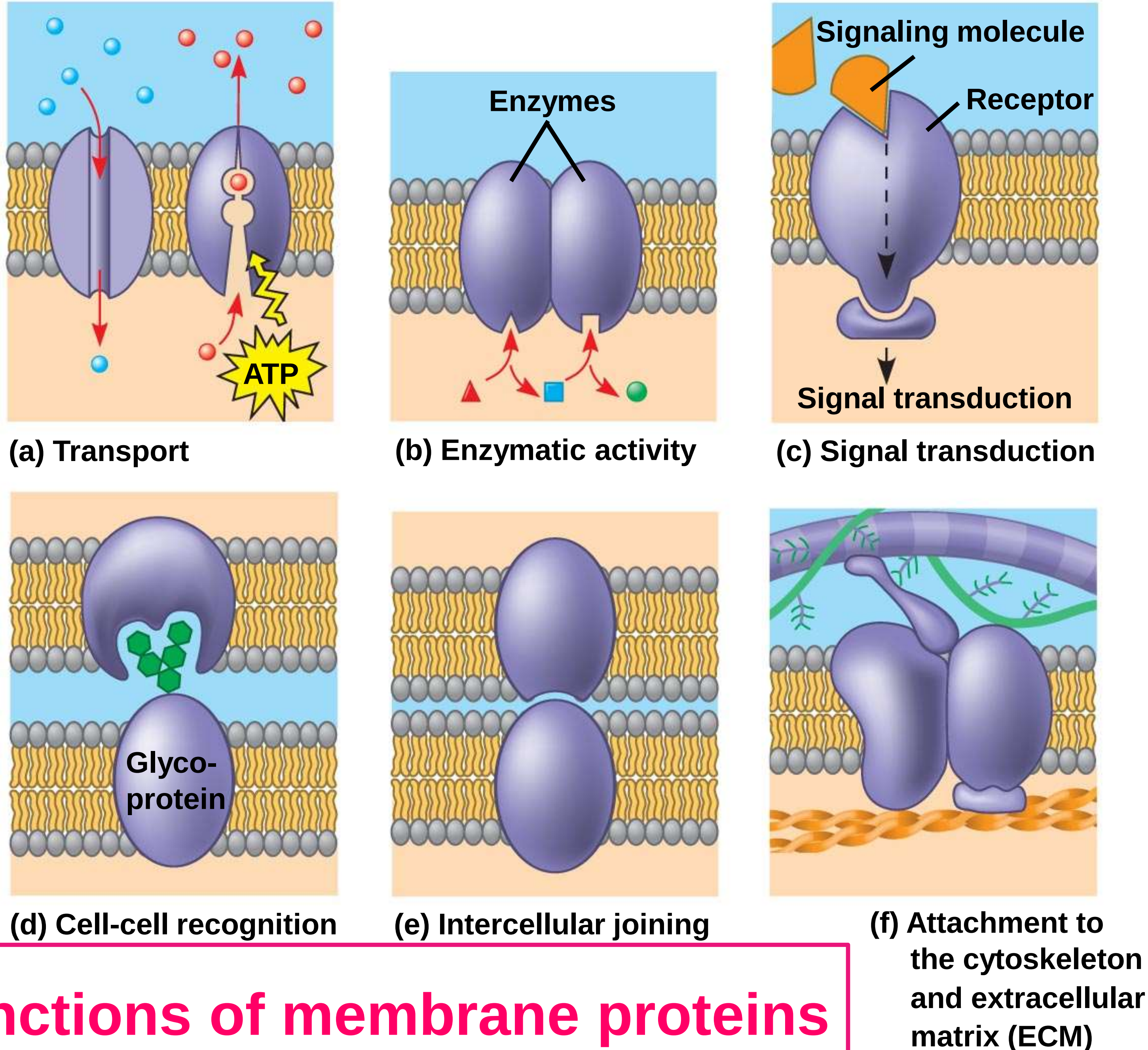
- **Peripheral proteins** are bound to the surface of the membrane
- **Integral proteins** penetrate the hydrophobic core
- Integral proteins that span the membrane are called **transmembrane proteins**

Figure 7.9

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)



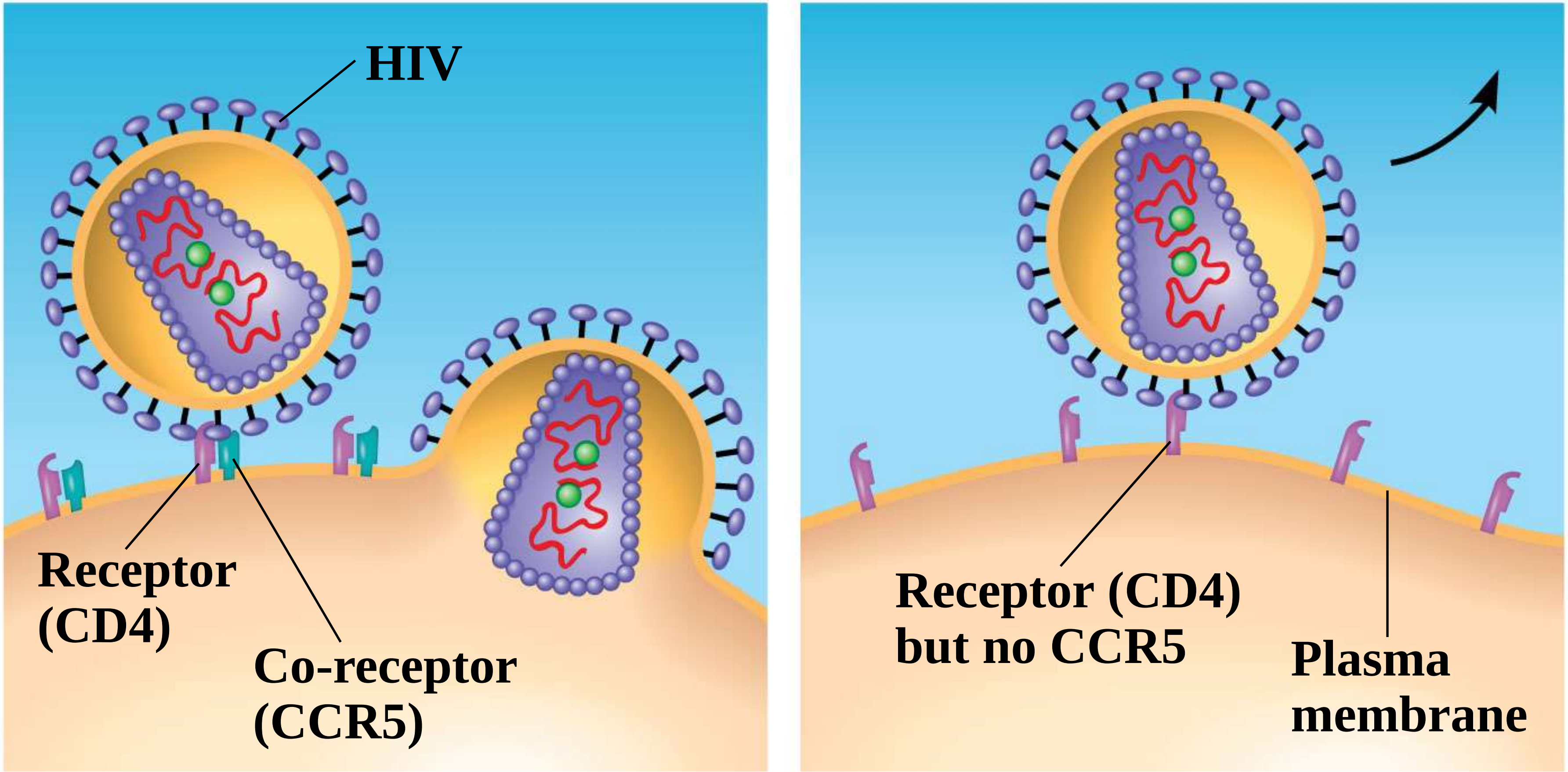
6 major functions of membrane proteins

The Role of **Membrane Carbohydrates** in Cell-Cell Recognition

- Cells **recognize each other** by binding to surface molecules (which are often carbohydrates), on the plasma membrane

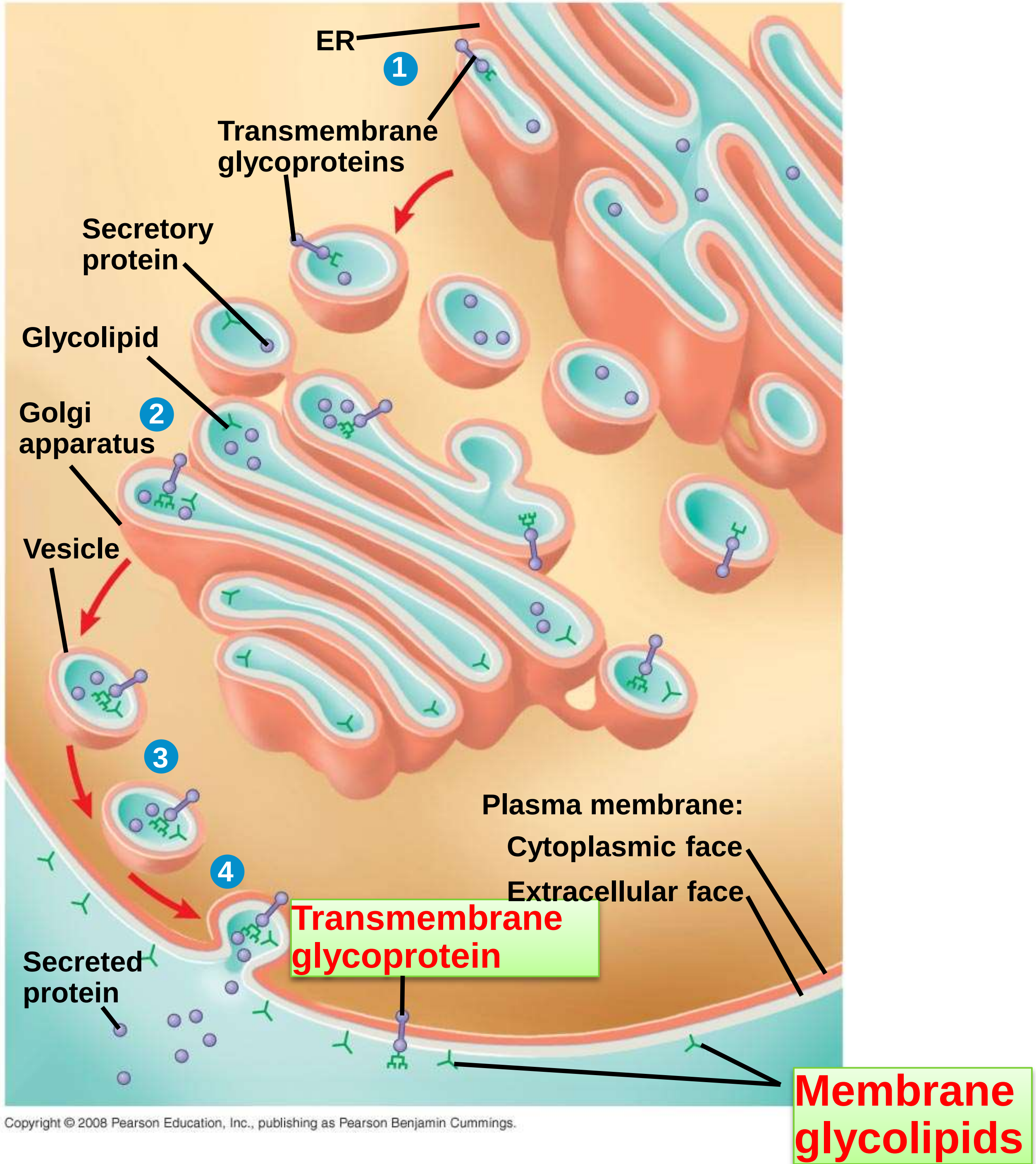
- **Membrane carbohydrates** may be covalently bonded to lipids (forming **glycolipids**) or more commonly to proteins (forming **glycoproteins**)

Figure 7.11



HIV can infect a cell that has CCR5 on its surface, as in most people.

HIV cannot infect a cell lacking CCR5 on its surface, as in resistant individuals.


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

The Permeability of the Lipid Bilayer

- 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

- **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 facilitating the passage of water are called **aquaporins**

- Other transport proteins, called *carrier proteins*, bind to molecules and **change their shape** to shuttle them across the membrane

- A transport protein is **specific** for the substance it moves

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

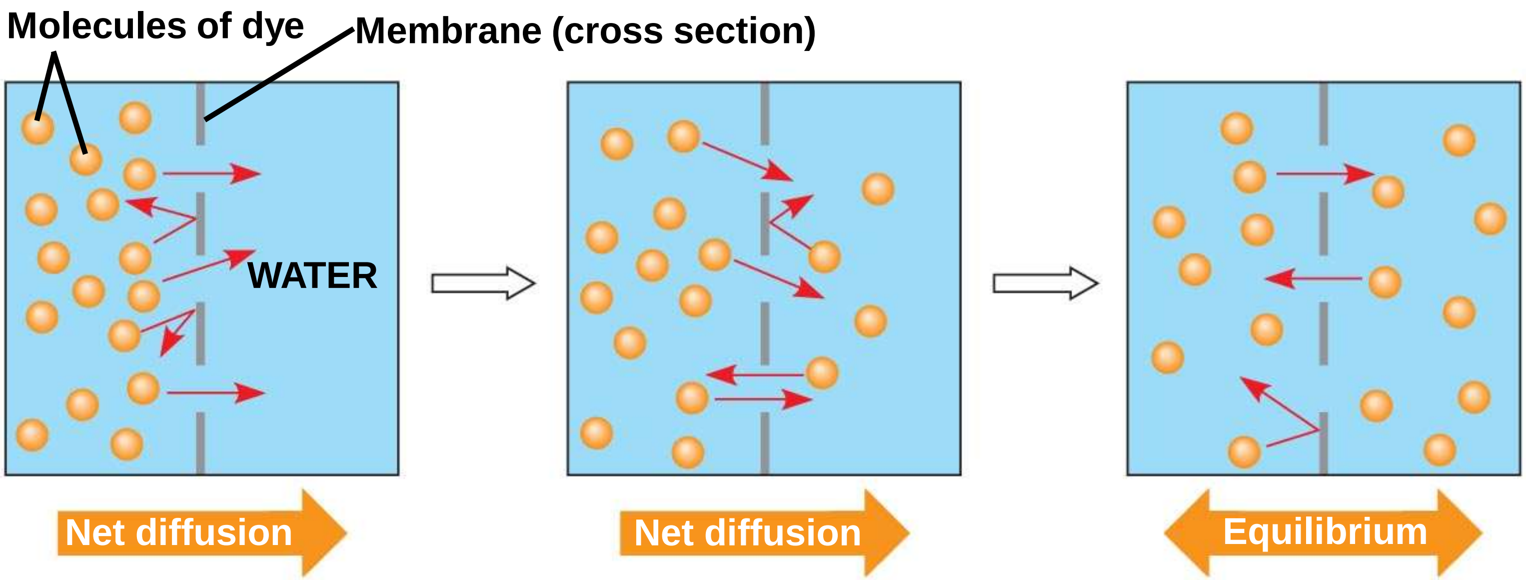
- **Diffusion** is the tendency for molecules to spread out evenly into the available space

- Although each molecule moves randomly, diffusion of a population of molecules may exhibit a net movement in one direction

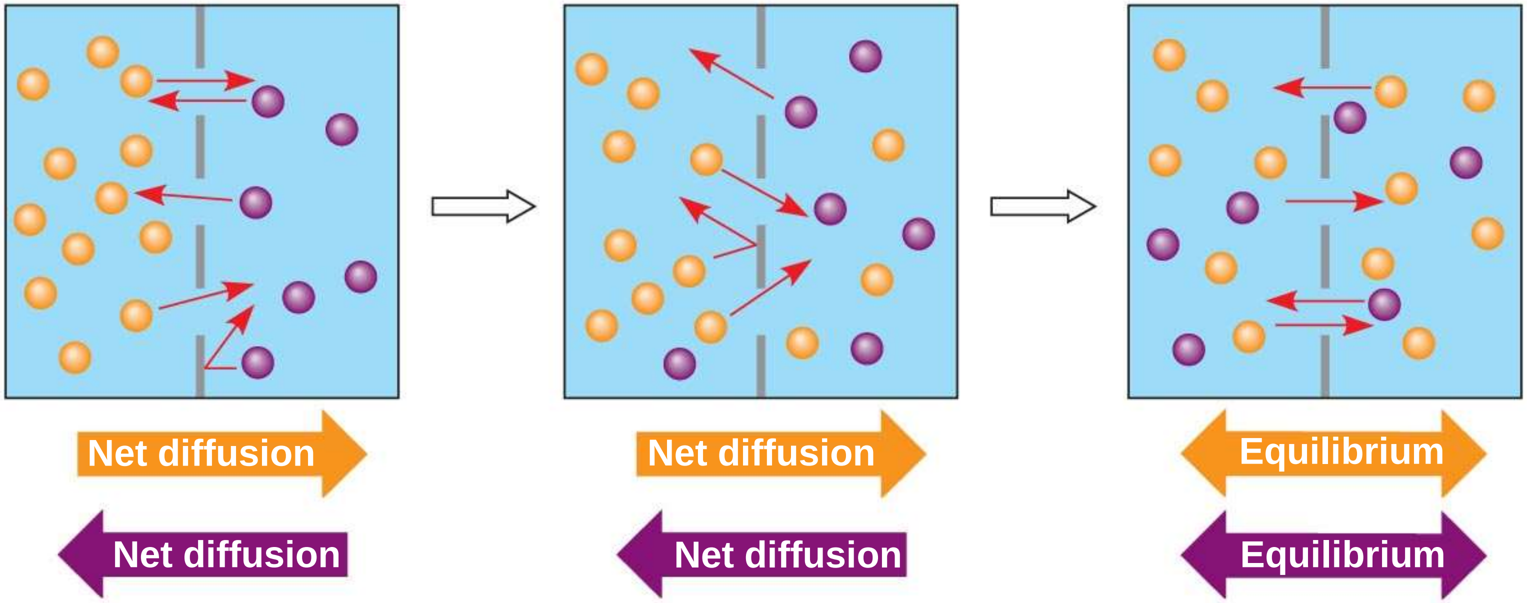
- At dynamic equilibrium, as many molecules cross one way as cross in the other direction

PLAY Animation: Membrane Selectivity

PLAY Animation: Diffusion



(a) Diffusion of one solute

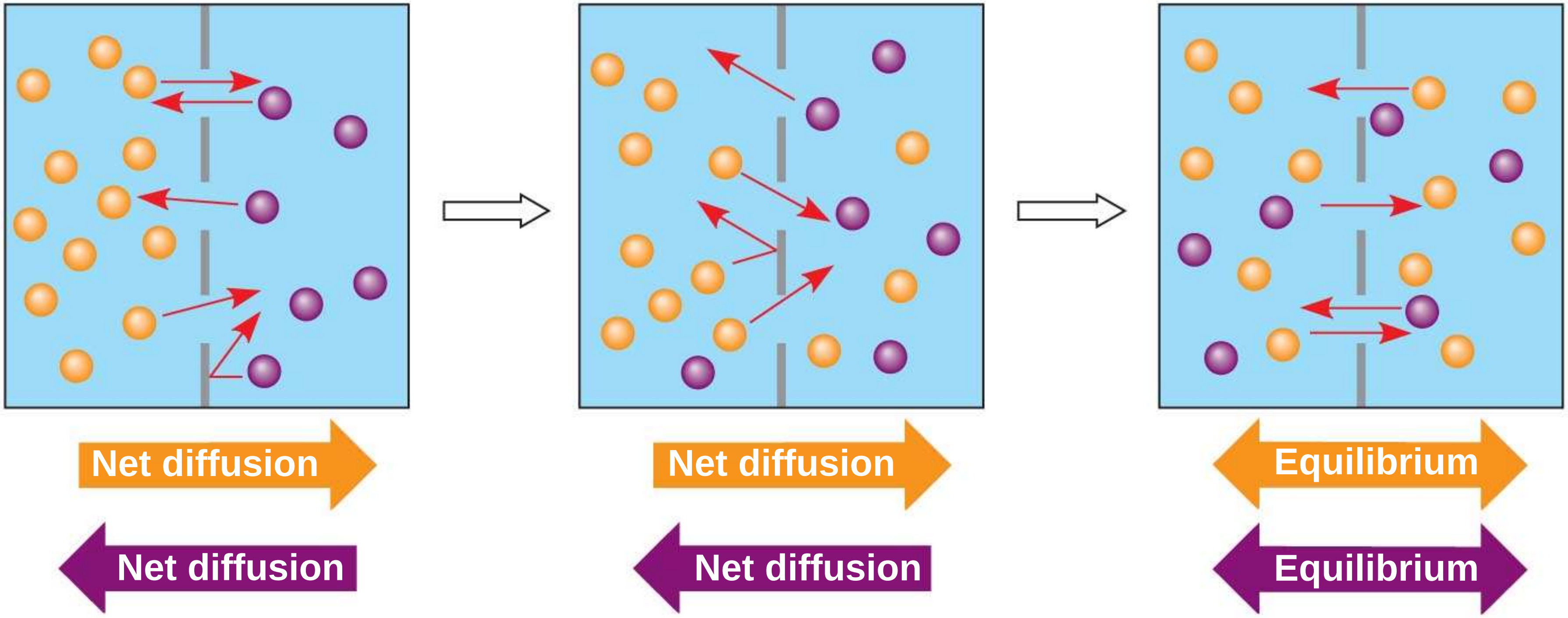


(b) Diffusion of two solutes

- 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**

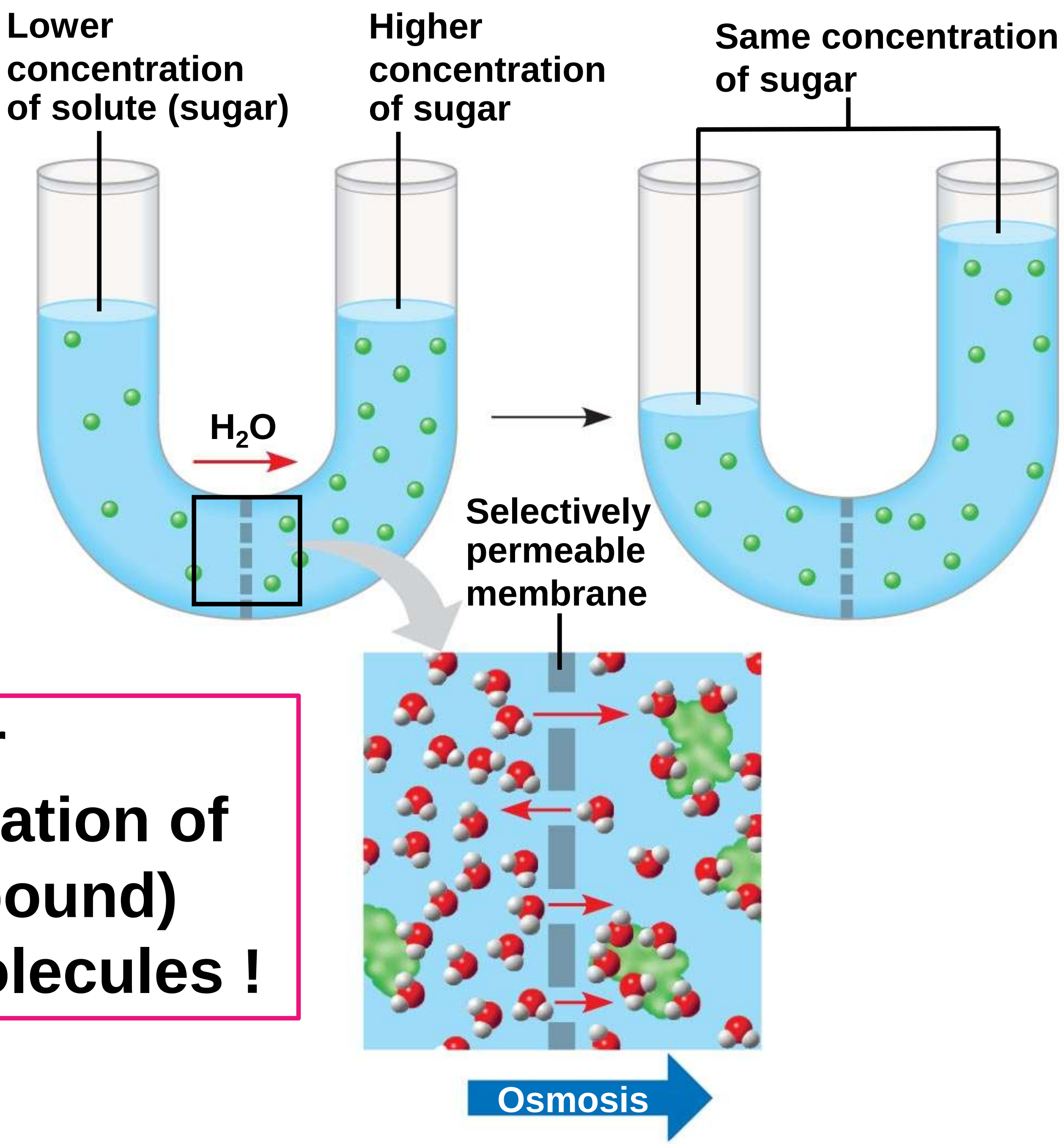
- The **diffusion** of a substance across a biological membrane is **passive transport** because it requires no energy from the cell to make it happen



(b) Diffusion of two solutes

Effects of Osmosis on Water Balance

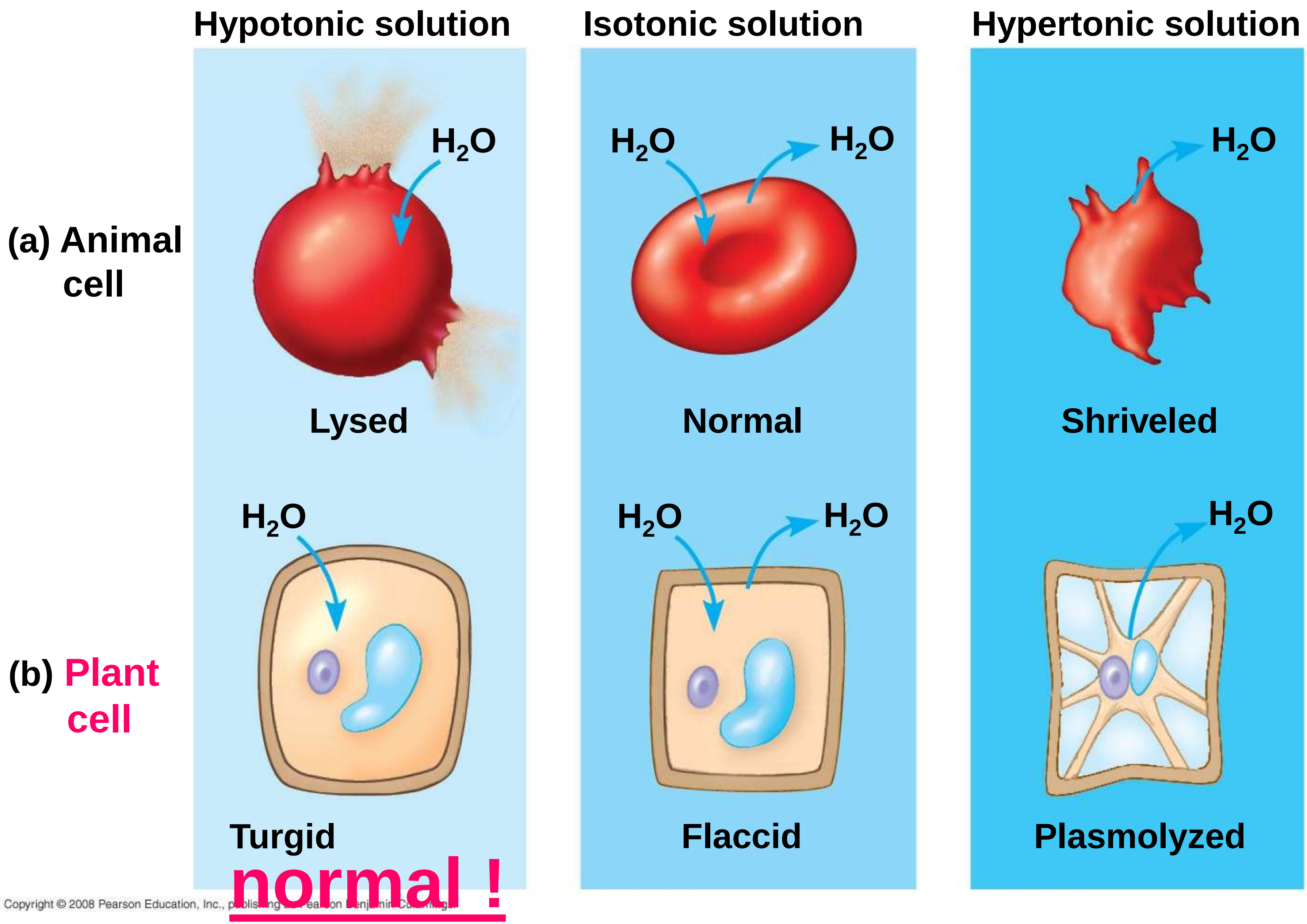
- **Osmosis** is **the diffusion of water across a selectively permeable membrane**
- Water diffuses across a membrane from the region of lower solute concentration to the region of higher solute concentration



Consider concentration of free (unbound) water molecules !

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

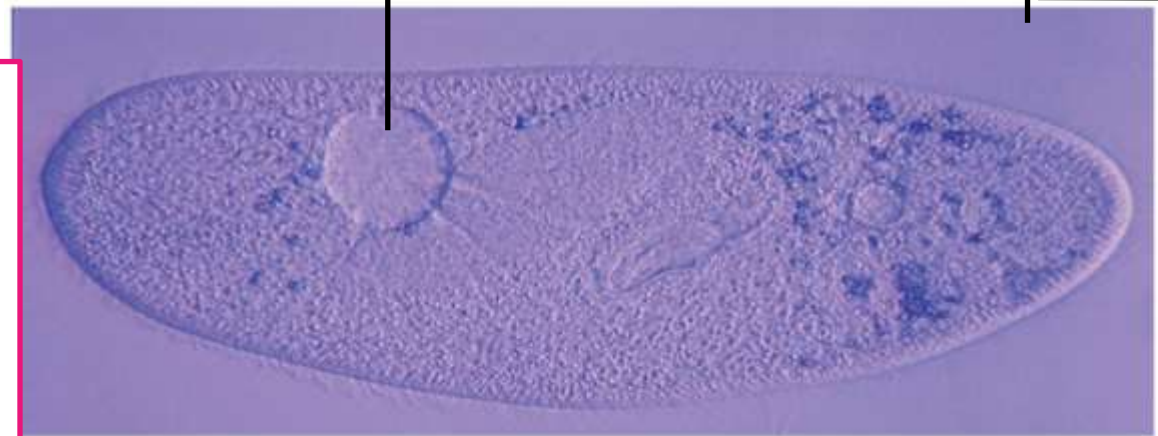

Hypotonic solution
Isotonic solution
Hypertonic solution
(a) Animal cell
H_2O
H_2O
H_2O
H_2O
Lysed
Normal
Shriveled
(b) Plant cell
H_2O
H_2O
H_2O
H_2O
Turgid
Flaccid
Plasmolyzed
normal !

- 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**

The contractile vacuole of *Paramecium*: an evolutionary adaptation for osmoregulation



(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

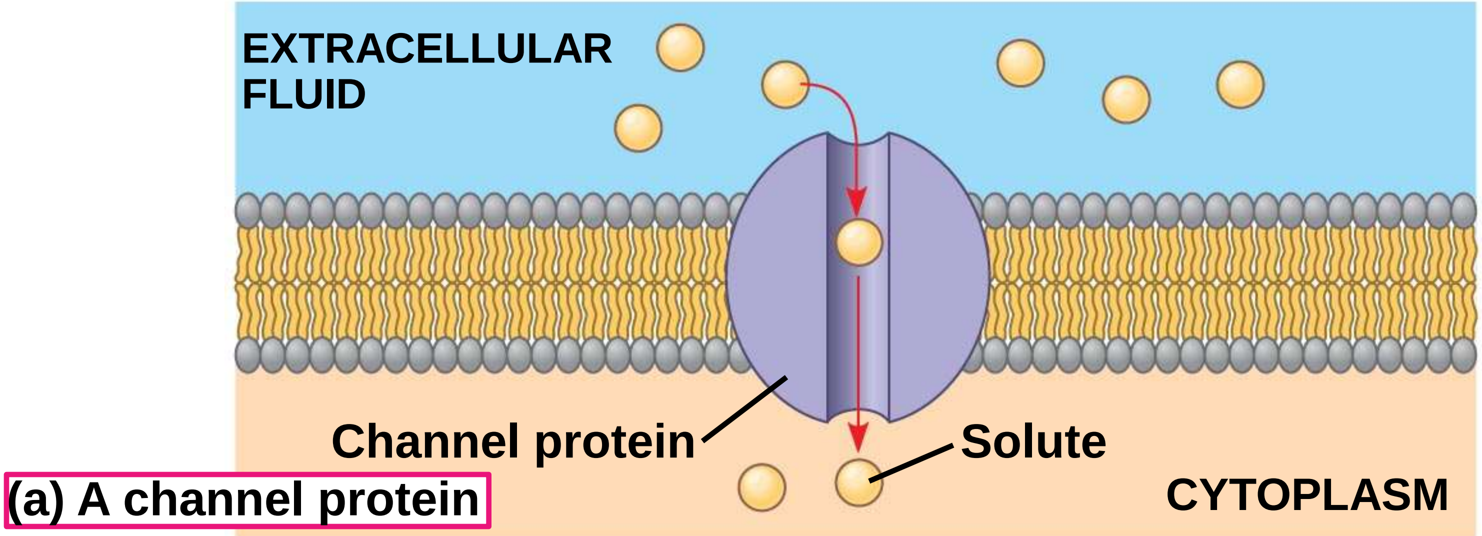
- Cell walls help maintain water balance
- A plant cell in a **hypotonic** solution swells until the wall opposes uptake; the cell is now **turgid** (firm)
- If a plant cell and its surroundings are **isotonic**, there is no net movement of water into the cell; the cell becomes **flaccid** (limp), and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

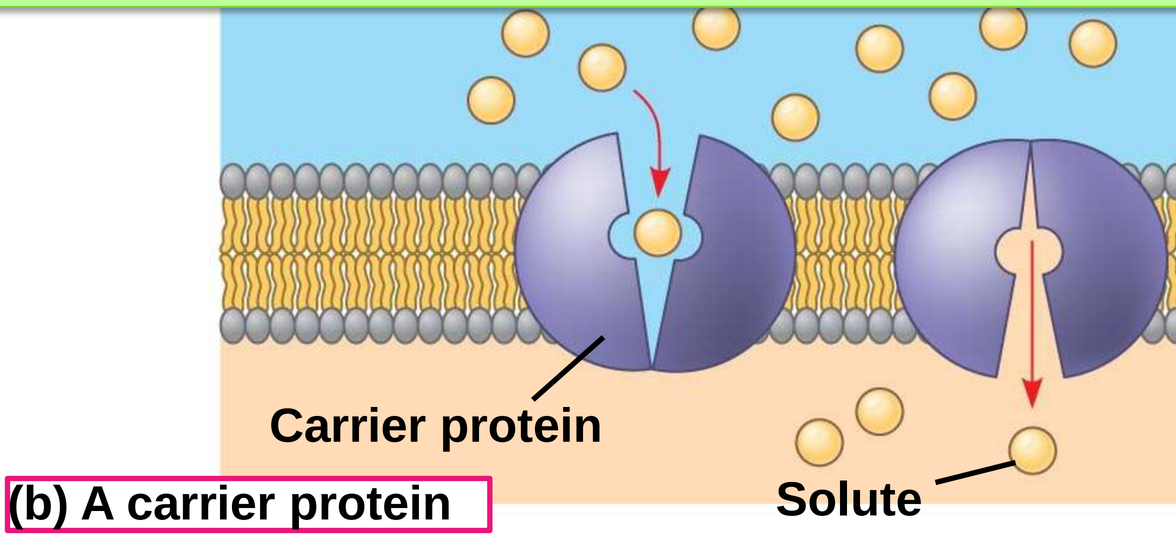
PLAY Animation: Osmosis

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**)



Two types of transport proteins that carry out facilitated diffusion



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

Active transport uses energy to move solutes against their gradients

- **Facilitated diffusion** is still **passive** because the solute moves down its concentration gradient

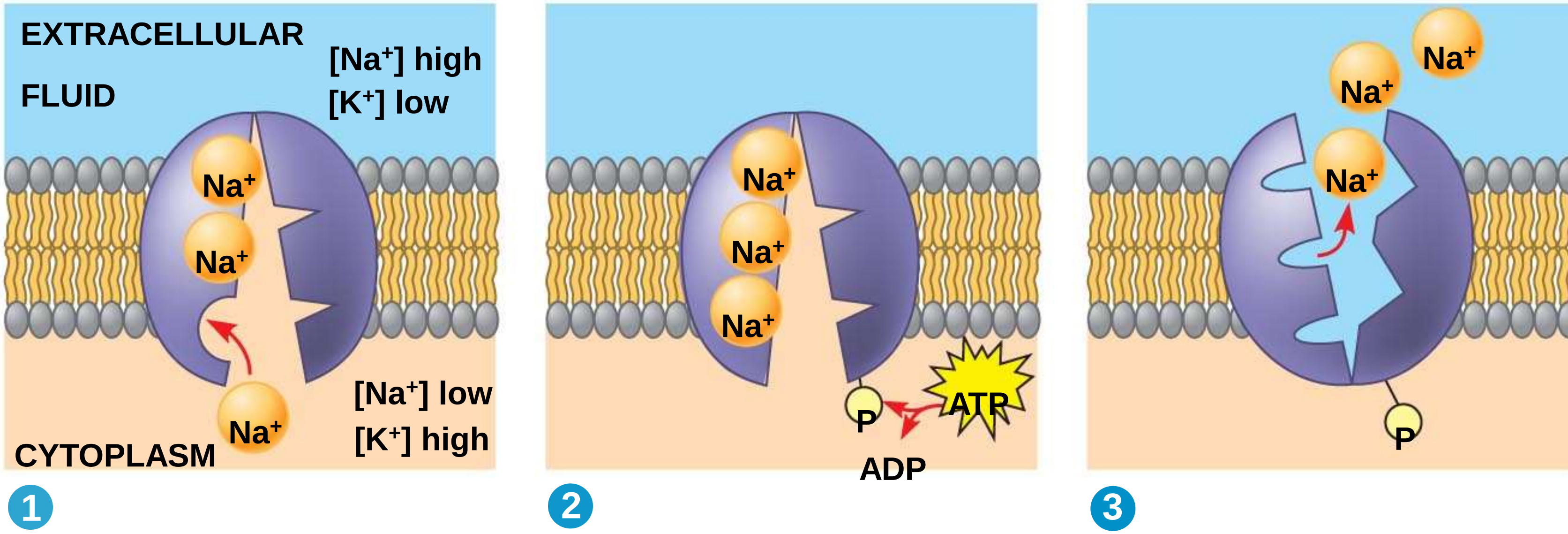
- Some transport proteins, however, **can move solutes against their concentration gradients**

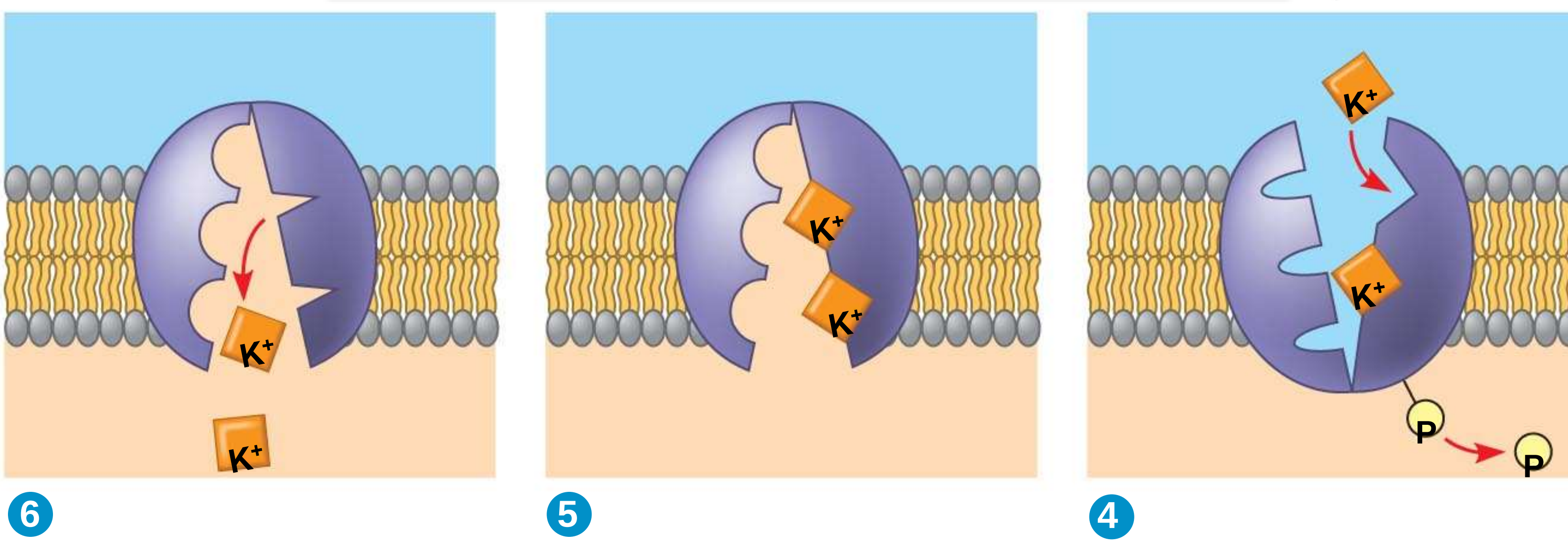
The Need for Energy in Active Transport

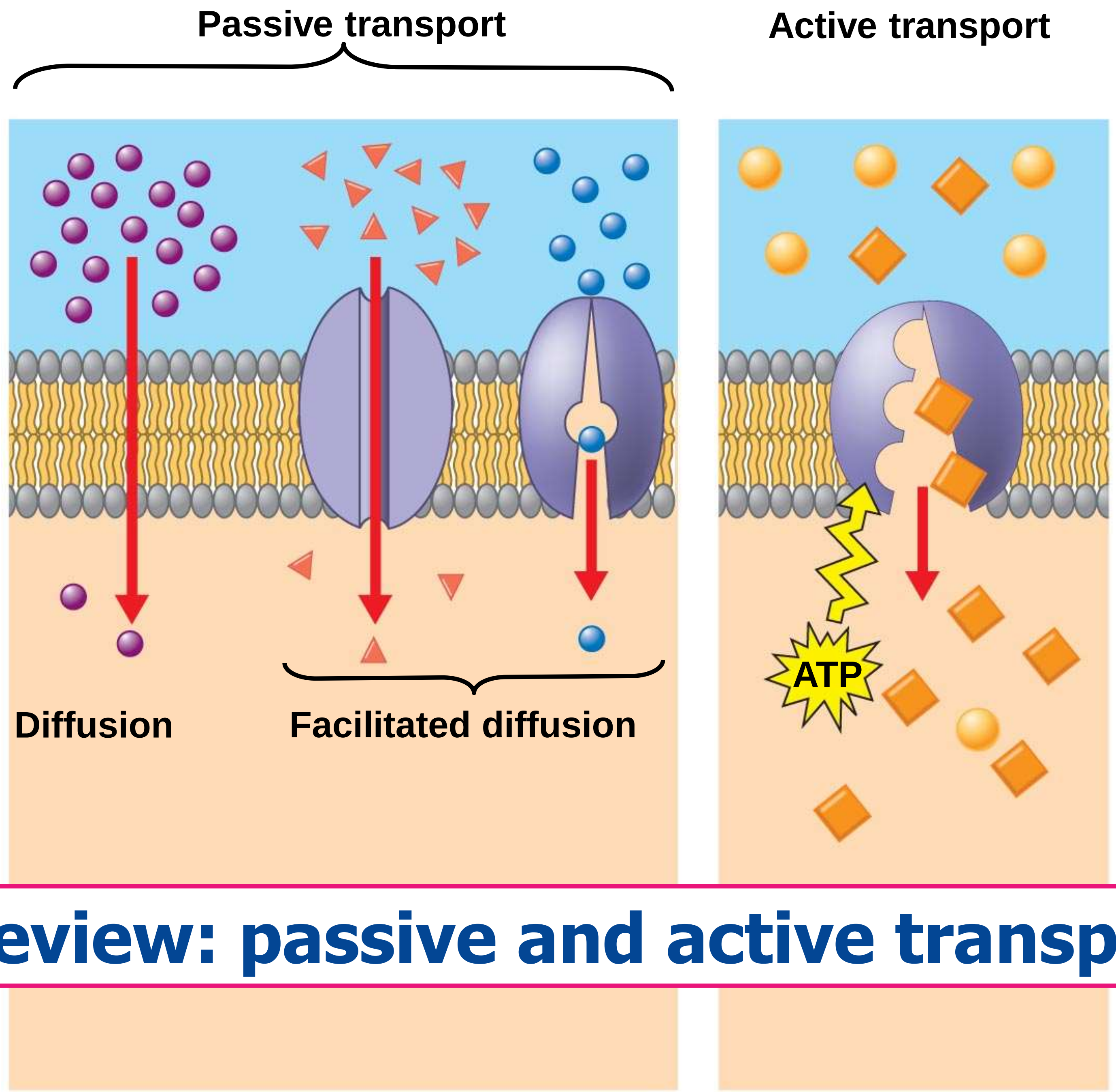
- **Active transport** moves substances against their concentration gradient
- Active transport **requires energy**, usually in the form of ATP
- Active transport is performed by specific proteins embedded in the membranes
- Active transport allows cells to maintain concentration gradients that differ from their surroundings
- The **sodium-potassium pump** is one type of active transport system

PLAY Animation: Active Transport

The sodium-potassium pump: a specific case of active transport







Review: passive and active transport

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

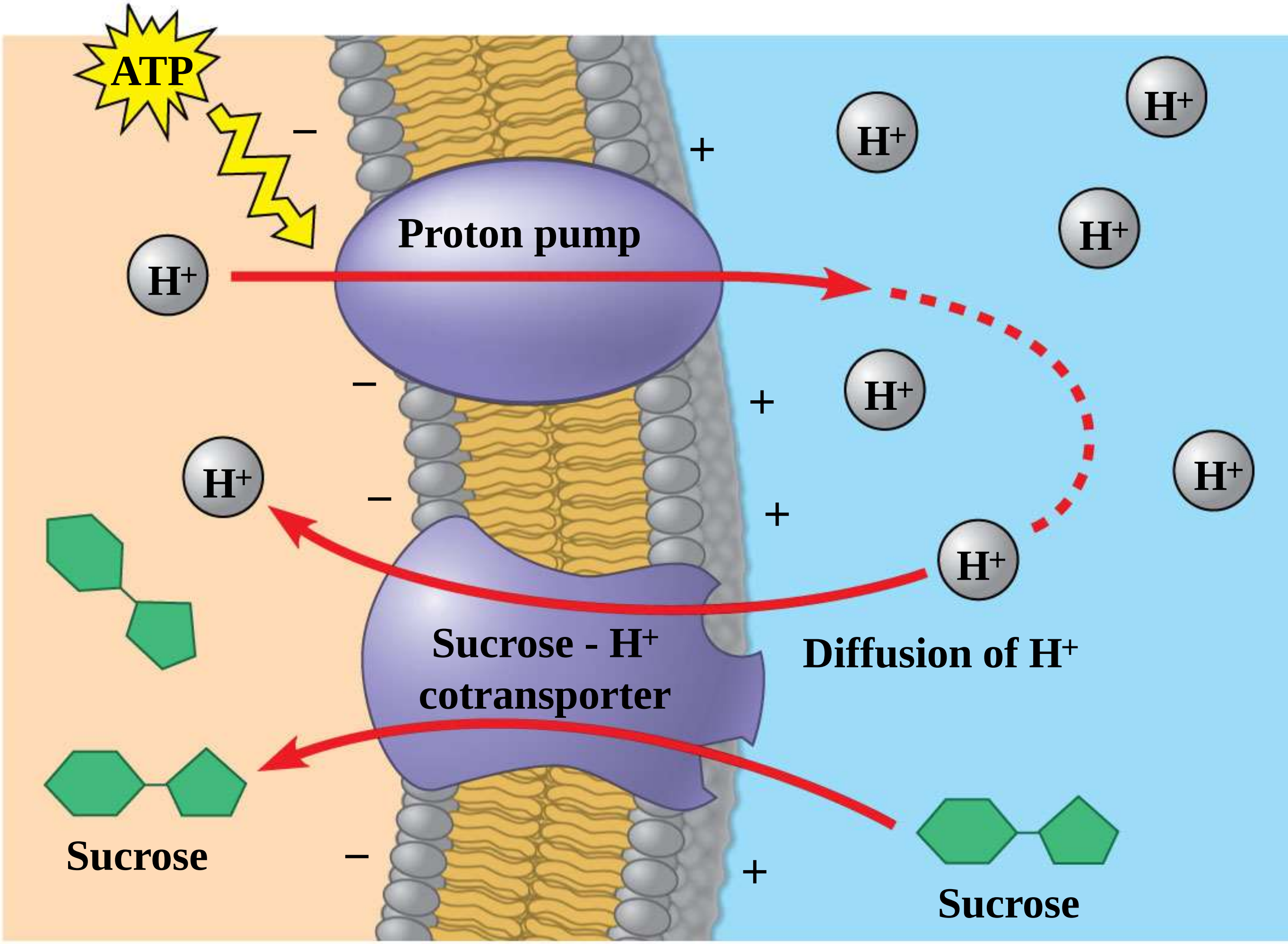
  - Two combined forces, collectively called the **electrochemical gradient**, drive the diffusion of ions across a membrane:
    - A **chemical force** (the ion's concentration gradient)
    - An **electrical force** (the effect of the membrane potential on the ion's movement)

- 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**

Cotransport: Coupled Transport by a Membrane Protein

- **Cotransport** occurs when active transport of a solute **indirectly** drives transport of another solute

- **Plants**, for example, commonly **use the gradient of hydrogen ions generated by proton pumps** to drive **active transport of nutrients into the cell**


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

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

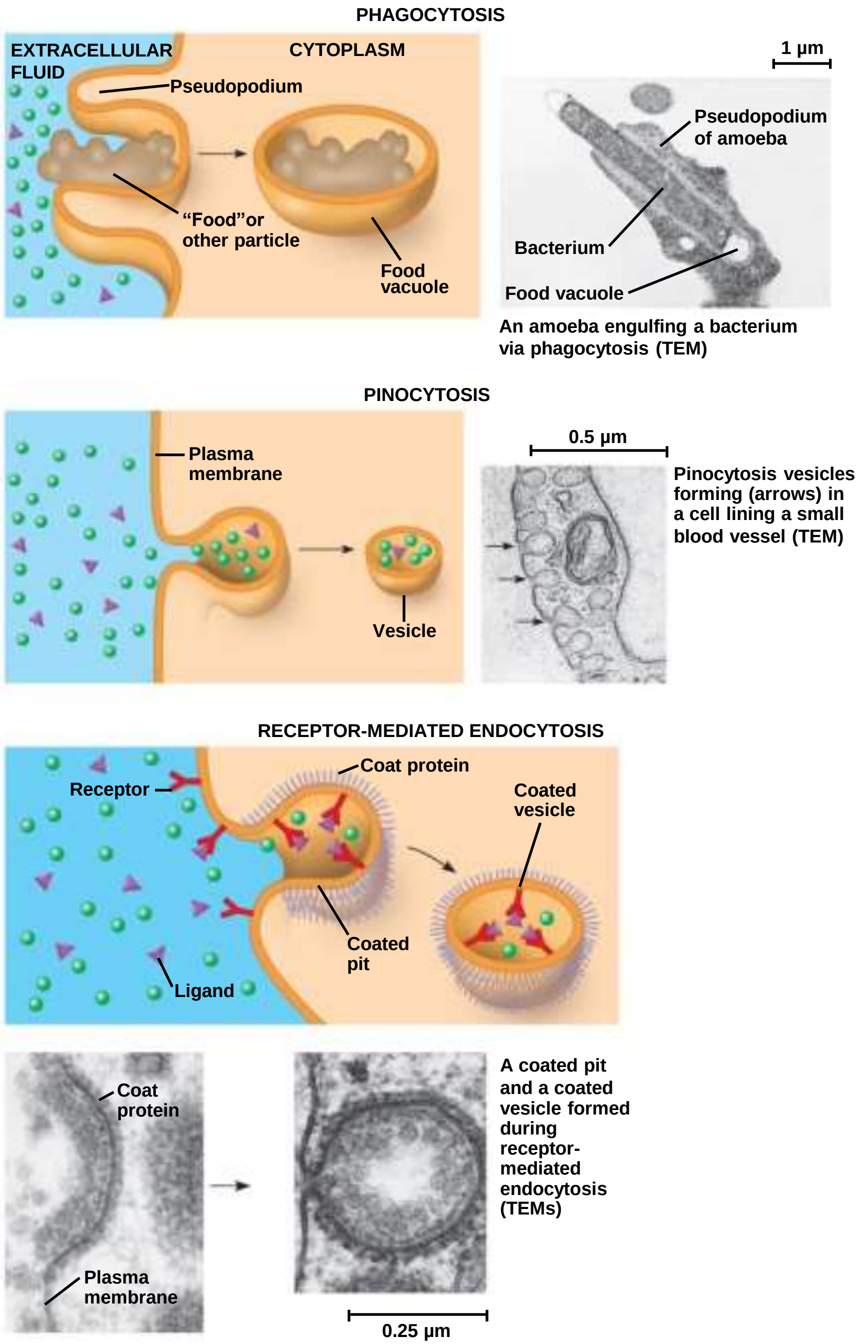
- In **exocytosis**, transport vesicles migrate to the membrane, fuse with it, and release their contents
- Many secretory cells use exocytosis to export their products

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**



Endocytosis in animal cells

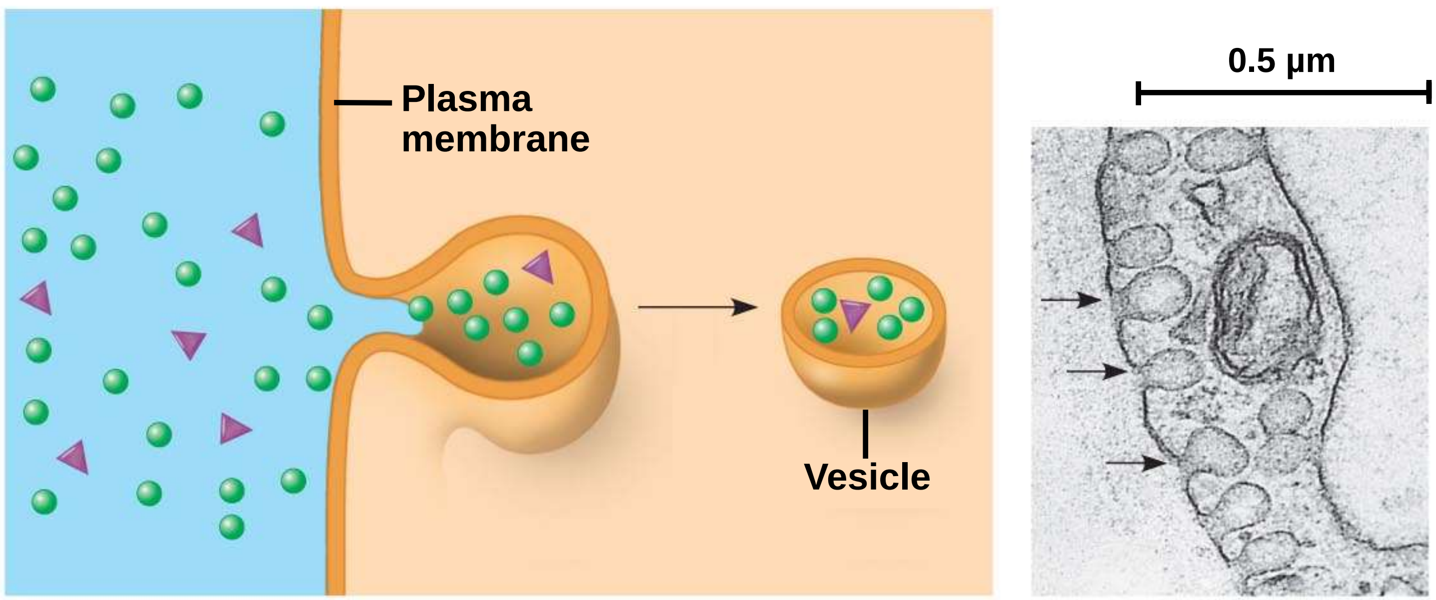
- In **phagocytosis** a cell engulfs a particle in a vacuole
- The vacuole fuses with a lysosome to digest the particle

PLAY **Animation: Phagocytosis**

Fig. 7-20b

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

PINOCYTOSIS



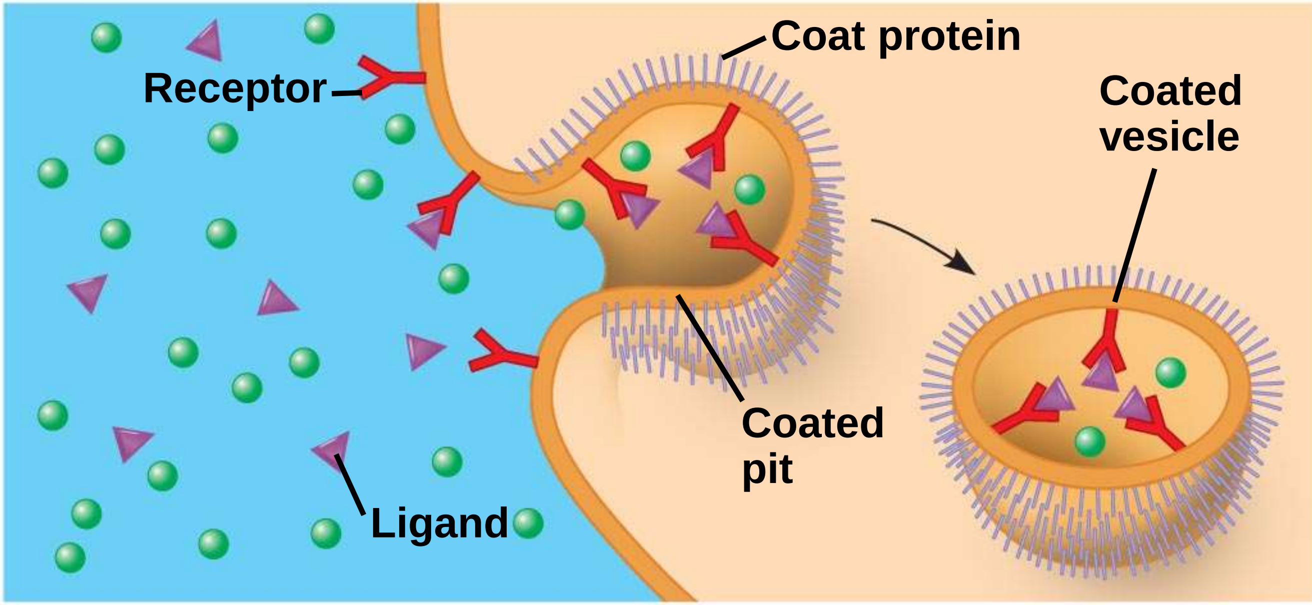
Pinocytosis vesicles forming (arrows) in a cell lining a small blood vessel (TEM)

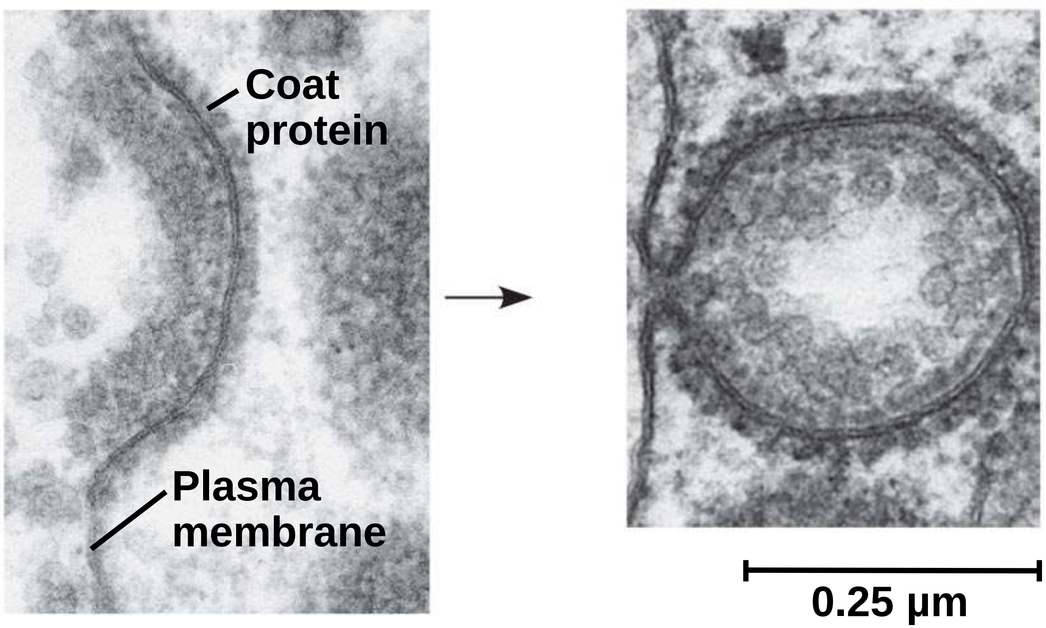
PLAY Animation: Pinocytosis

- 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**

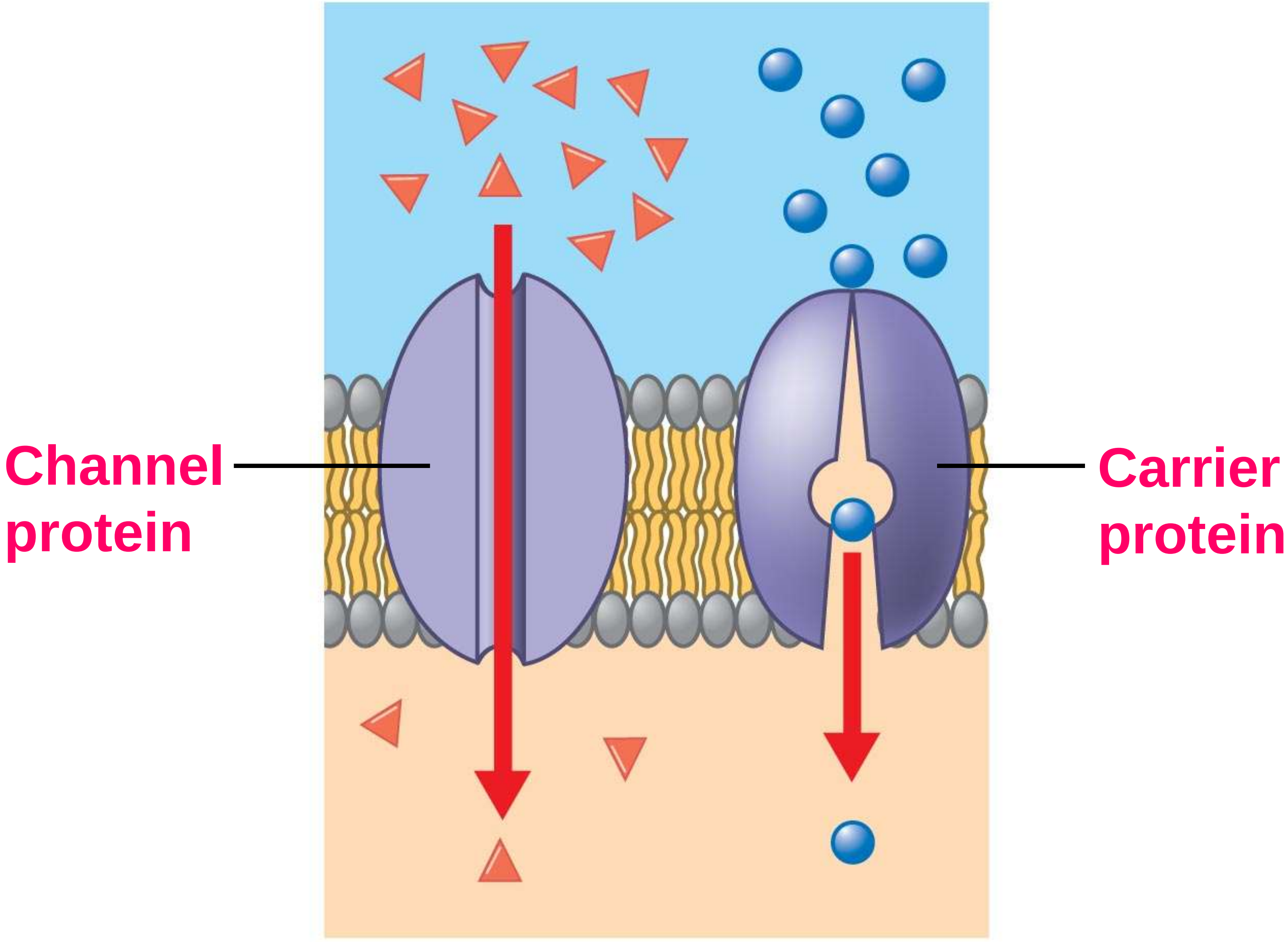
RECEPTOR-MEDIATED ENDOCYTOSIS



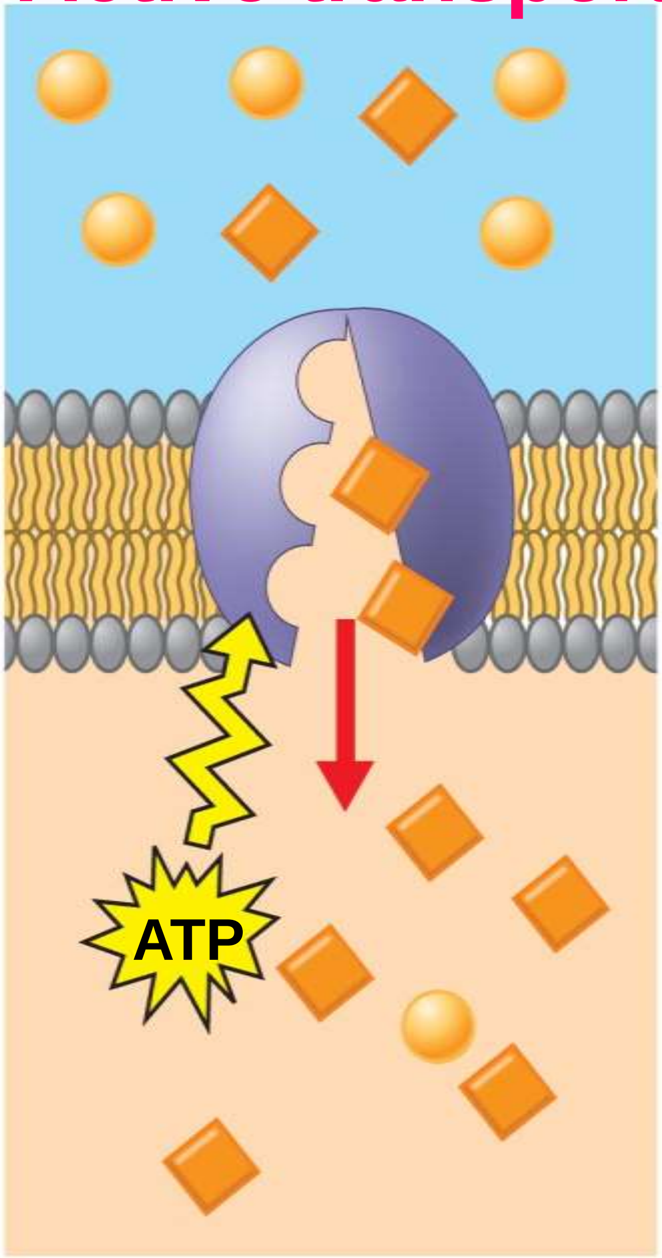


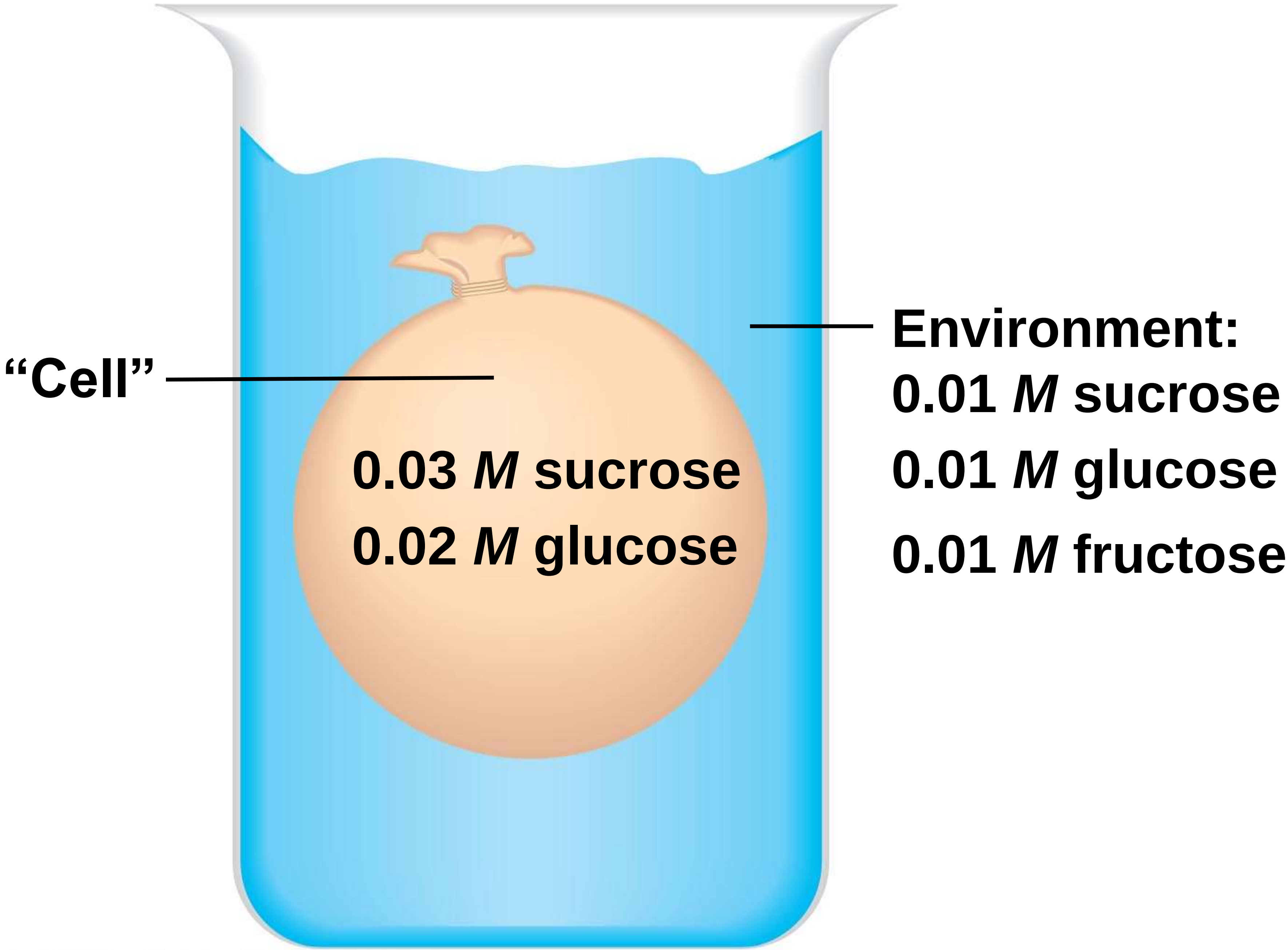
A coated pit and a coated vesicle formed during receptor-mediated endocytosis (TEMs)

Passive transport: Facilitated diffusion



Active transport:




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

Questions ?

Questions ?