Membranes and membrane transport

Life at the Edge

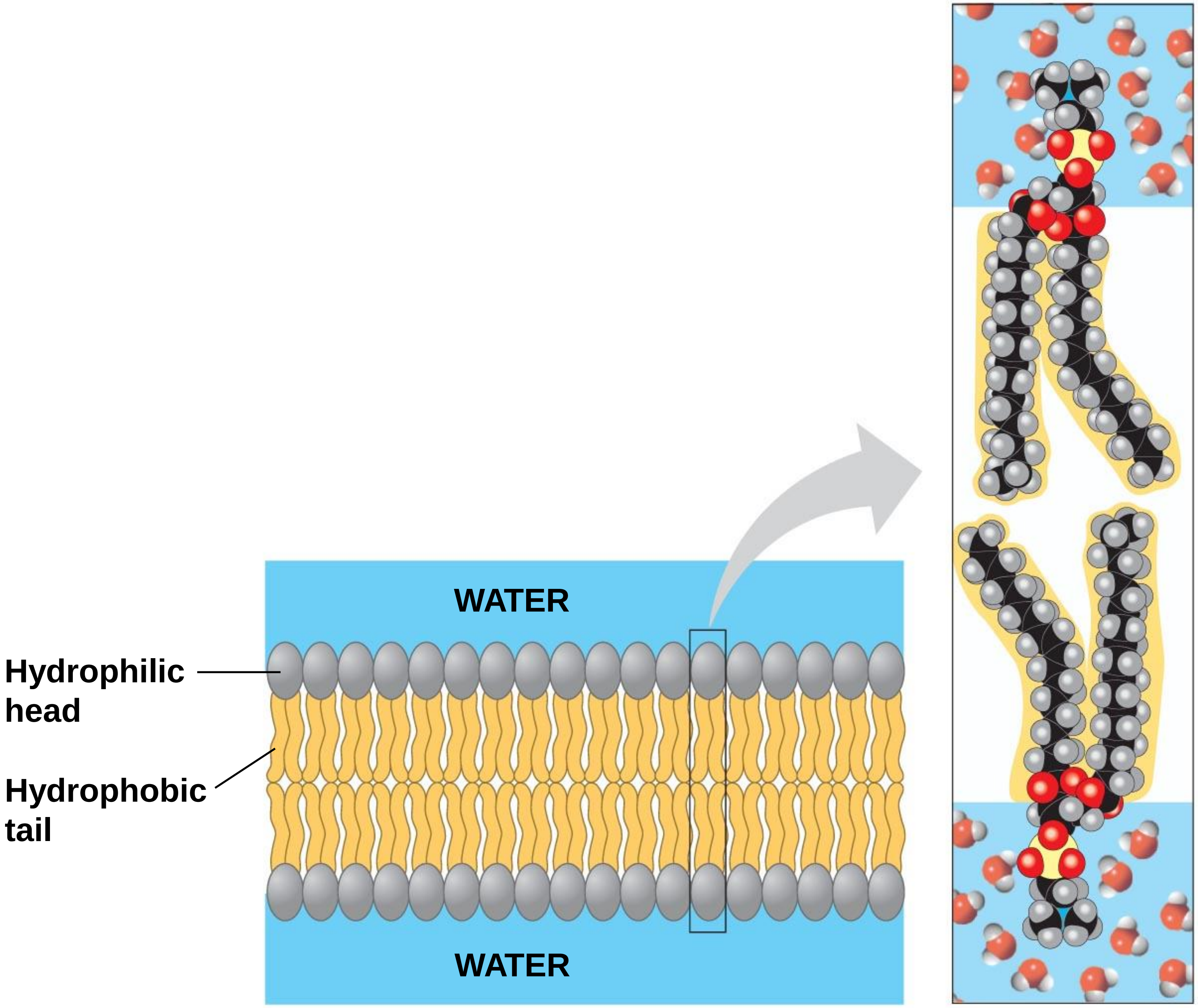
- The **plasma membrane** is the boundary that separates the living cell from its nonliving surroundings
- The plasma membrane exhibits **selective permeability**, allowing some substances to cross it more easily than others

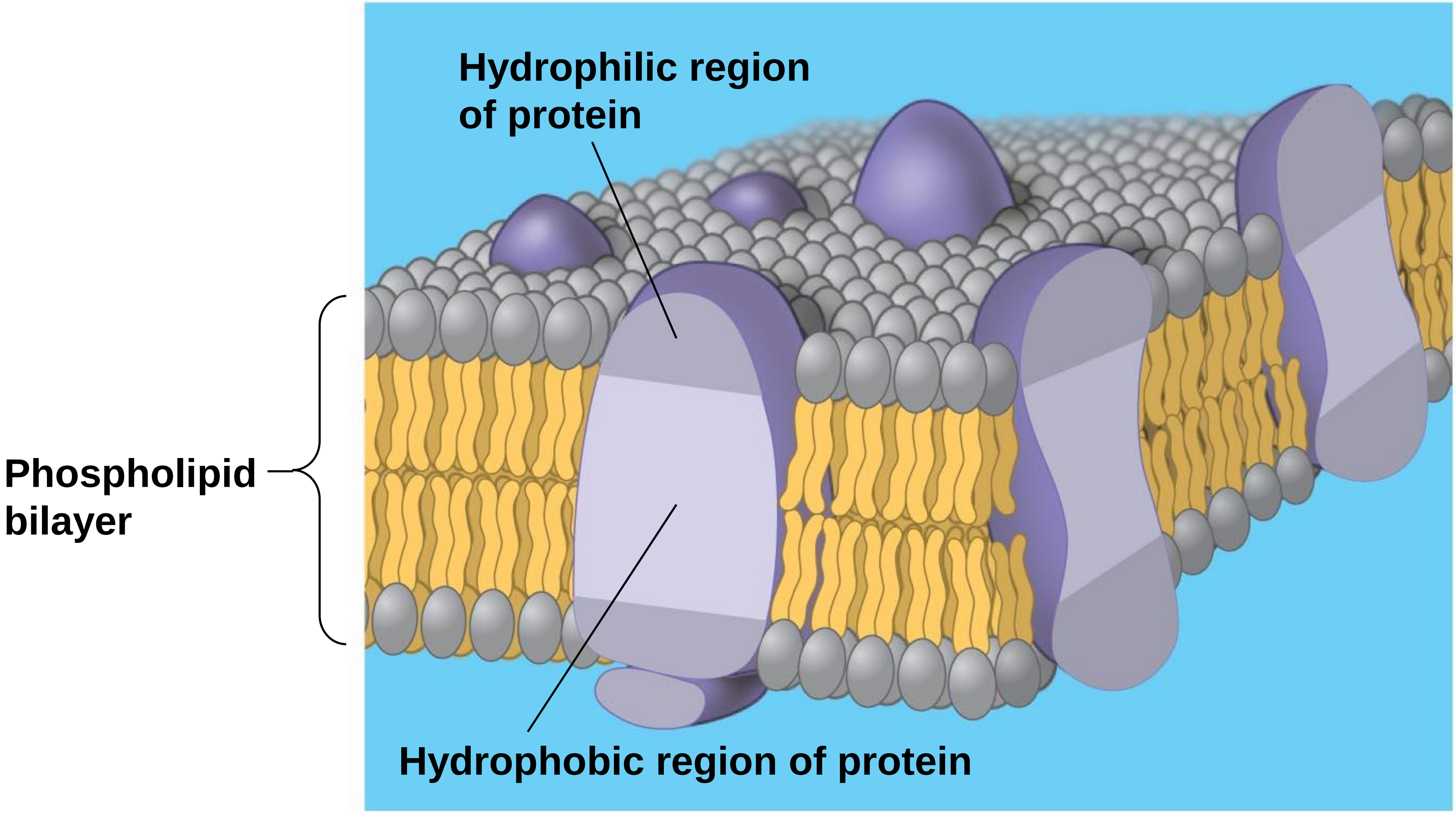
Cellular membranes are fluid mosaics of lipids and proteins

- **Phospholipids** are the most abundant lipid in the plasma membrane

- Phospholipids are **amphipathic molecules**, containing **hydrophobic and hydrophilic regions**

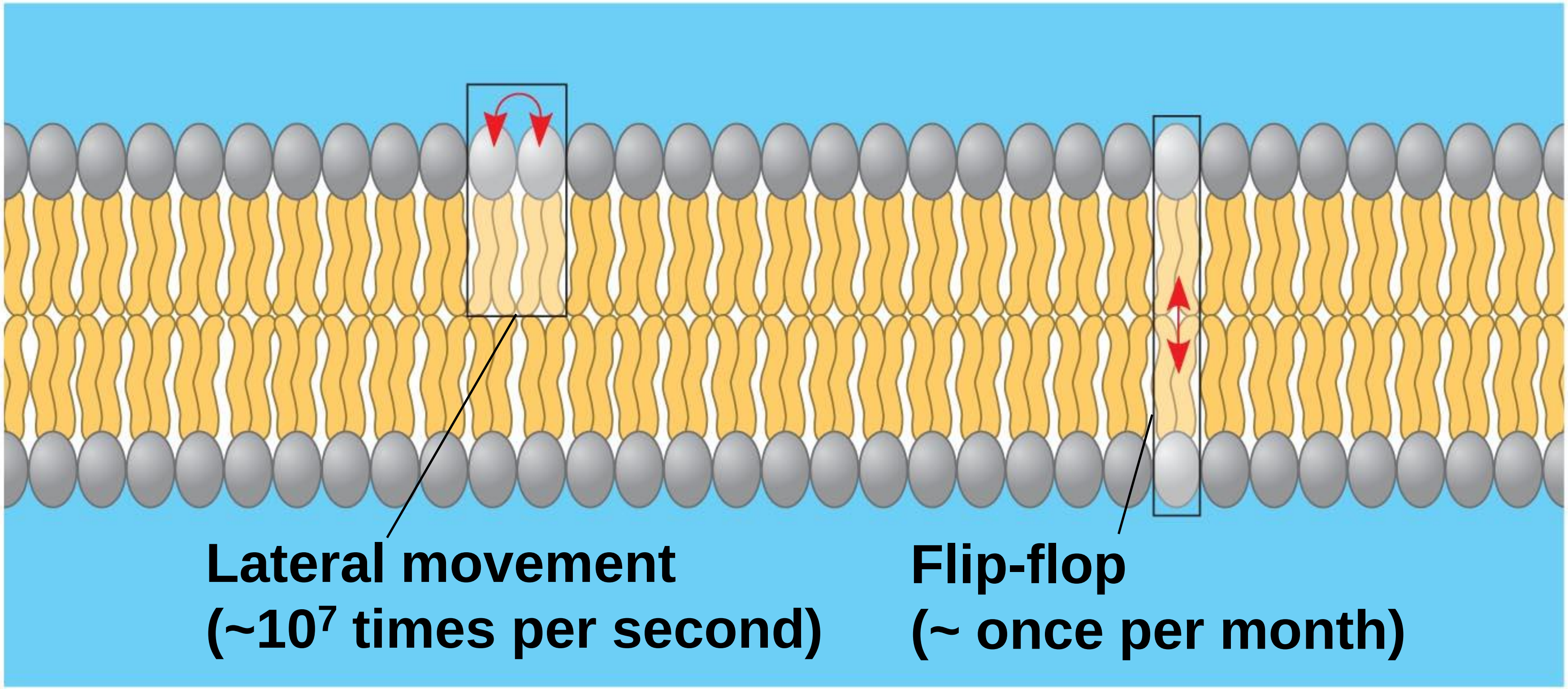
- The **fluid mosaic** model states that a membrane is a fluid structure with a “mosaic” of various proteins embedded in it


WATER
Hydrophilic head
Hydrophobic tail
WATER


Hydrophilic region
of protein
Phospholipid
bilayer
Hydrophobic region of protein

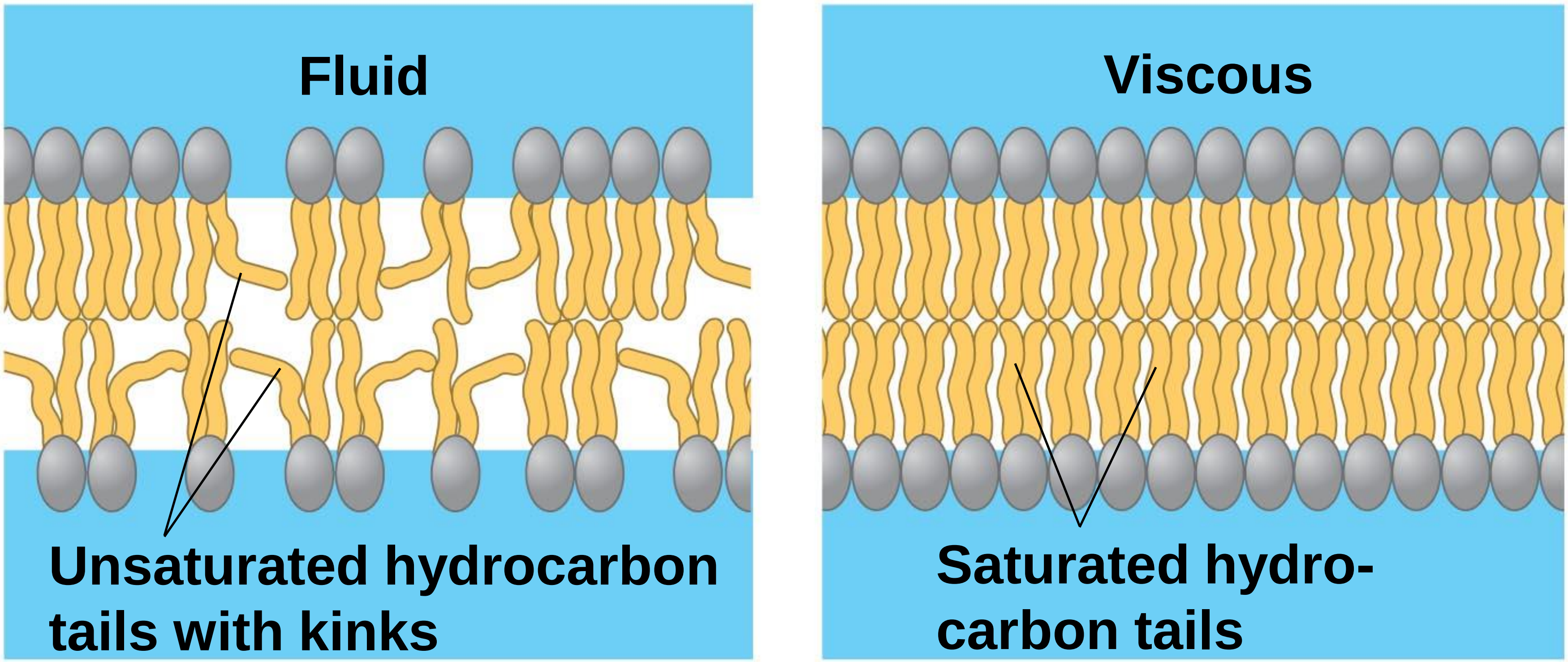
The Fluidity of Membranes

- 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**



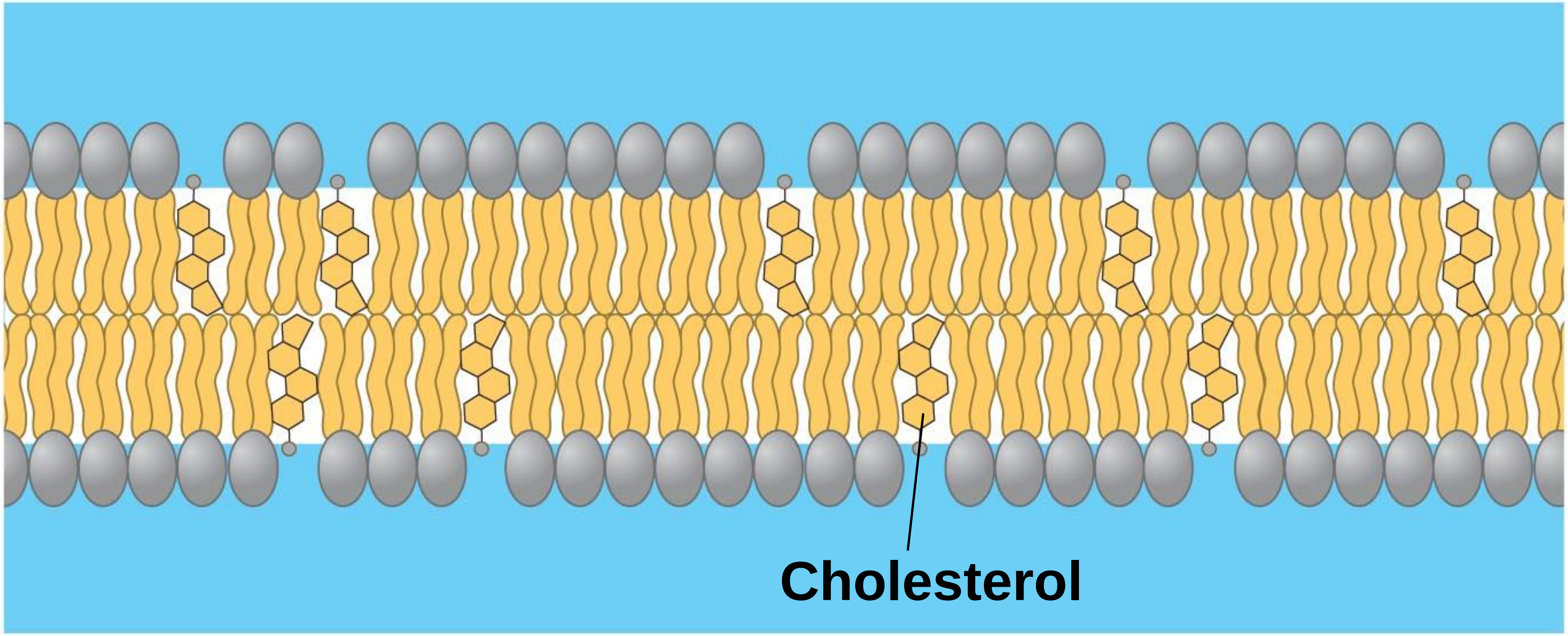
(a) Movement of phospholipids

- 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*



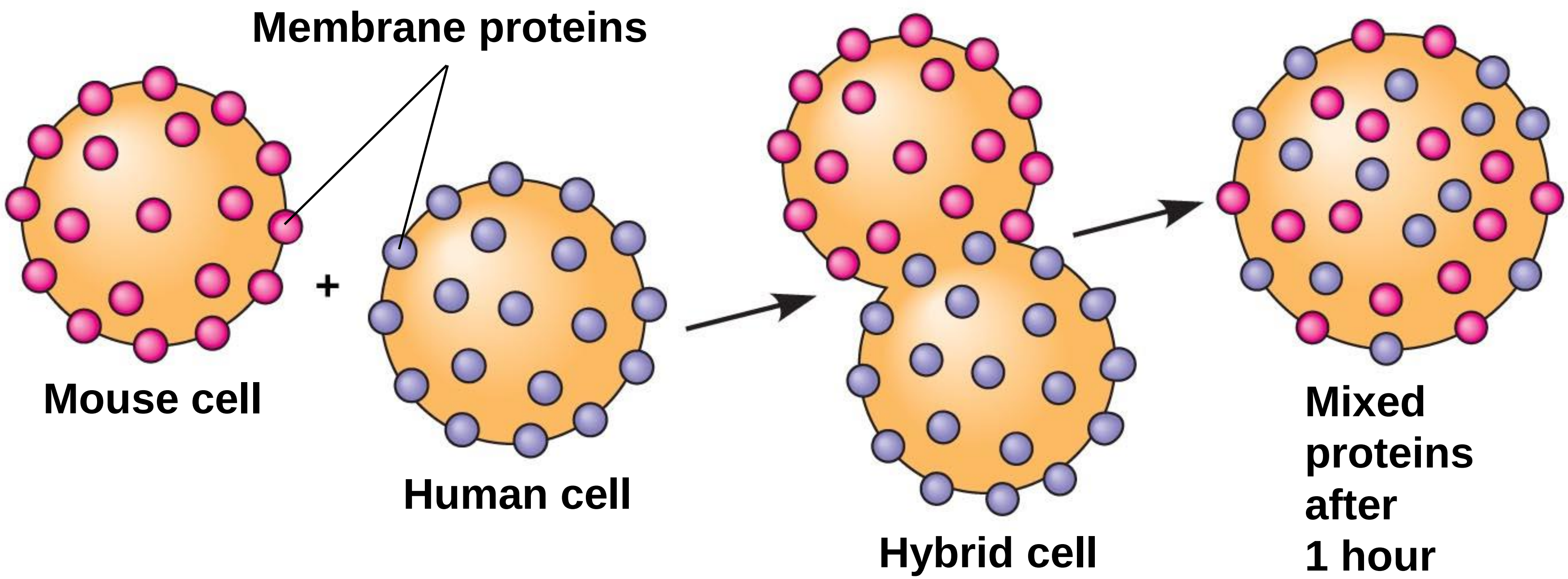
(b) Membrane fluidity

- 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



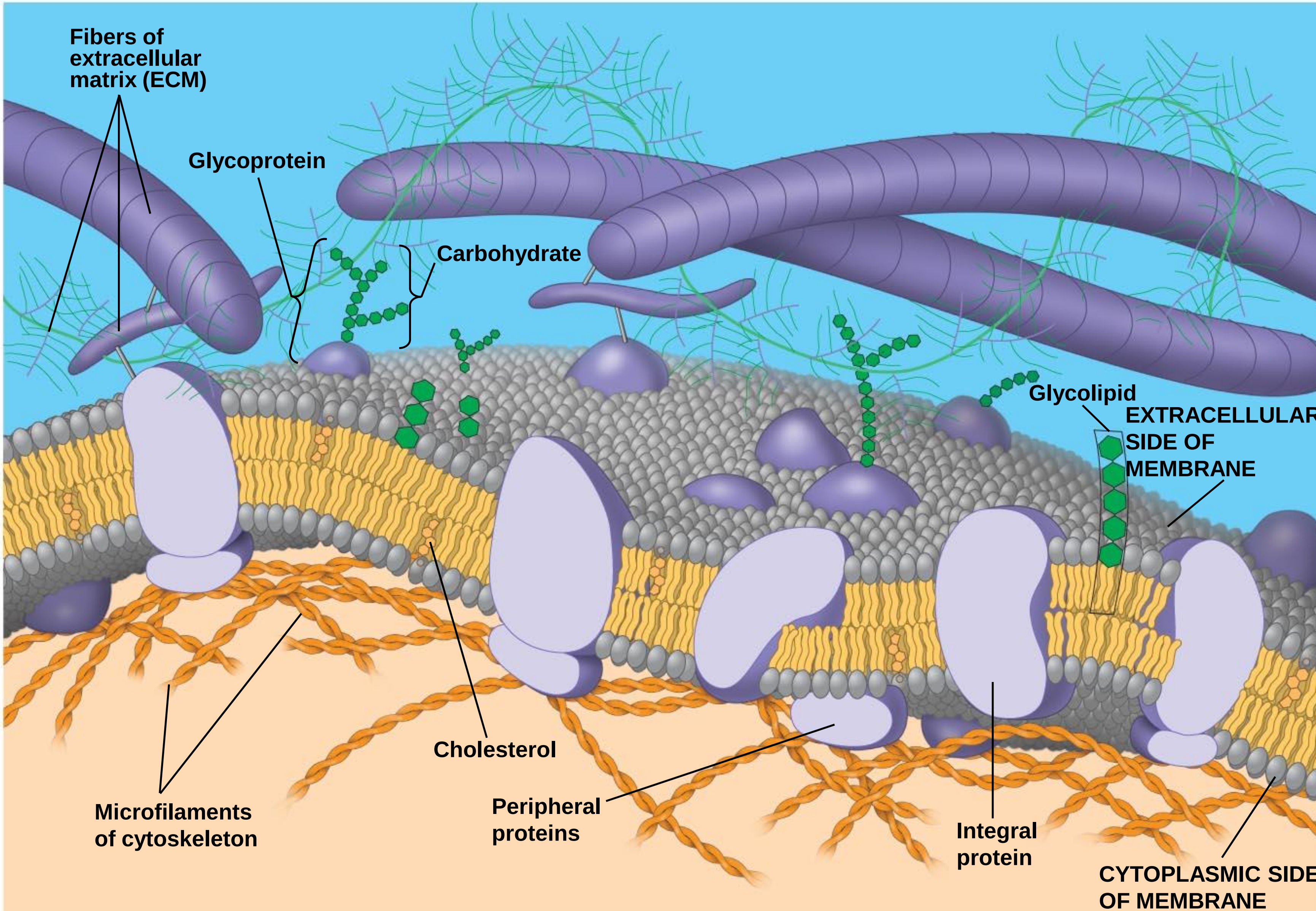
(c) Cholesterol within the animal cell membrane

- Some proteins in the plasma membrane can drift within the bilayer
- Proteins are much larger than lipids and move more slowly

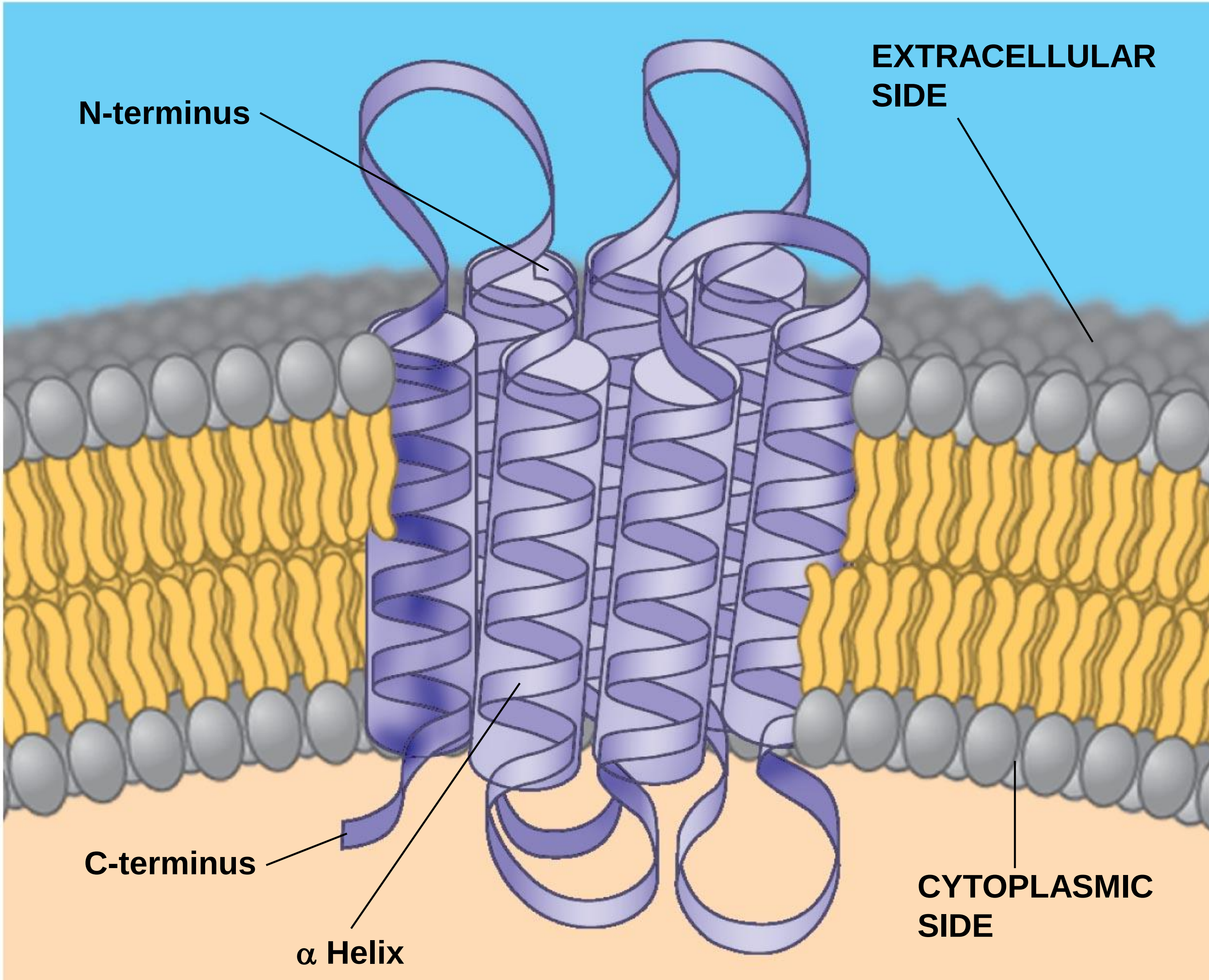

Membrane proteins
Mouse cell
+
Human cell
Hybrid cell
Mixed
proteins
after
1 hour

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 not embedded
- **Integral proteins** penetrate the hydrophobic core and often span the membrane

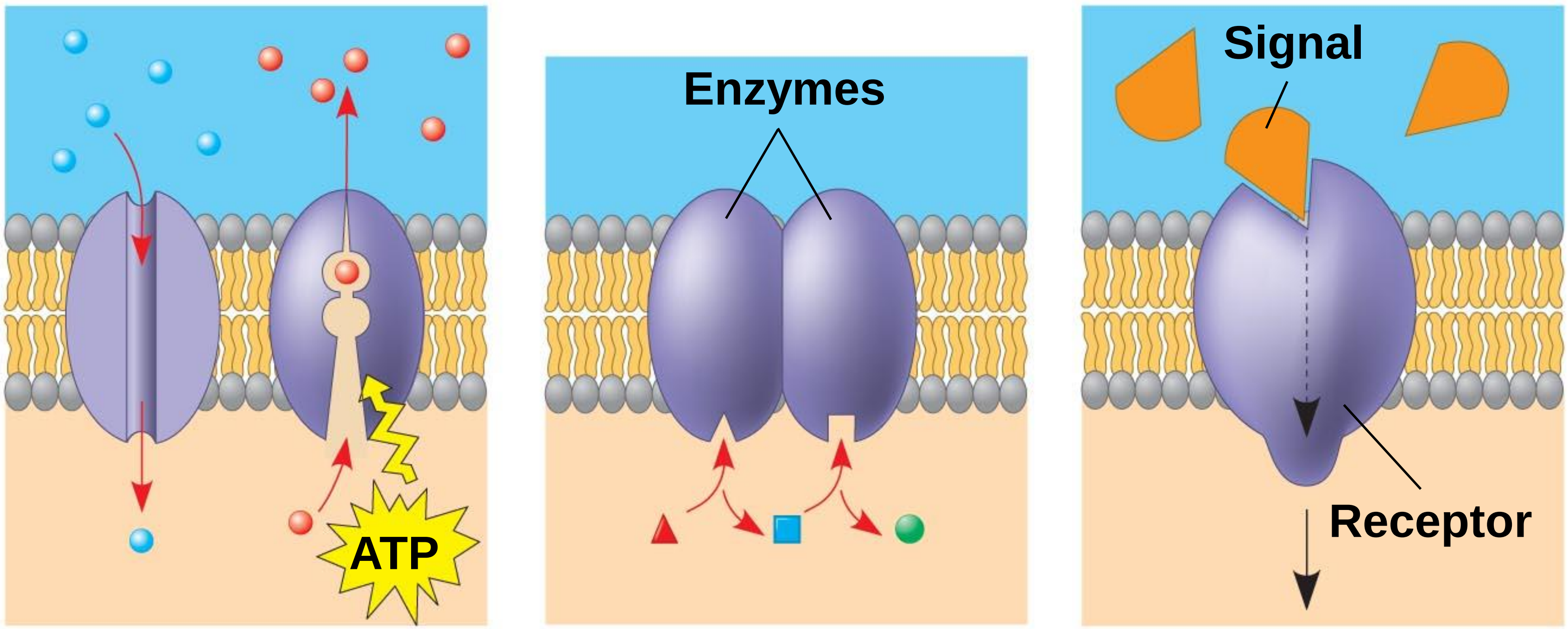

Fibers of extracellular matrix (ECM)
Glycoprotein
Carbohydrate
Glycolipid
EXTRACELLULAR SIDE OF MEMBRANE
Cholesterol
Microfilaments of cytoskeleton
Peripheral proteins
Integral protein
CYTOPLASMIC SIDE OF MEMBRANE

- 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*

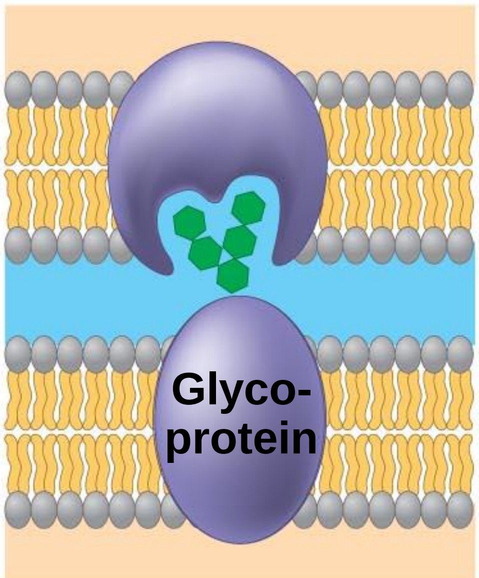


EXTRACELLULAR SIDE
N-terminus
C-terminus
α Helix
CYTOPLASMIC SIDE

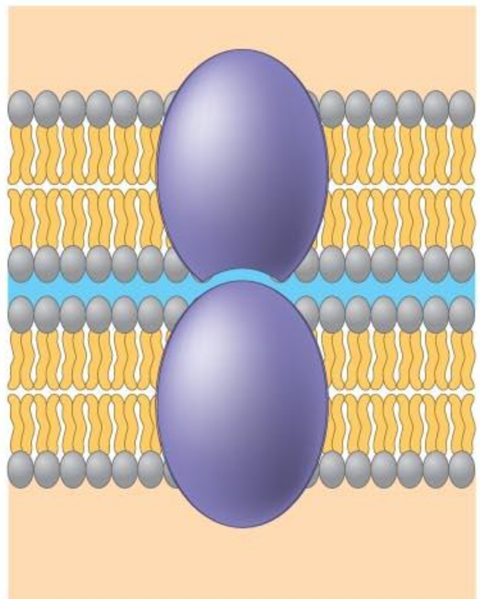
- Six major functions of membrane proteins:
  - **Transport**
  - **Enzymatic activity**
  - **Signal transduction**
  - **Cell-cell recognition**
  - **Intercellular joining**
  - **Attachment to the cytoskeleton and extracellular matrix (ECM)**



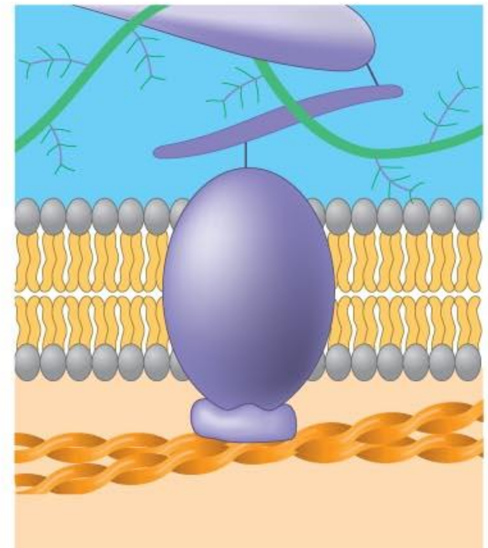
(a) Transport **(b) Enzymatic activity** **(c) Signal transduction**



(d) Cell-cell recognition



(e) Intercellular joining



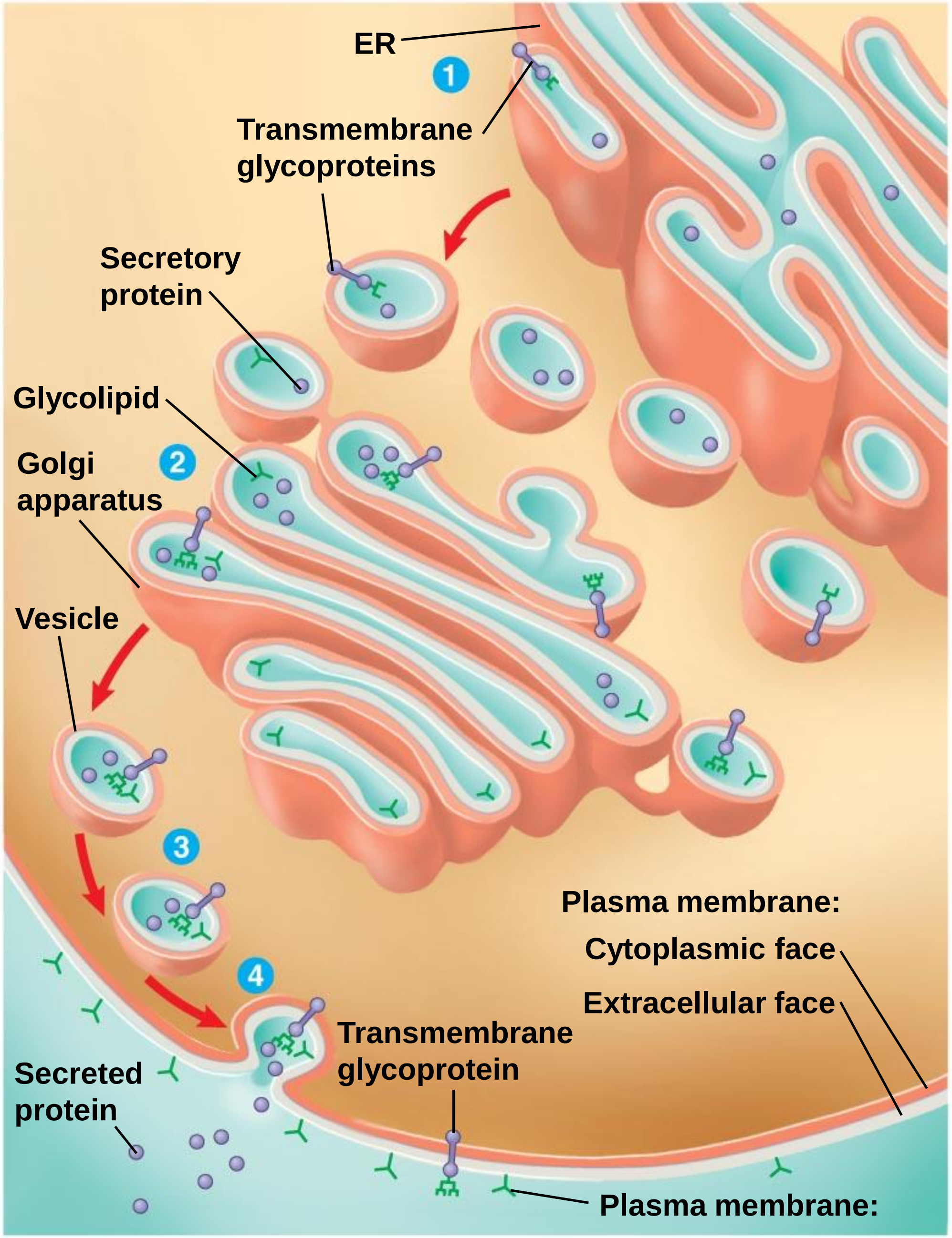
(f) Attachment to the cytoskeleton and extra-cellular matrix (ECM)

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


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

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**

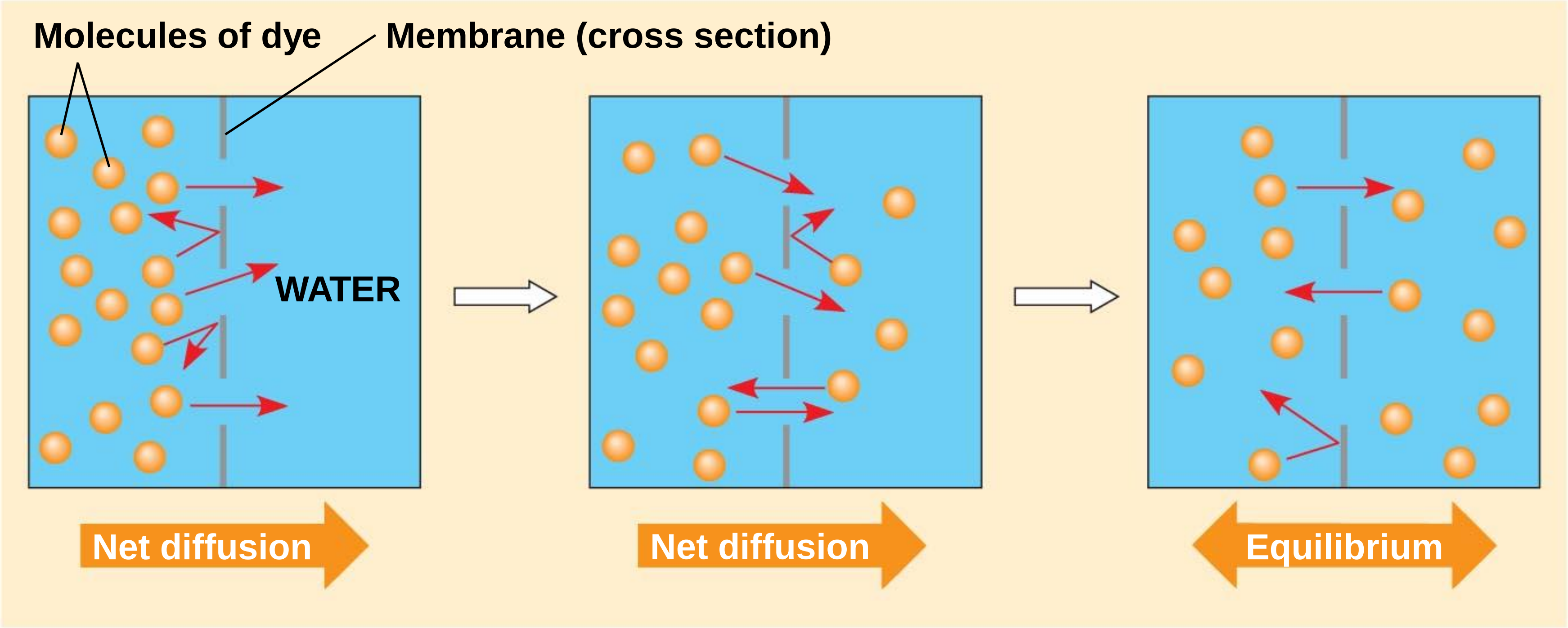
Transport Proteins

- 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

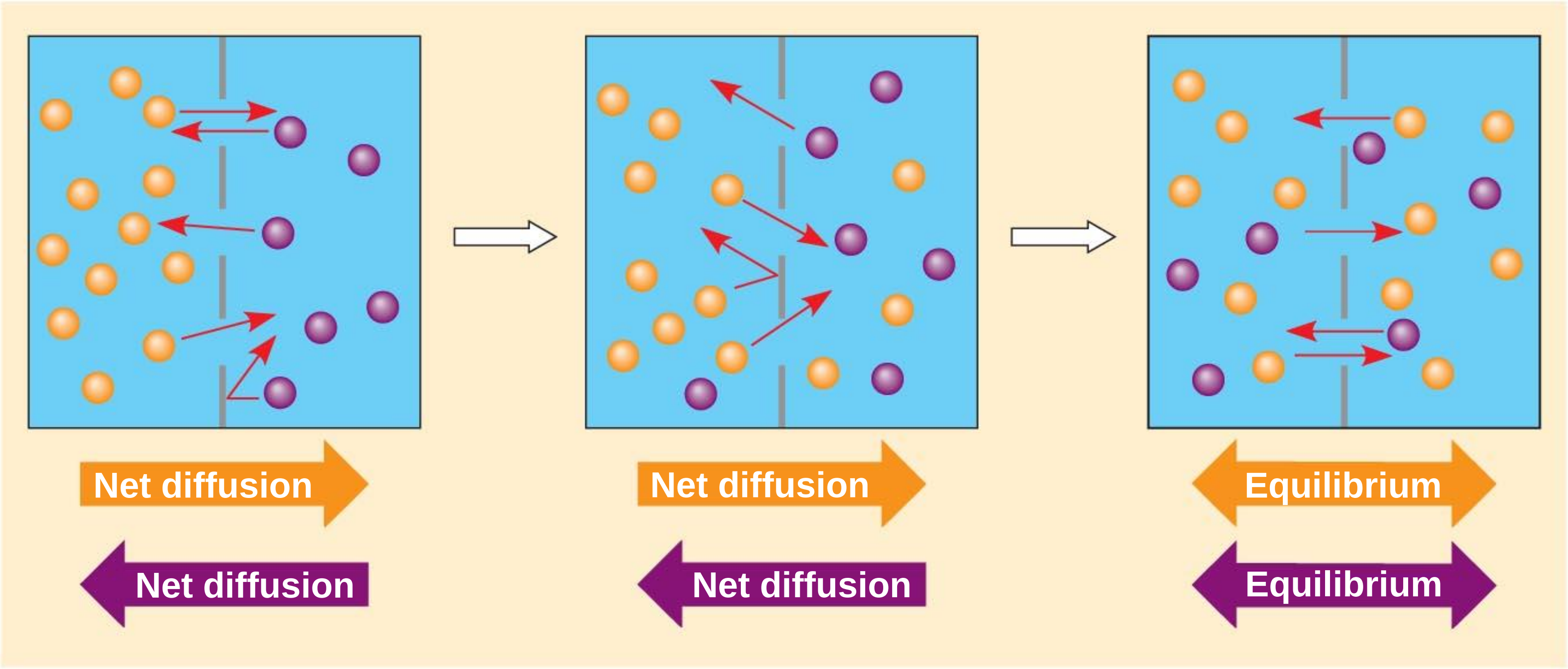
Passive transport is diffusion of a substance across a membrane with no energy investment

- 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



(a) Diffusion of one solute

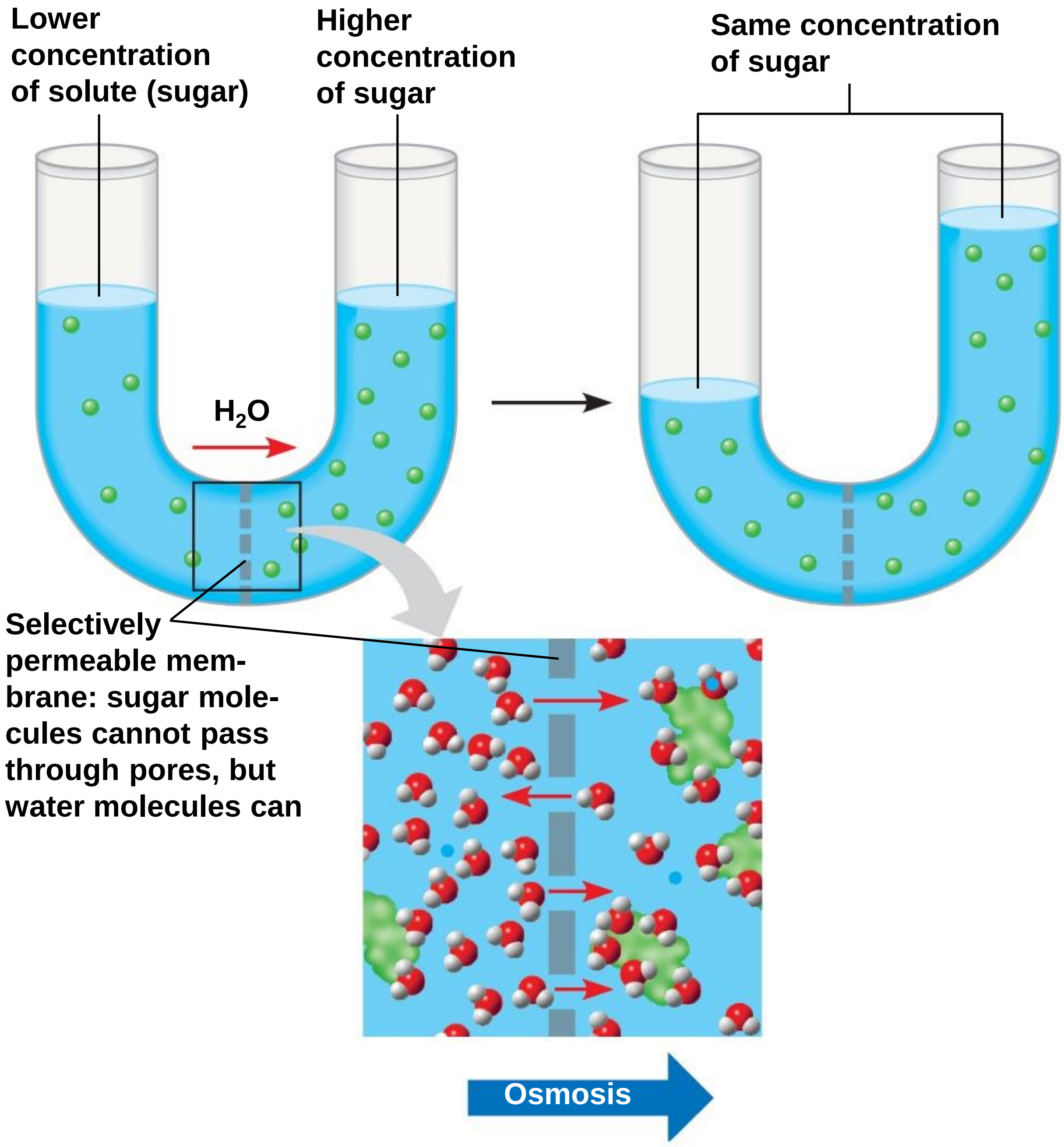
- Substances diffuse down their concentration gradient, the difference in concentration of a substance from one area to another
- No work must be done to move substances down the concentration gradient
- The diffusion of a substance across a biological membrane is **passive transport** because it requires no energy from the cell to make it happen



(b) Diffusion of two solutes

Effects of Osmosis on Water Balance

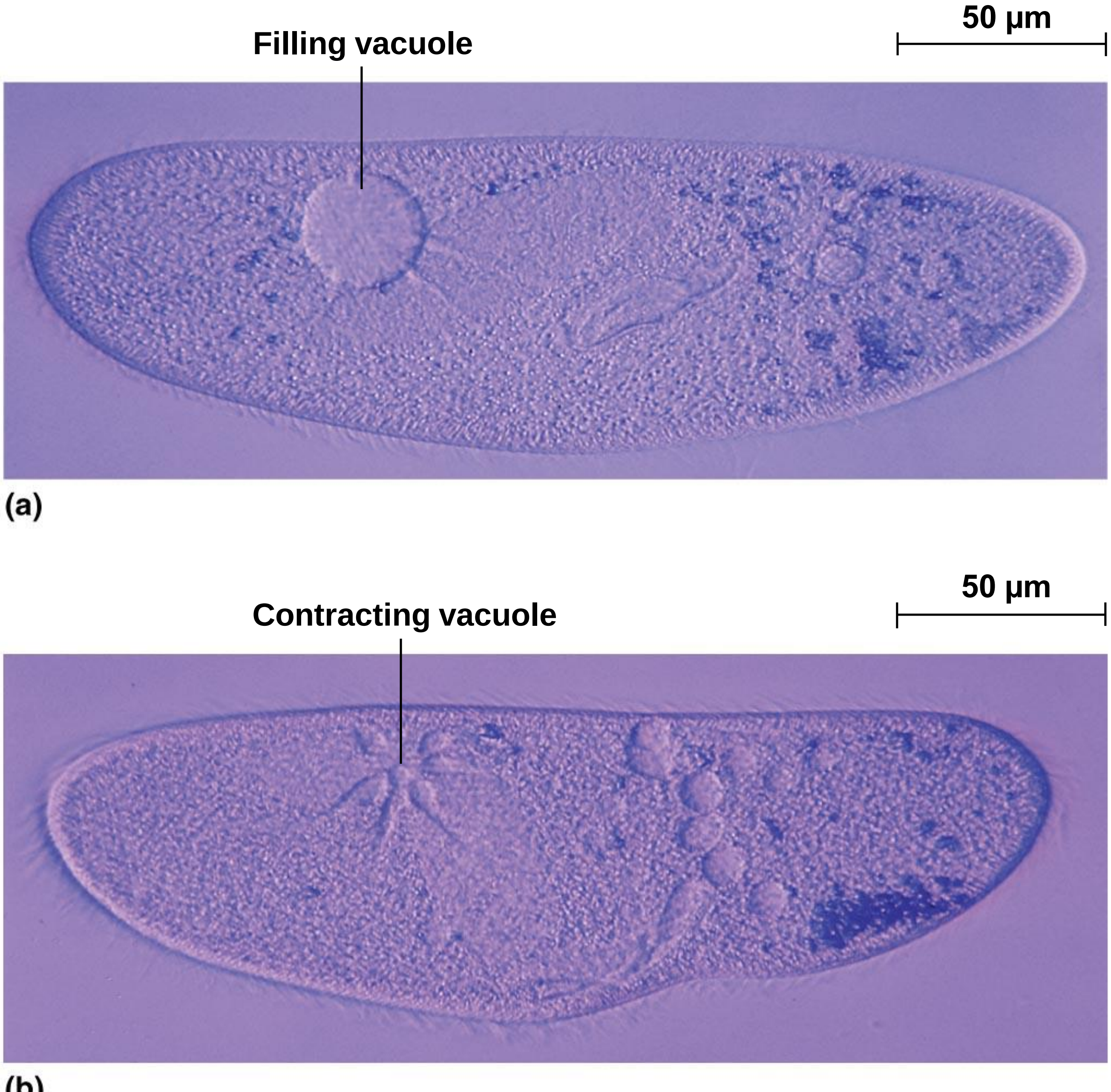
- **Osmosis** is the diffusion of water across a selectively permeable membrane
- The direction of osmosis is determined only by a difference in *total* solute concentration
- Water diffuses across a membrane from the region of lower solute concentration to the region of higher solute concentration


Lower concentration of solute (sugar)
Higher concentration of sugar
Same concentration of sugar
H_2O
Selectively permeable mem- brane: sugar mole- cules cannot pass through pores, but water molecules can
Osmosis

Water Balance of Cells Without Walls

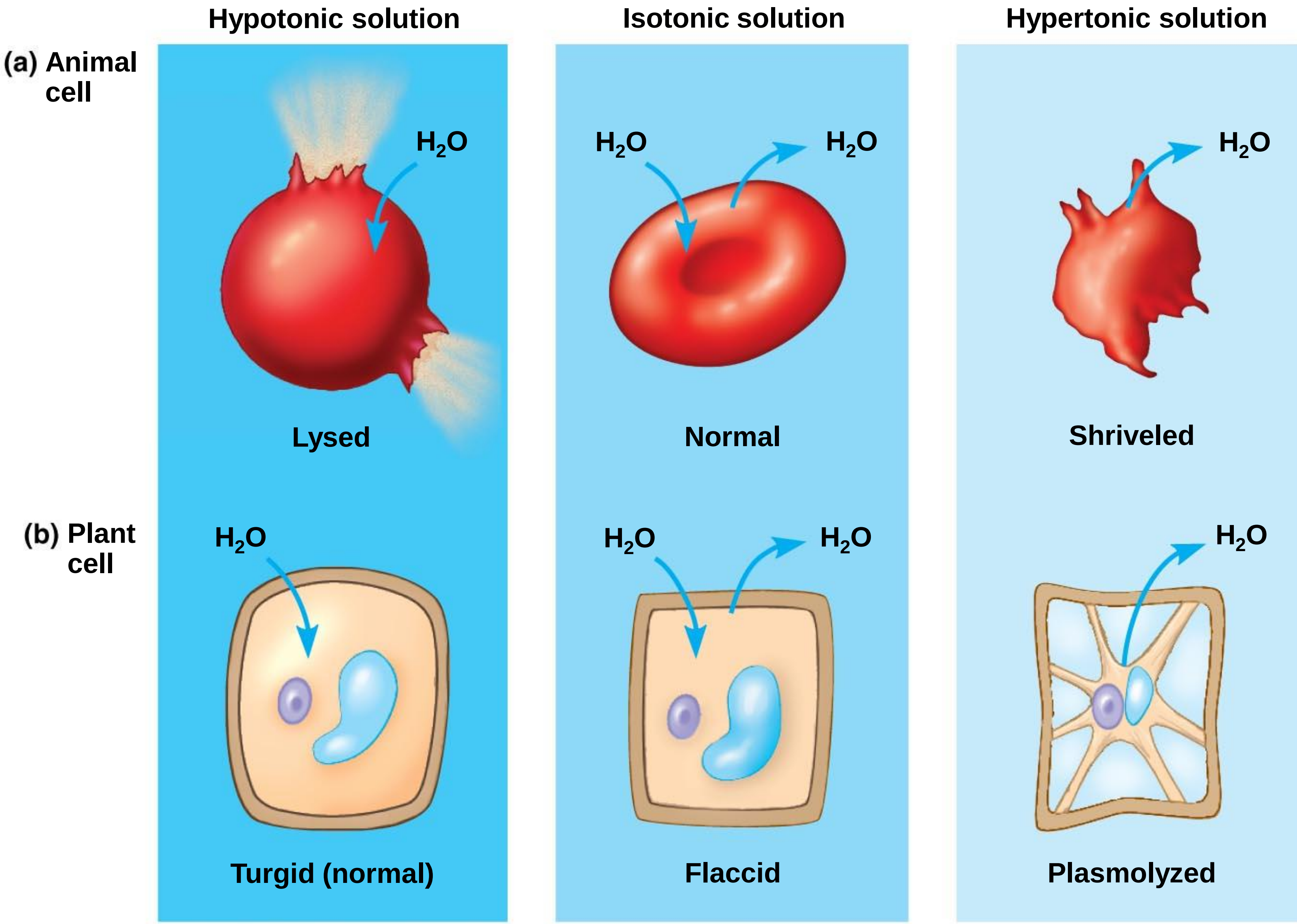
- **Tonicity** is the ability of a solution to cause a cell to gain or lose water
- **Isotonic solution:** solute concentration is the same as that inside the cell; no net water movement across the plasma membrane
- **Hypertonic solution:** solute concentration is greater than that inside the cell; cell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

- Animals and other organisms without rigid cell walls have osmotic problems in either a hypertonic or hypotonic environment
- To maintain their internal environment, such organisms must have adaptations for osmoregulation, the control of water balance
- The protist *Paramecium,* which is hypertonic to its pond water environment, has a contractile vacuole that acts as a pump


Filling vacuole
50 µm
(a)
Contracting vacuole
50 µm
(b)

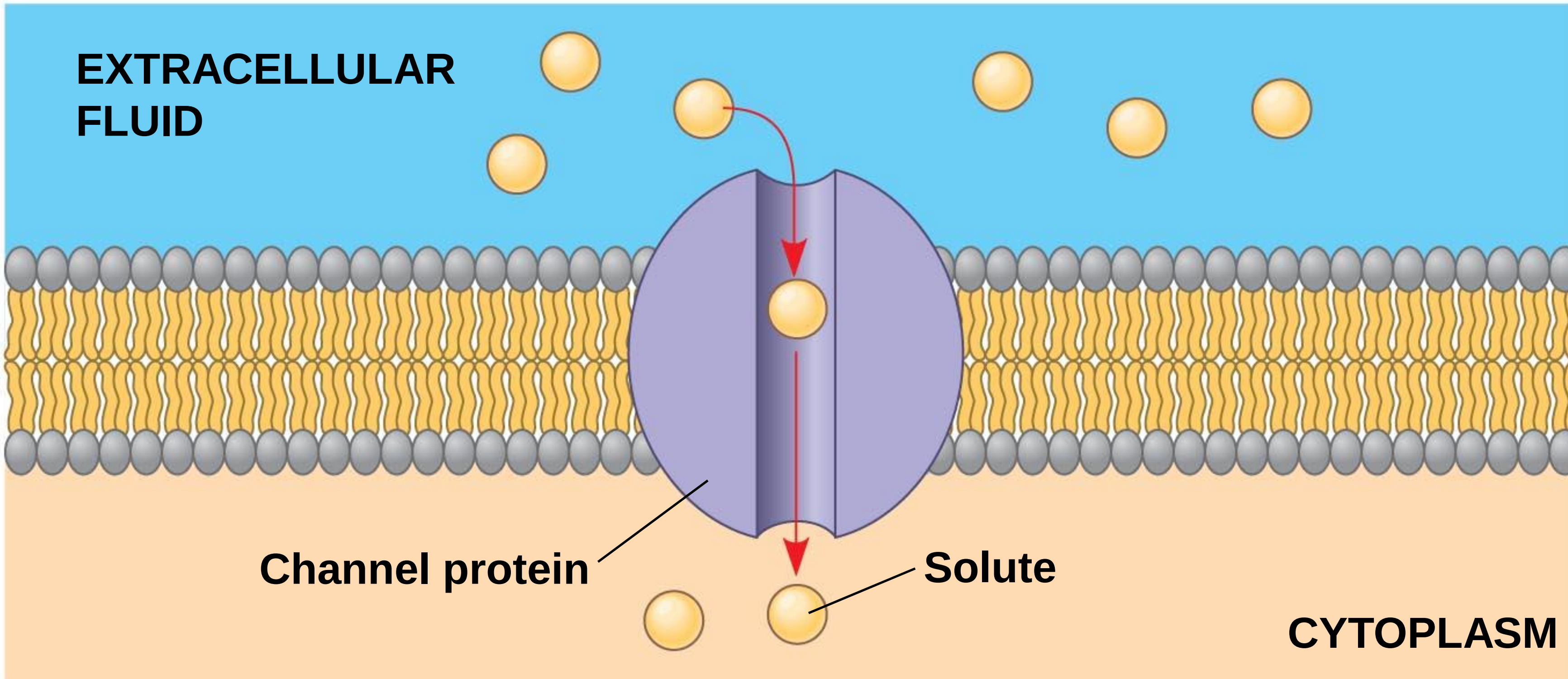
Water Balance of Cells with Walls

- 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

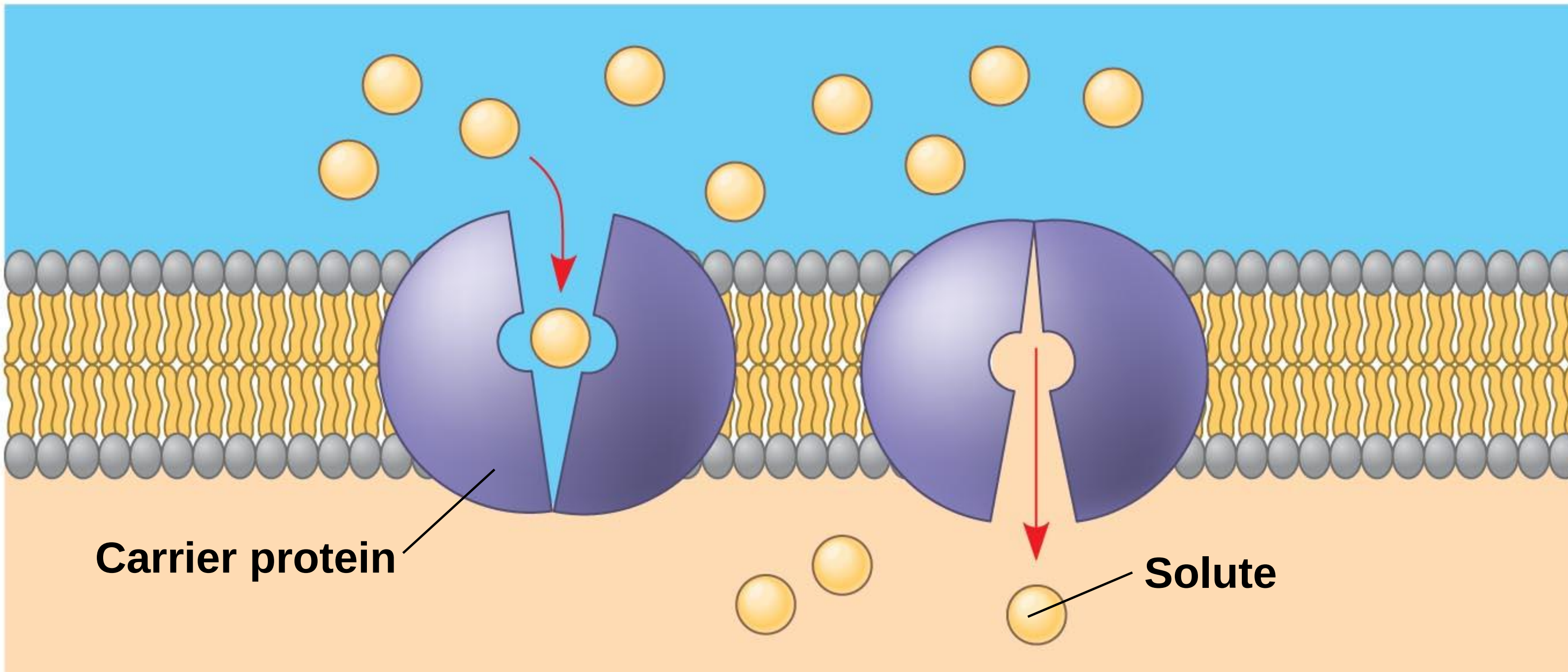

Hypotonic solution
Isotonic solution
Hypertonic solution
(a) Animal cell
H_2O
H_2O
H_2O
H_2O
Lysed
Normal
Shriveled
(b) Plant cell
H_2O
H_2O
H_2O
H_2O
Turgid (normal)
Flaccid
Plasmolyzed

Facilitated Diffusion: Passive Transport Aided by Proteins

- In facilitated diffusion, transport proteins speed movement of molecules across the plasma membrane
- Channel proteins provide corridors that allow a specific molecule or ion to cross the membrane
- Carrier proteins undergo a subtle change in shape that translocates the solute-binding site across the membrane



(a)



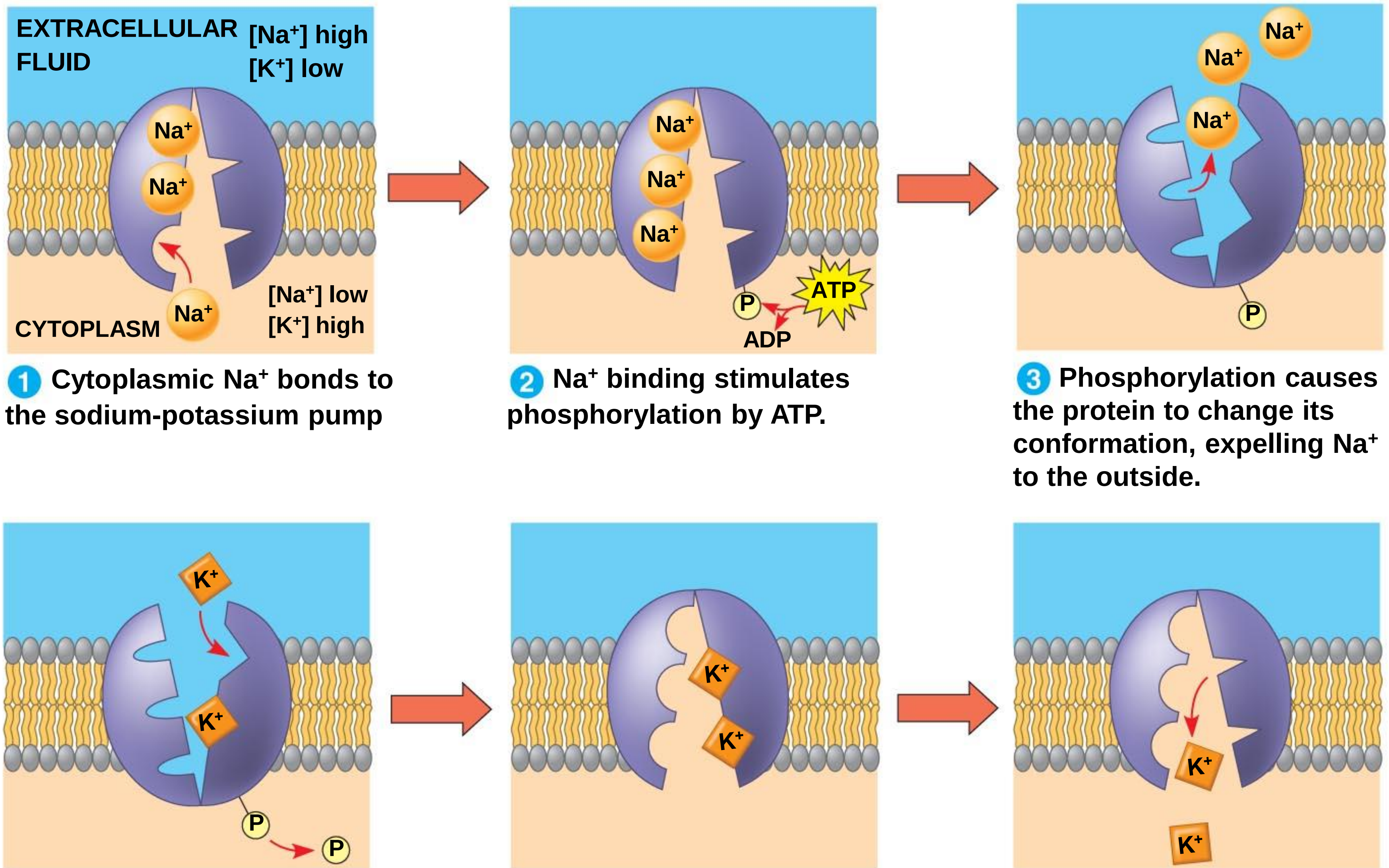
(b)

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
- The sodium-potassium pump is one type of active transport system



1 Cytoplasmic Na^+ bonds to the sodium-potassium pump

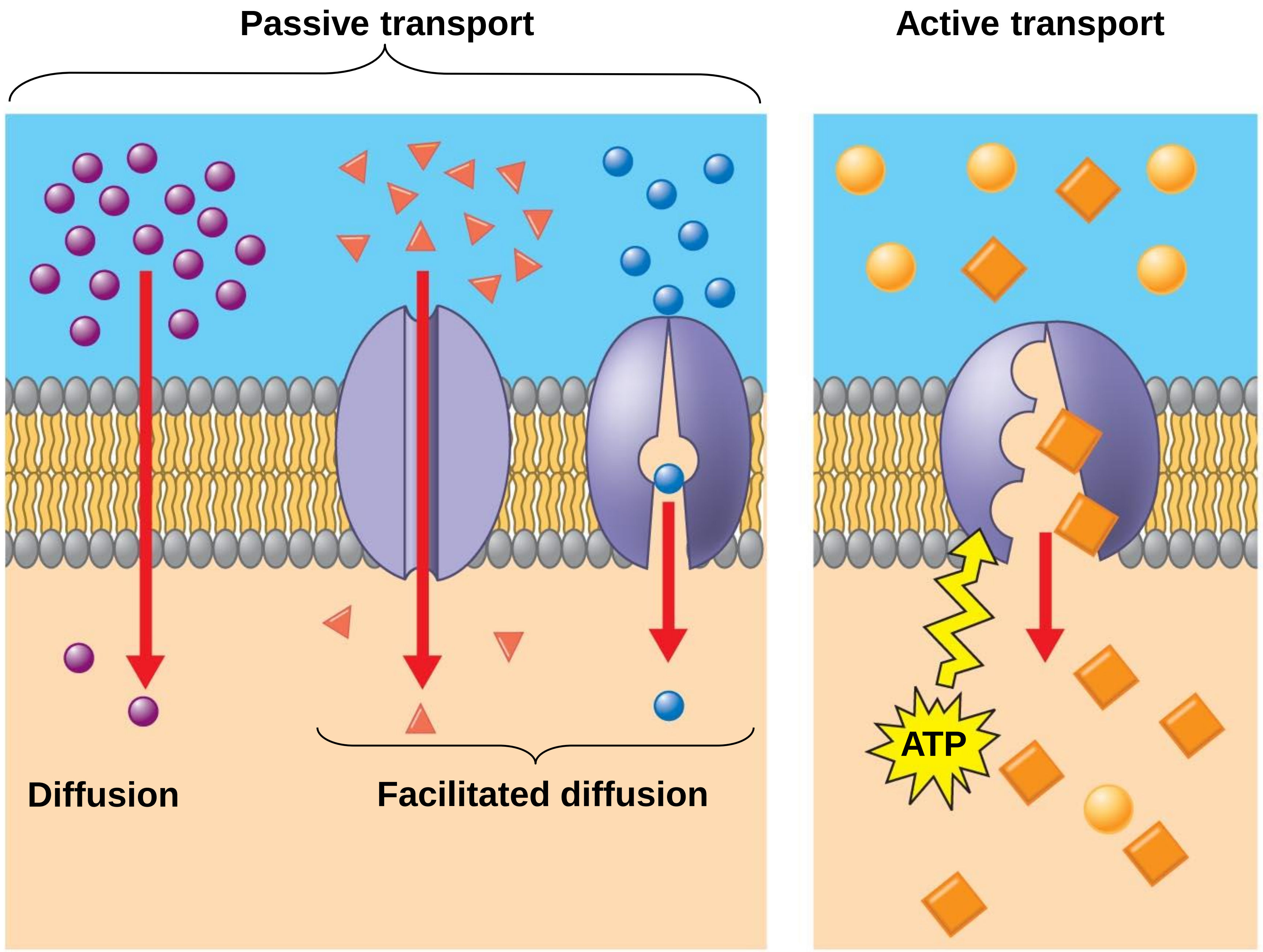
2 Na^+ binding stimulates phosphorylation by ATP.

3 Phosphorylation causes the protein to change its conformation, expelling Na^+ to the outside.

4 Extracellular K^+ binds to the protein, triggering release of the phosphate group.

5 Loss of the phosphate restores the protein's original conformation.

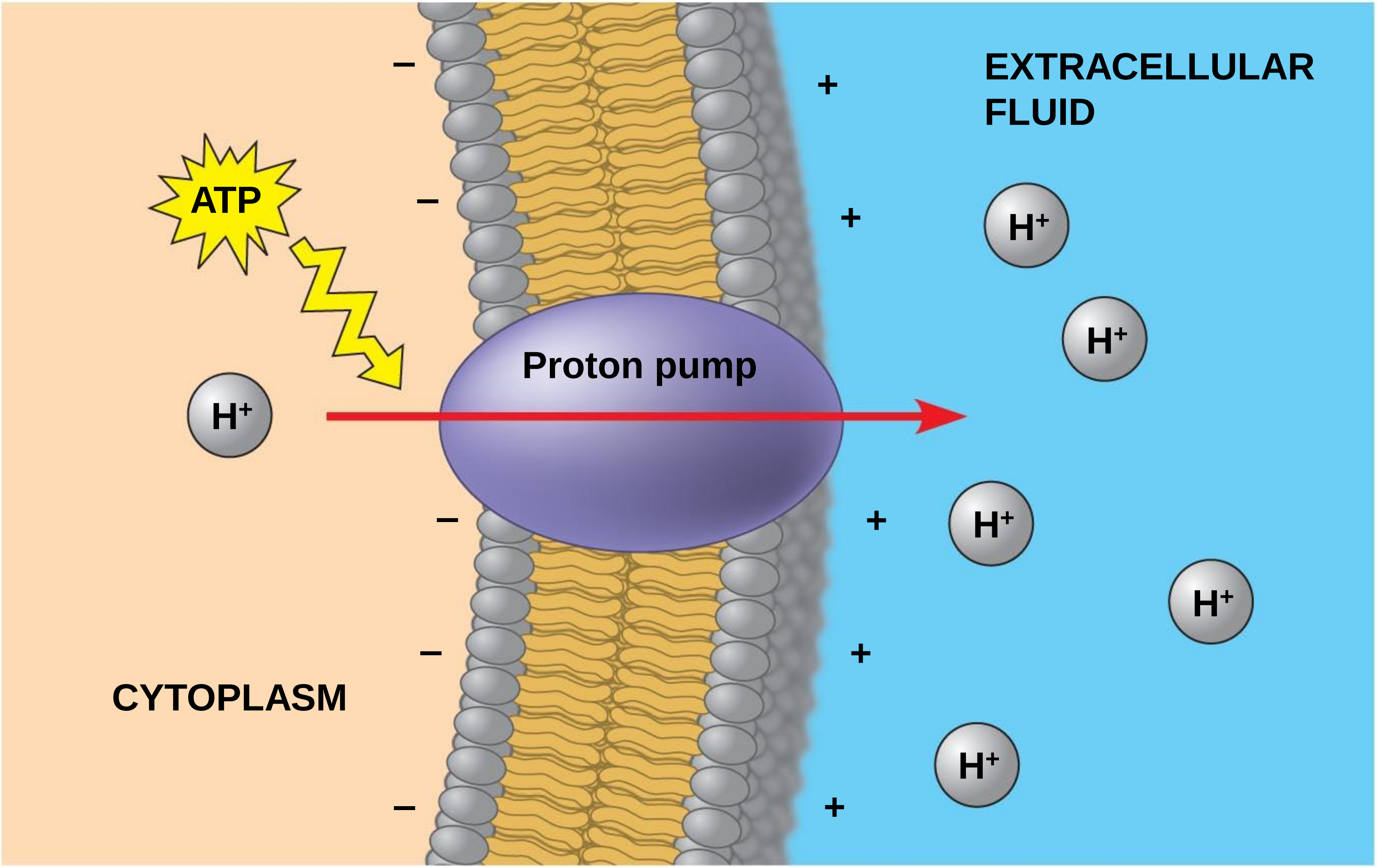
6 K^+ is released and Na^+ sites are receptive again; the cycle repeats.


Passive transport
Active transport
ATP
Diffusion
Facilitated diffusion

Maintenance of Membrane Potential by Ion Pumps

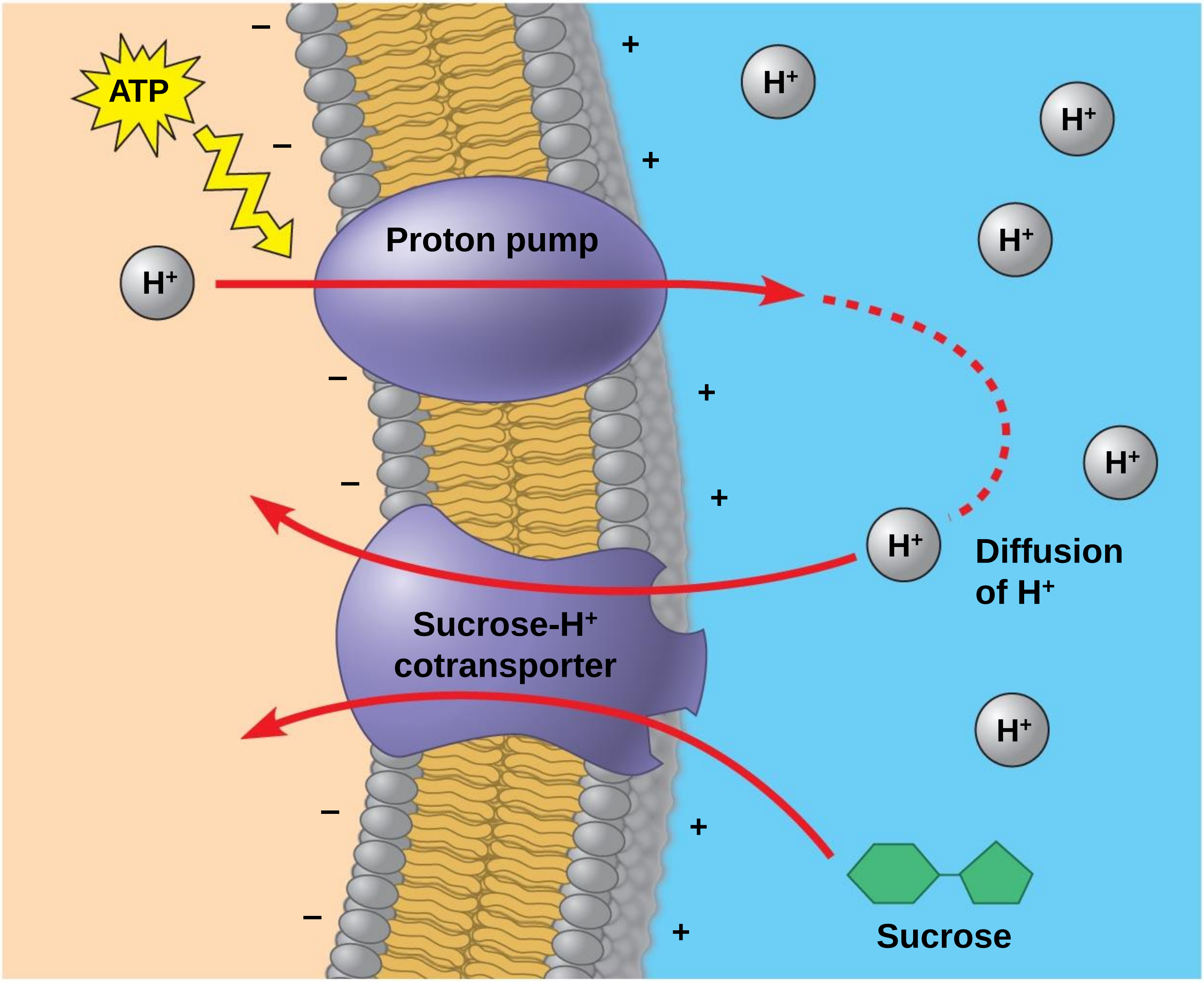
- Membrane potential is the voltage difference across a membrane
- Two combined forces, collectively called the electrochemical gradient, drive the diffusion of ions across a membrane:
  - A chemical force (the ion’s concentration gradient)
  - An electrical force (the effect of the membrane potential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

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


EXTRACELLULAR
FLUID
ATP
Proton pump
H+
CYTOPLASM
–
+

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


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

Exocytosis

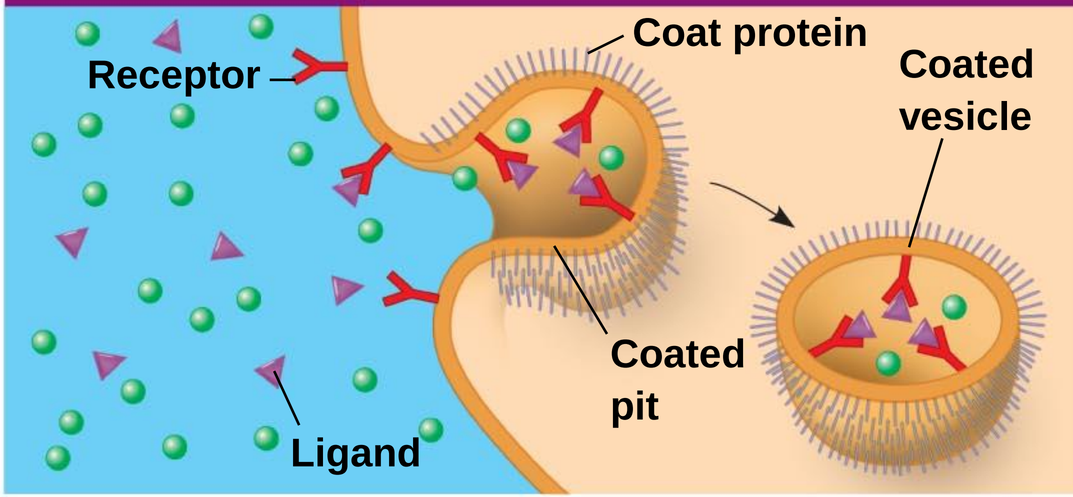
- In exocytosis, transport vesicles migrate to the membrane, fuse with it, and release their contents
- Many secretory cells use exocytosis to export their products

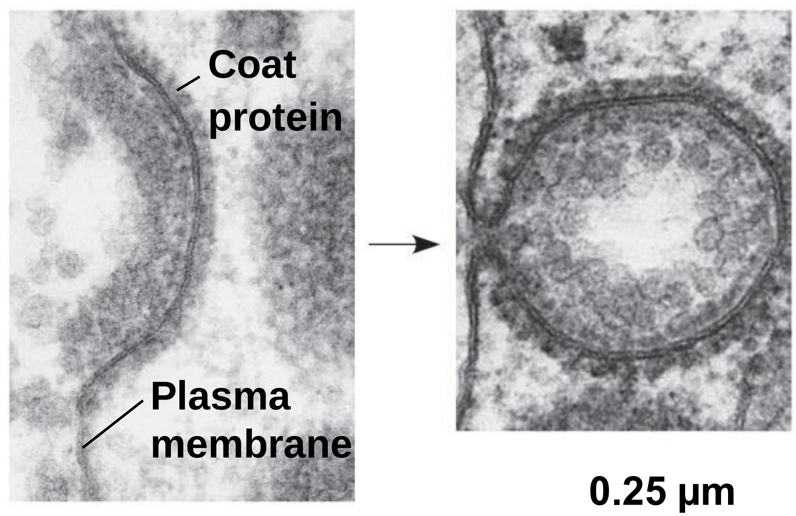
Endocytosis

- In endocytosis, the cell takes in macromolecules by forming vesicles from the plasma membrane
- Endocytosis is a reversal of exocytosis, involving different proteins

- Three types of endocytosis:
  - Phagocytosis (“cellular eating”): Cell engulfs particle in a vacuole
  - Pinocytosis (“cellular drinking”): Cell creates vesicle around fluid
  - Receptor-mediated endocytosis: Binding of ligands to receptors triggers vesicle formation

RECEPTOR-MEDIATED ENDOCYTOSIS





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