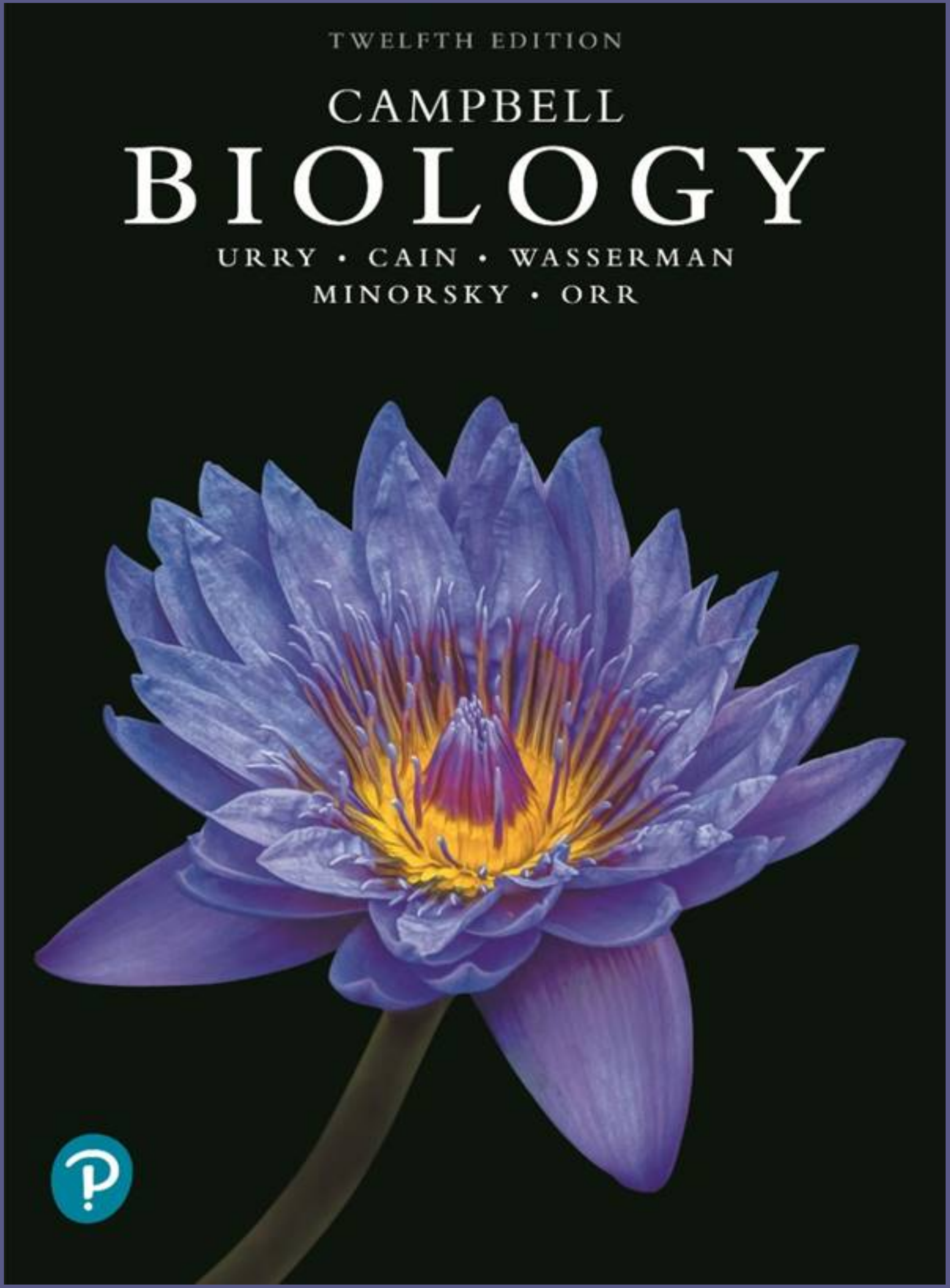
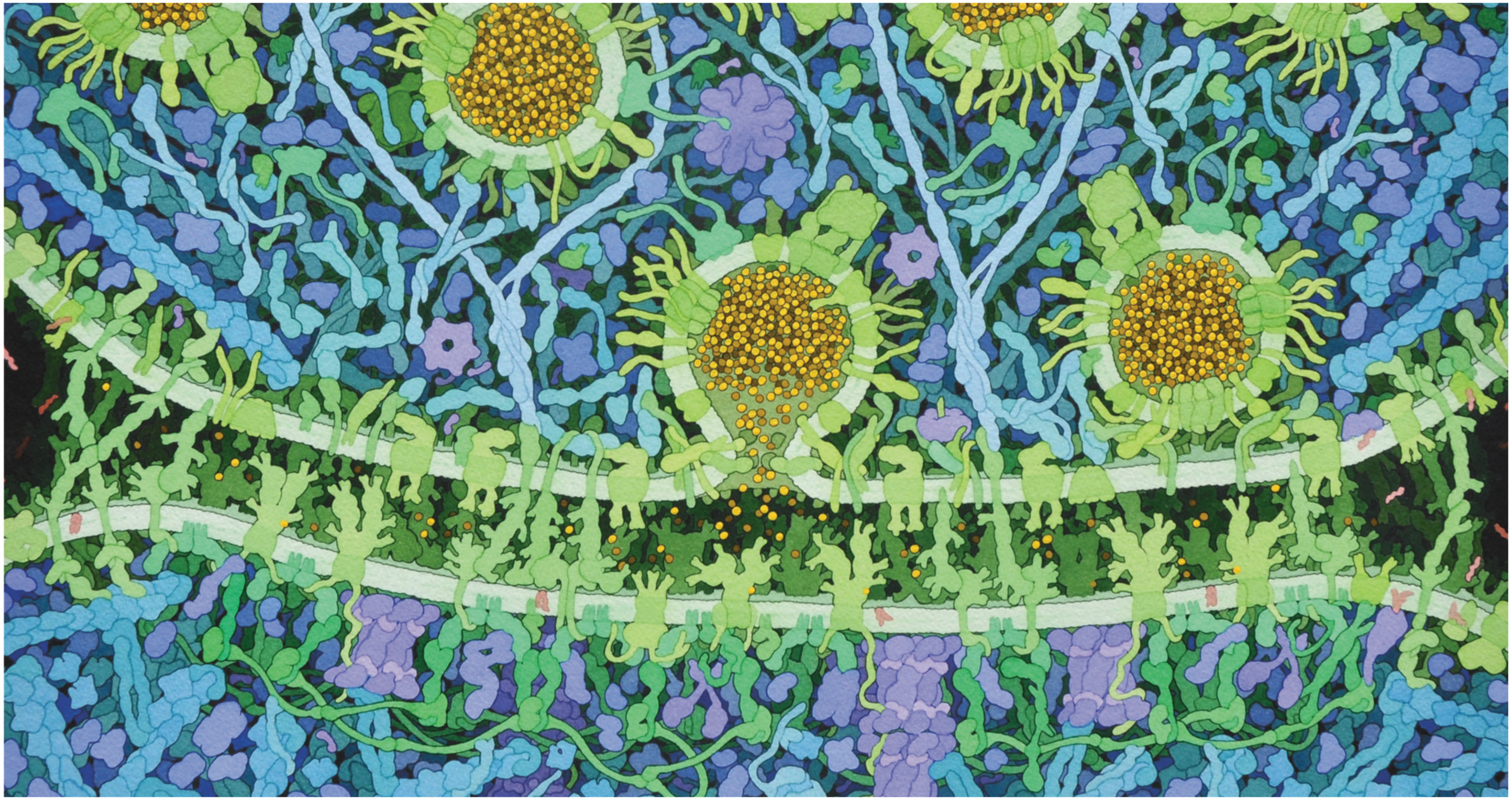


Chapter 7

Membrane Structure and Function

Lecture Presentations by
Nicole Tunbridge and
Kathleen Fitzpatrick

Figure 7.1a

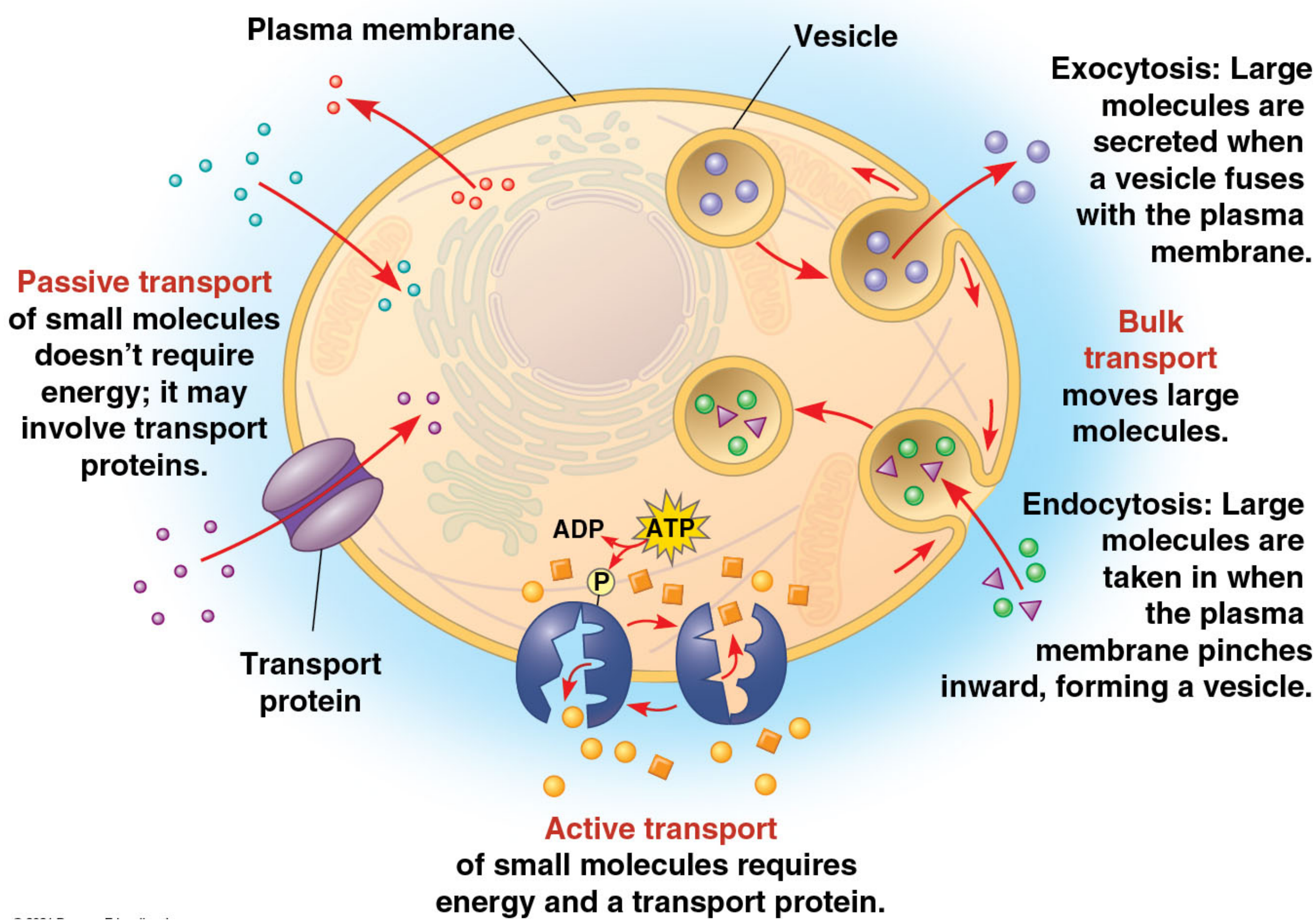


How does the plasma membrane regulate inbound and outbound traffic?

- Some small molecules move across the cell membrane using passive transport—no input of energy—and may require transport proteins
- Some small molecules use active transport, which requires both energy and a transport protein
- Large molecules move in and out, using bulk transport; exocytosis or endocytosis

Figure 7.1b

How does the plasma membrane regulate inbound and outbound traffic?

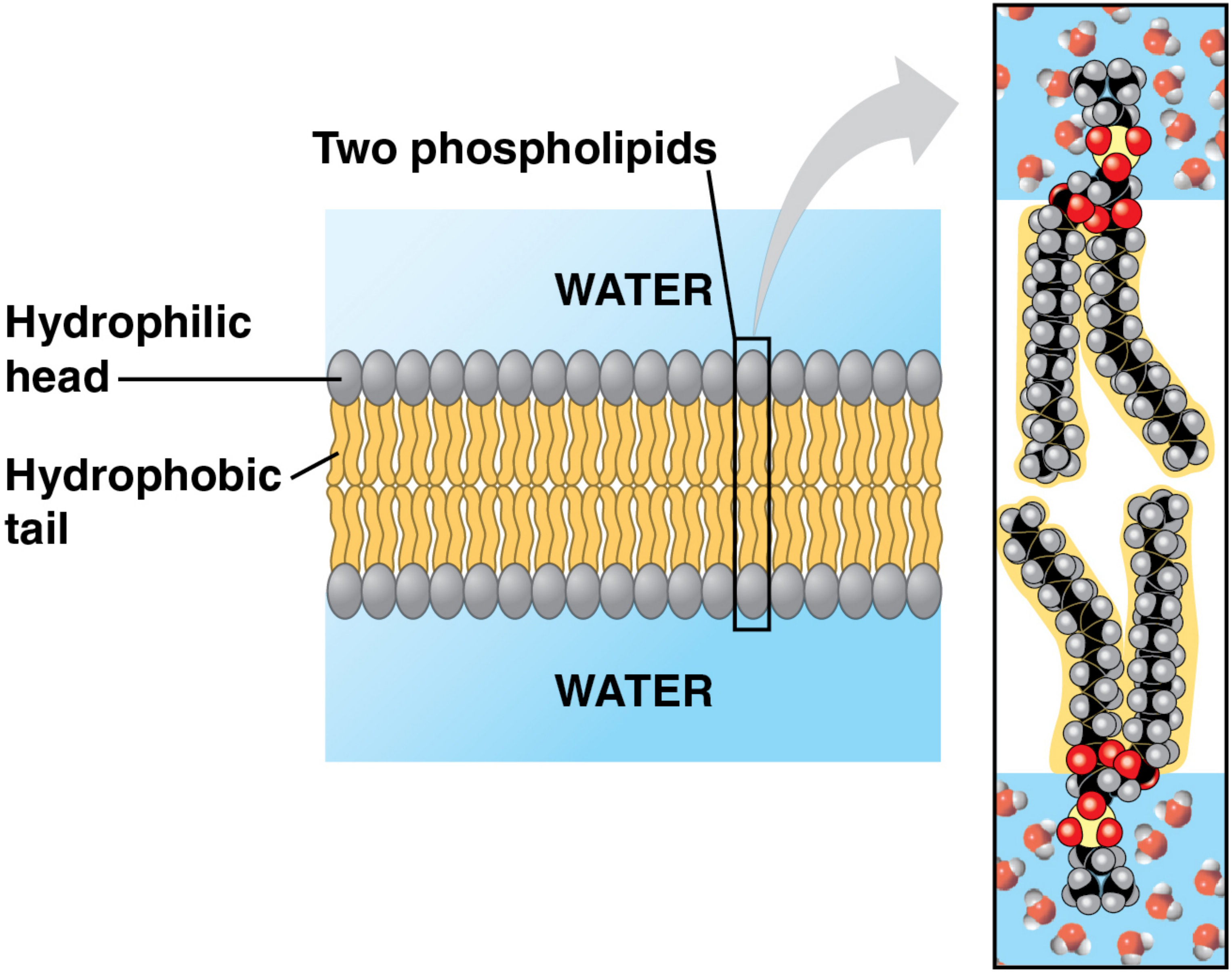


CONCEPT 7.1: Cellular membranes are fluid mosaics of lipids and proteins

- Lipids and proteins are the main components of membranes, but carbohydrates are also important
- Membranes are composed mainly of phospholipids
- Phospholipids are **amphipathic** molecules, containing hydrophobic (“water-fearing”) and hydrophilic (“water-loving”) regions

- Phospholipids form a bilayer with hydrophobic tails inside the membrane, and hydrophilic heads exposed to water on either side
- Most membrane proteins are also amphipathic
- Hydrophilic regions of the protein are oriented toward the cytosol and extracellular fluid inside and outside the membrane
- Hydrophobic regions are embedded in the bilayer

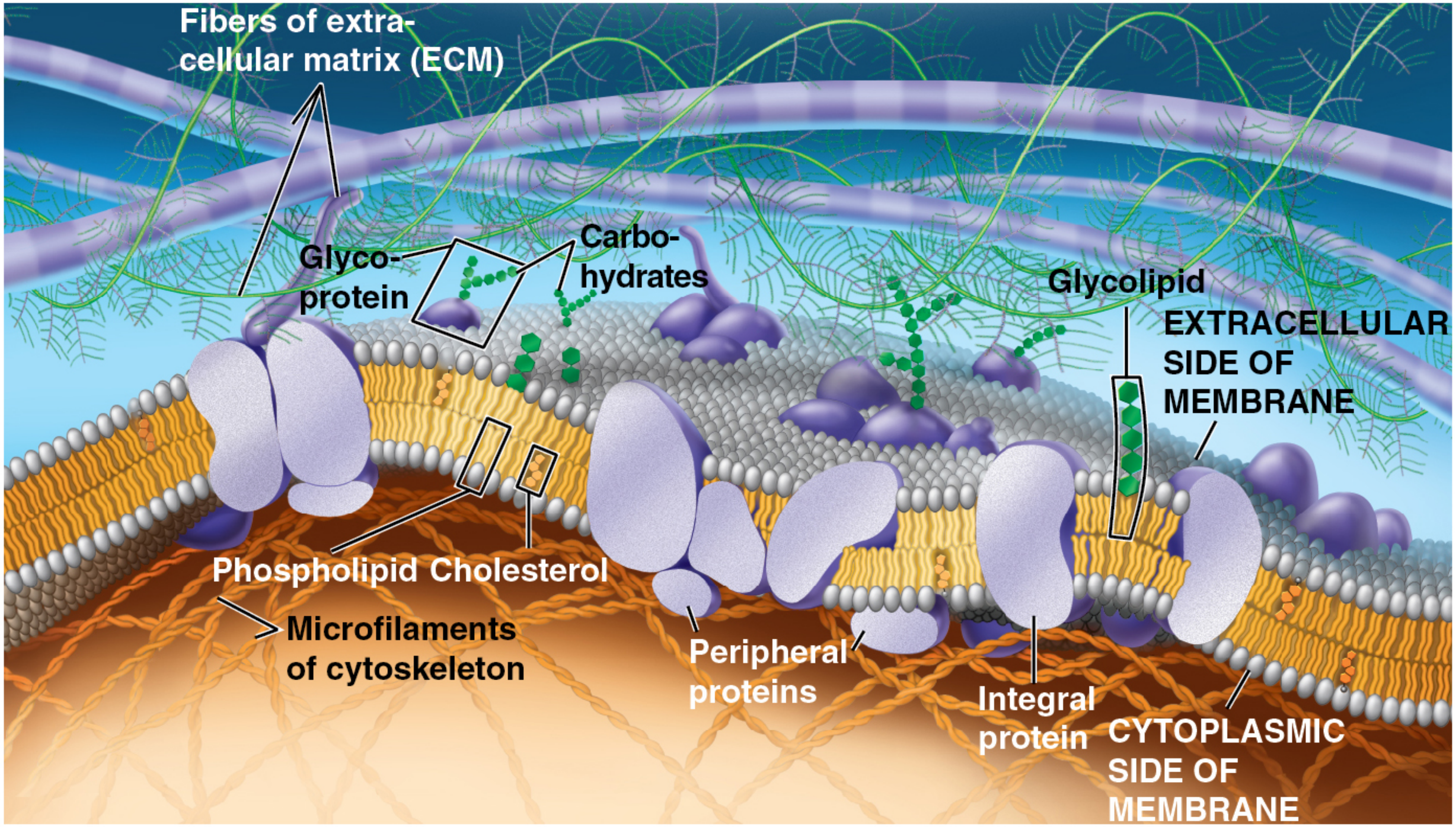
Figure 7.2



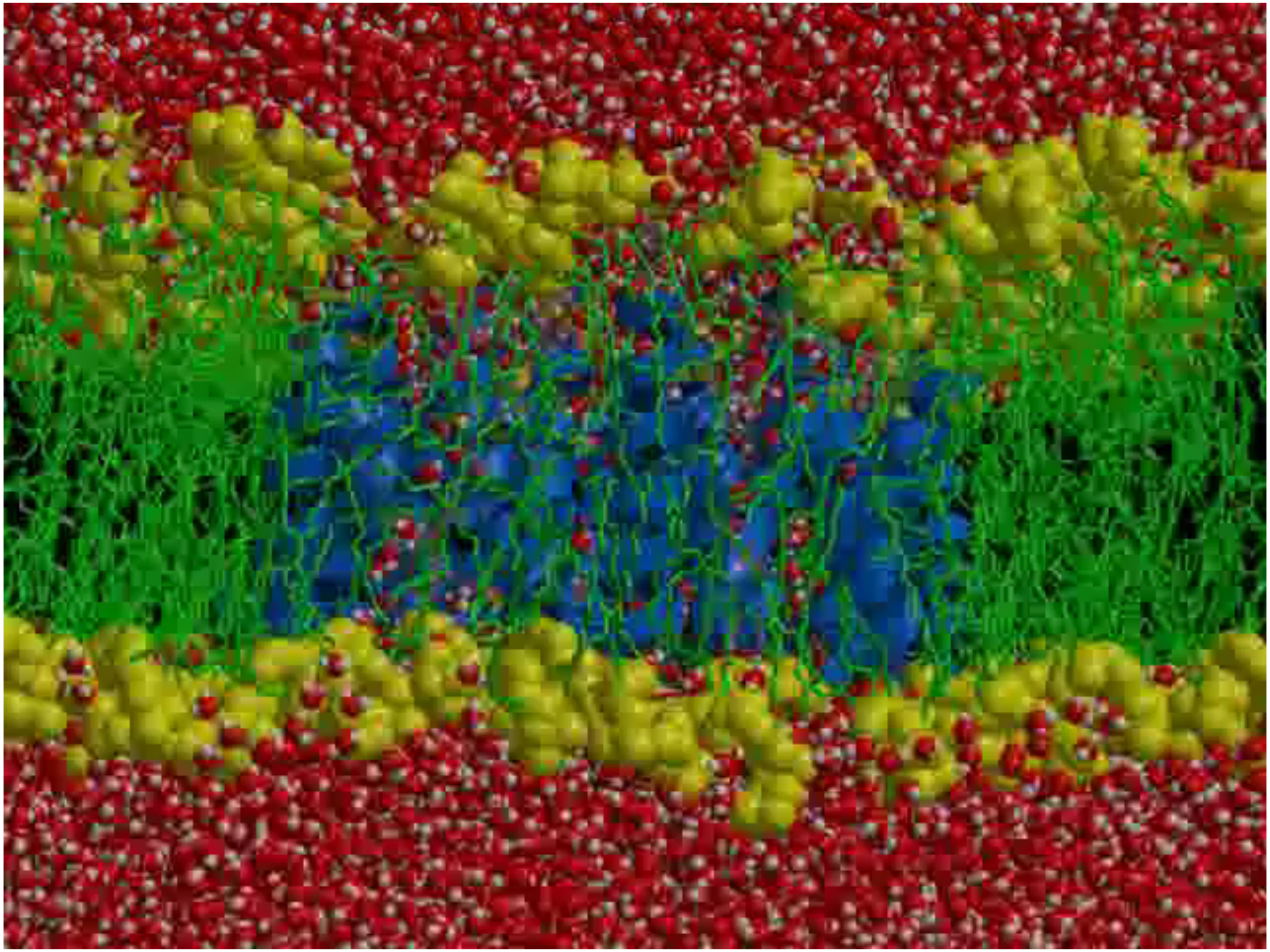
Two phospholipids
WATER
Hydrophilic head
Hydrophobic tail
WATER

- The **fluid mosaic model** of membrane structure depicts the membrane as a mosaic of protein molecules bobbing in a fluid bilayer of phospholipids
- Proteins are not randomly distributed in the membrane; they often form groups that carry out common functions

Figure 7.3


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

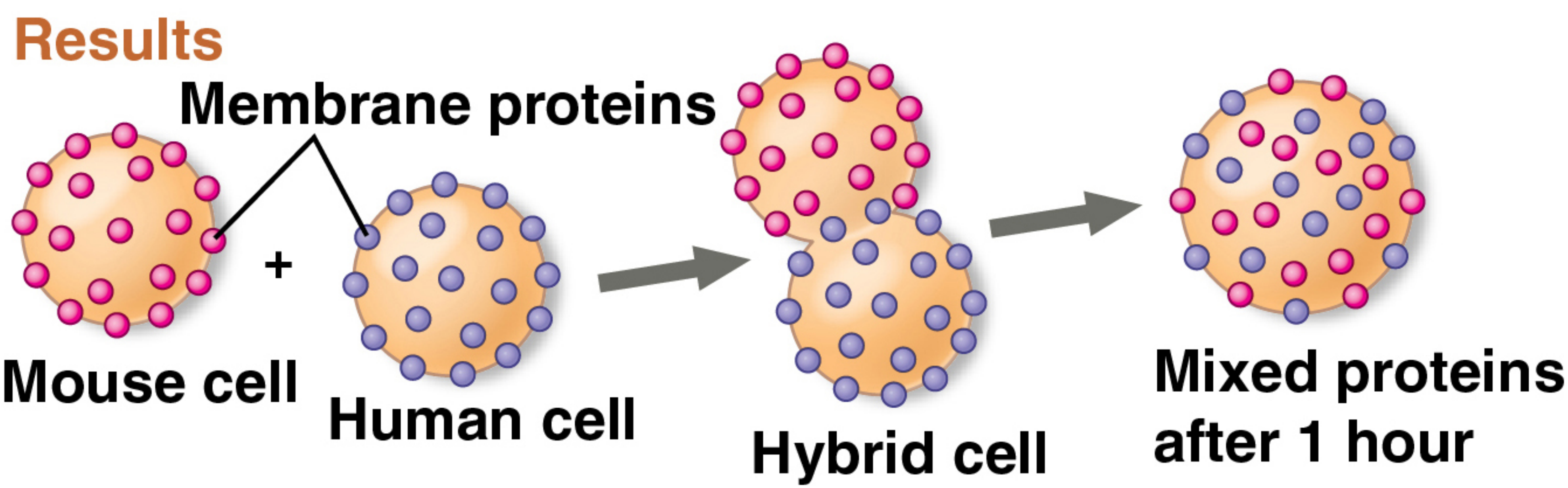
Video: Structure of the Cell Membrane



The Fluidity of Membranes

- Membranes are held together mainly by weak hydrophobic interactions
- Most of the lipids and some proteins can move sideways within the membrane
- Rarely, a lipid may flip-flop across the membrane, from one phospholipid layer to the other

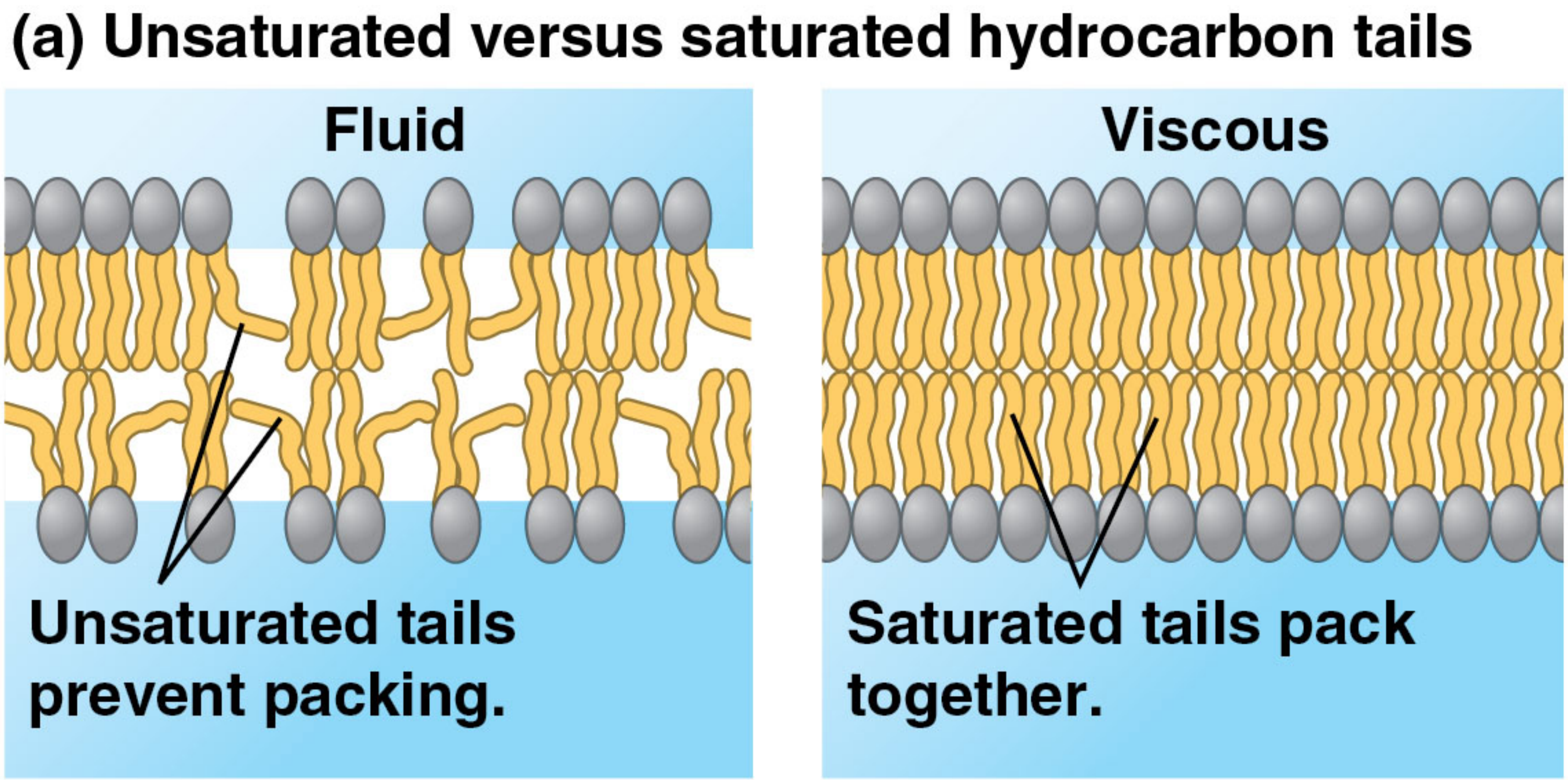
Figure 7.4



Data from L. D. Frye and M. Edidin, The rapid intermixing of cell surface antigens after formation of mouse-human heterokaryons, *Journal of Cell Science* 7:319 (1970).

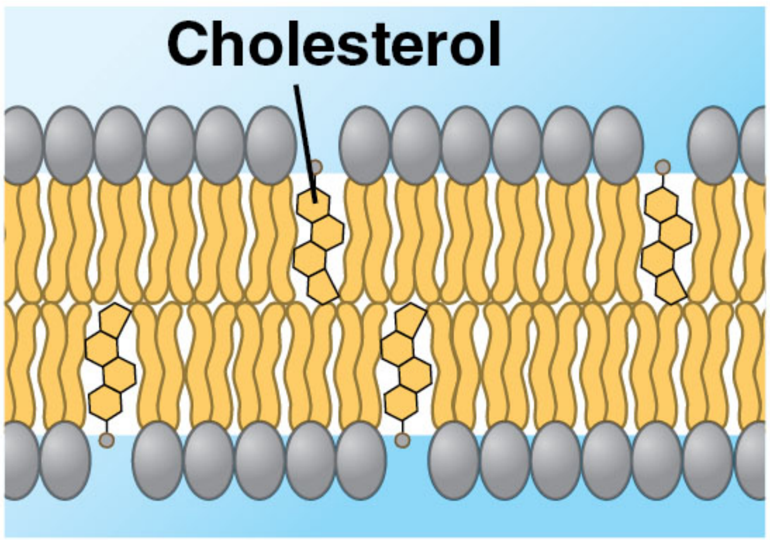
- As temperatures cool, membranes switch from a fluid state to a solid state
- The temperature at which a membrane solidifies depends on the types of lipids
- Membranes rich in unsaturated fatty acids are more fluid than those rich in saturated fatty acids
- Membranes must be fluid to work properly

Figure 7.5a


(a) Unsaturated versus saturated hydrocarbon tails
Fluid
Viscous
Unsaturated tails prevent packing.
Saturated tails pack together.

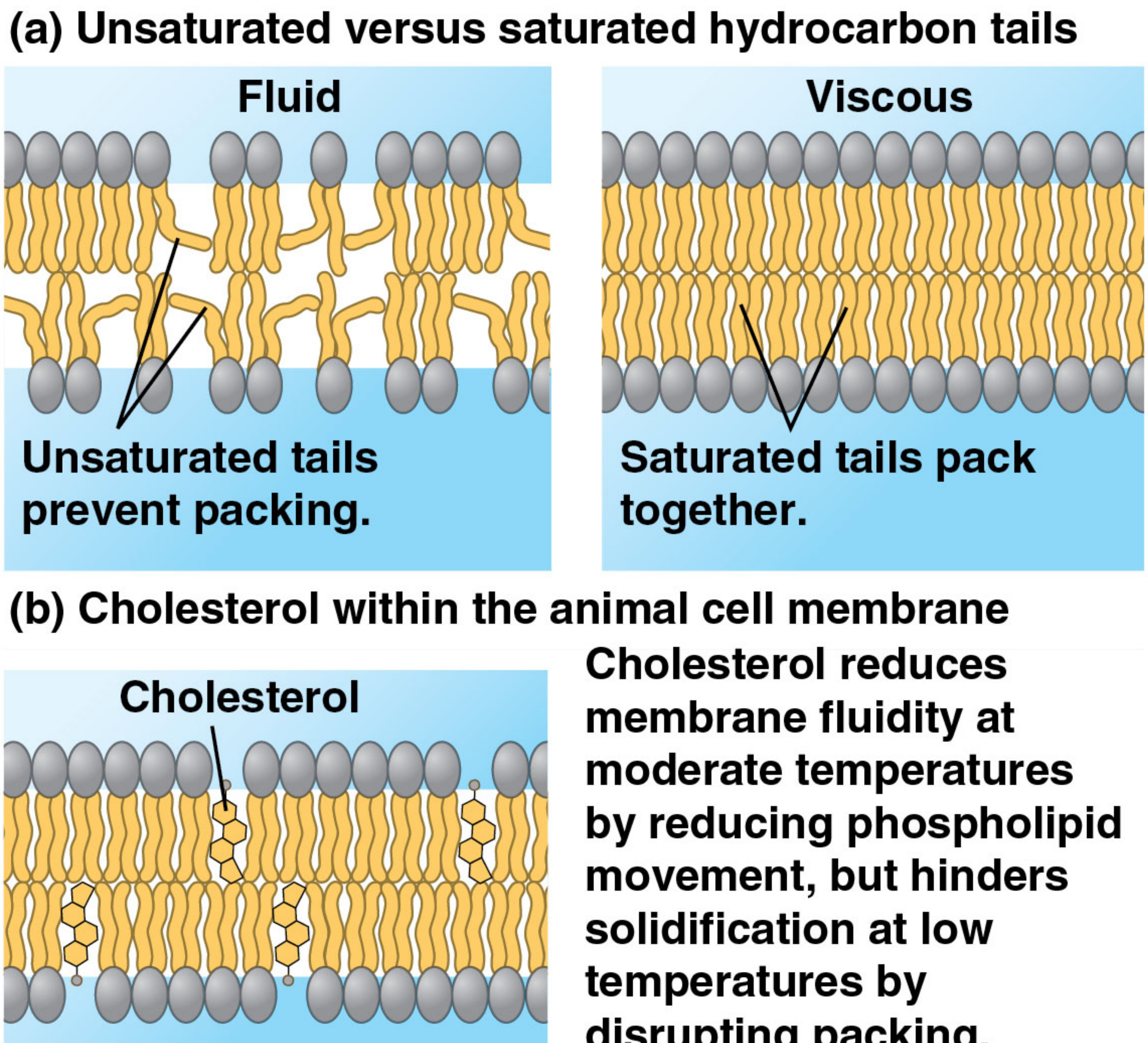
- Cholesterol is a membrane component in animal cells that has variable effects on membrane fluidity at different temperatures
  - At warm temperatures (such as 37ºC), cholesterol restrains movement of phospholipids
  - At cool temperatures, it maintains fluidity by preventing tight packing
- Plants use different but related steroid lipids to buffer membrane fluidity

(b) Cholesterol within the animal cell membrane



Cholesterol reduces membrane fluidity at moderate temperatures by reducing phospholipid movement, but hinders solidification at low temperatures by disrupting packing.

Figure 7.5



Cholesterol reduces membrane fluidity at moderate temperatures by reducing phospholipid movement, but hinders solidification at low temperatures by disrupting packing.

- Membranes must be fluid to work properly; fluidity affects both permeability and movement of transport proteins
- Membranes that are too fluid cannot support protein function
- Organisms living in extreme temperatures have adaptive differences in membrane lipid composition

Evolution of Differences in Membrane Lipid Composition

- The lipid composition of the cell membrane appears to be adapted to environmental conditions in many species
  - For example, cell membranes have a high proportion of unsaturated hydrocarbon tails in fish that live in extreme cold

- Organisms living in variable temperature conditions are able to change lipid composition in response to changing temperature
  - For example, in winter wheat, the percentage of unsaturated phospholipids increases in autumn to prevent membrane solidification during winter

Membrane Proteins and Their Functions

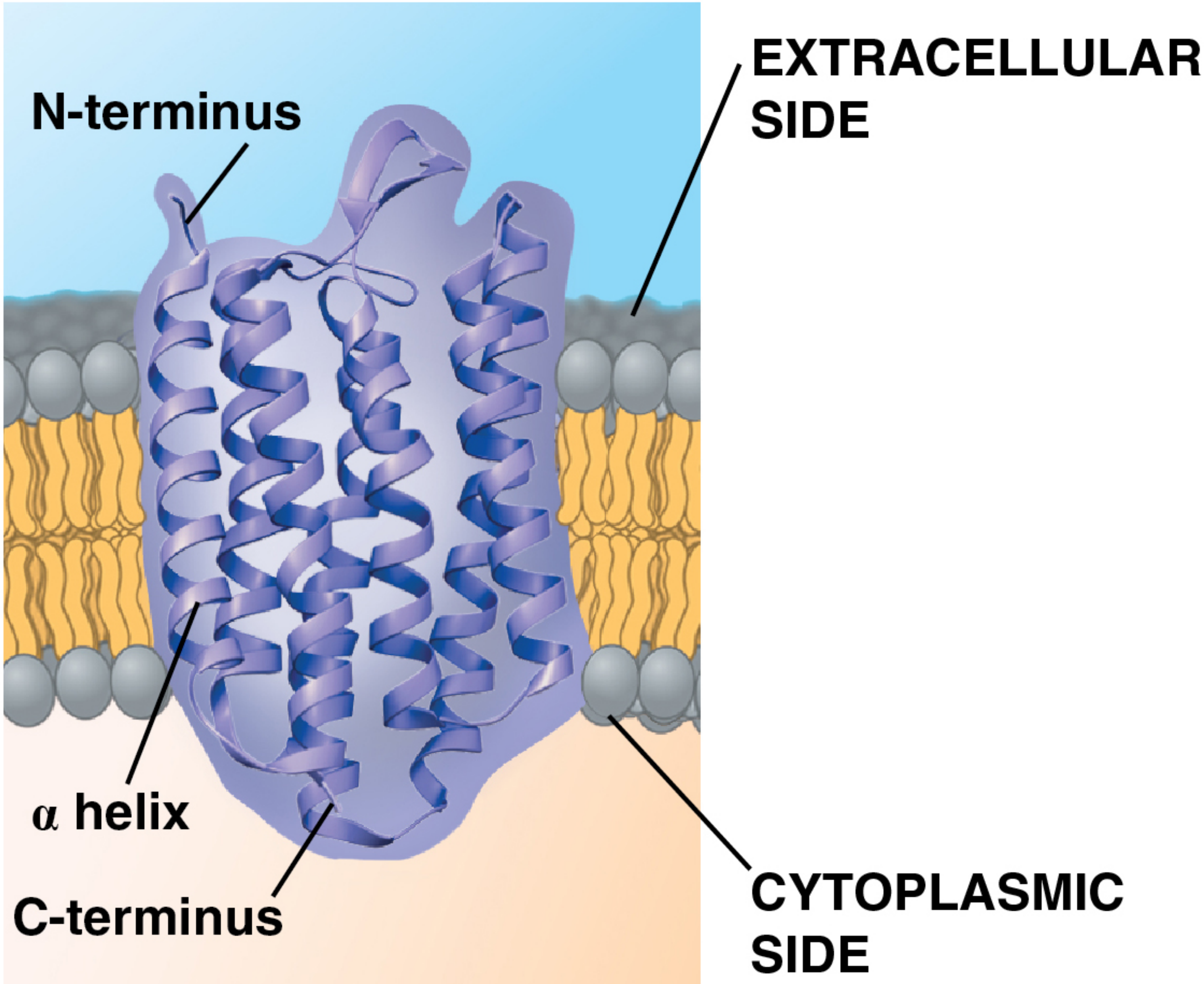
- A membrane is a collage of different proteins, often clustered in groups, embedded in the fluid matrix of the lipid bilayer
- This structure resembles a tile mosaic

Figure 7.UN01

- Phospholipids form the main fabric of the membrane, but proteins determine most of the membrane’s functions
- The protein composition of membranes varies among cells within an organism, and among intracellular membranes within a cell

- There are two major types of membrane proteins:
  - **Peripheral proteins** are bound to the surface of the membrane
  - **Integral proteins** penetrate the hydrophobic core
- **Transmembrane proteins** are integral proteins that span the membrane
- Hydrophobic regions of an integral protein consist of nonpolar amino acids, often coiled into α helices

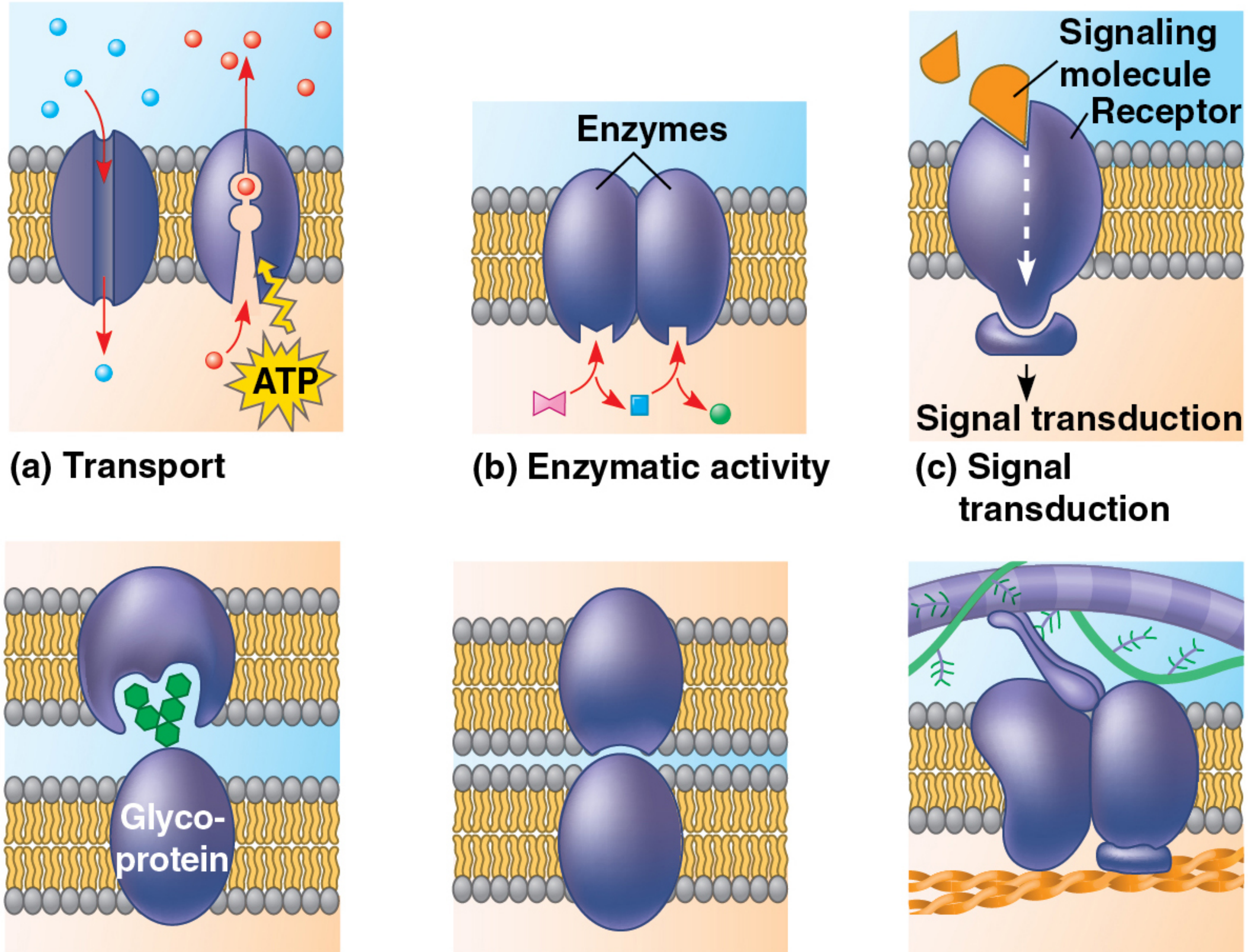
Figure 7.6


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

- Some membrane proteins are held in place by attachment to the cytoskeleton inside the cell
- Other proteins, attach to materials outside the cell
  - For example, proteins called integrins attach to fibers of the extracellular matrix

- Cell-surface membrane proteins can carry out several functions:
  - Transport
  - Enzymatic activity
  - Signal transduction
  - Cell-cell recognition
  - Intercellular joining
  - Attachment to the cytoskeleton and extracellular matrix (ECM)

Figure 7.7



(a) Transport

(b) Enzymatic activity

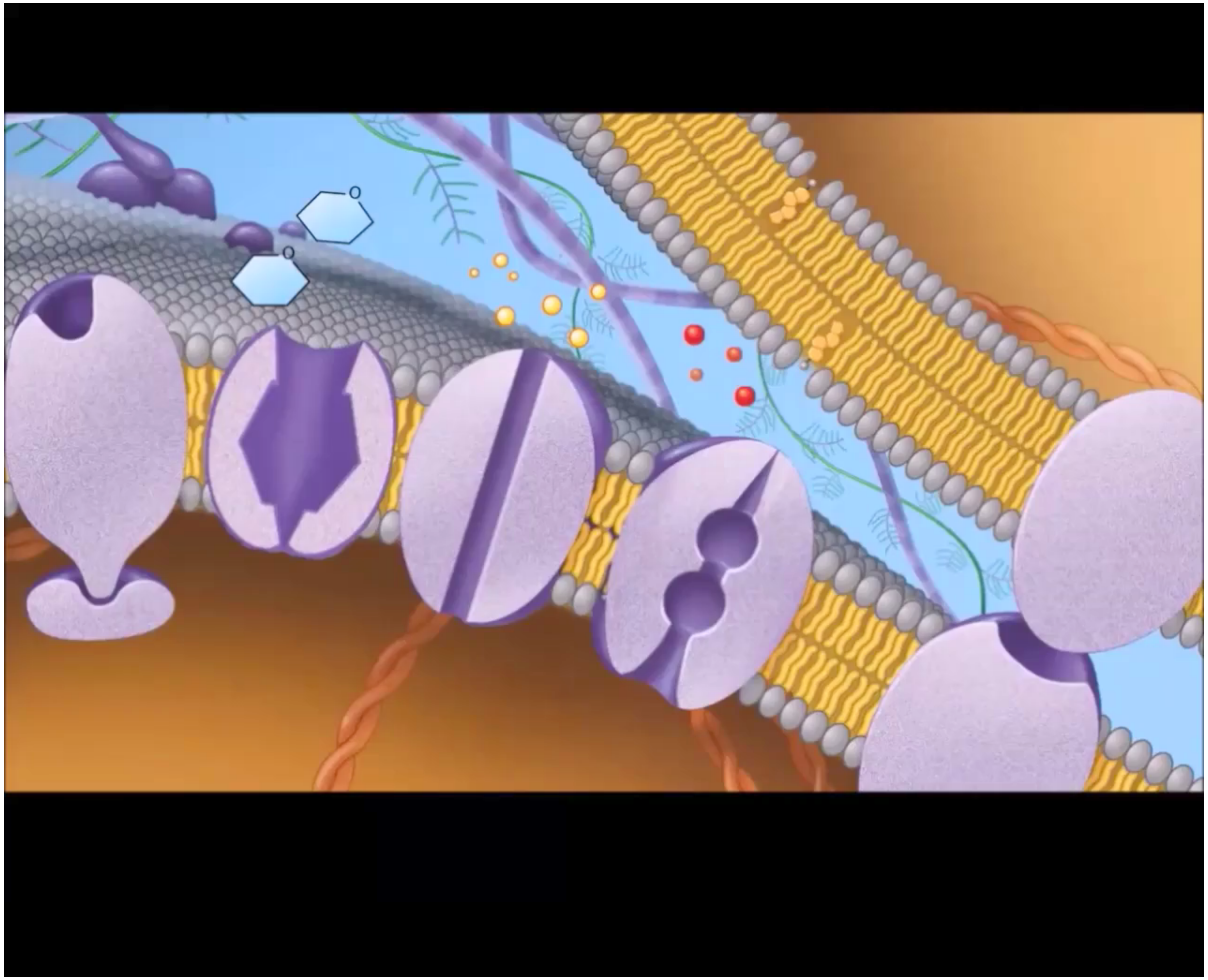
(c) Signal transduction

(d) Cell-cell recognition

(e) Intercellular joining

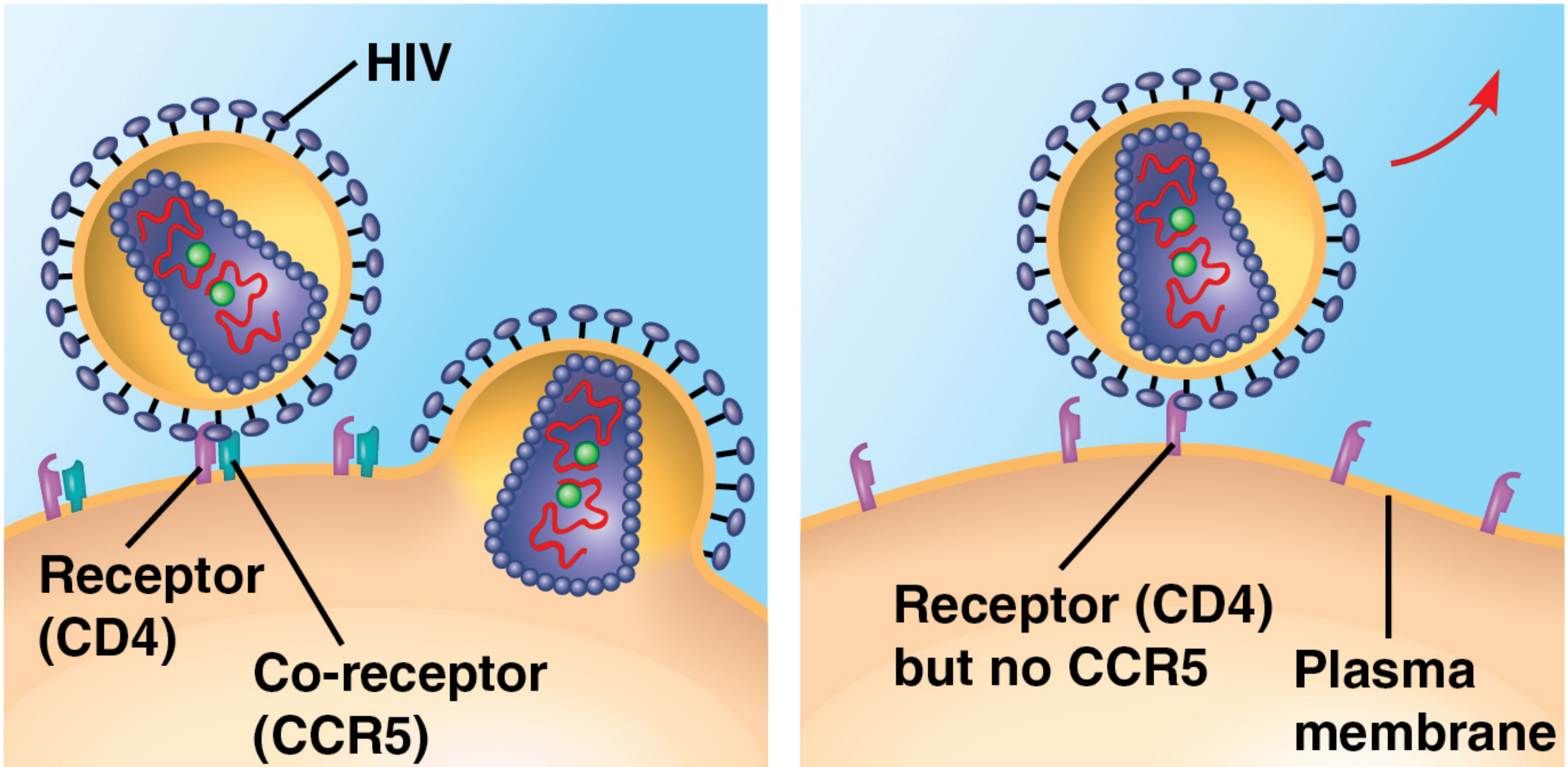
(f) Attachment to the cytoskeleton and extracellular matrix (ECM)

Animation: Functions of the Plasma Membrane



- Cell-surface proteins are important in medicine
  - For example, HIV enters immune cells by binding to cell-surface protein CD4 and a “co-receptor” CCR5
  - Individuals lacking CCR5 are immune to HIV infection
  - Drugs are in development to mask CCR5 and block HIV entrance in nonimmune individuals

Figure 7.8



(a) HIV can infect a cell with CCR5 on its surface, as in most people.

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

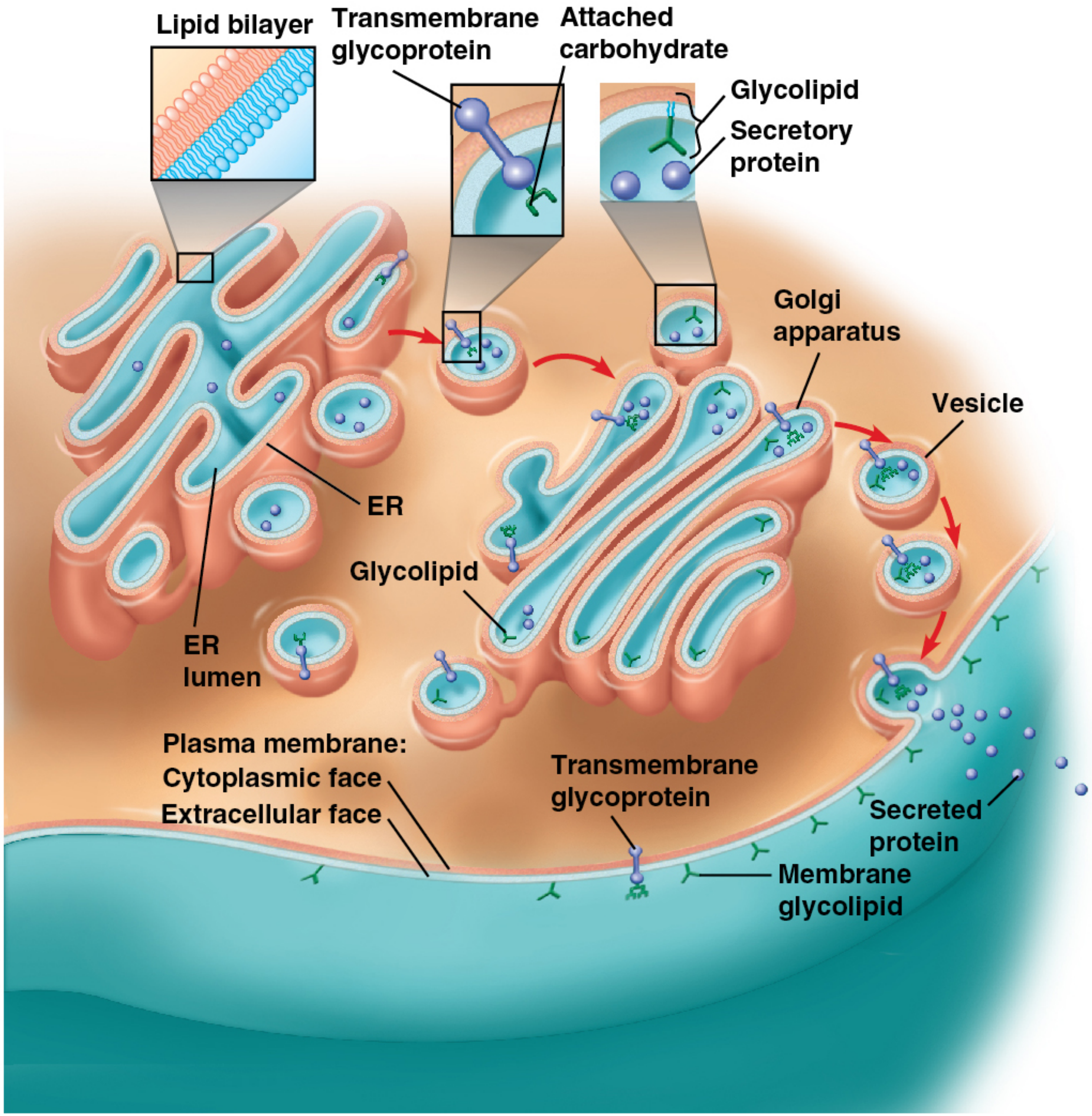
The Role of Membrane Carbohydrates in Cell-Cell Recognition

- Cells recognize each other by binding to molecules on the surface of the membrane
- Many of these surface molecules are bonded to short, branched chains of carbohydrates
  - **Glycolipids** are carbohydrates bonded to lipids
  - **Glycoproteins** are carbohydrates bonded to proteins
- The diversity of surface carbohydrates enables them to function as markers for cell identification

Synthesis and Sidedness of Membranes

- Membranes have distinct inside and outside faces
- The composition and distribution of proteins, lipids, and associated carbohydrates is asymmetrical across the membrane

Figure 7.9


Lipid bilayer
Transmembrane glycoprotein
Attached carbohydrate
Glycolipid
Secretory protein
Golgi apparatus
Vesicle
ER
Glycolipid
ER lumen
Plasma membrane:
Cytoplasmic face
Extracellular face
Transmembrane glycoprotein
Secreted protein
Membrane glycolipid

CONCEPT 7.2: Membrane structure results in selective permeability

- The plasma membrane controls the exchange of materials between the cell and its surroundings
- Membranes exhibit **selective permeability**; some substances cross more easily than others
- The fluid mosaic model explains how membranes regulate molecular traffic across the membrane

The Permeability of the Lipid Bilayer

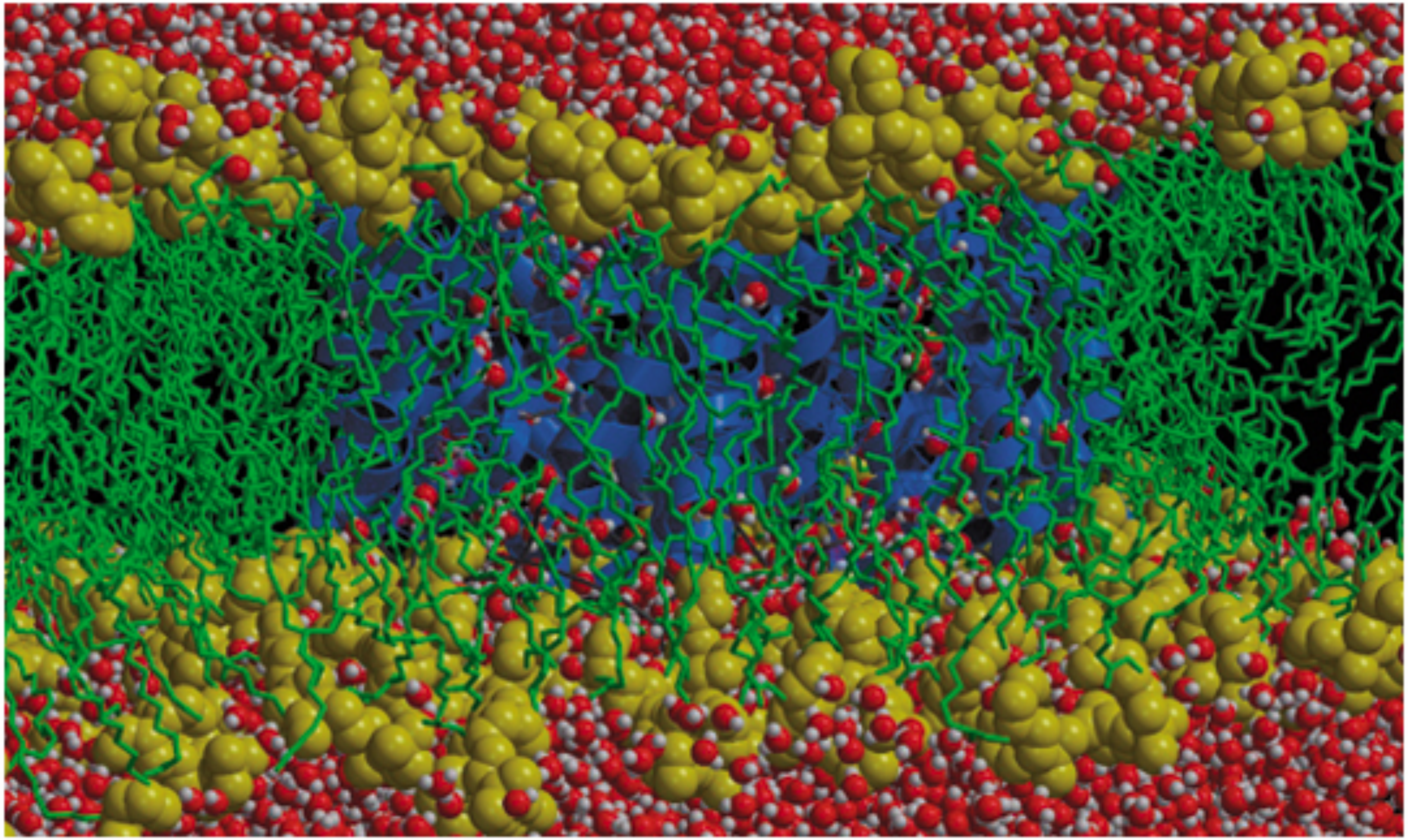
- Hydrophobic (nonpolar) molecules dissolve in the lipid bilayer and pass through the membrane rapidly
  - For example, hydrocarbons, CO_2 and O_2 pass easily through the membrane
- The hydrophobic interior of the membrane impedes the passage of hydrophilic (polar) molecules
  - For example, sugars, water and ions pass through slowly, if at all

Transport Proteins

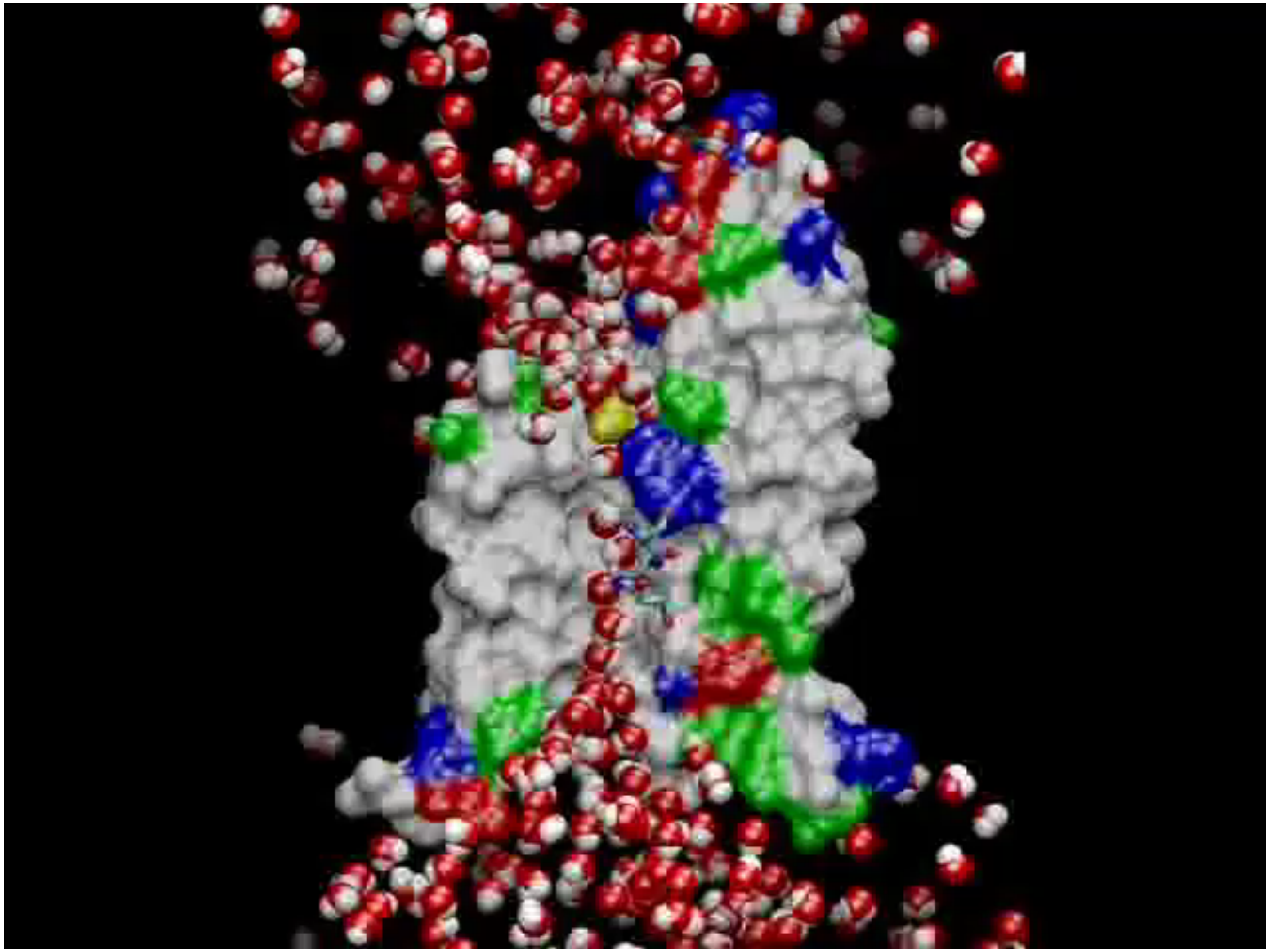
- Hydrophilic substances cross membranes more quickly by passing through **transport proteins**
- *Channel proteins* have a hydrophilic channel that certain molecules or ions can use as a tunnel
- *Carrier proteins*, bind to molecules and change shape to shuttle them across the membrane

- Channel proteins called **aquaporins** greatly increase the rate of passage of water molecules
- They are composed of four polypeptide subunits that each form a channel for the passage of water
- Overall, up to 3 billion water molecules pass through per second

Figure 7.10

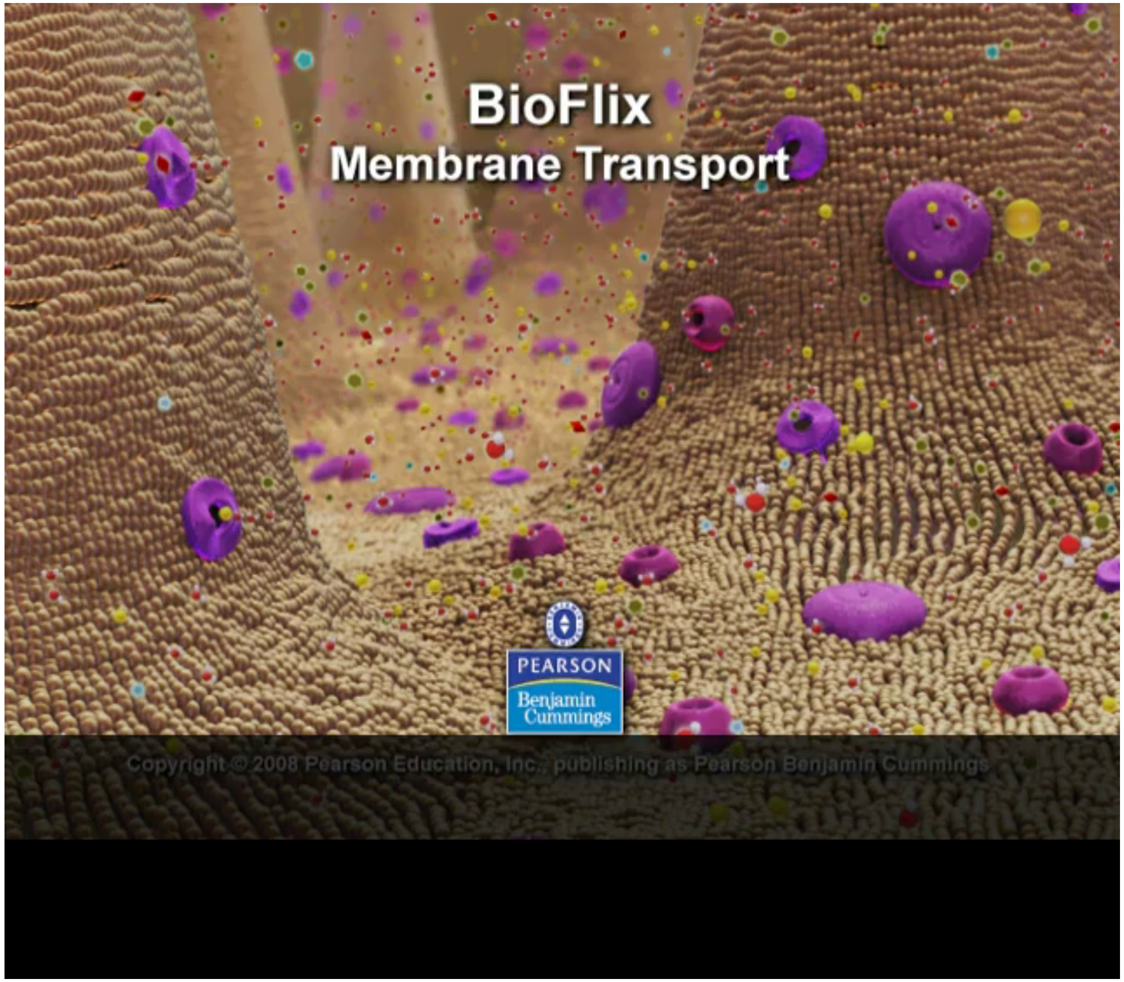


Video: Water Movement Through an Aquaporin



- Transport proteins move only specific substances
  - For example, glucose carrier proteins only transport glucose; they will not transport fructose, a structural isomer of glucose
- The selective permeability of a membrane is dependent on both the lipid bilayer and the specific transport proteins it contains

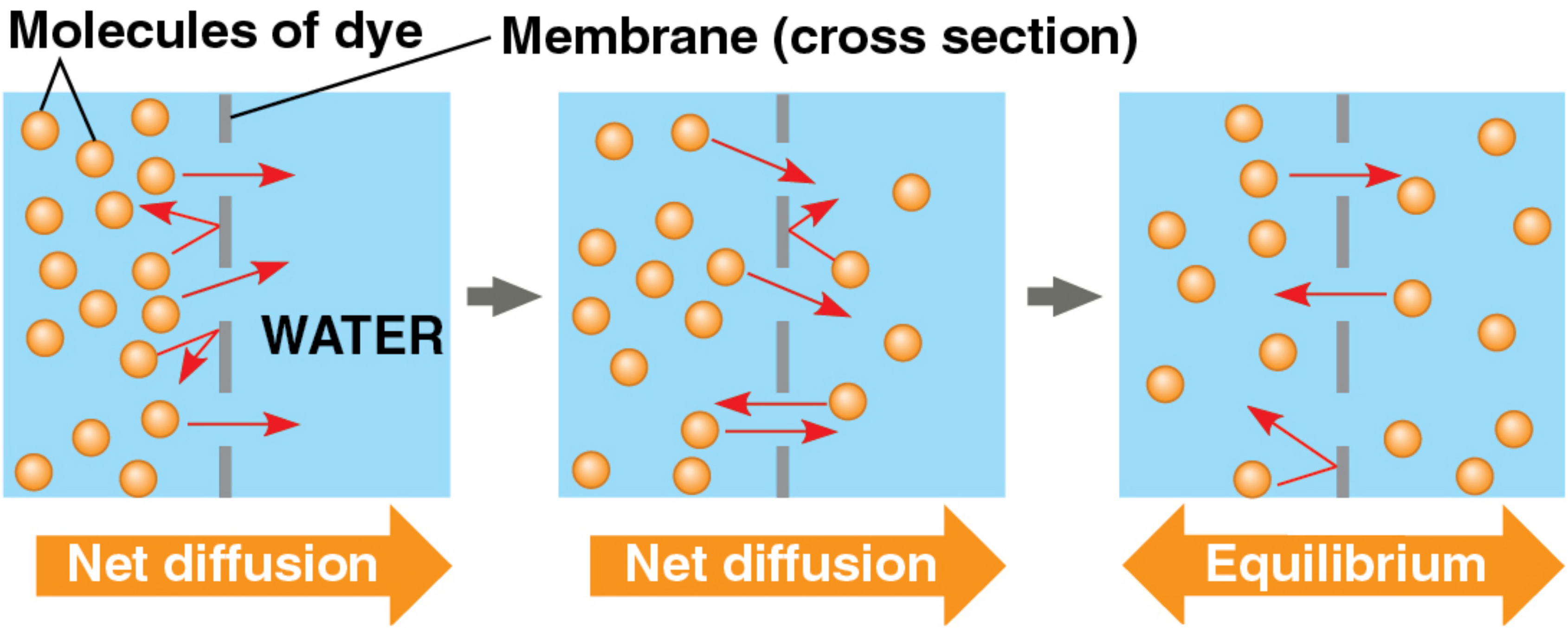
Video: Membrane Selectivity



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

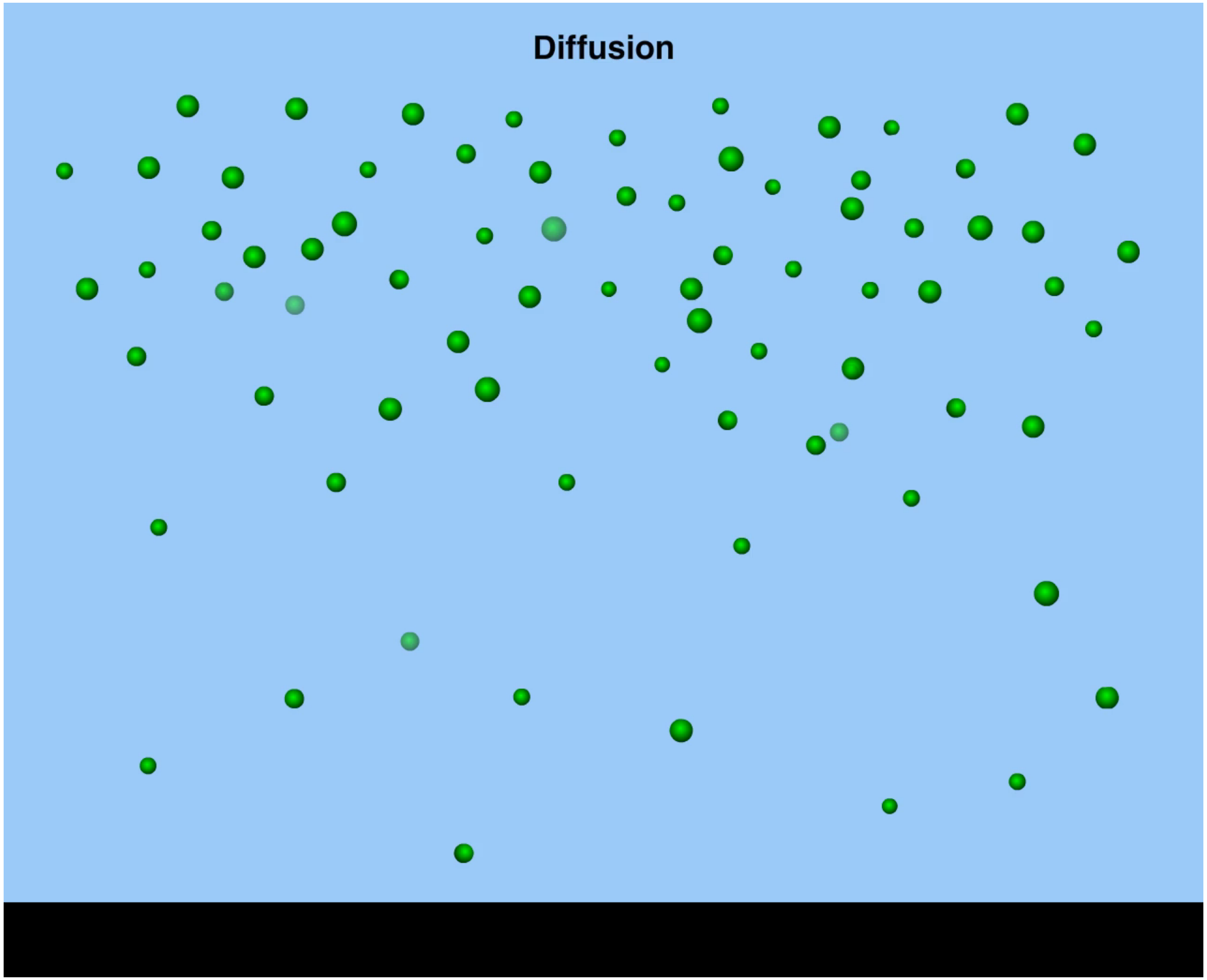
- **Diffusion** is the movement of particles of any substance so that they spread out evenly into the available space
- Although each molecule moves randomly, diffusion of a population of molecules may be directional
- At dynamic equilibrium, as many molecules cross the membrane in one direction as in the other

Figure 7.11a



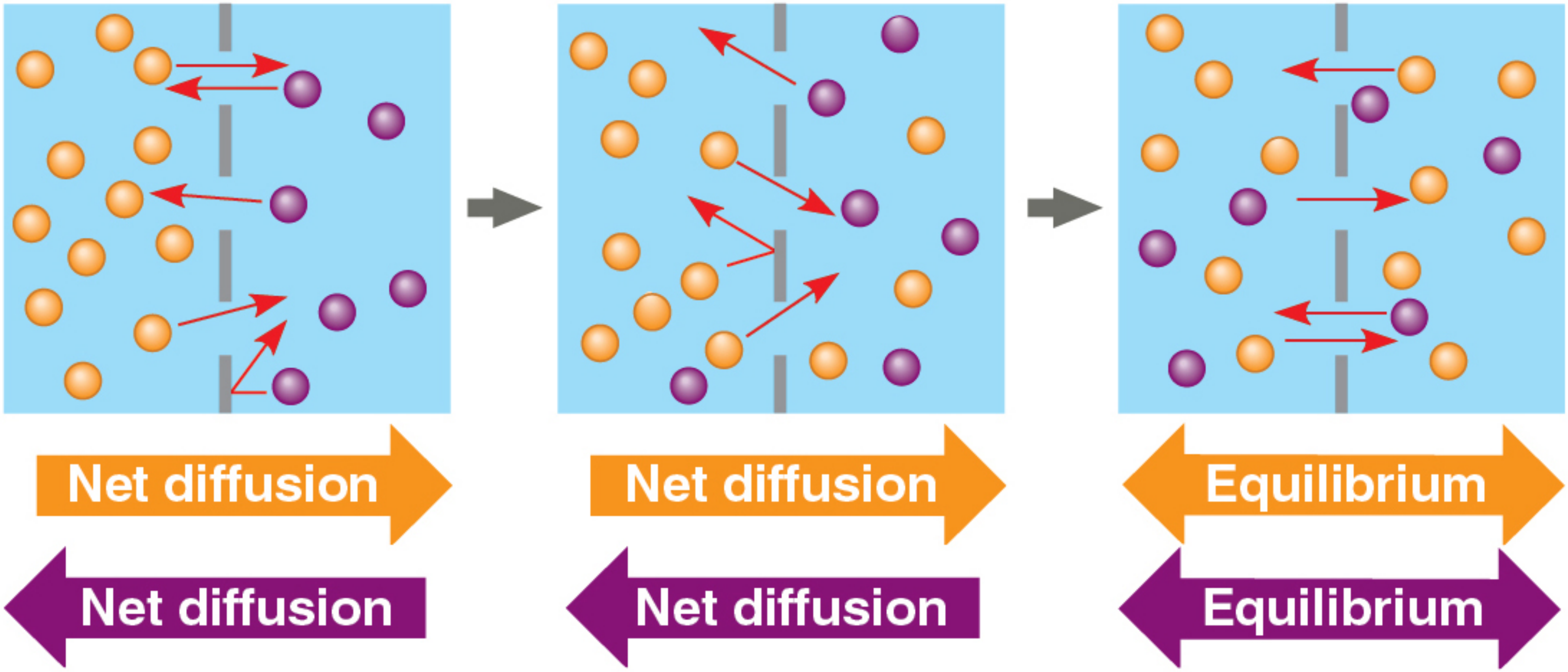
(a) Diffusion of one solute

Video: Diffusion



- Substances diffuse down their **concentration gradient**, the region along which the density of a chemical substance increases or decreases
- Each substance moves down its own concentration gradient, unaffected by the concentrations of other substances

Figure 7.11b



(b) Diffusion of two solutes

- The diffusion of a substance across a biological membrane is **passive transport** because no energy is expended by the cell
- The concentration gradient represents potential energy that drives diffusion
- But the rate of diffusion also depends on membrane permeability to the specific substance

Effects of Osmosis on Water Balance

- **Osmosis** is the diffusion of free water (water molecules not clustered around another substance) across a selectively permeable membrane
- Free water molecules diffuse across a membrane from the region of lower solute concentration to the region of higher solute concentration
- Water keeps moving until the solute concentration is equal on both sides

Figure 7.12

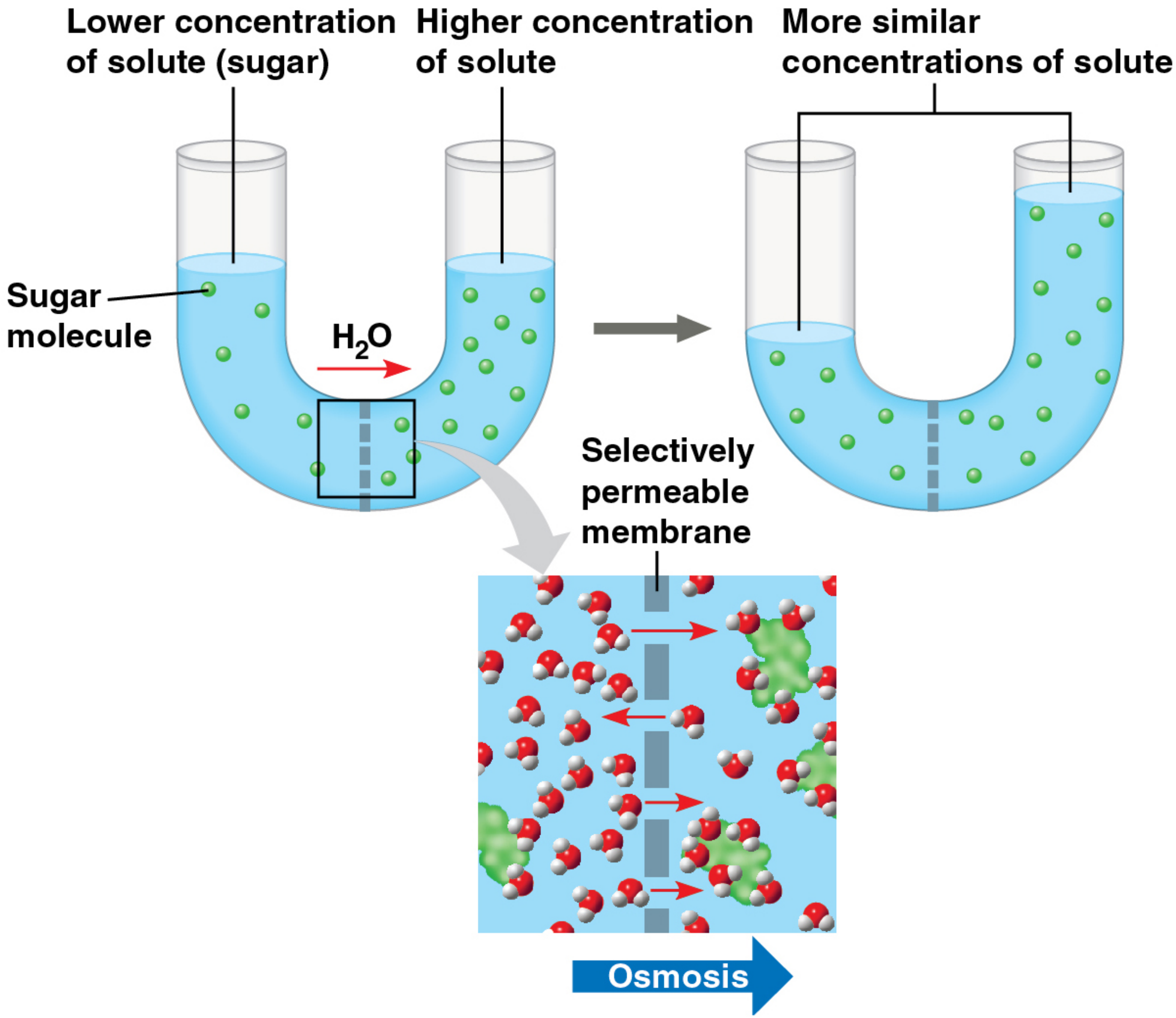
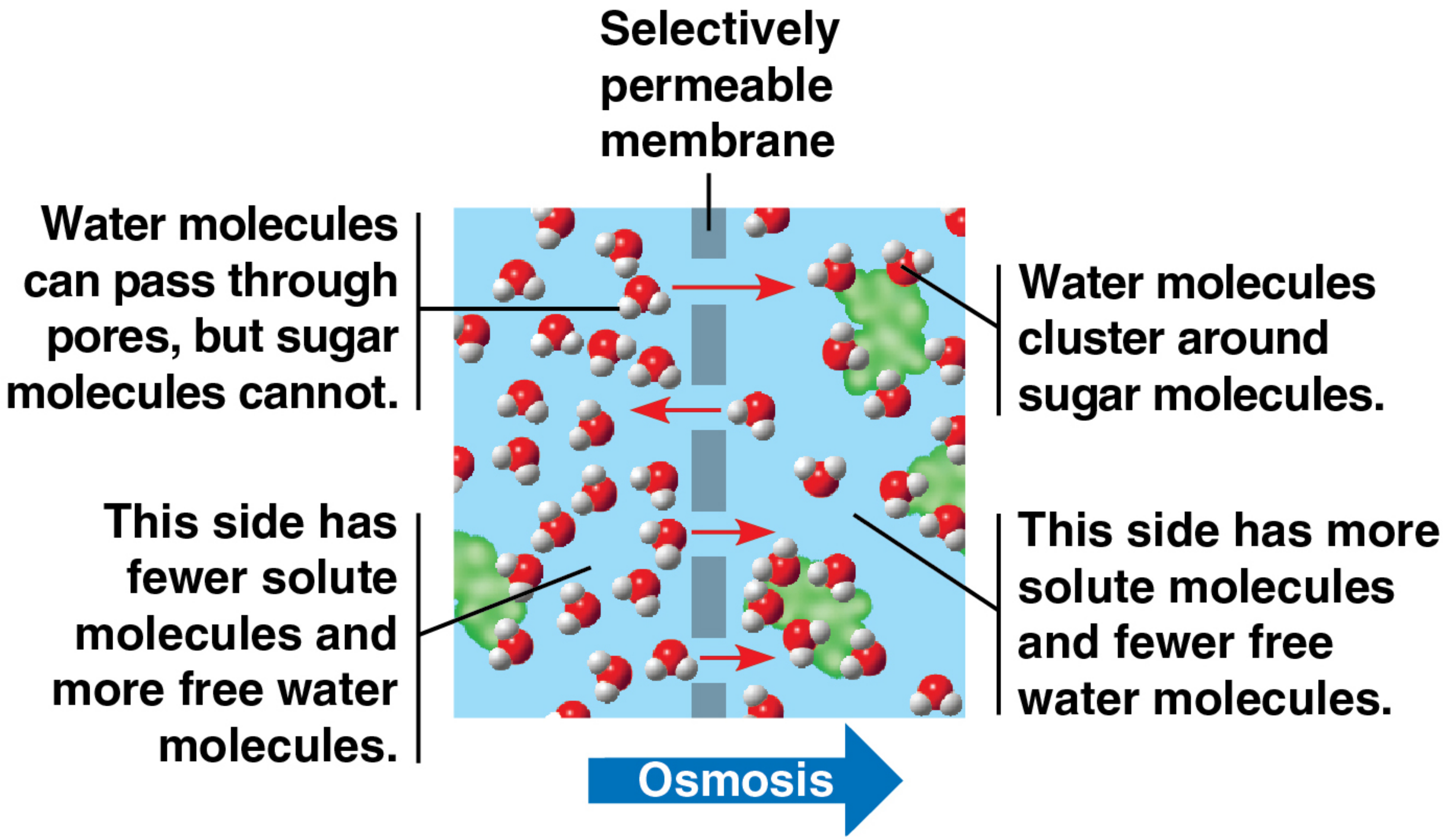
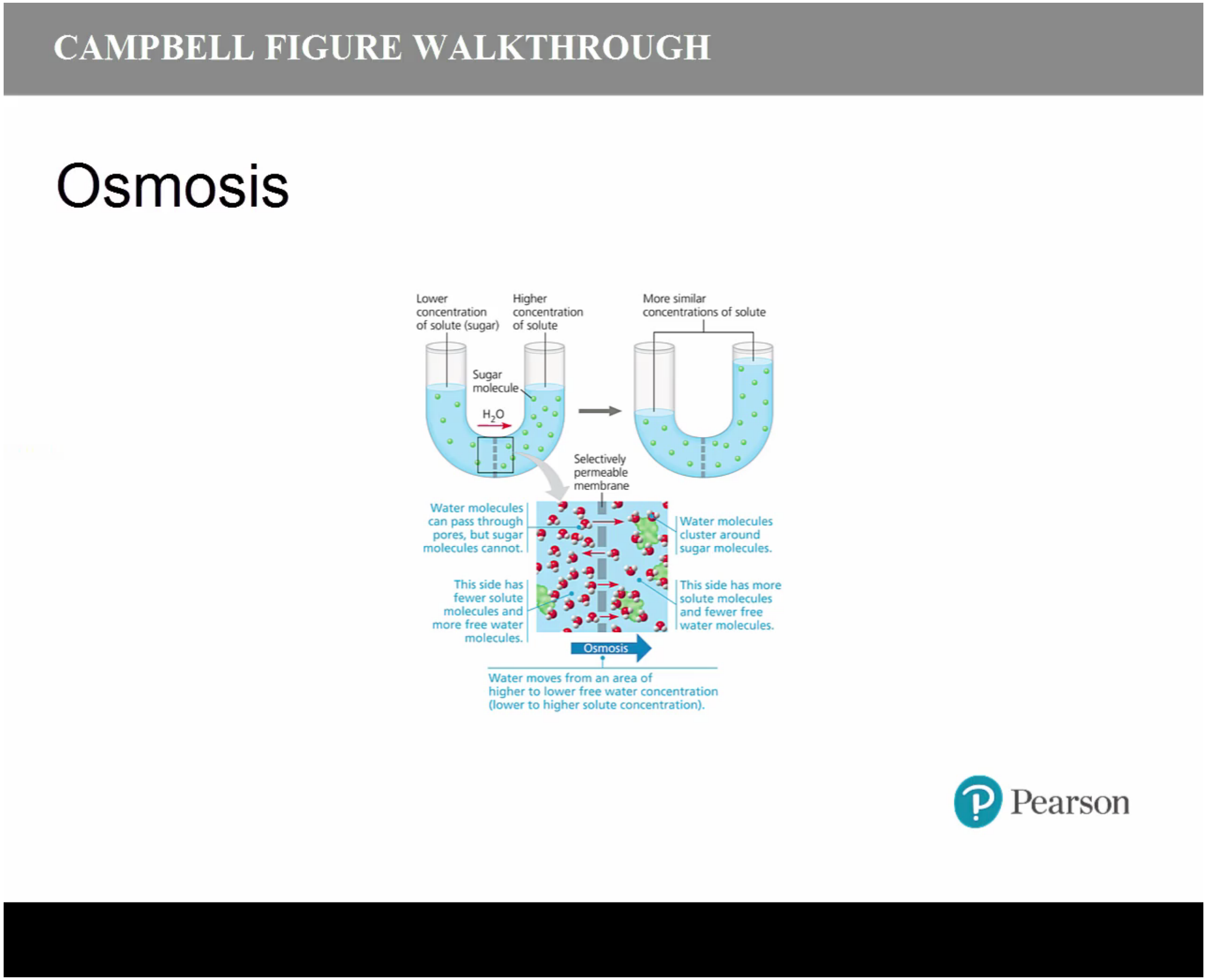

Lower concentration of solute (sugar)
Higher concentration of solute
More similar concentrations of solute
Sugar molecule
H_2O
Selectively permeable membrane
Osmosis

Figure 7.12a


Selectively permeable membrane
Water molecules can pass through pores, but sugar molecules cannot.
Water molecules cluster around sugar molecules.
This side has fewer solute molecules and more free water molecules.
This side has more solute molecules and fewer free water molecules.
Osmosis

Video: Osmosis



Water Balance of Cells Without Cell Walls

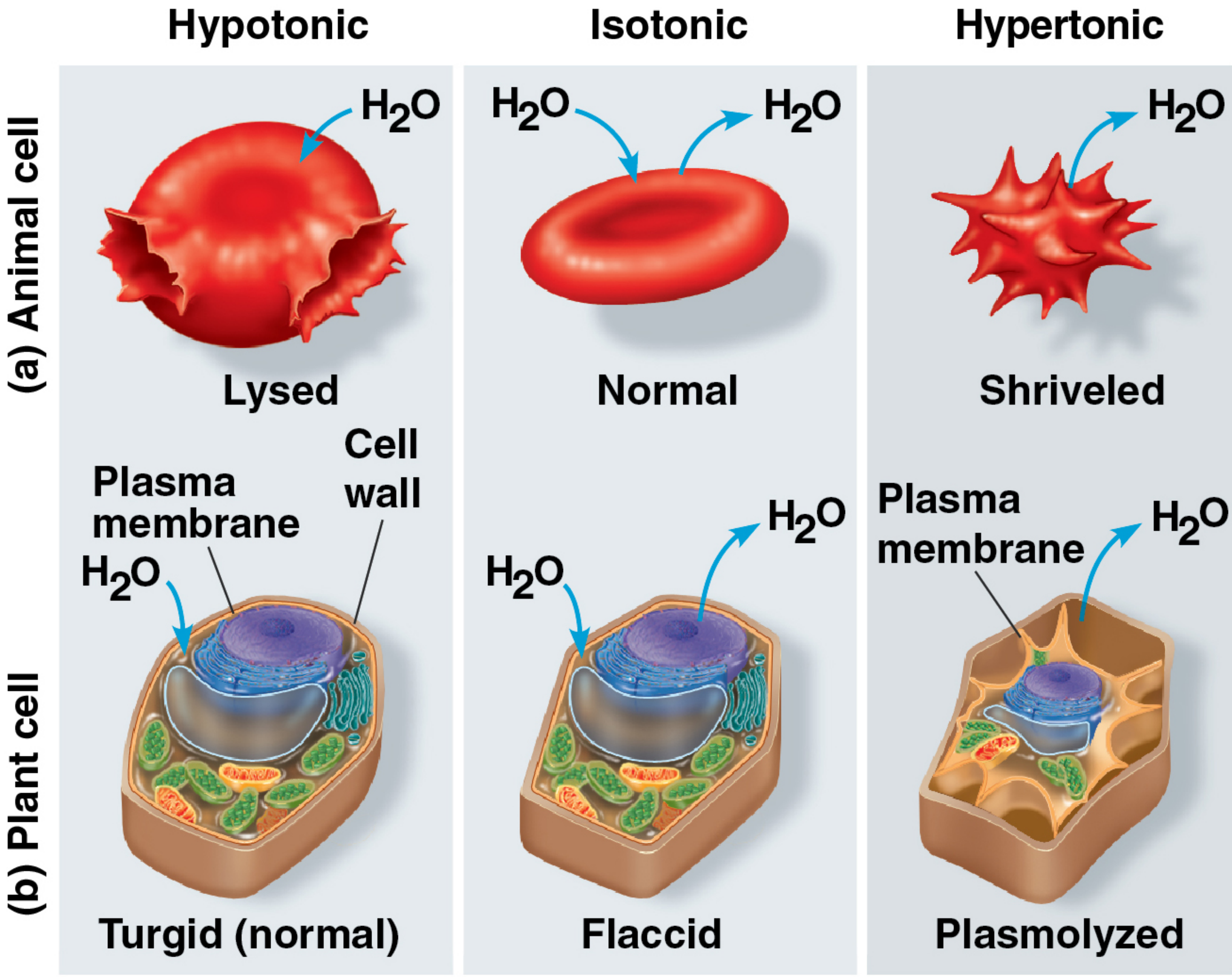
- **Tonicity** is the ability of a surrounding solution to cause a cell to gain or lose water
- Tonicity depends on the concentration of solutes in the solution that cannot cross the membrane, relative to that inside the cell
- If the solution has a higher concentration of these solutes than the inside of the cell, water will tend to leave the cell, and vice versa

- A solution is **isotonic** if its solute concentration is the same as that inside the cell
- Water diffuses across the membrane at the same rate in both directions; there is no *net* movement of water across the membrane
- The volume of a cell without a cell wall is stable in an isotonic solution

- A solution is **hypertonic** if the solute concentration is greater than that inside the cell
- Net diffusion of water is from inside the cell to the surrounding solution
- Cells without cell walls will lose water, shrivel, and likely die in hypertonic solution

- A solution is **hypotonic** if the solute concentration is less than that inside the cell
- Net diffusion of water is from the surrounding solution to the inside of the cell
- Cells without cell walls will gain water, swell and lyse (burst) in a hypotonic solution

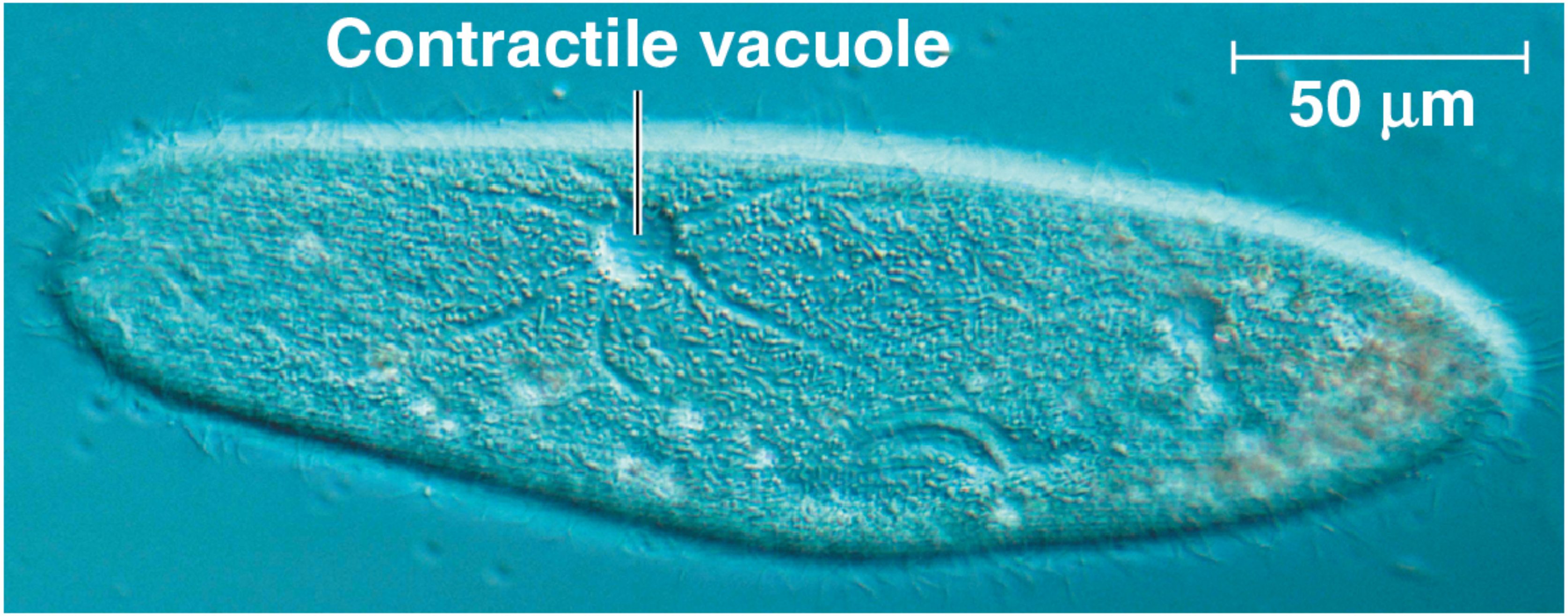
Figure 7.13



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

- Hypotonic or hypertonic environments cause problems for cells without walls because they cannot tolerate excessive water loss or uptake
- Organisms that live in such environments require a method of **osmoregulation**, control of solute concentration and water balance
  - For example, *Paramecium* live in a hypotonic environment; they have a contractile vacuole to pump excess water out of the cell

Figure 7.14



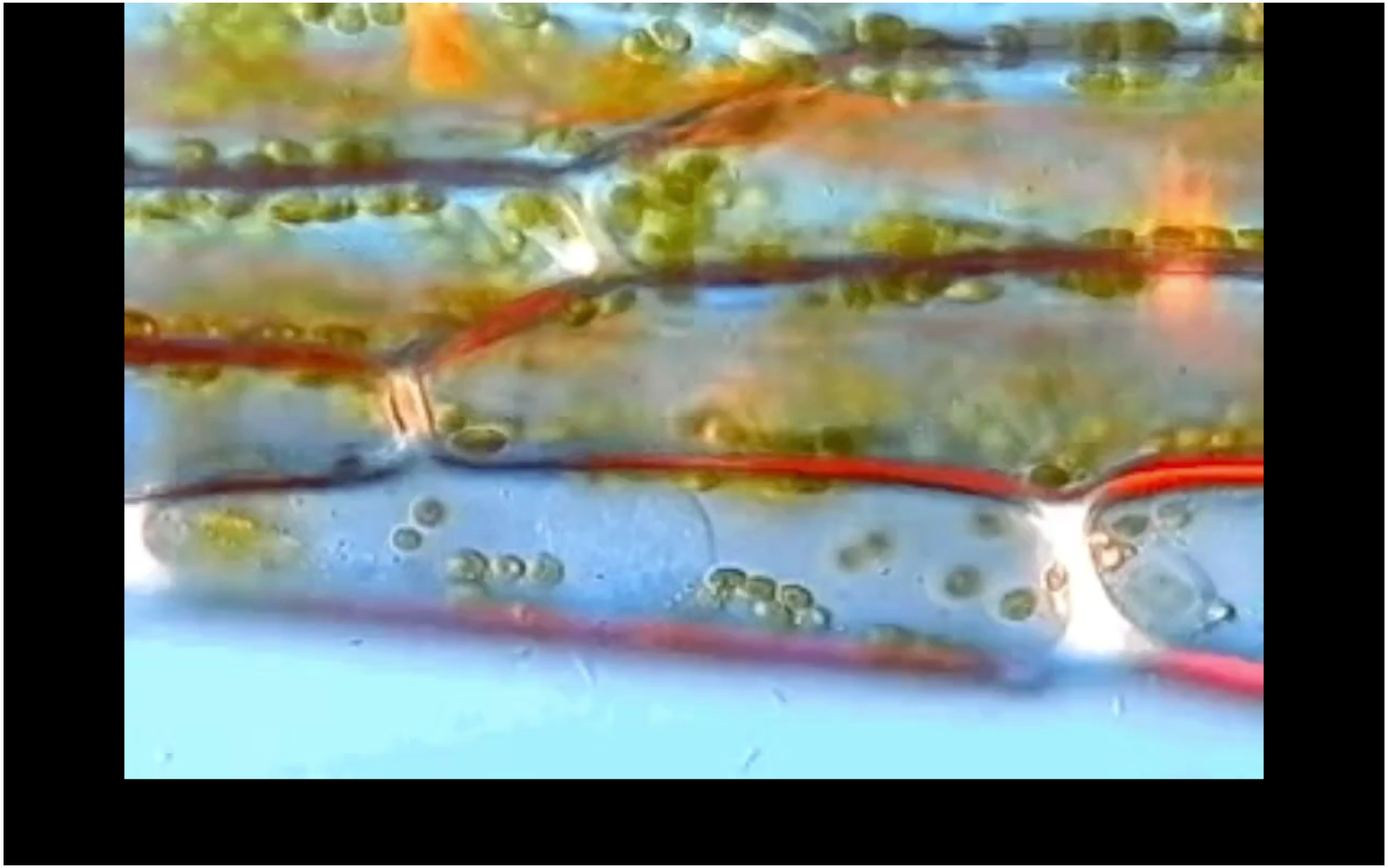
Video: *Paramecium* Vacuole

- Bacteria and archaea living in hypersaline (excessively salty) environments have mechanisms to ensure that water does not leave the cell

Water Balance of Cells with Cell Walls

- The cells of plants, prokaryotes, fungi and some protists have cell walls
- A plant cell in a hypotonic solution takes up water and swells until the inelastic wall exerts back a pressure on the cell, called turgor pressure
- At this point the cell is **turgid** (very firm), the healthy state for most plant cells

Video: Turgid *Elodea*



- If a plant cell and its surroundings are isotonic, there is no net movement of water into the cell
- Plant cells become **flaccid** (limp) in an isotonic solution, and the plant wilts

- Plant cells lose water in a hypertonic environment
- The cell shrivels and the membrane pulls away from the cell wall in multiple locations, a phenomenon called **plasmolysis**
- In response, the plant will wilt and may die

Video: Plasmolysis in *Elodea*

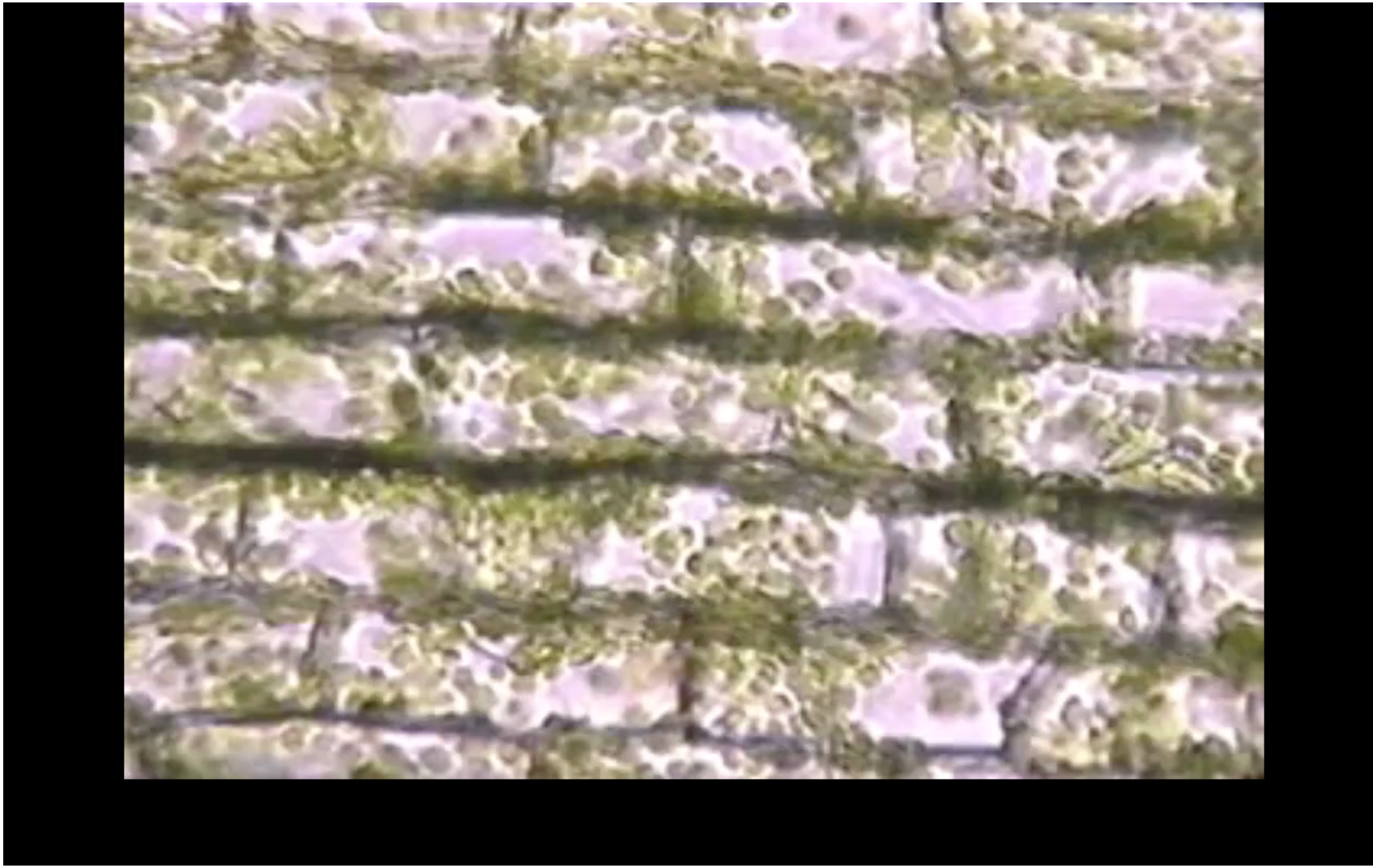
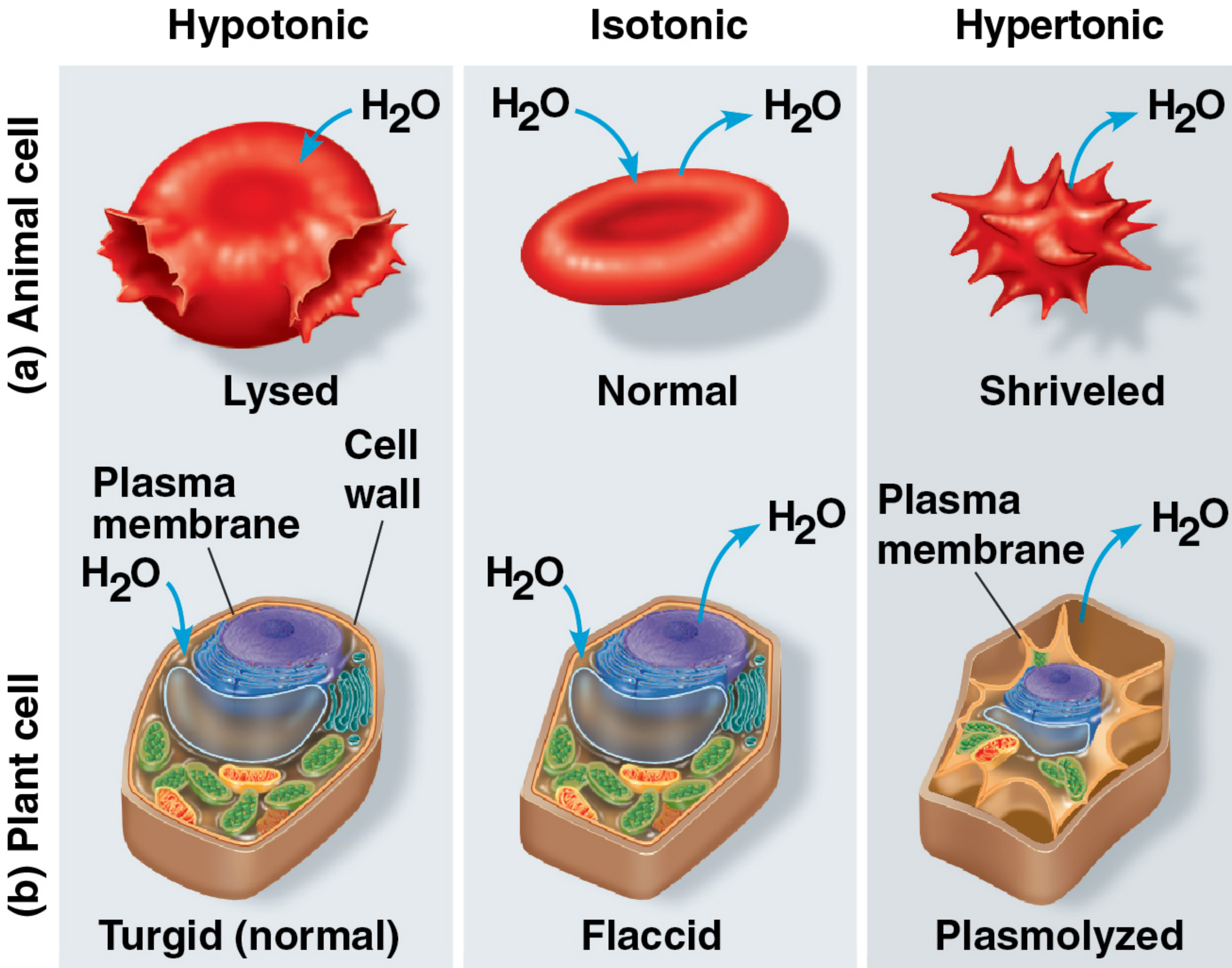


Figure 7.13

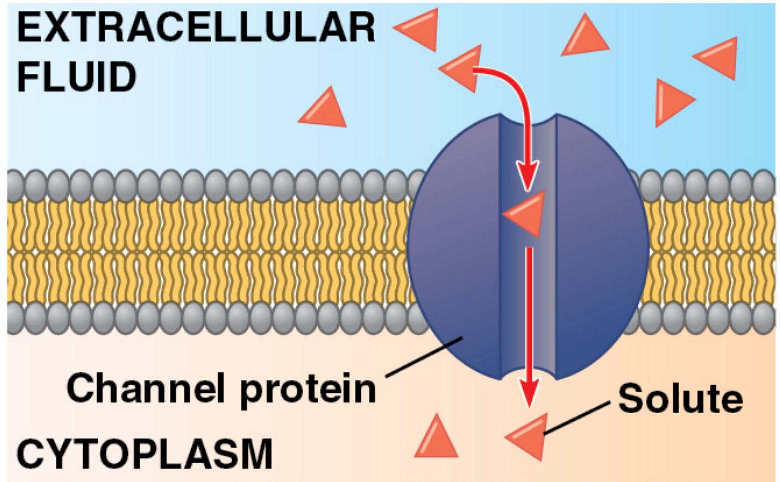


Hypotonic
Isotonic
Hypertonic
(a) Animal cell
H_2O
H_2O
H_2O
H_2O
Lysed
Normal
Shriveled
(b) Plant cell
Cell wall
Plasma membrane
H_2O
H_2O
H_2O
Plasma membrane
H_2O
Turgid (normal)
Flaccid
Plasmolyzed

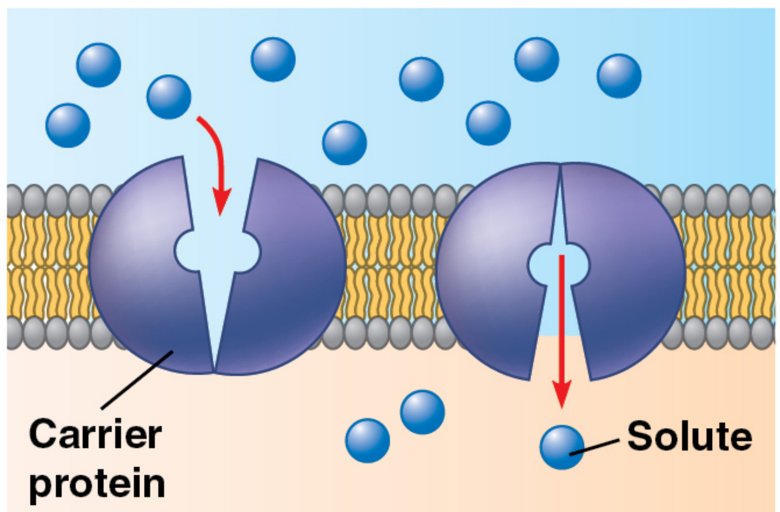
Facilitated Diffusion: Passive Transport Aided by Proteins

- In **facilitated diffusion**, transport proteins speed the passive movement of molecules across the plasma membrane
- Transport proteins include channel proteins and carrier proteins

Figure 7.15

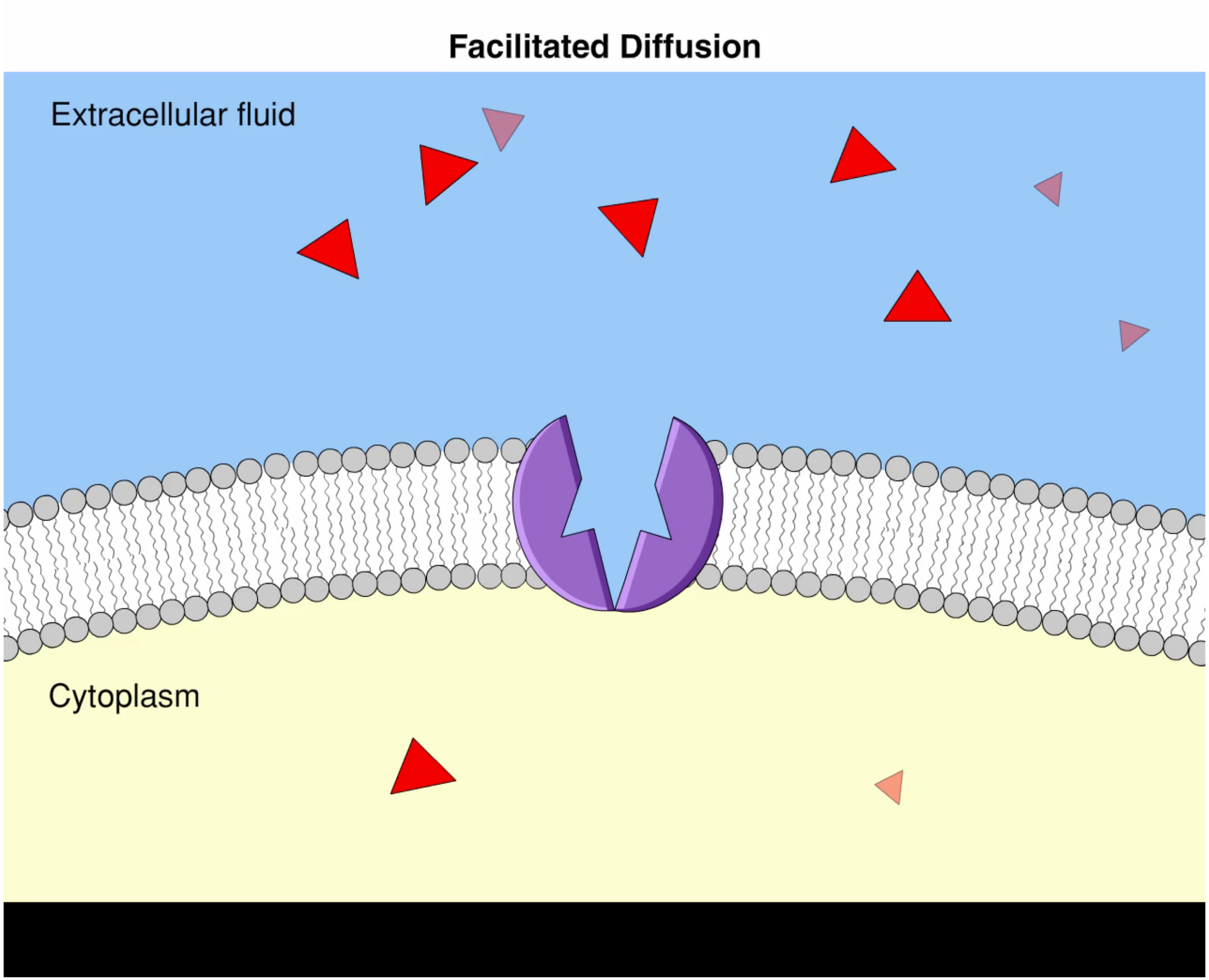


(a) A channel protein



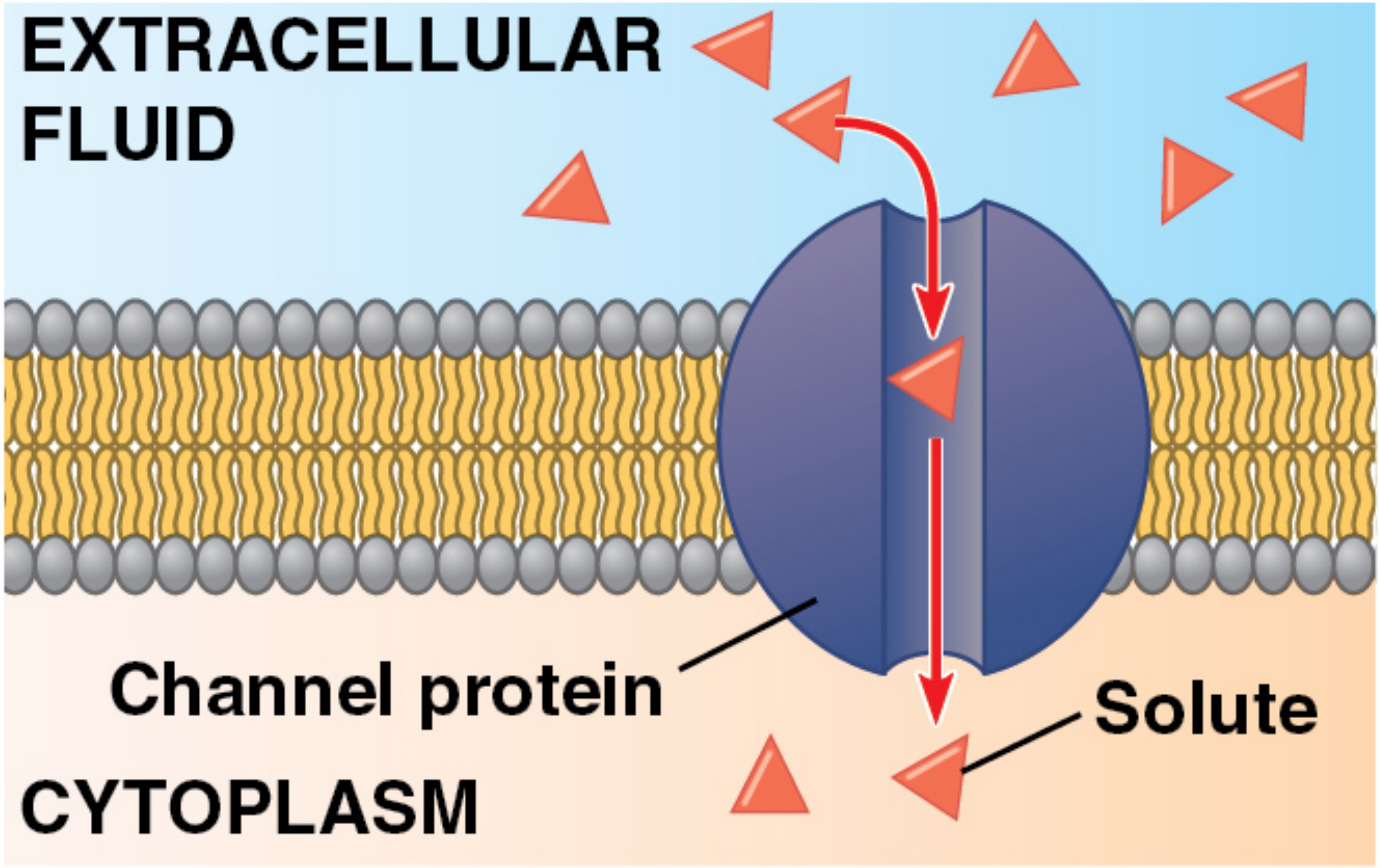
(b) A carrier protein

Animation: Facilitated Diffusion



- Channel proteins provide corridors that allow a specific molecule or ion to cross the membrane
- Aquaporins facilitate the diffusion of water
- **Ion channels** facilitate the transport of ions

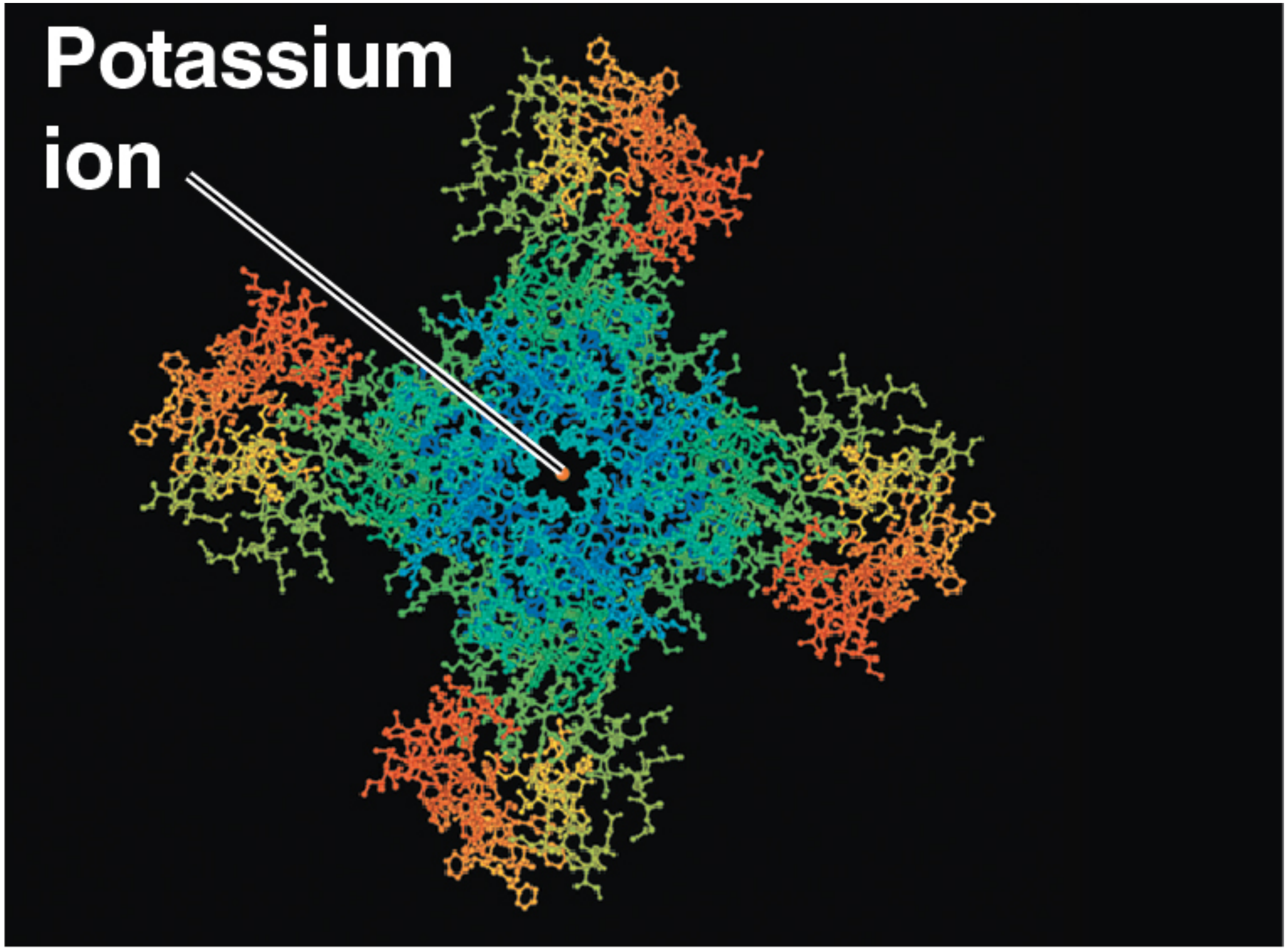
Figure 7.15a



(a) A channel protein

- Some ion channels, called **gated channels**, open or close in response to a stimulus
  - For example, in nerve cells, potassium ion channels open in response to electrical stimulus
  - Other gated channels open in response to chemical stimulus—binding of a specific substance to the protein

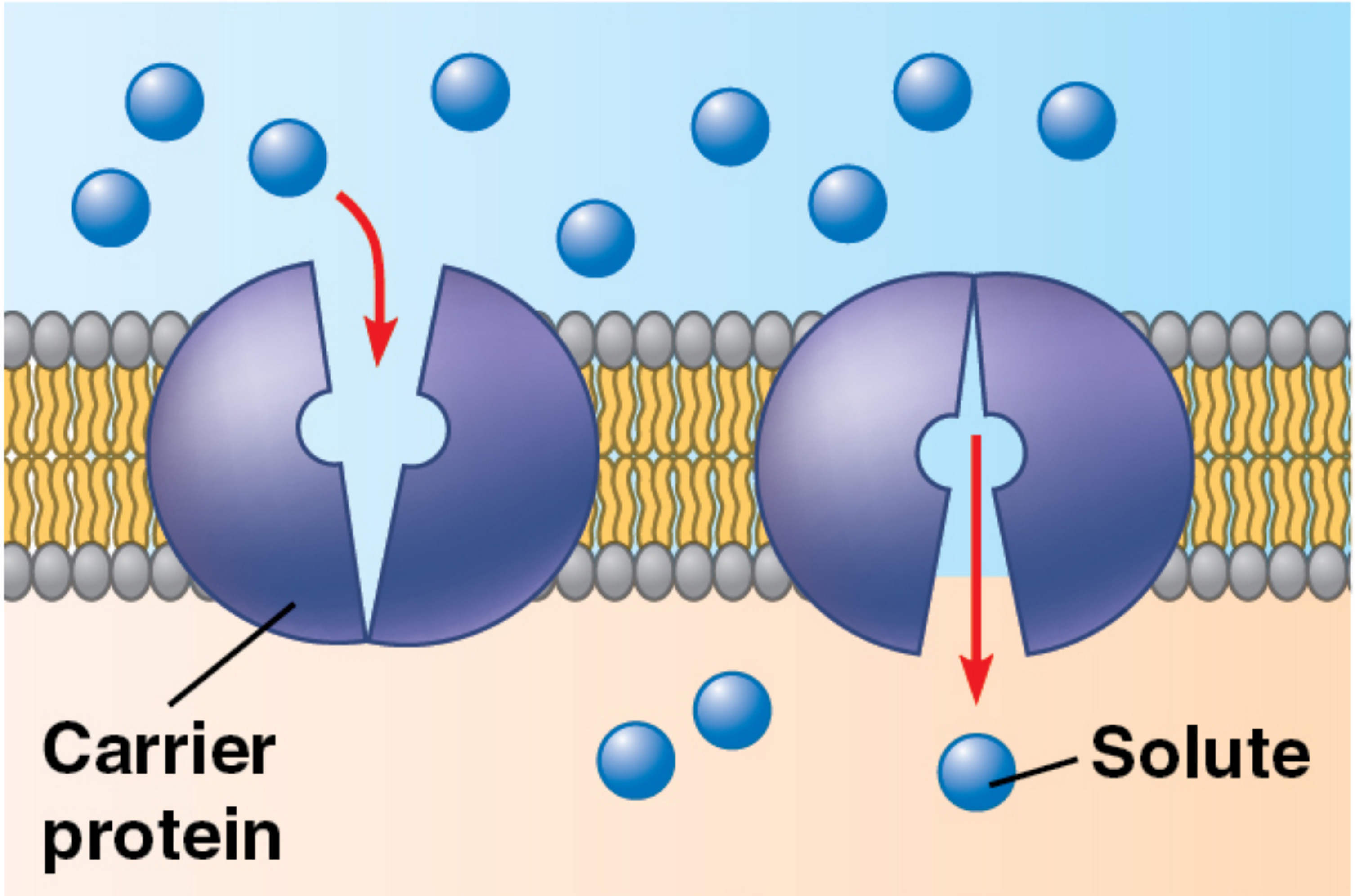
Figure 7.UN02



Potassium ion channel protein

- Carrier proteins undergo a subtle shape change that moves the solute-binding site across the membrane
- This change in shape can be triggered by the binding and release of the transported molecule
- Carrier proteins involved in facilitated diffusion move substances down their concentration gradients; no energy input is required

Figure 7.15b



(b) A carrier protein

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

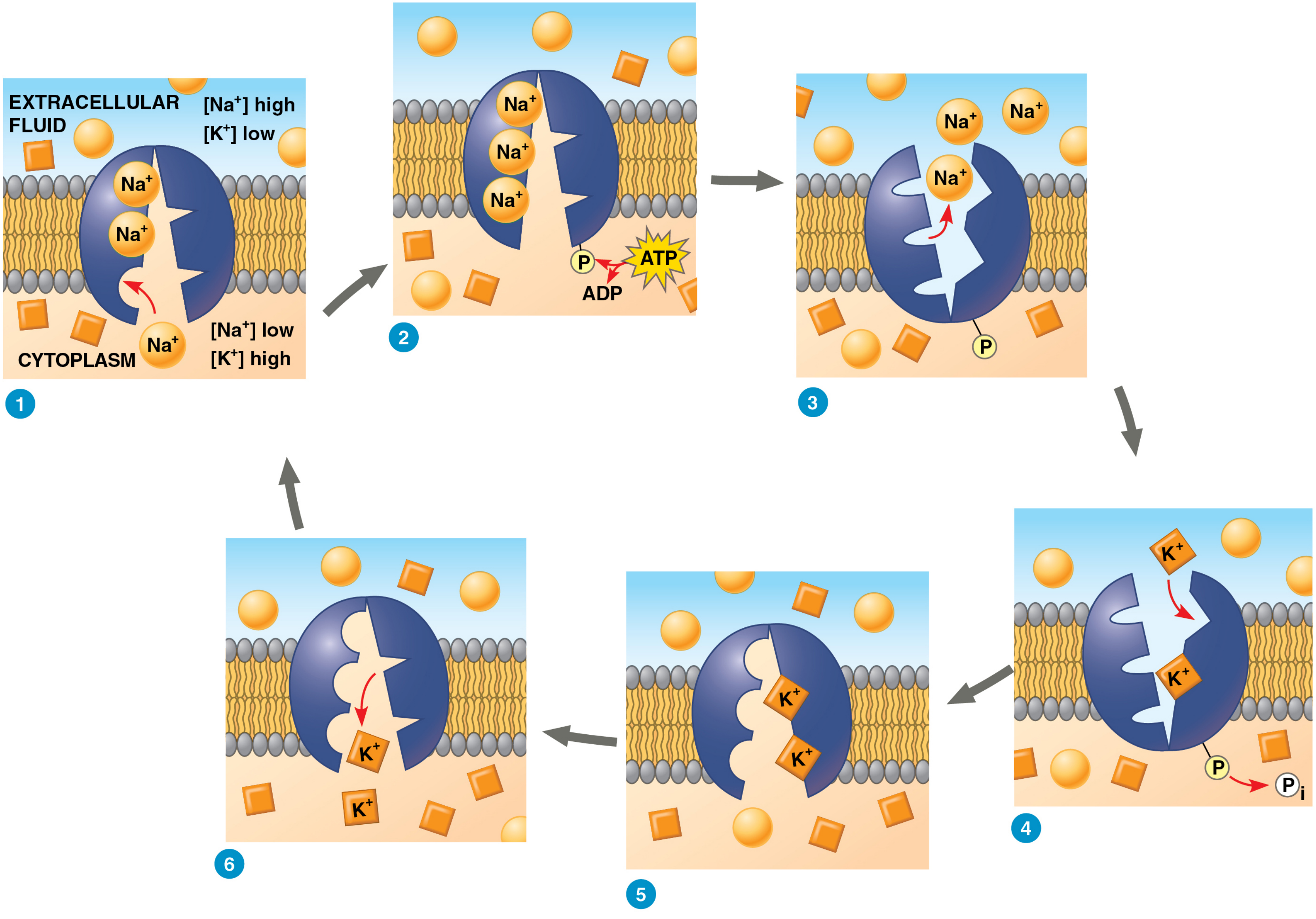
- Facilitated diffusion is passive because the solute moves down its concentration gradient, and the transport requires no energy
- Some transport proteins use energy to move solutes *against* their concentration gradients

The Need for Energy in Active Transport

- **Active transport** requires energy, usually in the form of ATP hydrolysis, to move substances against their concentration gradients
- All proteins involved in active transport are carrier proteins

- Active transport enables cells to maintain solute concentrations that differ from the environment
  – For example, the concentration of potassium ions (K^+) is higher and the concentration of sodium ions (Na^+) is lower inside animal cells than their surroundings
  – Transfer of a phosphate group from ATP to the **sodium-potassium pump** energizes the transport of K^+ into the cell and Na^+ out of the cell

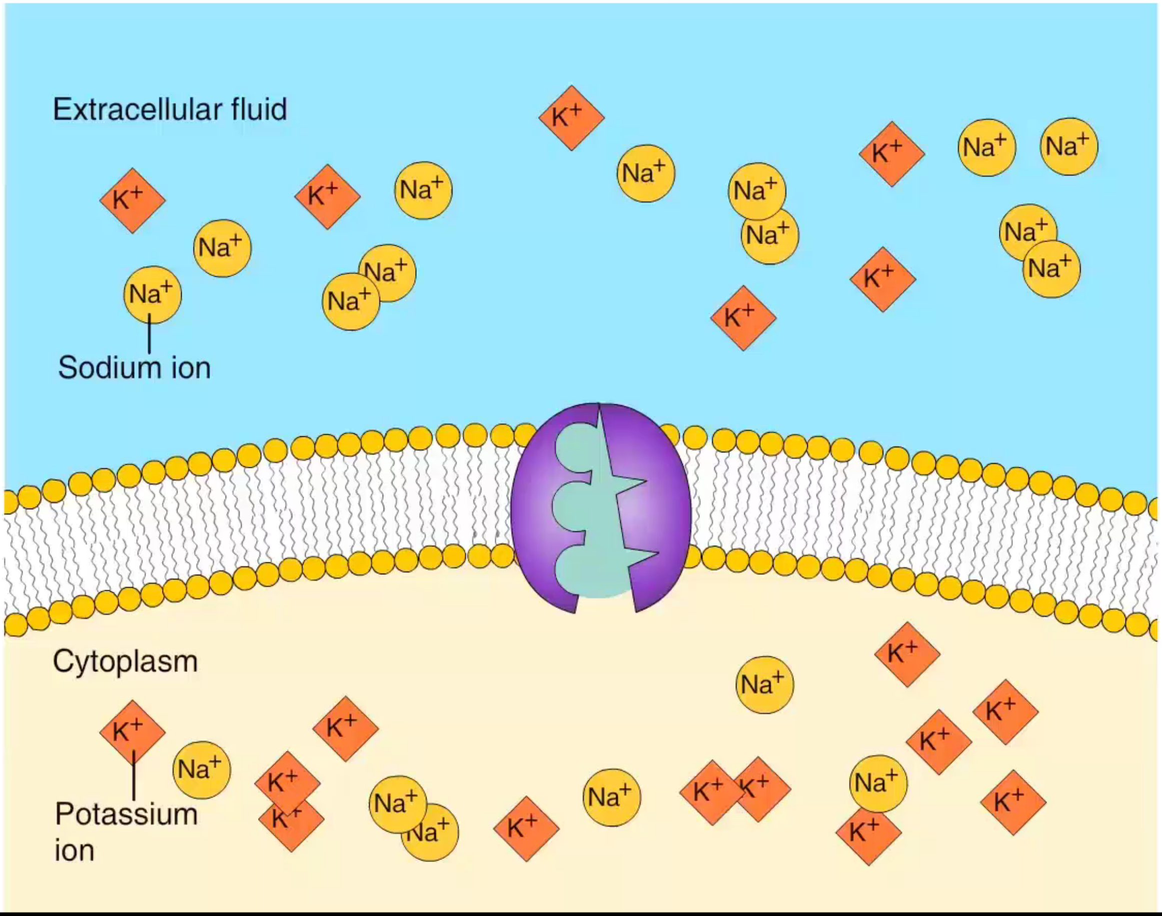
Figure 7.16



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

Animation: Active Transport

Active Transport



Video: Na^+/K^+ ATPase Cycle

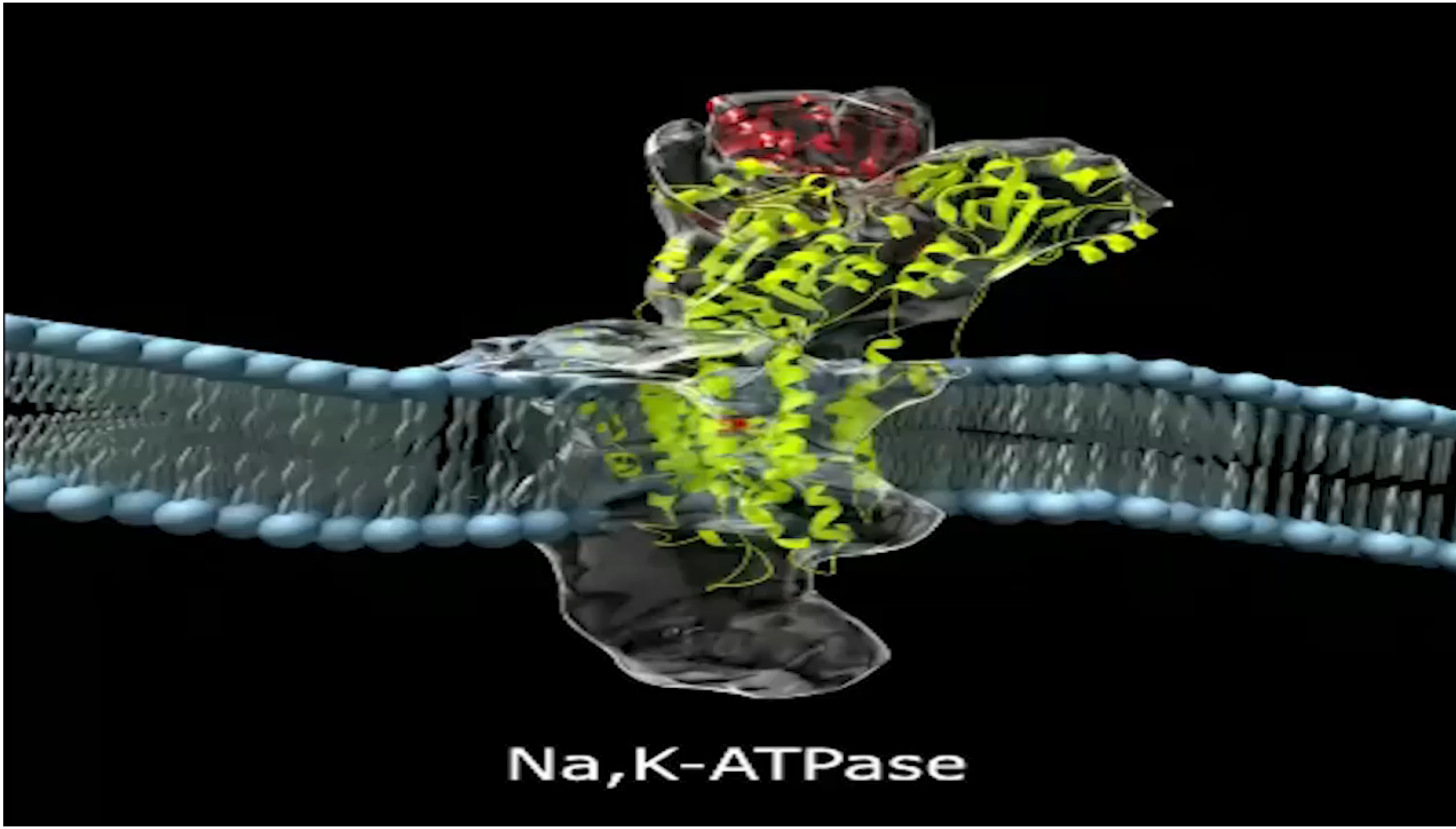
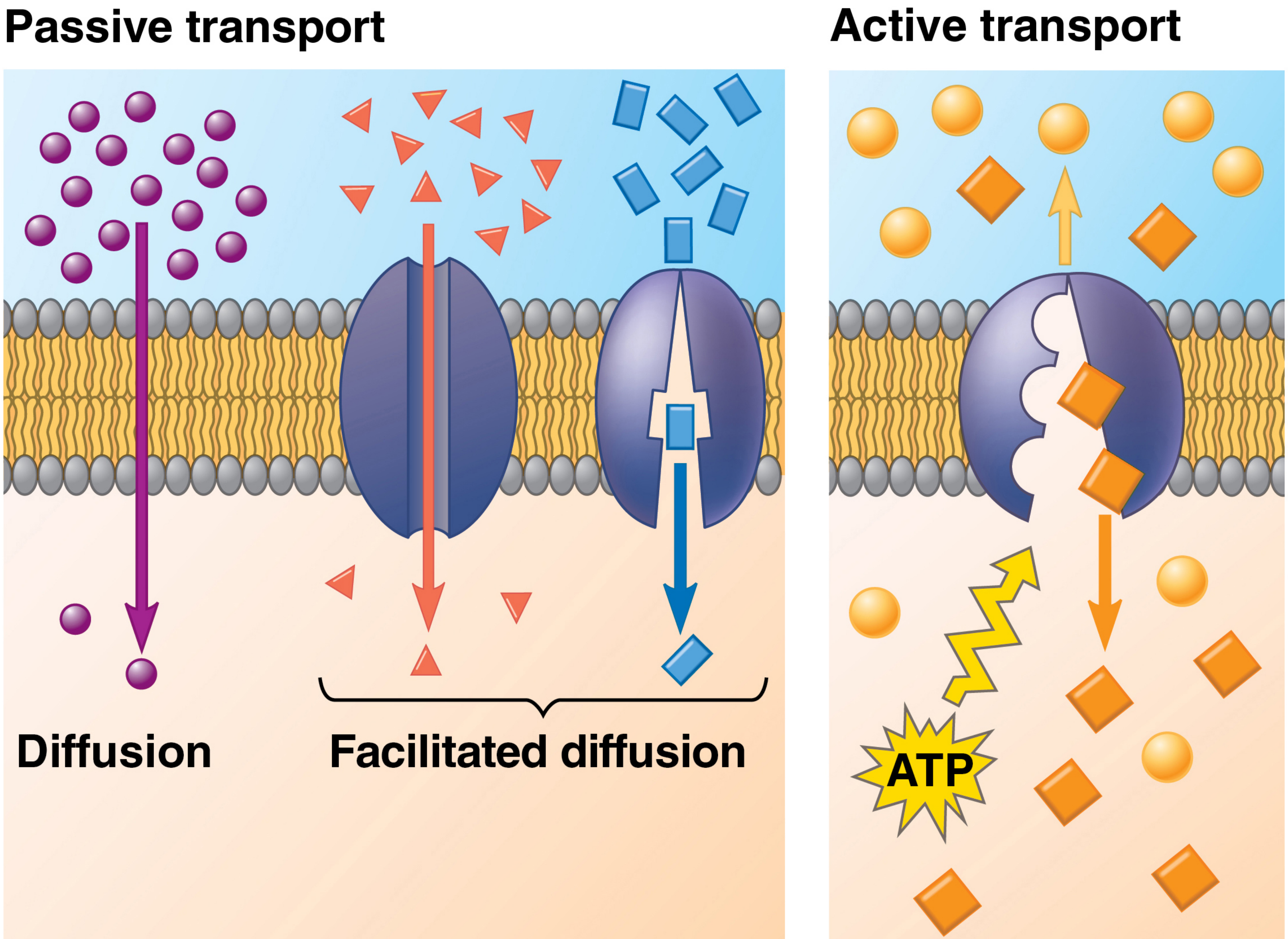


Figure 7.17


Passive transport
Active transport
ATP
Diffusion
Facilitated diffusion

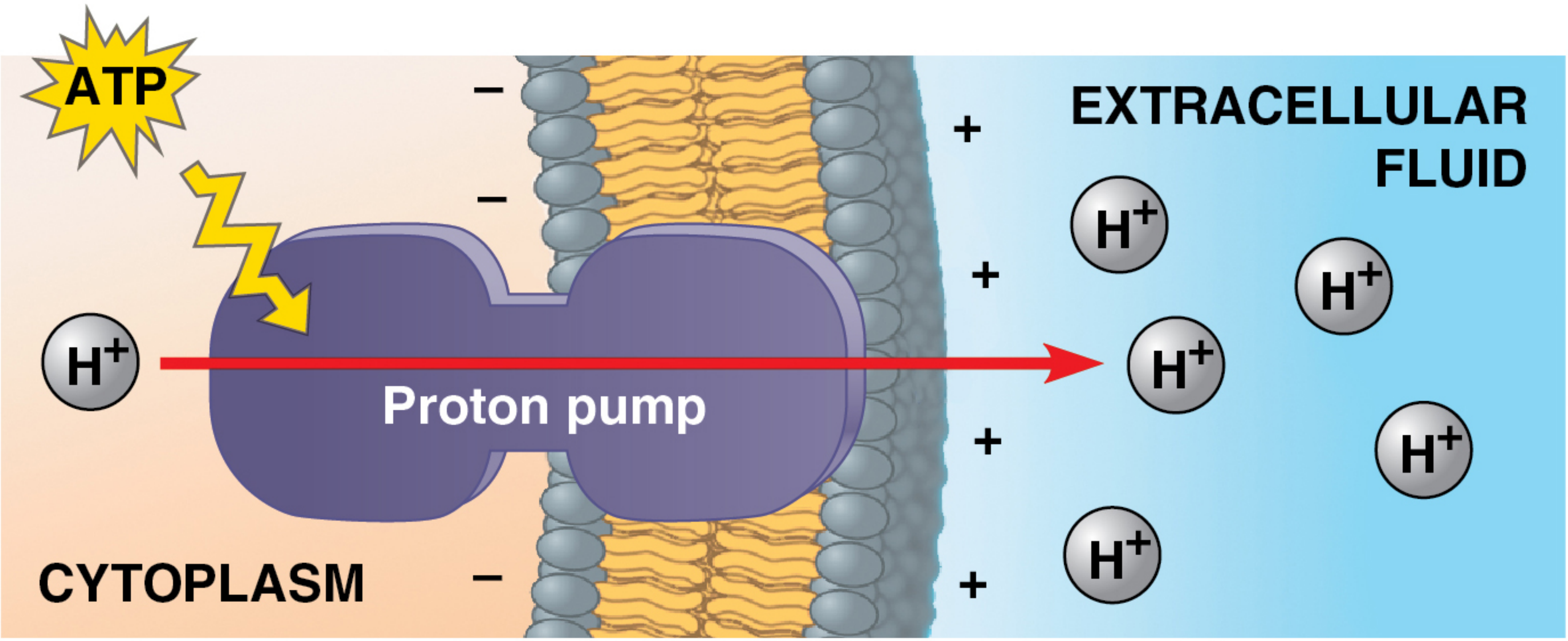
How Ion Pumps Maintain Membrane Potential

- **Membrane potential** is the voltage across a membrane
- Voltage is created by differences in the distribution of positive and negative ions across a membrane
- The inside of the cell is negative in charge relative to the outside, favoring passive transport of cations into and anions out of the cell

- 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 ion diffuses down its electrochemical gradient

- An **electrogenic pump** is a transport protein that generates voltage across a membrane, storing energy that can be used for cellular work
- The main electrogenic pump differs between plants and animals
  - In animals, it is the sodium-potassium pump
  - In plants, fungi, and bacteria, it is the **proton pump**, which actively transports hydrogen ions (H^+) out of the cell

Figure 7.18



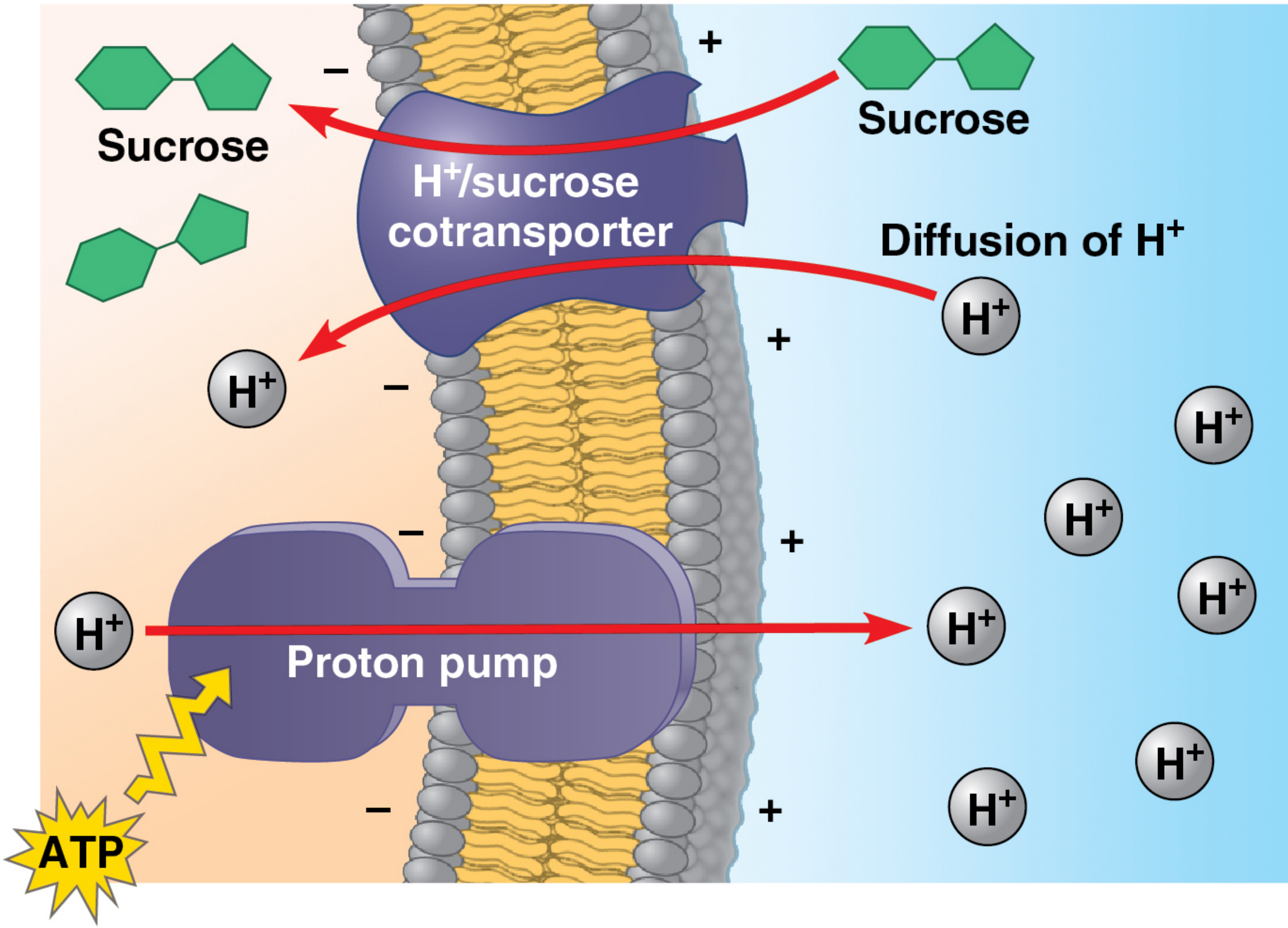
Cotransport: Coupled Transport by a Membrane Protein

- **Cotransport** occurs when active transport of a solute indirectly drives transport of other substances
- The “downhill” diffusion of solute is coupled to the “uphill” transport of a second substance against its own concentration gradient

How Ion Pumps Maintain Membrane Potential

- Plant cells use proton pumps to generate an H^+ gradient across the cell membrane
- A cotransporter couples the movement of H^+ back down its concentration gradient to the active transport of sucrose into the cell
- This is how plants load sucrose into their veins for transport around the plant body

Figure 7.19



Sucrose
Sucrose
H+/sucrose cotransporter
Diffusion of H+
H+
Proton pump
ATP

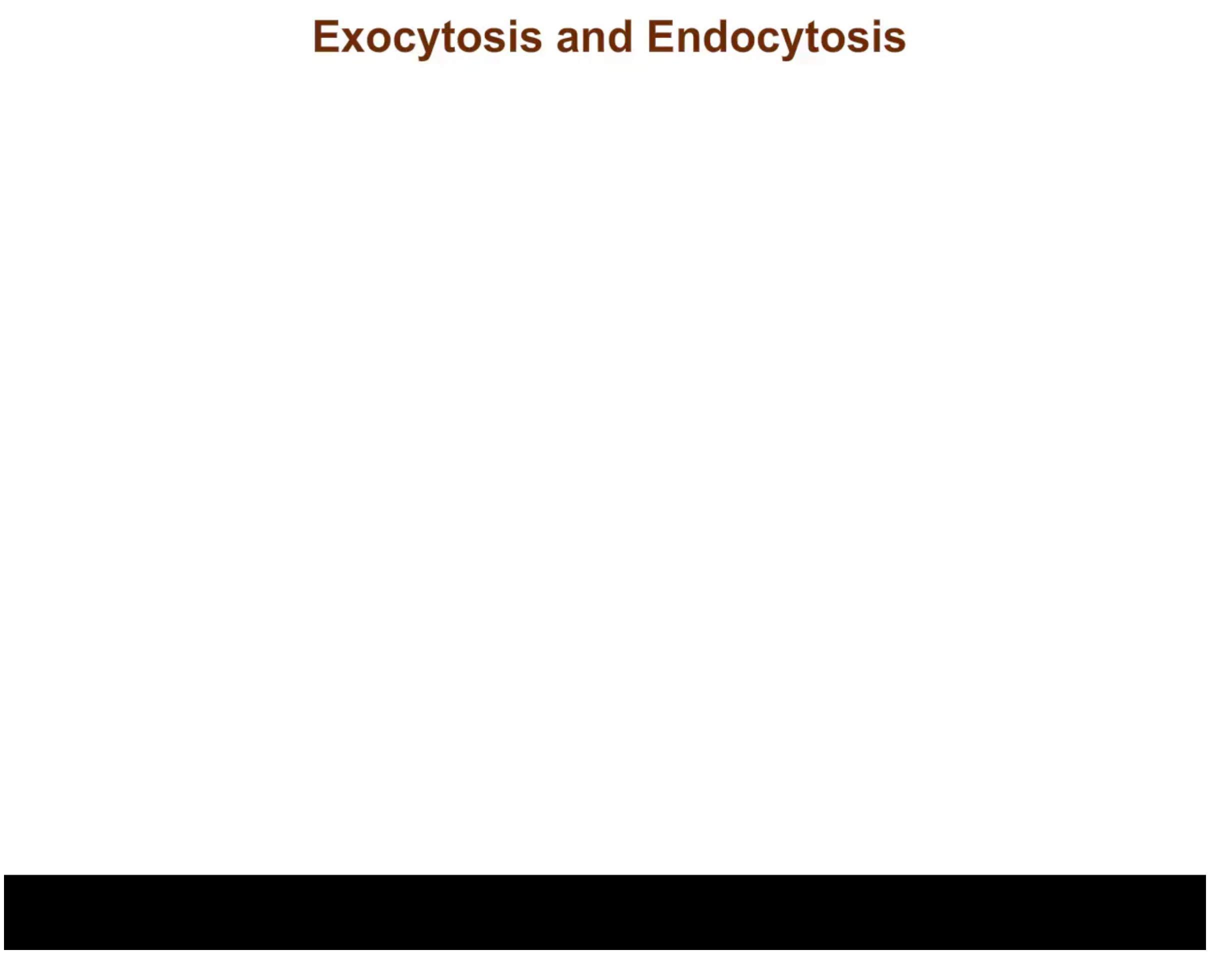
- Animal cells use a similar cotransporter to couple the active transport of glucose to the diffusion of Na^+ into cells lining the intestine
- Sodium potassium pumps actively transport Na^+ out of the cell to maintain the electrochemical gradient
- Normally, sodium in waste is reabsorbed in the colon to maintain a constant level in the body

- When a person has diarrhea, waste is expelled too fast for reabsorption, causing sodium levels to drop
- A rapid drop in sodium can be life-threatening
- Drinking a concentrated salt (NaCl) and glucose solution enables uptake through the Na^+/glucose transporters in the intestine

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 via transport proteins
- Large molecules, such as polysaccharides and proteins, cross the membrane in bulk inside vesicles

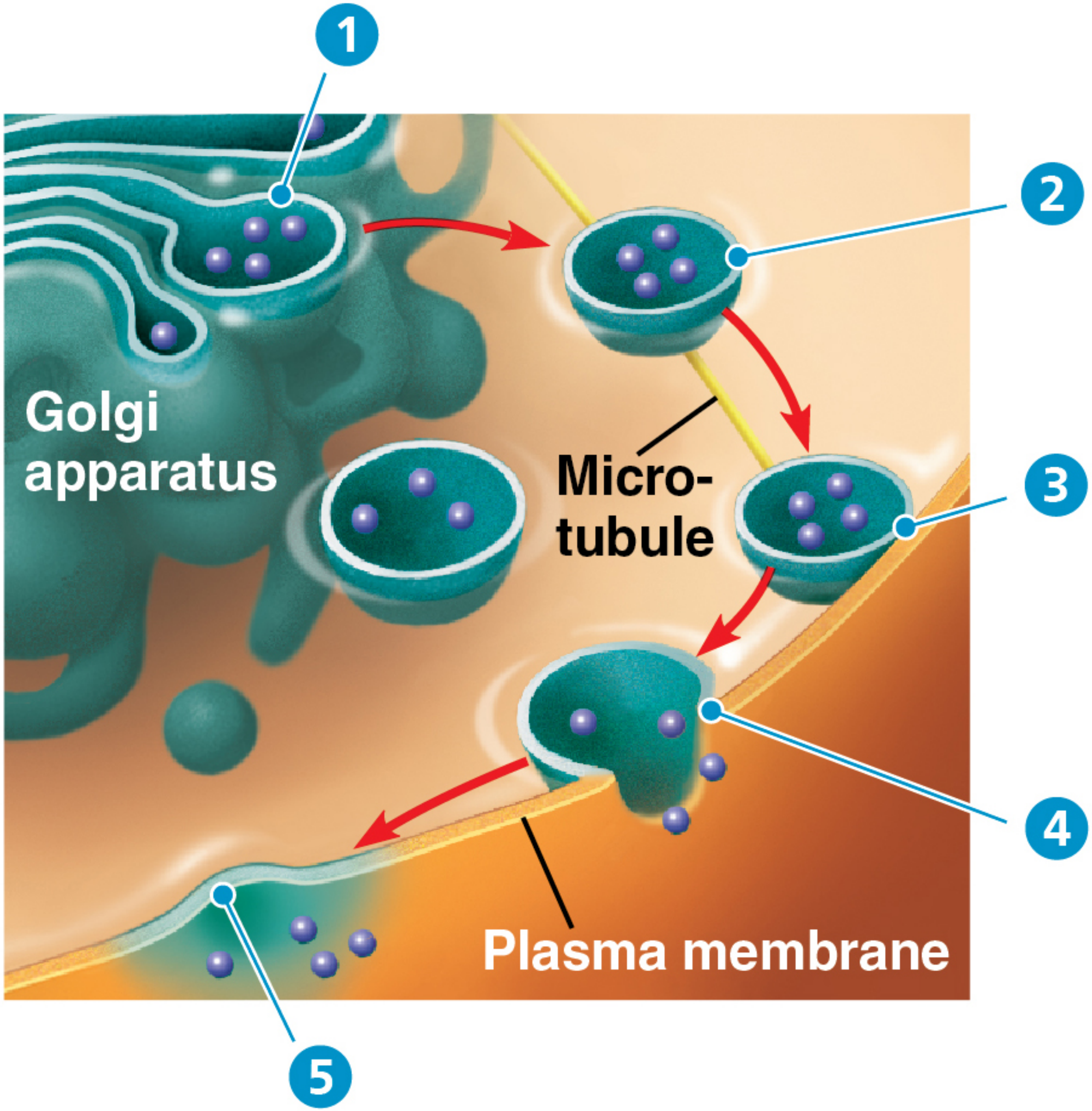
Animation: Exocytosis and Endocytosis Introduction



Exocytosis

- In **exocytosis**, transport vesicles migrate to the membrane, fuse with it, and release their contents outside the cell
- Many secretory cells use exocytosis to export their products
  - For example, cells in the pancreas secrete insulin by exocytosis

Figure 7.20

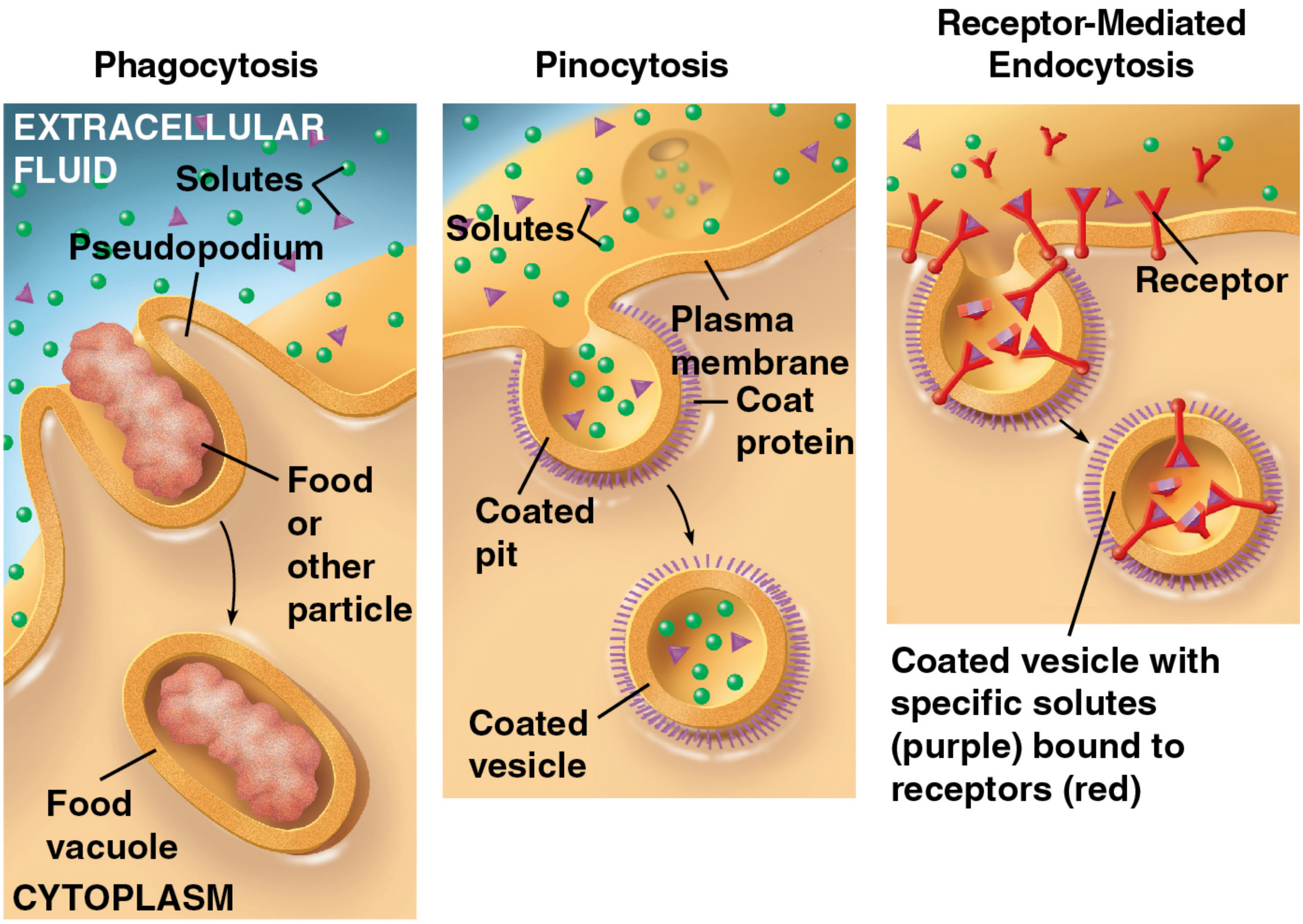


Endocytosis

- In **endocytosis**, macromolecules are taken into the cell in vesicles
- The membrane forms a pocket that deepens and pinches off forming a vesicle around the material for transport

- There are three types of endocytosis
  - Phagocytosis (“cellular eating”)
  - Pinocytosis (“cellular drinking”)
  - Receptor-mediated endocytosis

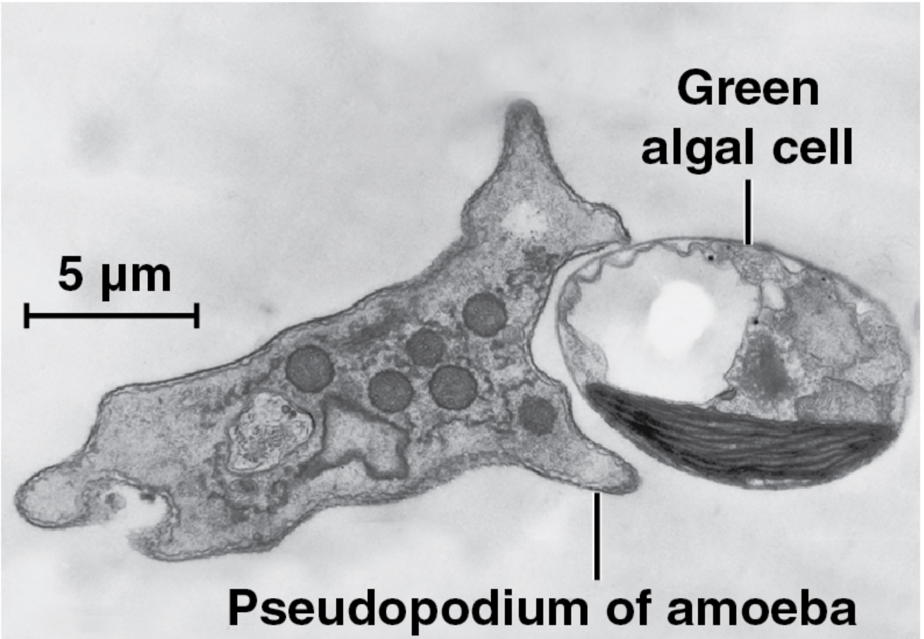
Figure 7.21



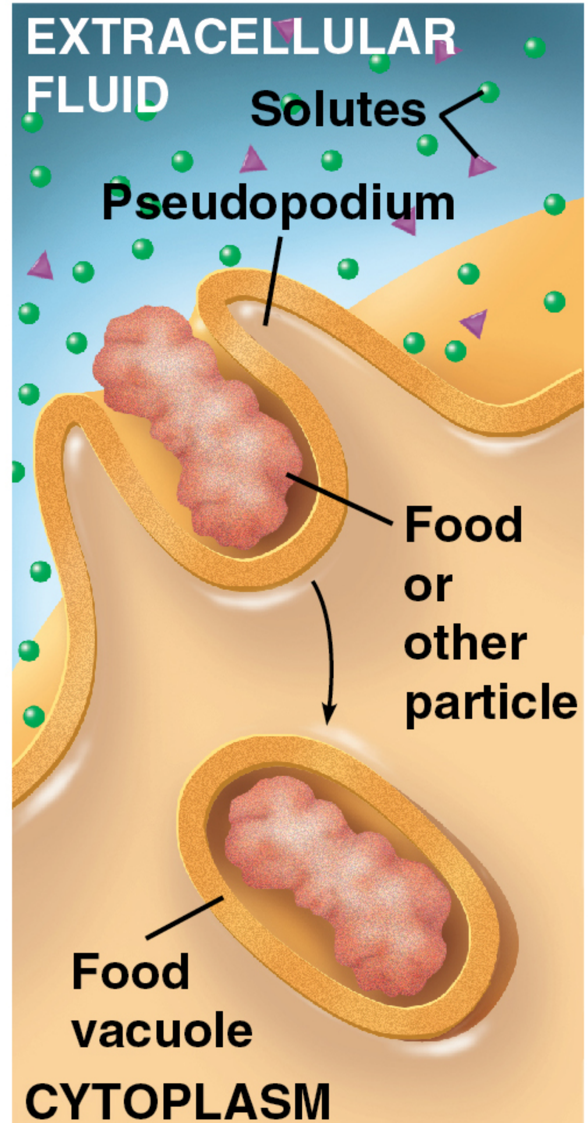
Phagocytosis
Pinocytosis
Receptor-Mediated Endocytosis
EXTRACELLULAR FLUID
Solutes
Pseudopodium
Food or other particle
Food vacuole
CYTOPLASM
Solutes
Plasma membrane
Coat protein
Coated pit
Coated vesicle
Receptor
Coated vesicle with specific solutes (purple) bound to receptors (red)

- In **phagocytosis**, a cell engulfs a particle by extending pseudopodia around it and packing it in a membranous sac called a food vacuole
- The vacuole fuses with a lysosome to digest the particle

Phagocytosis



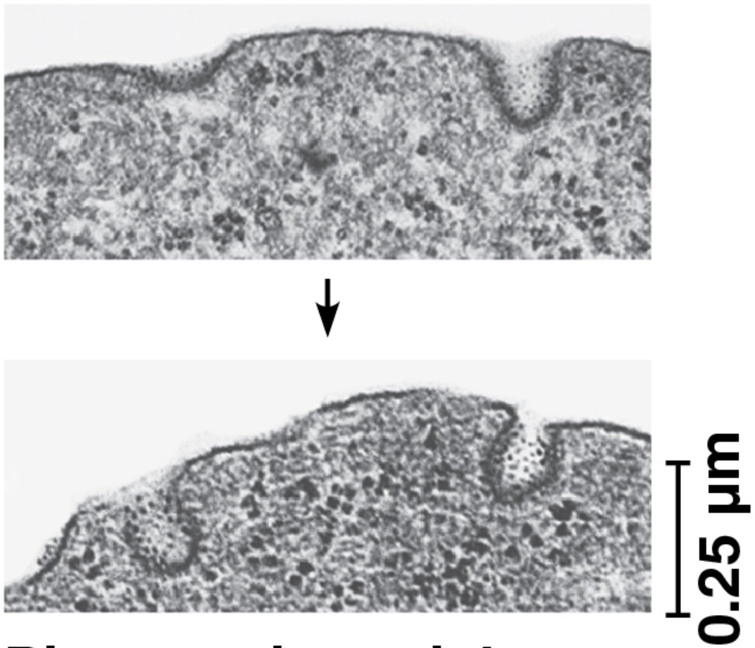
An amoeba engulfing a green algal cell via phagocytosis (TEM)



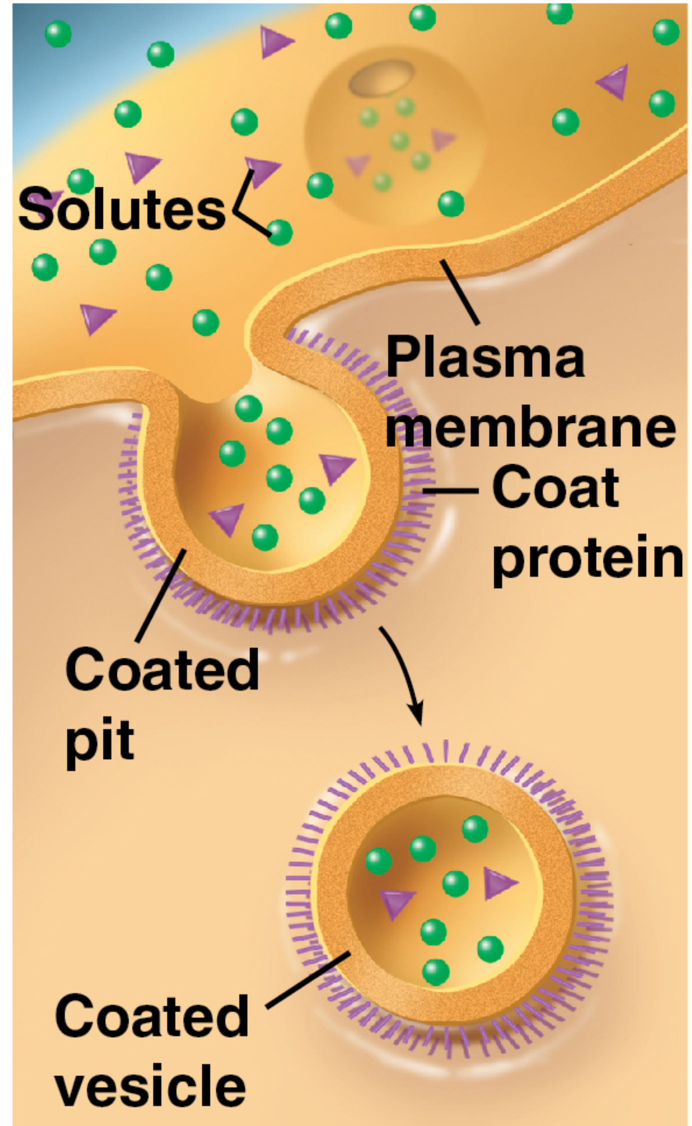
- In **pinocytosis**, molecules are taken up when extracellular fluid is “gulped” into tiny vesicles
- Pinocytosis is nonspecific for the substances it transports; any and all solutes are taken into the cell
- Parts of the plasma membrane that form vesicles are lined on the inner side with coat proteins, forming coated vesicles

Figure 7.21b

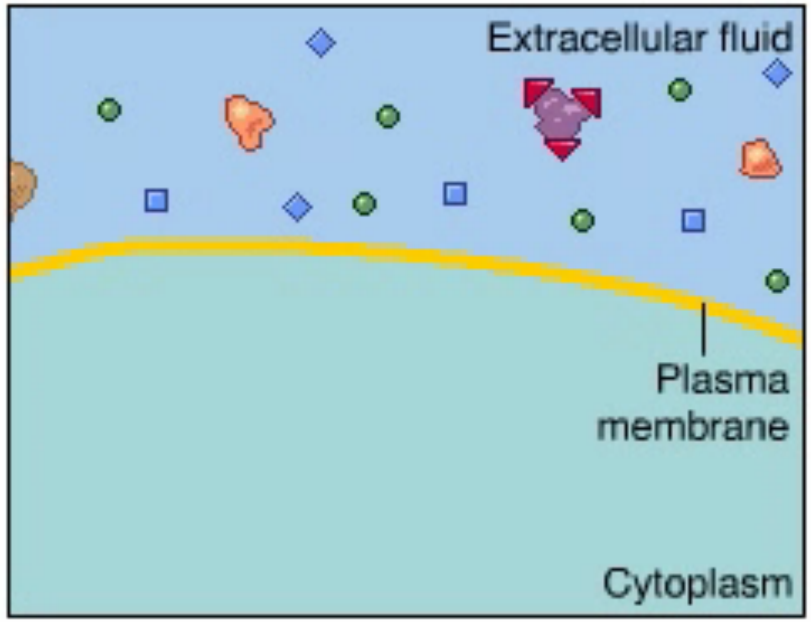
Pinocytosis



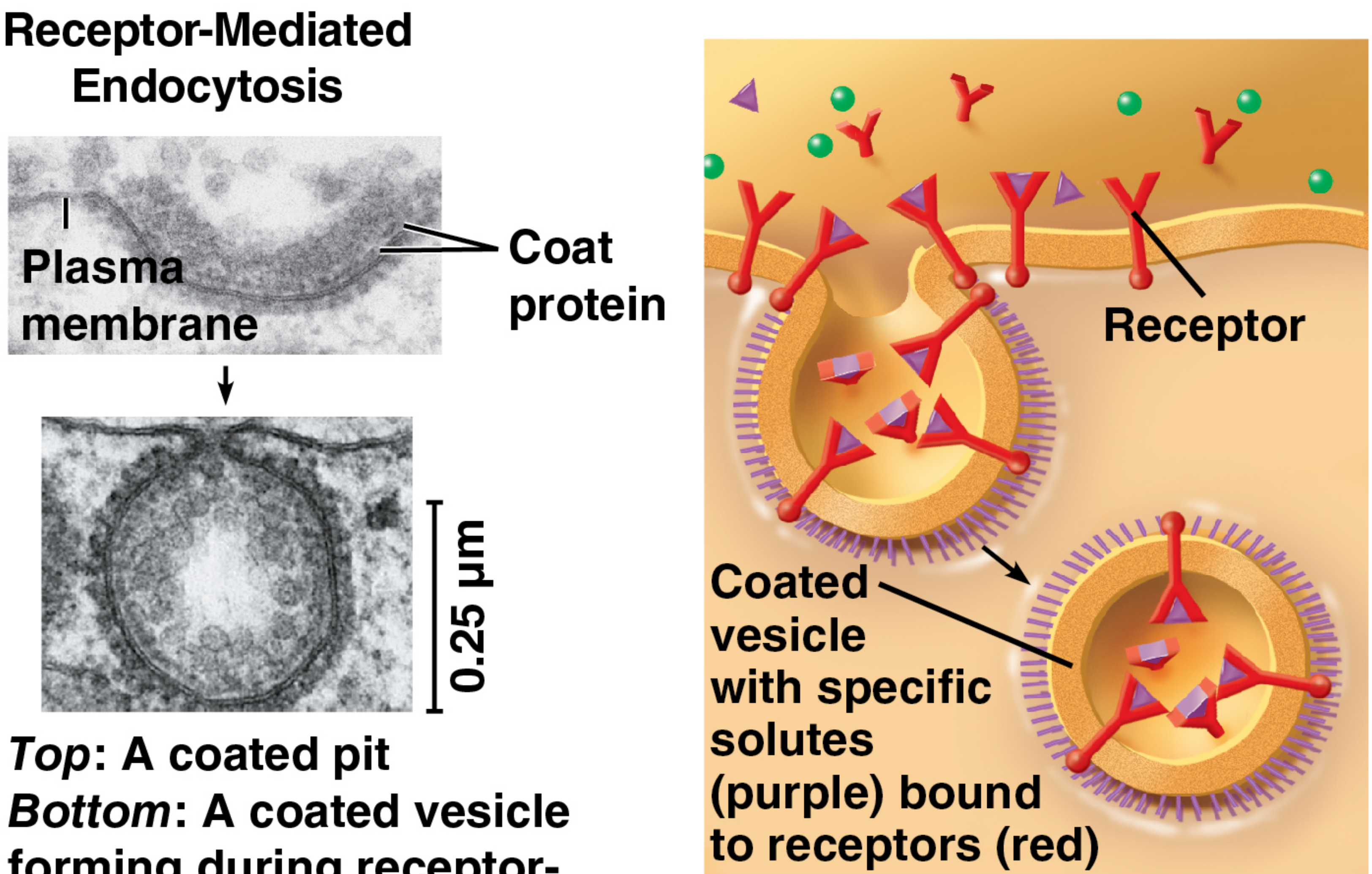
Pinocytotic vesicles forming (TEMs)



Animation: Pinocytosis

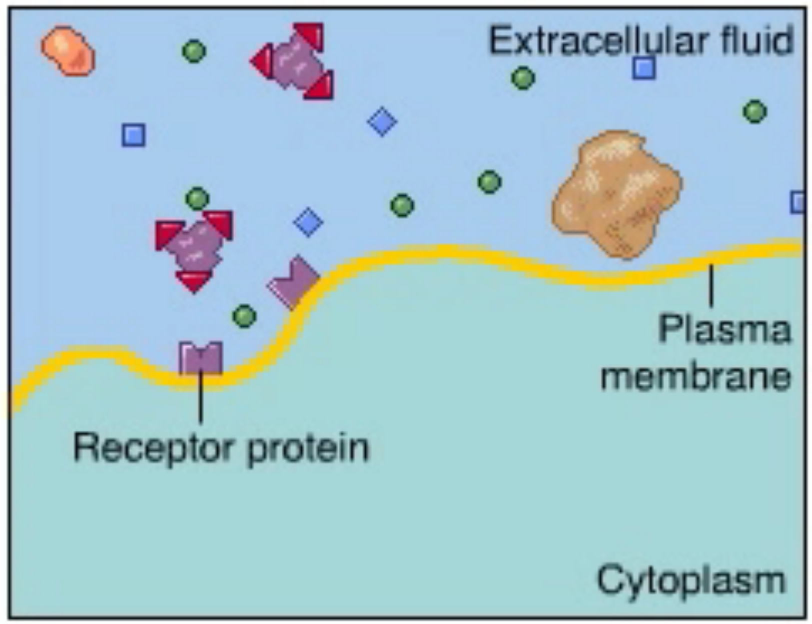


- In **receptor-mediated endocytosis**, vesicle formation is triggered by solute binding to receptors
- Receptor proteins bound to specific solutes from the extracellular fluid are clustered in coated pits that form coated vesicles
- Emptied receptors are recycled to the plasma membrane by the same vesicle



Top: A coated pit
Bottom: A coated vesicle forming during receptor-mediated endocytosis (TEMs)

Animation: Receptor-mediated endocytosis



- Human cells use receptor-mediated endocytosis to take in cholesterol, which is carried in particles called low-density lipoproteins (LDLs)
- Individuals with familial hypercholesterolemia have missing or defective LDL receptor proteins
- Cholesterol accumulates in the blood, building up lipids and narrowing the space in the blood vessels, resulting in potential heart damage or stroke

BioFlix Animation: Membrane Transport

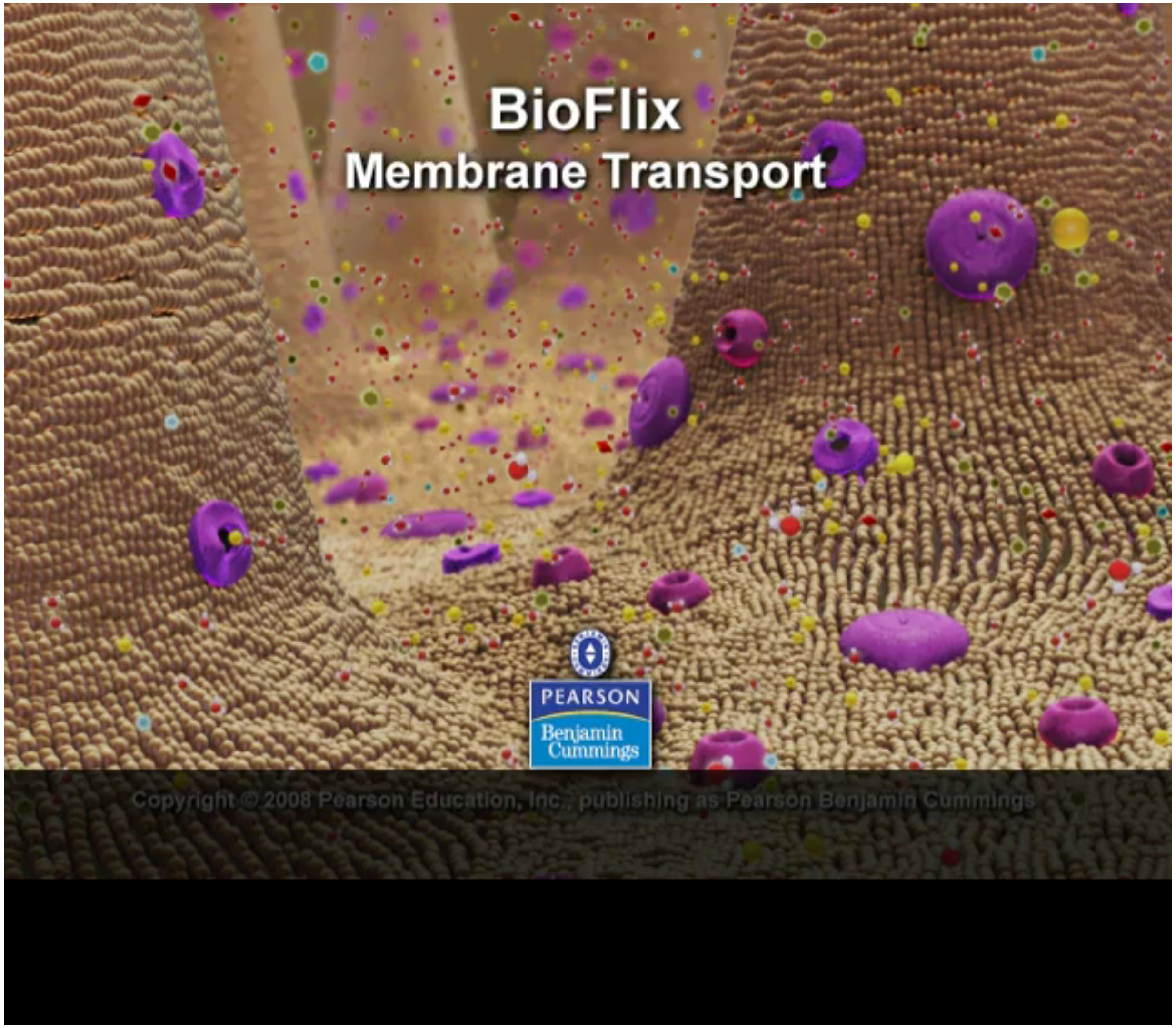
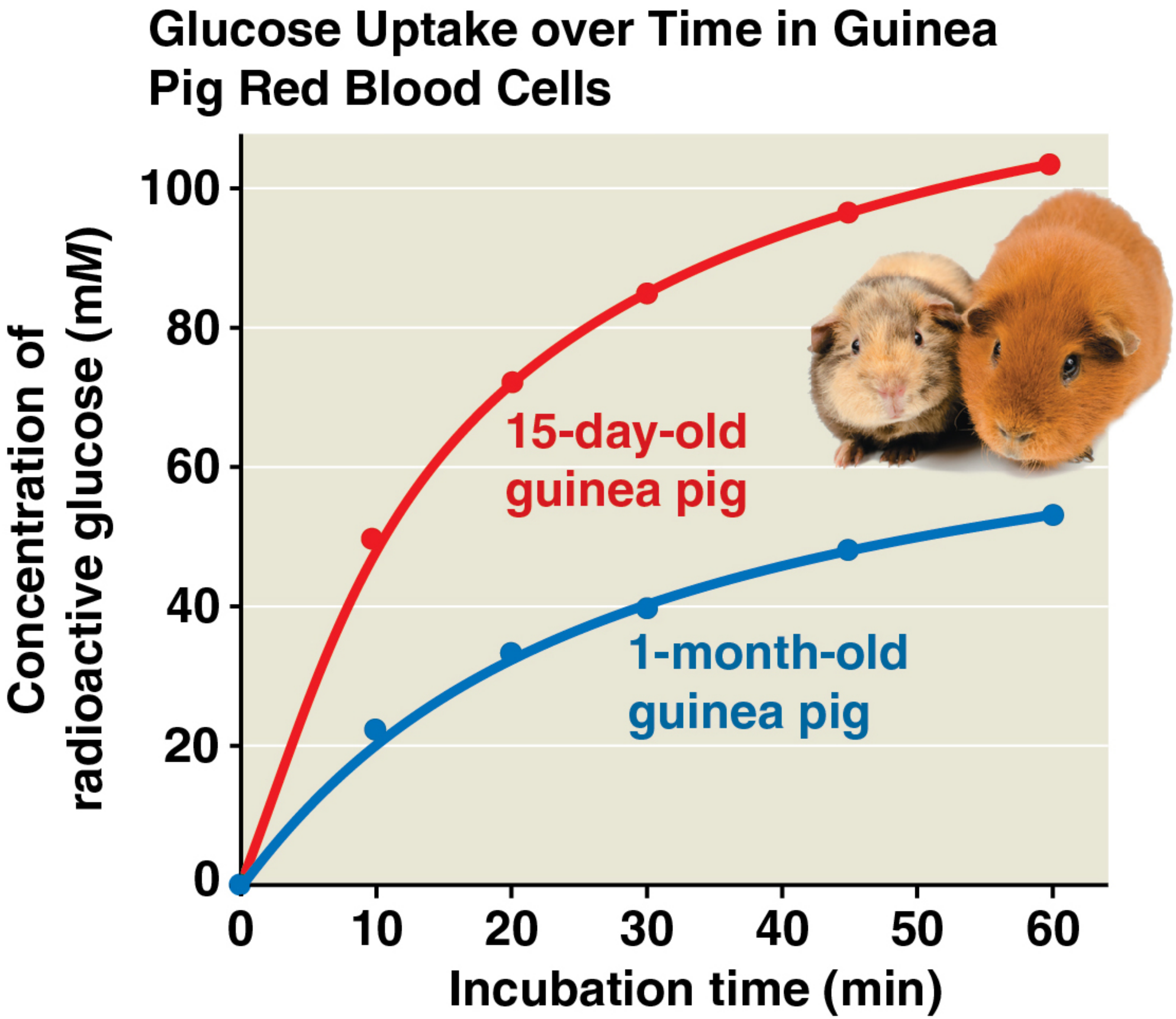


Figure 7.UN03



Data from T. Kondo and E. Beutler, Developmental changes in glucose transport of guinea pig erythrocytes, *Journal of Clinical Investigation* 65:1–4 (1980).

Figure 7.UN04

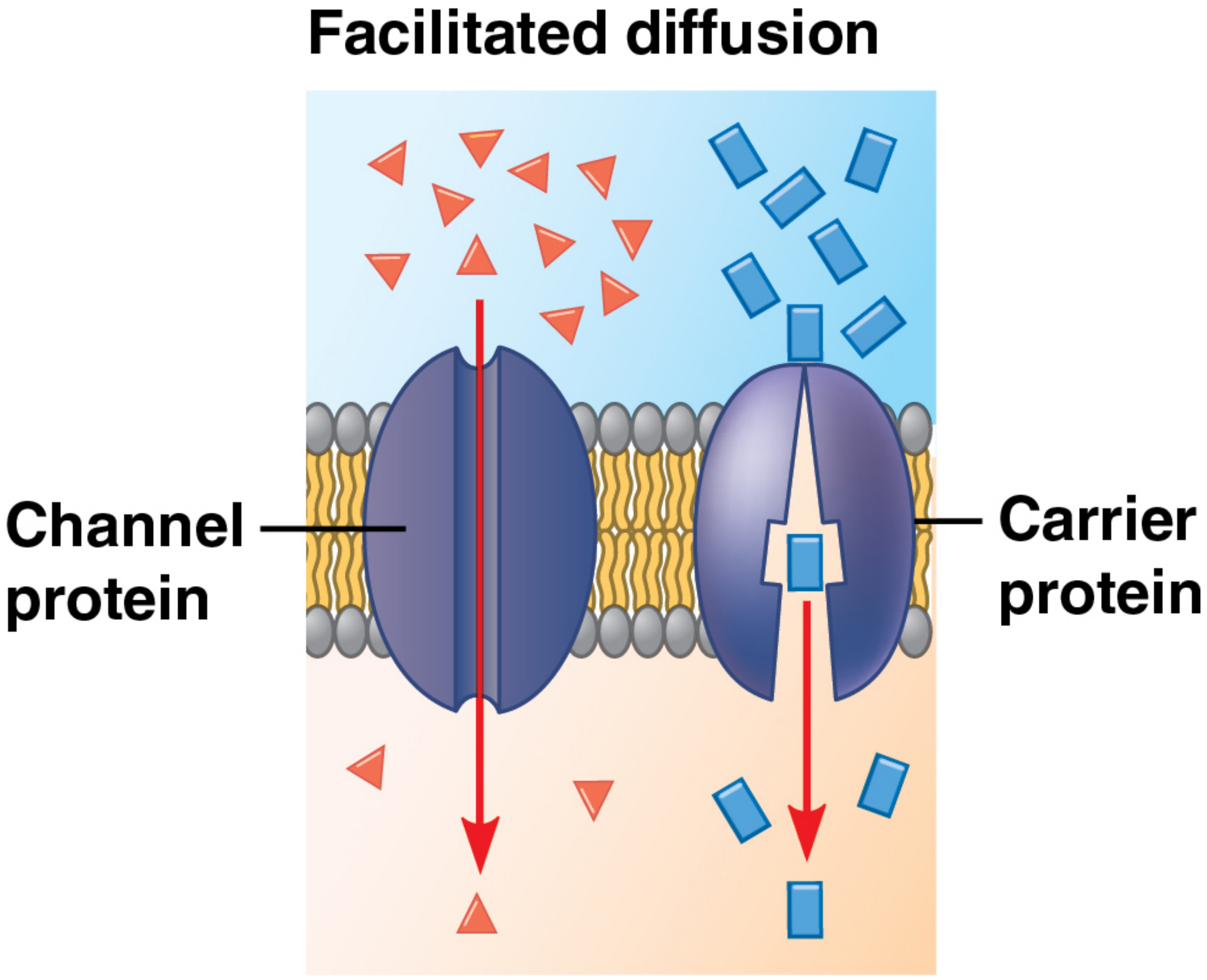


Figure 7.UN05

Active transport

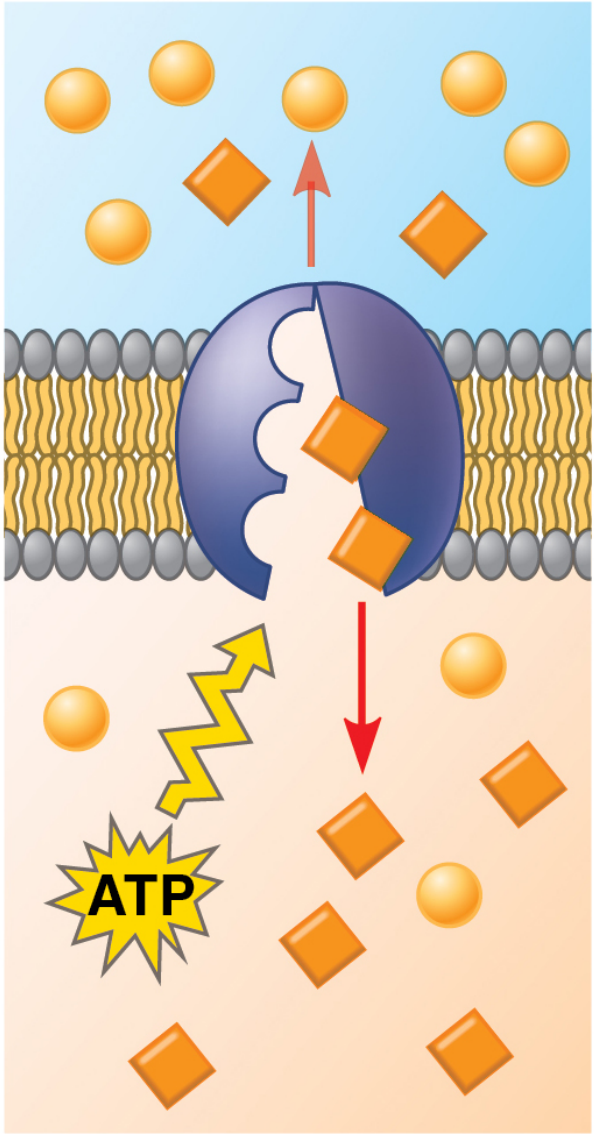


Figure 7.UN06

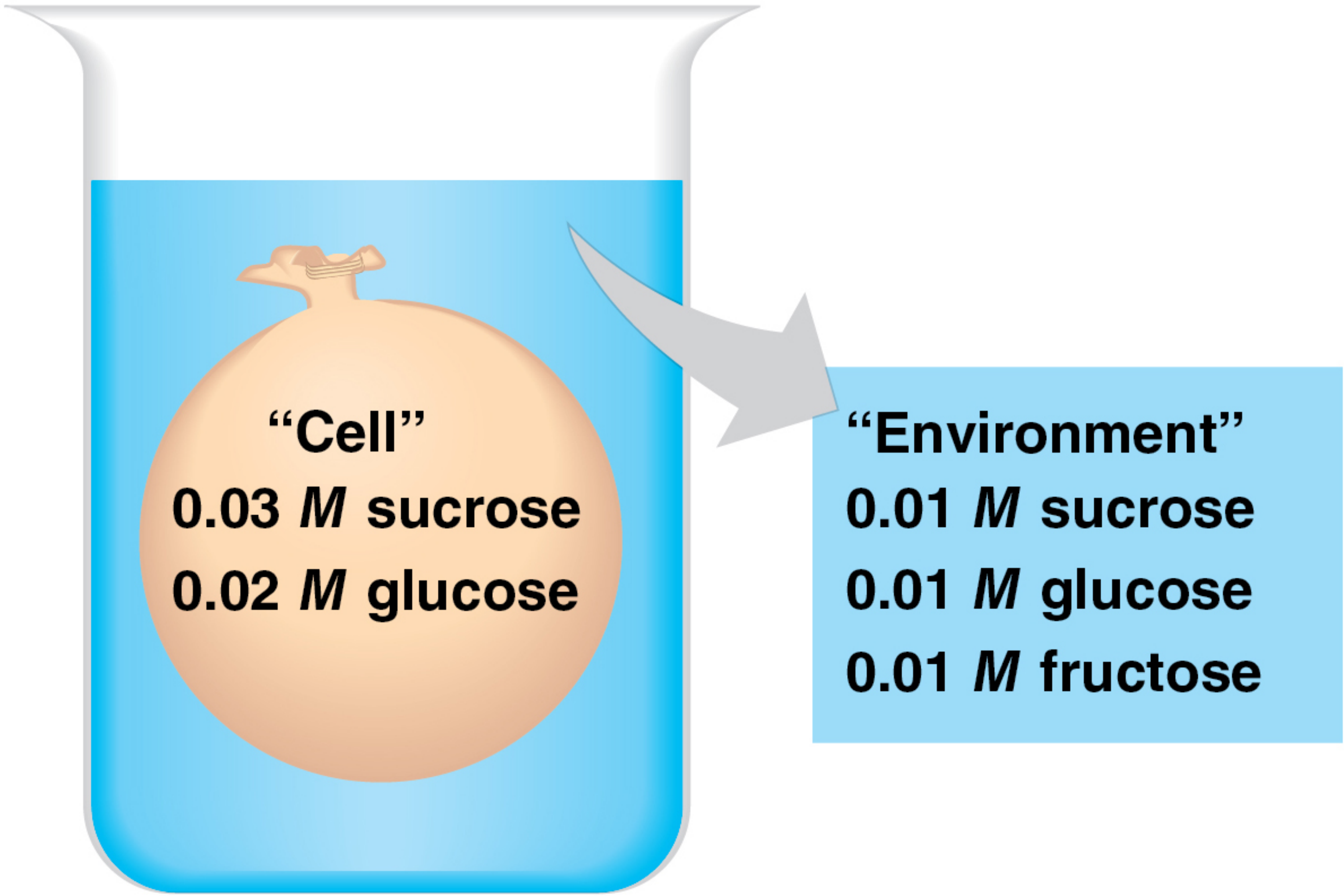


Figure 7.UN07