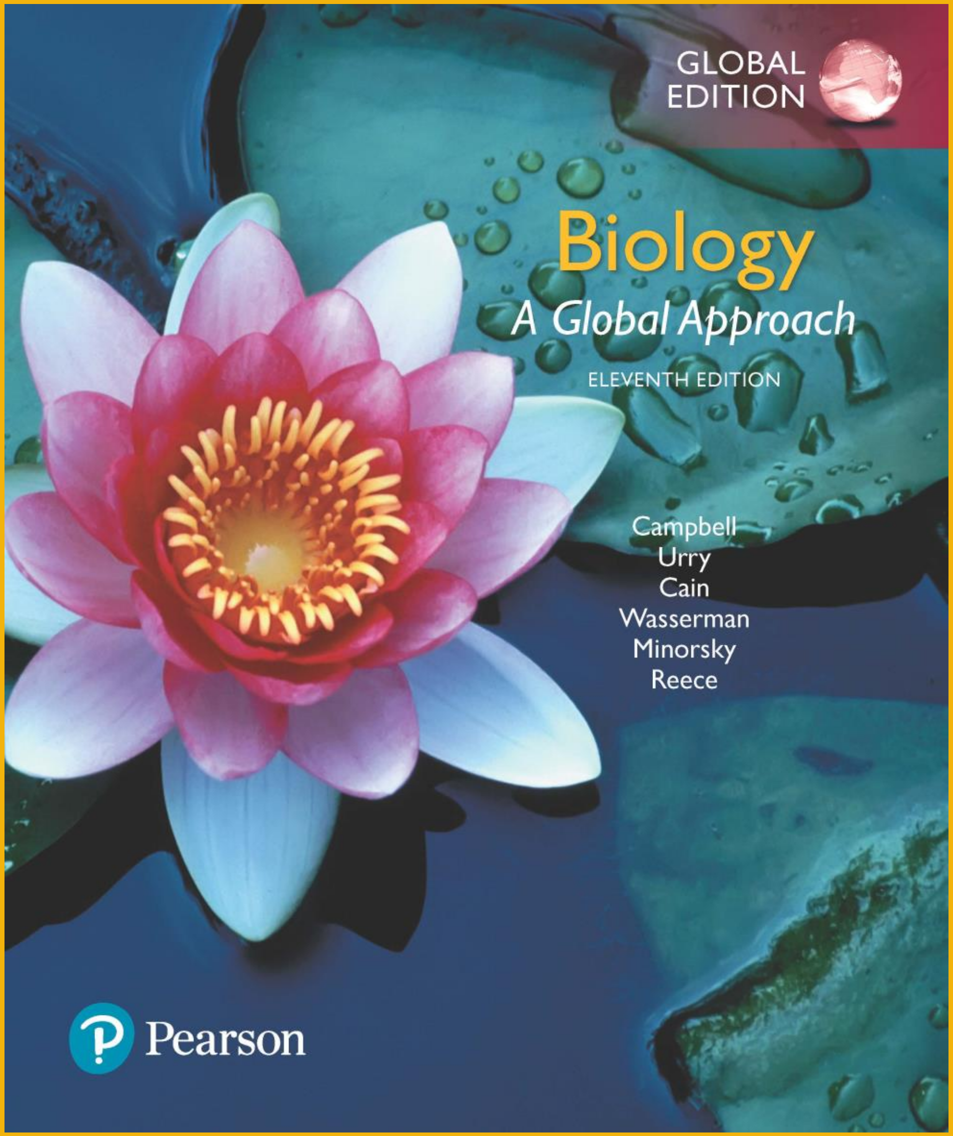


Chapter 8

Cell Membranes

Lecture Presentations by
Nicole Tunbridge and
Kathleen Fitzpatrick

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
- Transport proteins are often responsible for controlling passage across cellular membranes

Figure 8.1

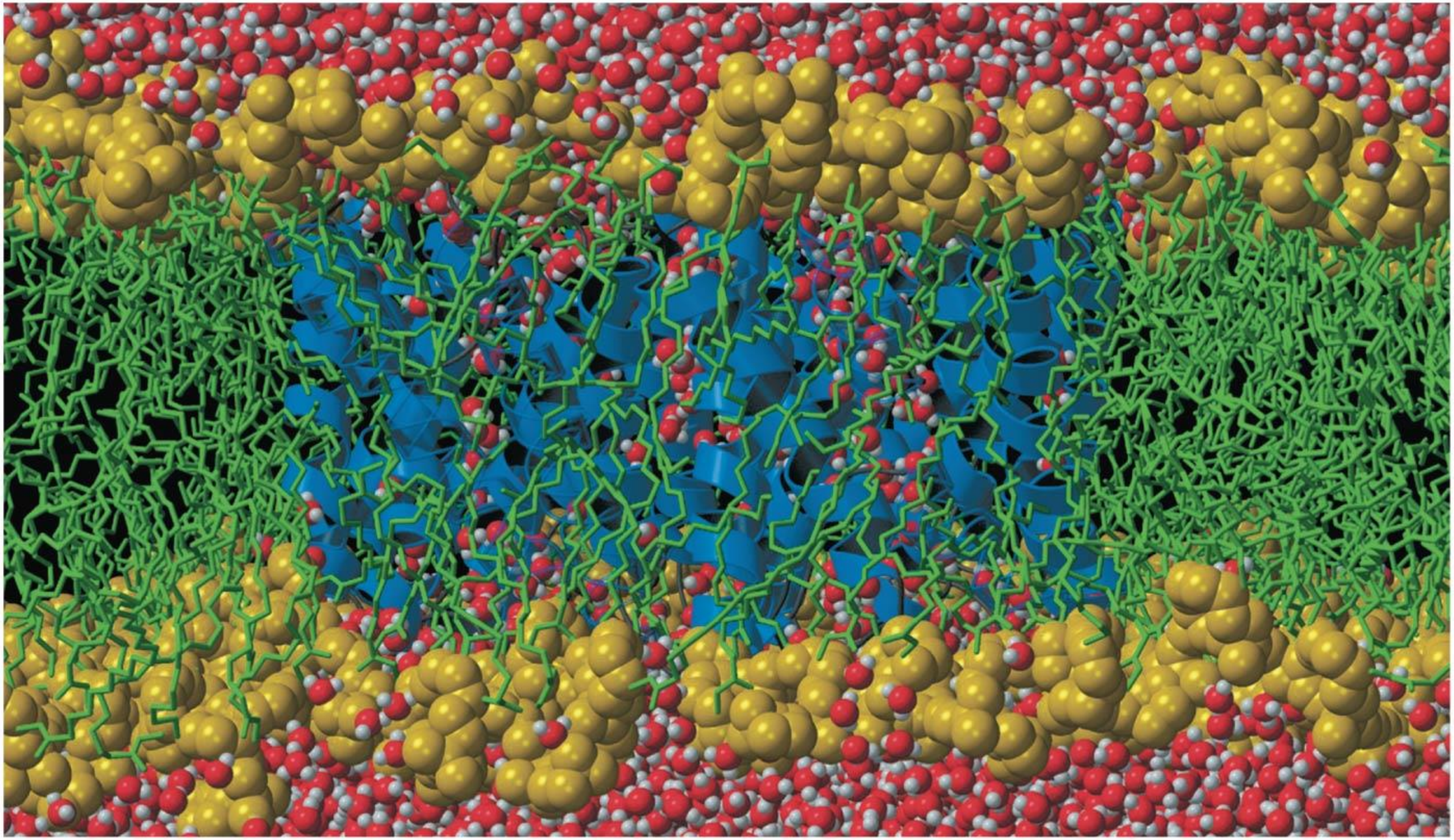
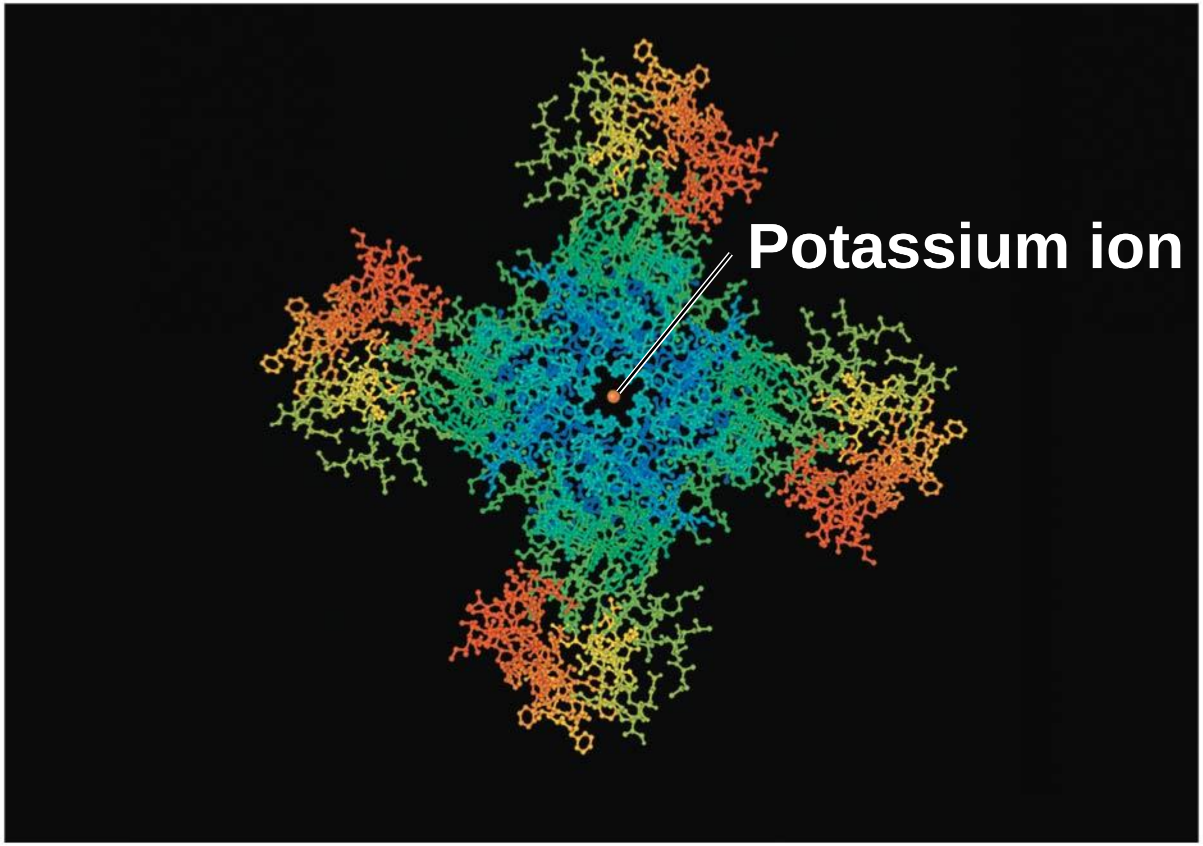
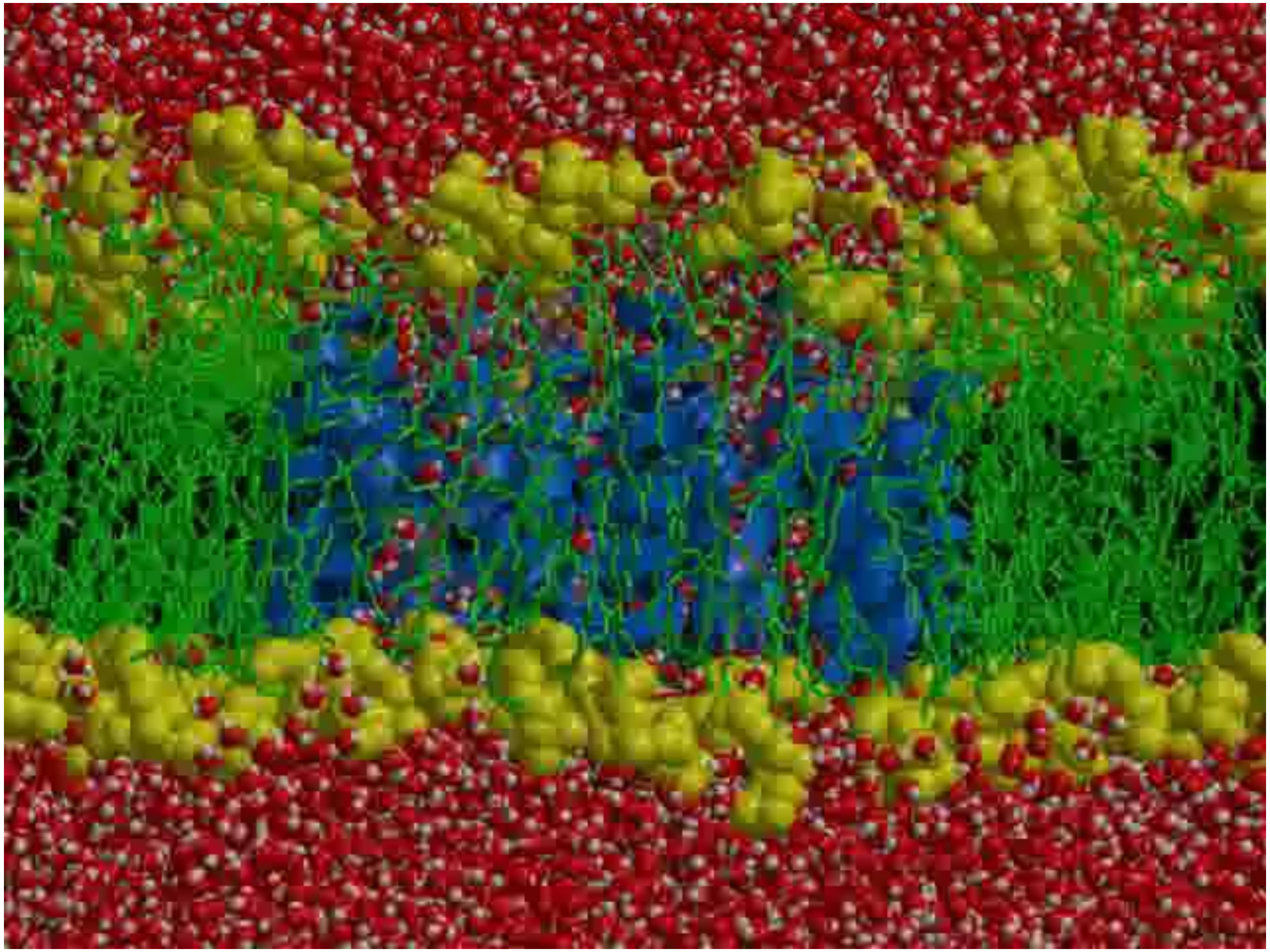


Figure 8.1a

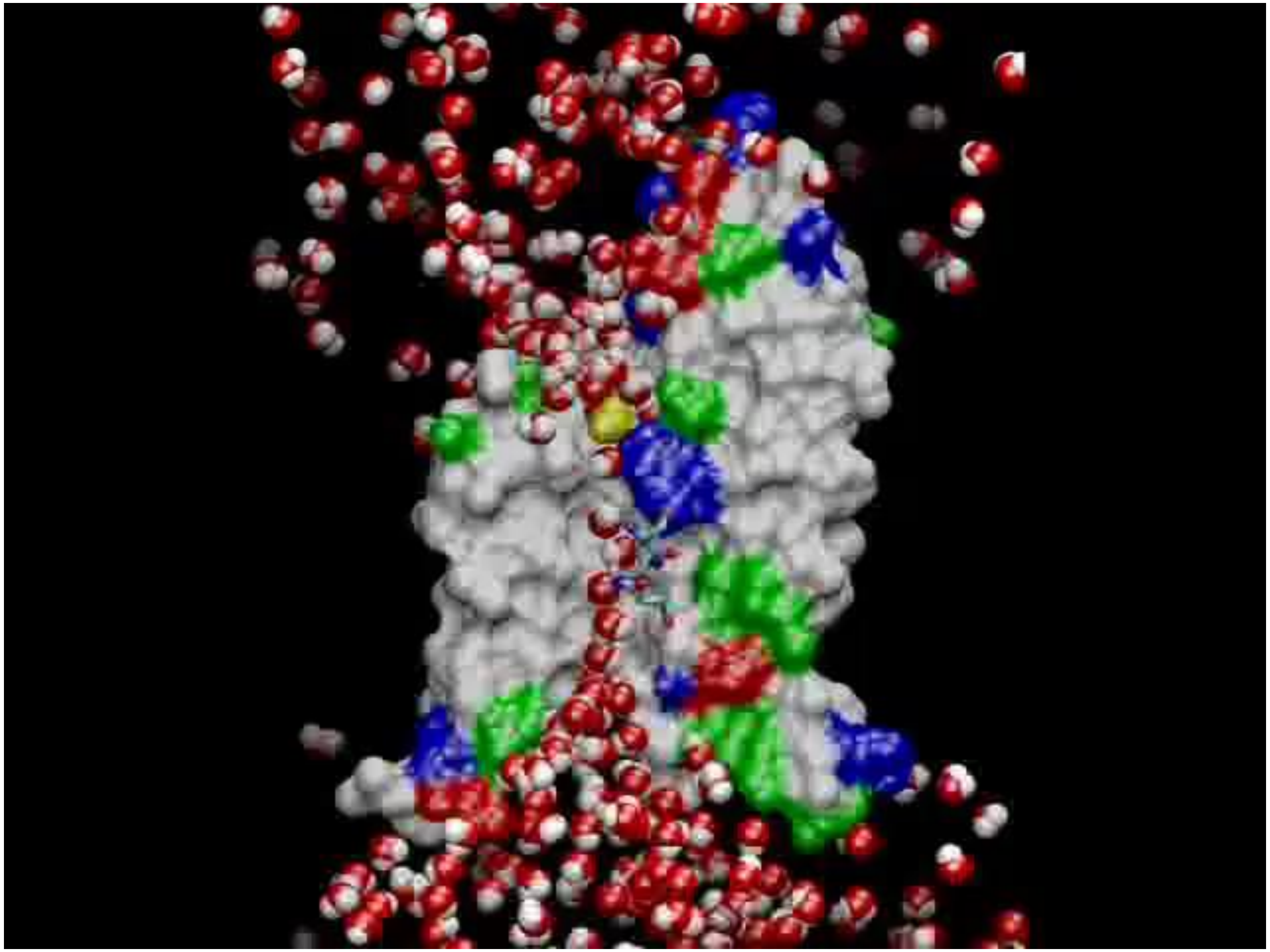


Potassium ion channel protein

Video: Structure of the Cell Membrane



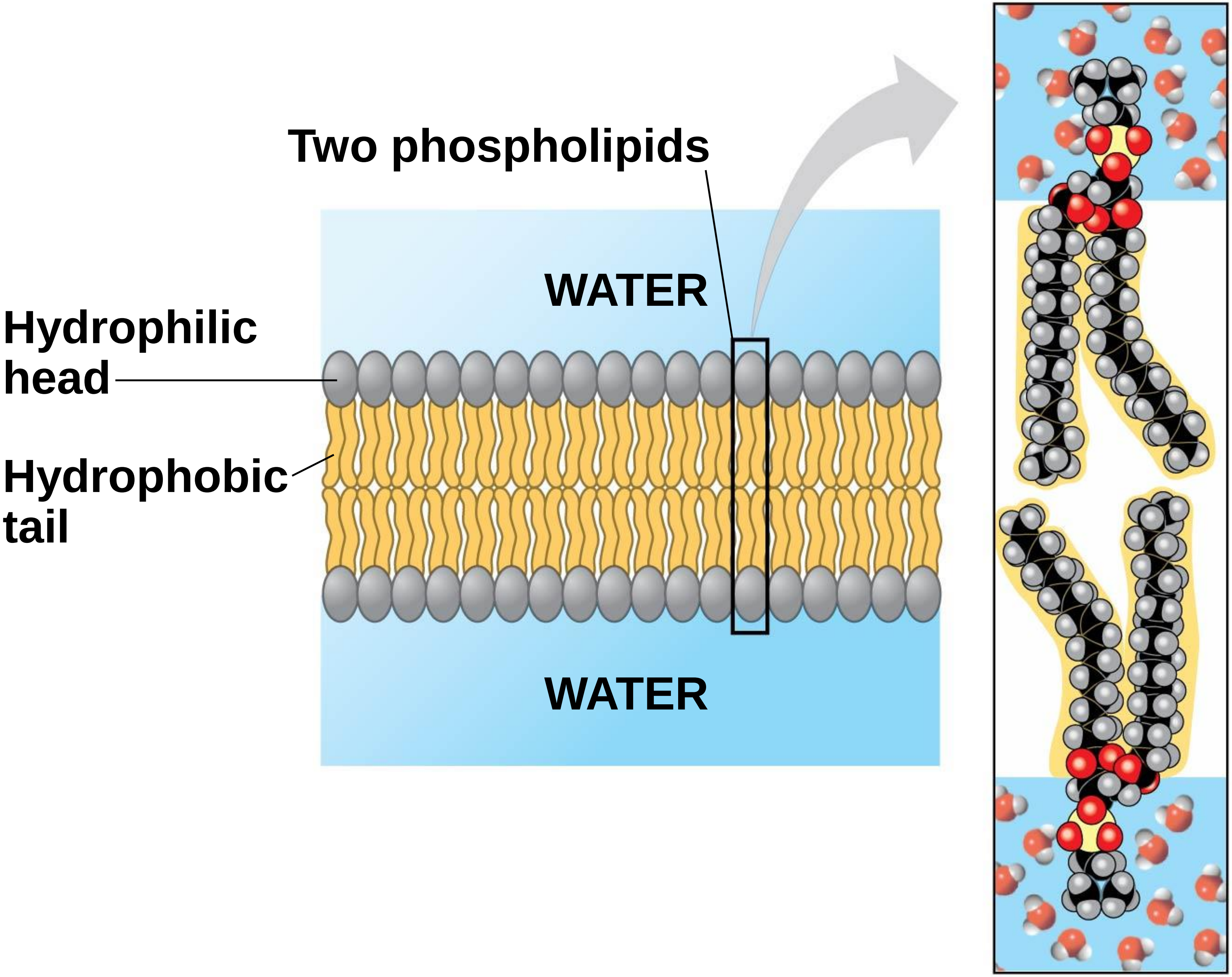
Video: Water Movement Through an Aquaporin



Concept 8.1: 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 (“water-fearing”) and hydrophilic (“water-loving”) regions
- The hydrophobic tails of the phospholipids are sheltered inside the membrane, while the hydrophilic heads are exposed to water on either side

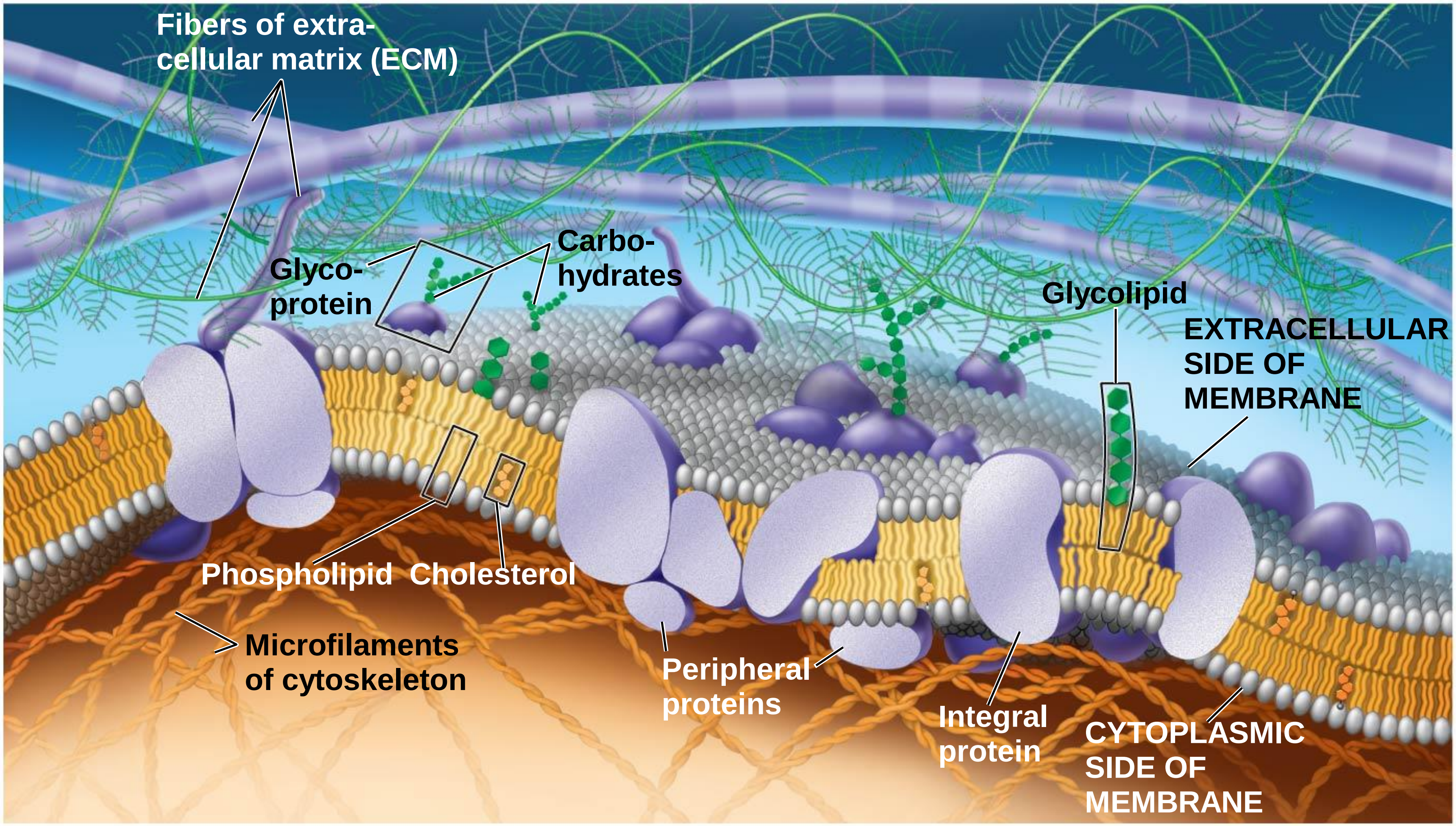
Figure 8.2



Two phospholipids
WATER
Hydrophilic head
Hydrophobic tail
WATER

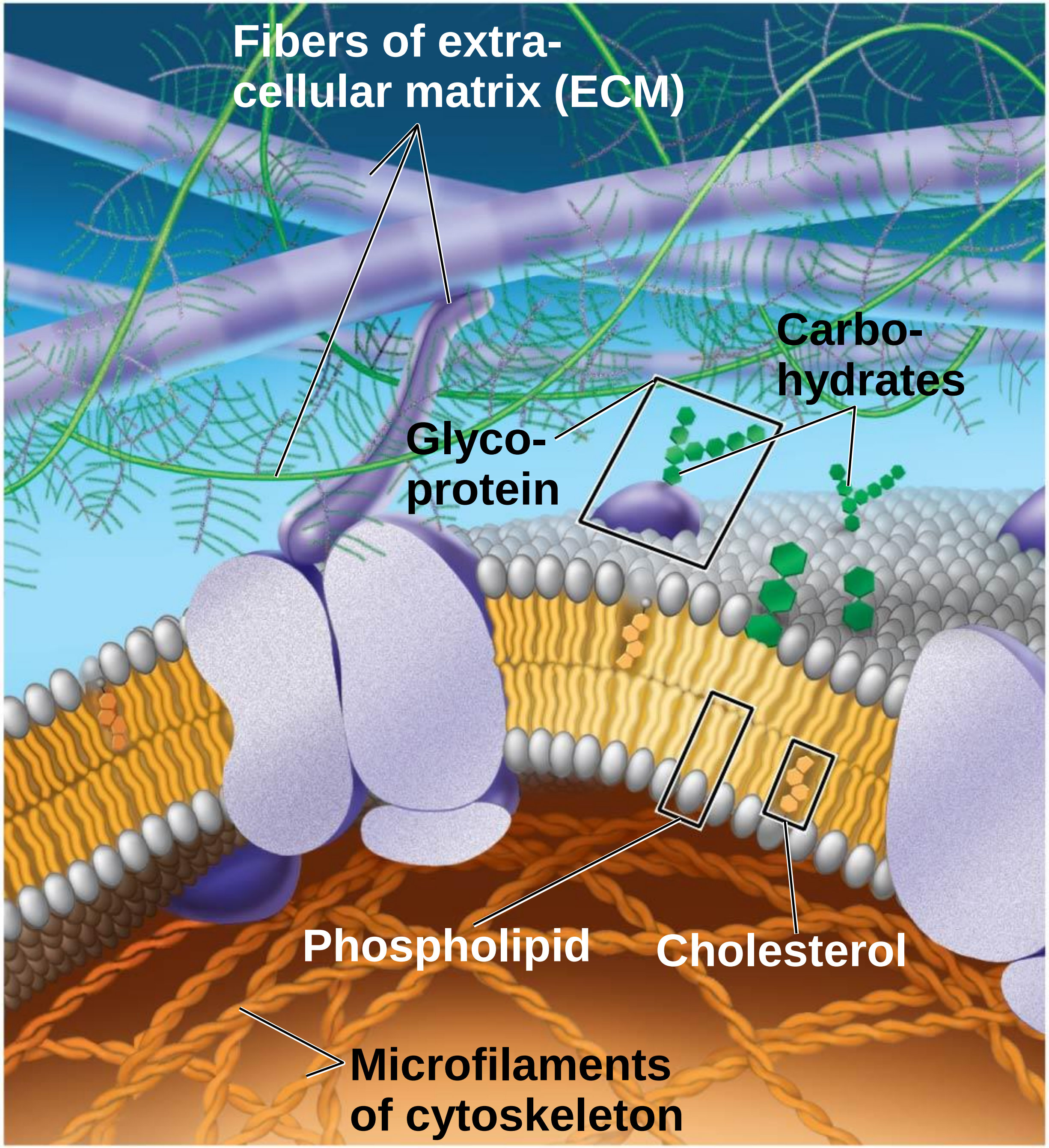
- In the **fluid mosaic model**, the membrane is a mosaic of protein molecules bobbing in a fluid bilayer of phospholipids
- Proteins are not randomly distributed in the membrane

Figure 8.3



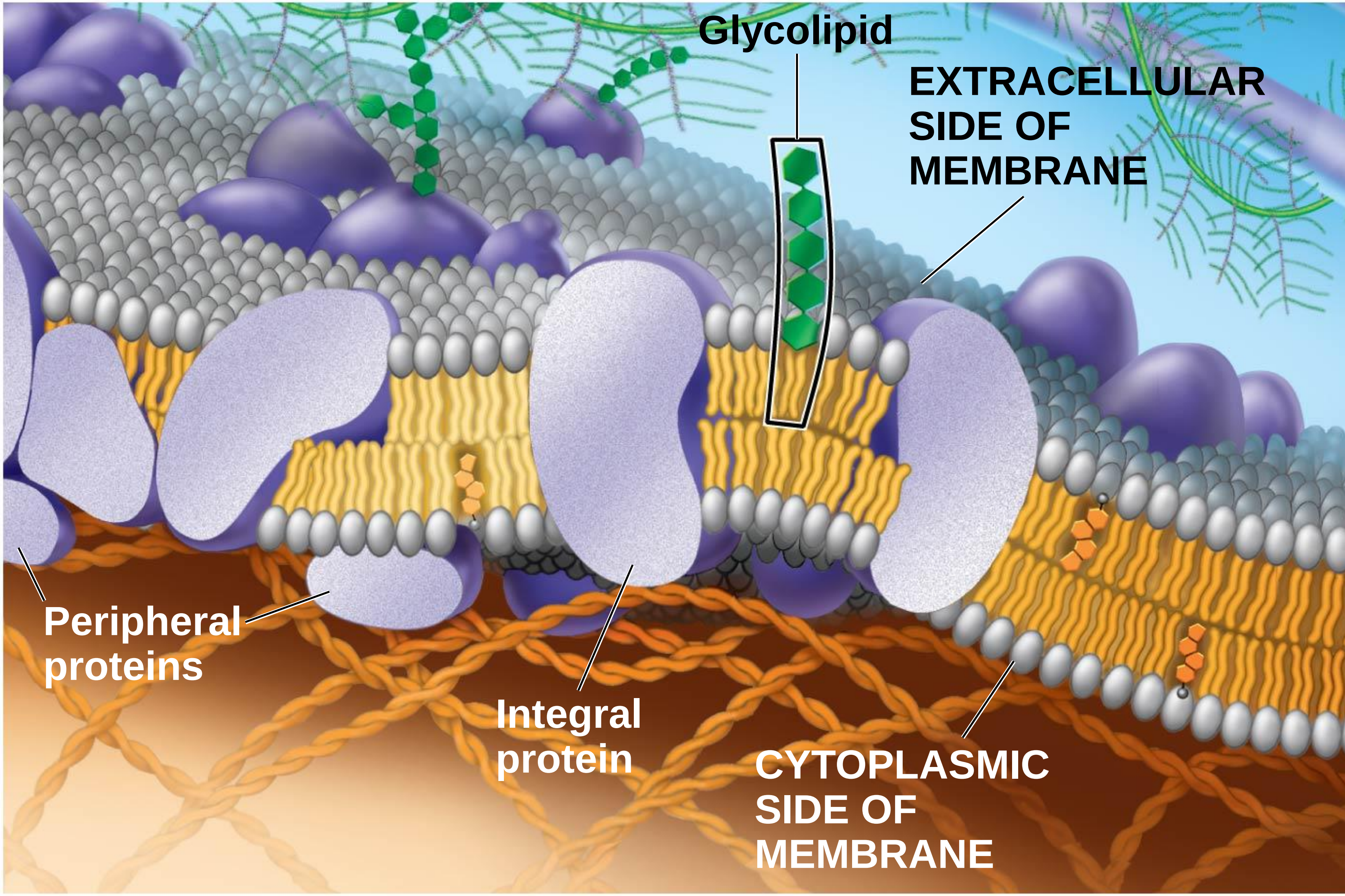
Fibers of extra-
cellular matrix (ECM)
Glyco-
protein
Carbo-
hydrates
Glycolipid
EXTRACELLULAR
SIDE OF
MEMBRANE
Phospholipid
Cholesterol
Microfilaments
of cytoskeleton
Peripheral
proteins
Integral
protein
CYTOPLASMIC
SIDE OF
MEMBRANE

Figure 8.3a



Fibers of extra-cellular matrix (ECM)
Carbo-hydrates
Glyco-protein
Phospholipid
Cholesterol
Microfilaments of cytoskeleton

Figure 8.3b

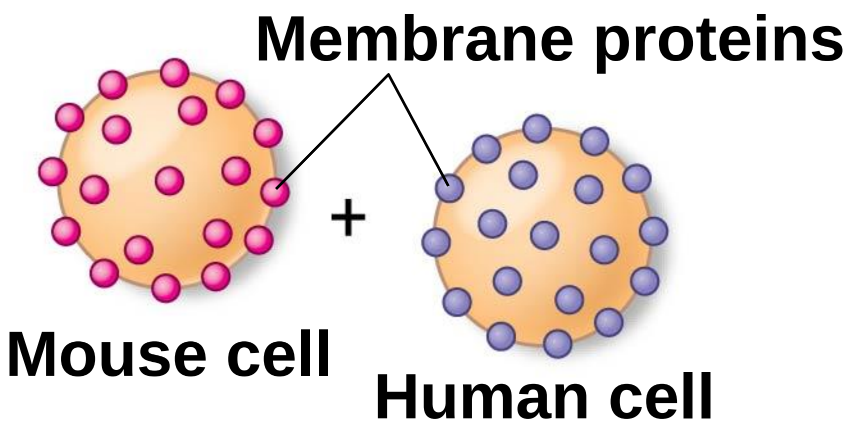

Glycolipid
EXTRACELLULAR SIDE OF MEMBRANE
Peripheral proteins
Integral protein
CYTOPLASMIC SIDE OF MEMBRANE

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 8.4_1

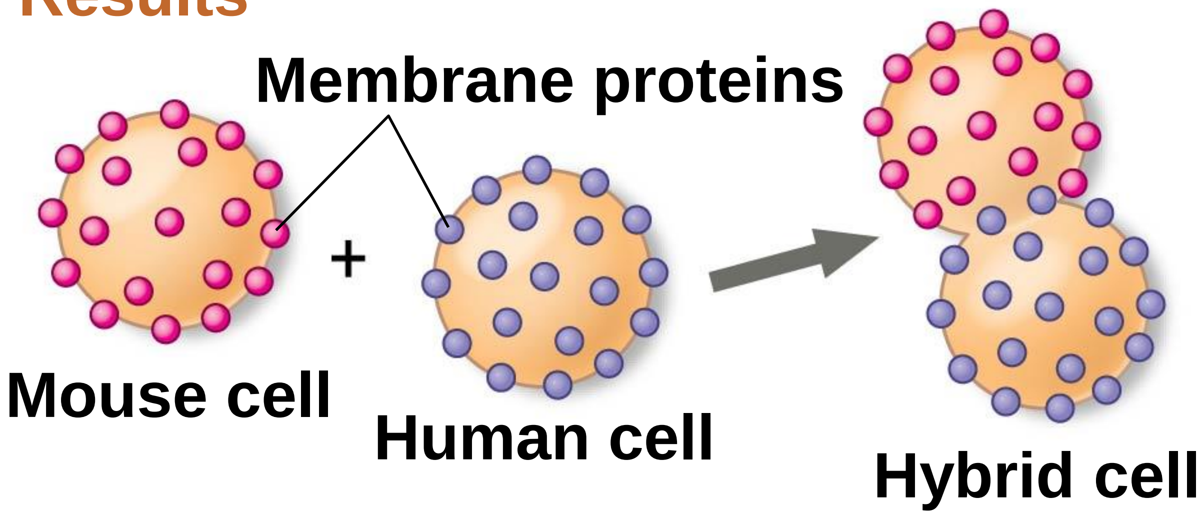
Results



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).

Figure 8.4_2

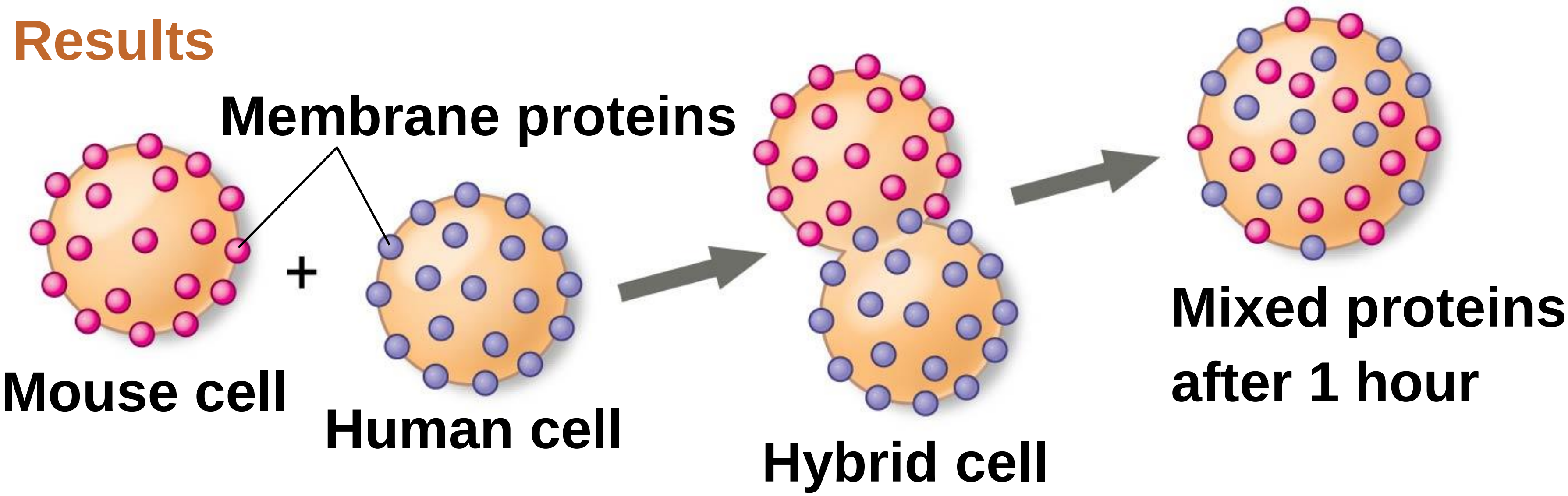
Results



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).

Figure 8.4_3

Results



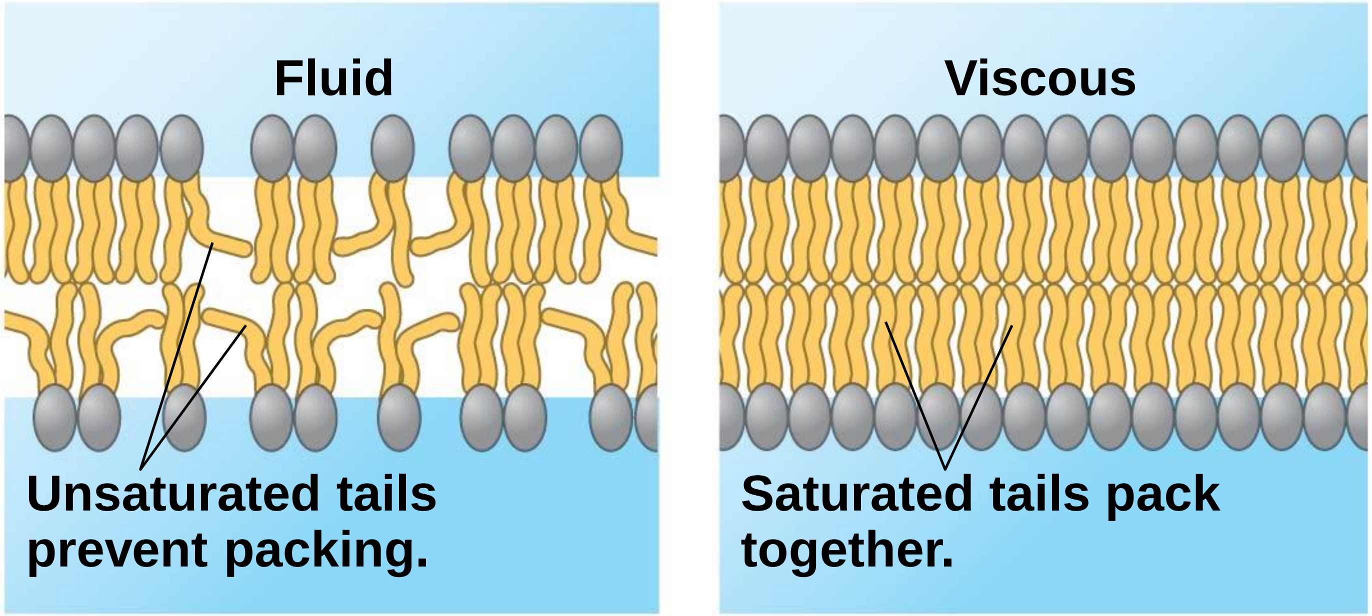
Data from L. D. Frye and M. Edidin, The rapid intermixing of cell surface antigens after formation of mouse-human heterokaryons, *Journal of Cell Science* 7:319 (1970).

- 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; membranes are usually about as fluid as salad oil

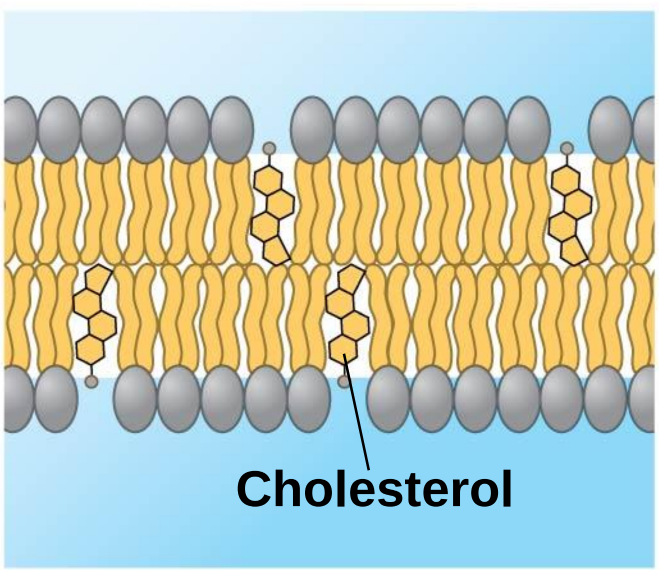
- The steroid cholesterol has different effects on the membrane fluidity of animal cells at different temperatures
- At warm temperatures (such as 37ºC), cholesterol restrains movement of phospholipids
- At cool temperatures, it maintains fluidity by preventing tight packing
- Though cholesterol is present in plants, they use related steroid lipids to buffer membrane fluidity

Figure 8.5

(a) Unsaturated versus saturated hydrocarbon tails



(b) Cholesterol within the animal cell membrane



Cholesterol reduces membrane fluidity at moderate temperatures, but at low temperatures hinders solidification.

Evolution of Differences in Membrane Lipid Composition

- Variations in lipid composition of cell membranes of many species appear to be adaptations to specific environmental conditions
- Ability to change the lipid compositions in response to temperature changes has evolved in organisms that live where temperatures vary

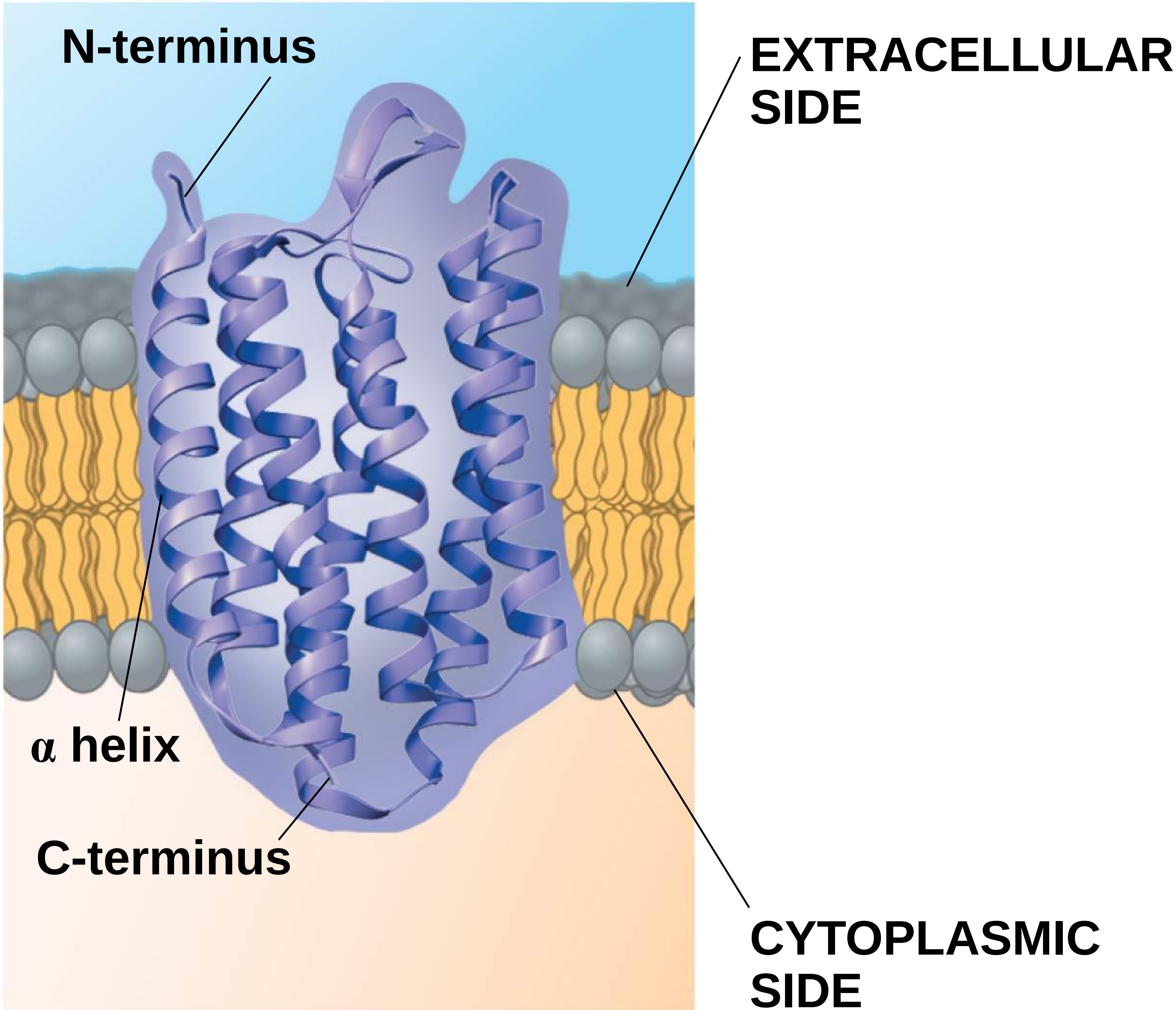
Membrane Proteins and Their Functions

- Somewhat like a tile mosaic, a membrane is a collage of different proteins, often clustered in groups, embedded in the fluid matrix of the lipid bilayer
- Phospholipids form the main fabric of the membrane
- Proteins determine most of the membrane's functions

Figure 8.UN01

- **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 α helices

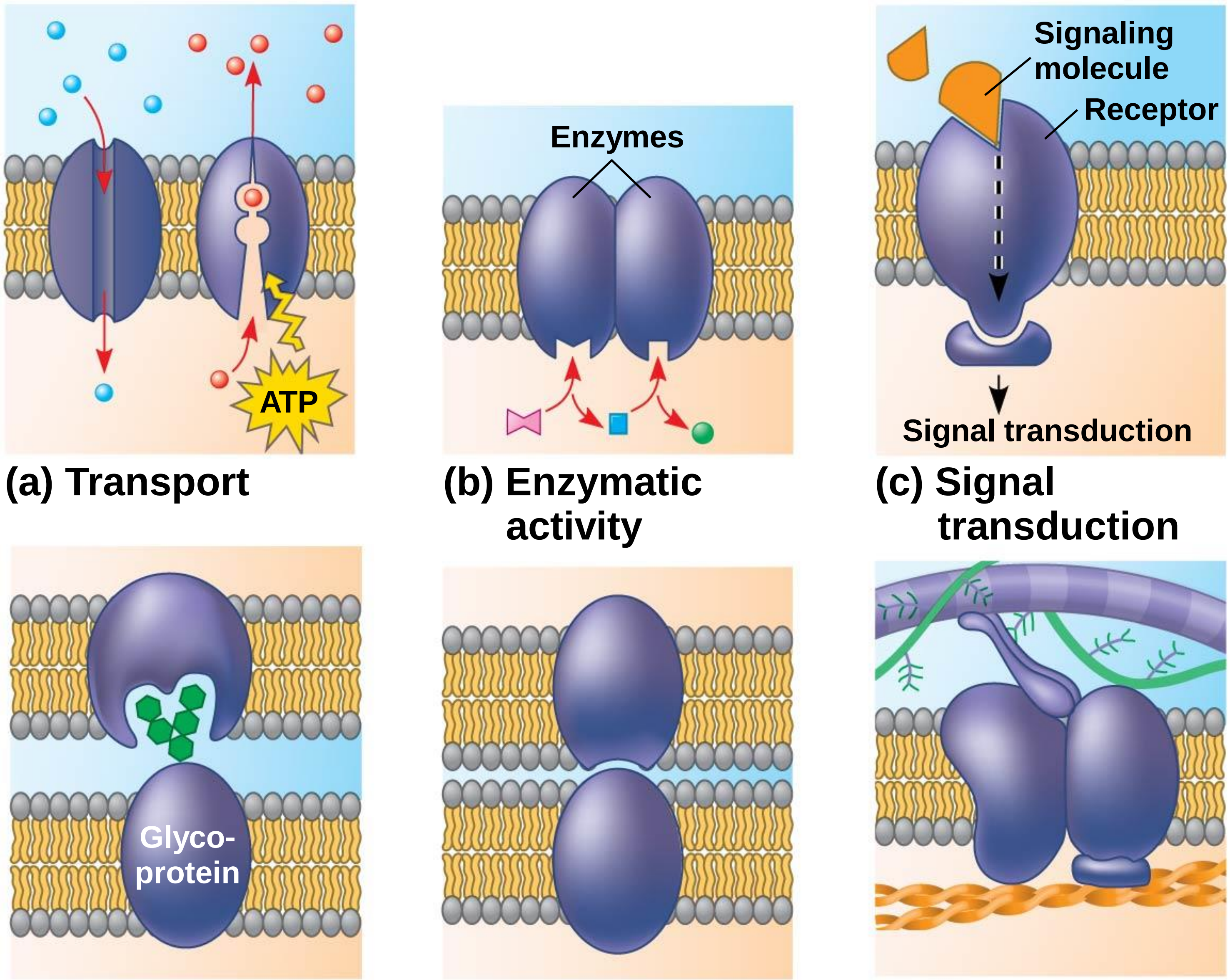
Figure 8.6



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

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

Figure 8.7



(a) Transport

(b) Enzymatic activity

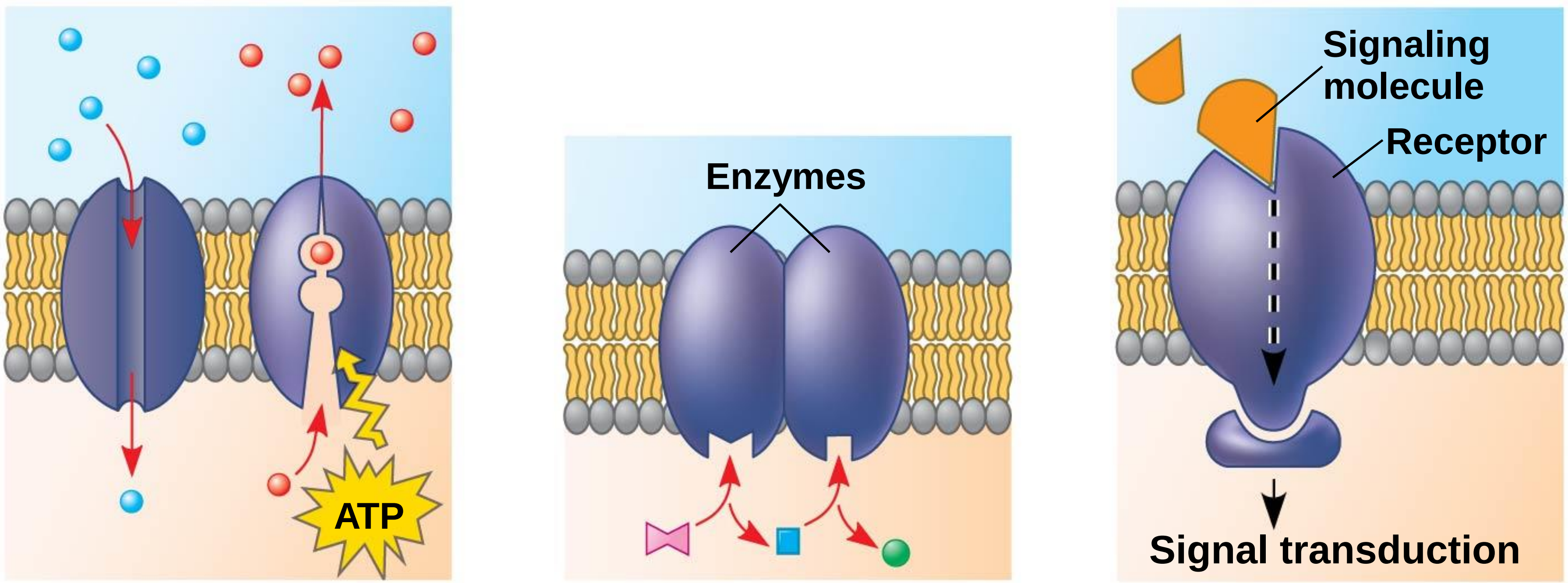
(c) Signal transduction

(d) Cell-cell recognition

(e) Intercellular joining

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

Figure 8.7a

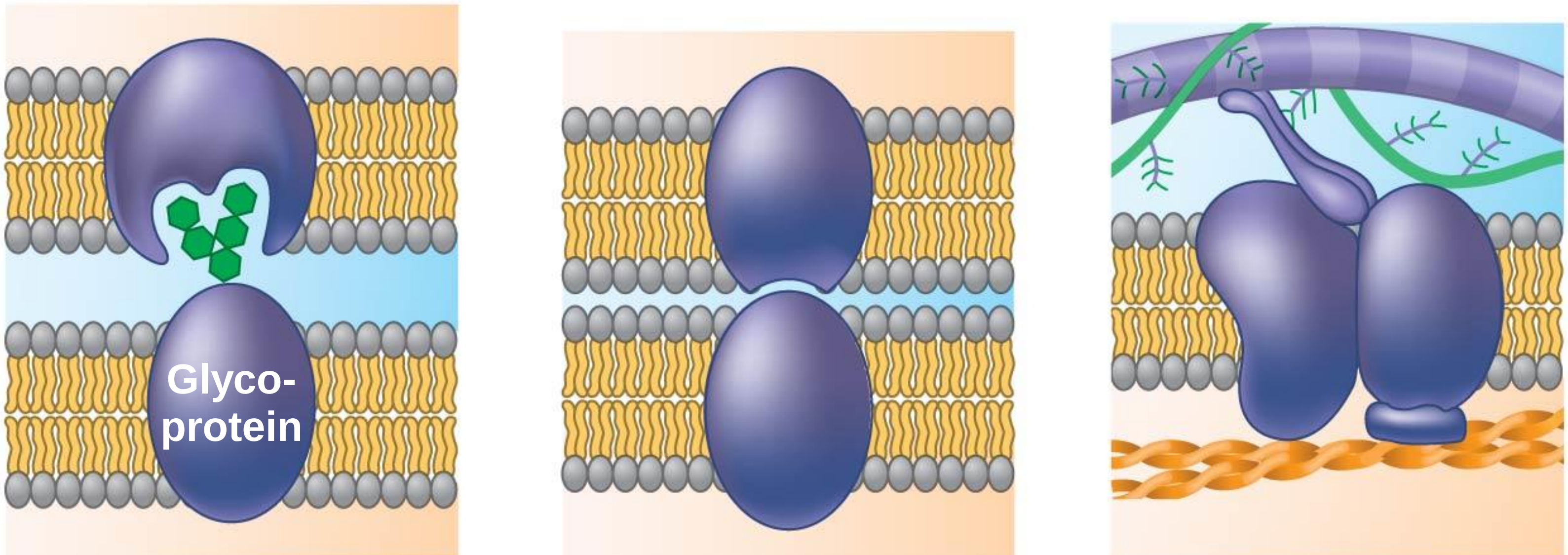


(a) Transport

(b) Enzymatic activity

(c) Signal transduction

Figure 8.7b



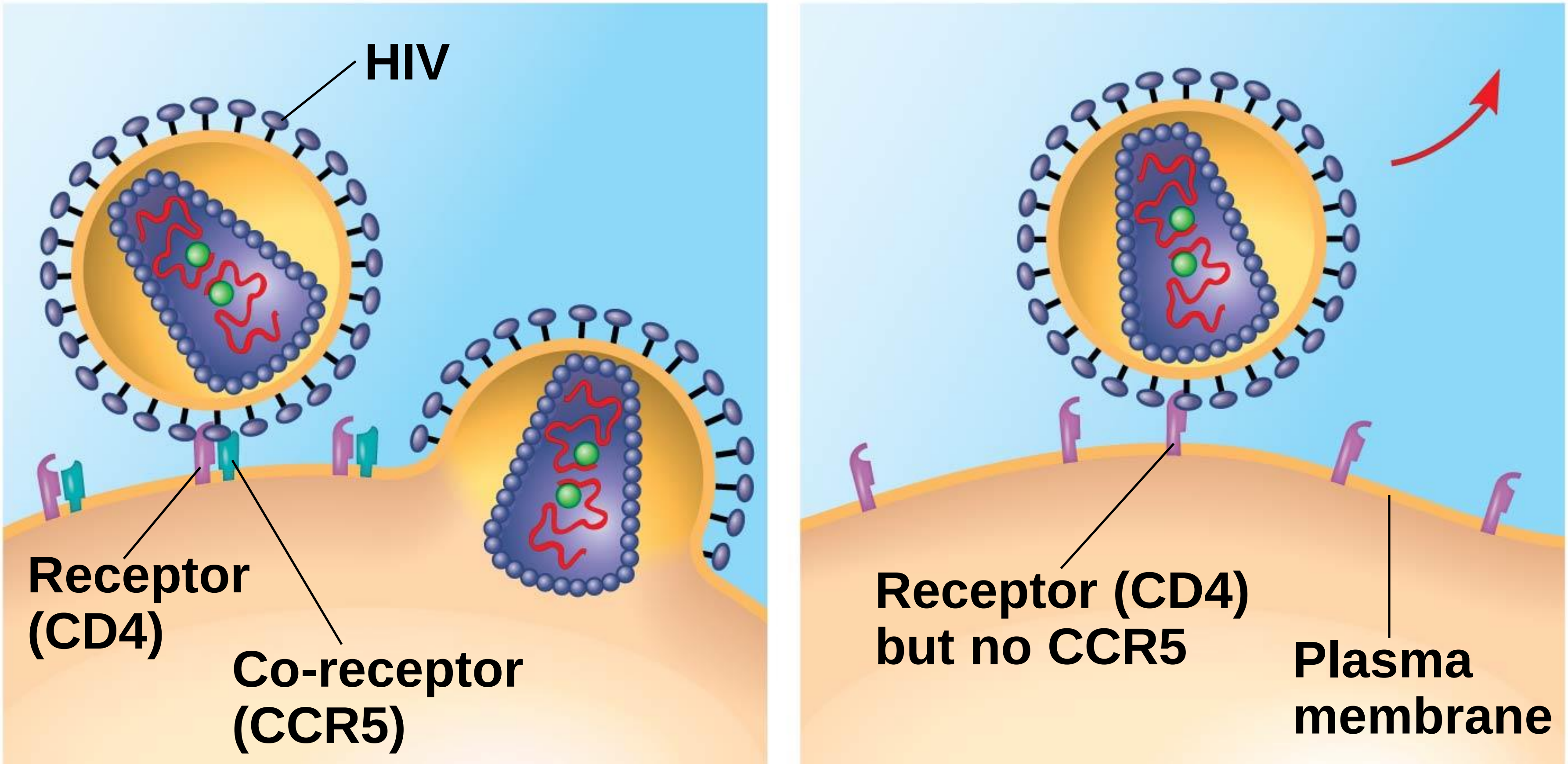
(d) Cell-cell recognition

(e) Intercellular joining

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

- Cell-surface proteins are important in the medical field
  - For example, HIV must bind to the immune cell-surface protein CD4 and a “co-receptor” CCR5 in order to infect a cell
  - HIV cannot enter the cells of resistant individuals who lack CCR5
  - Drugs are now being developed to mask the CCR5 protein

Figure 8.8



(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.

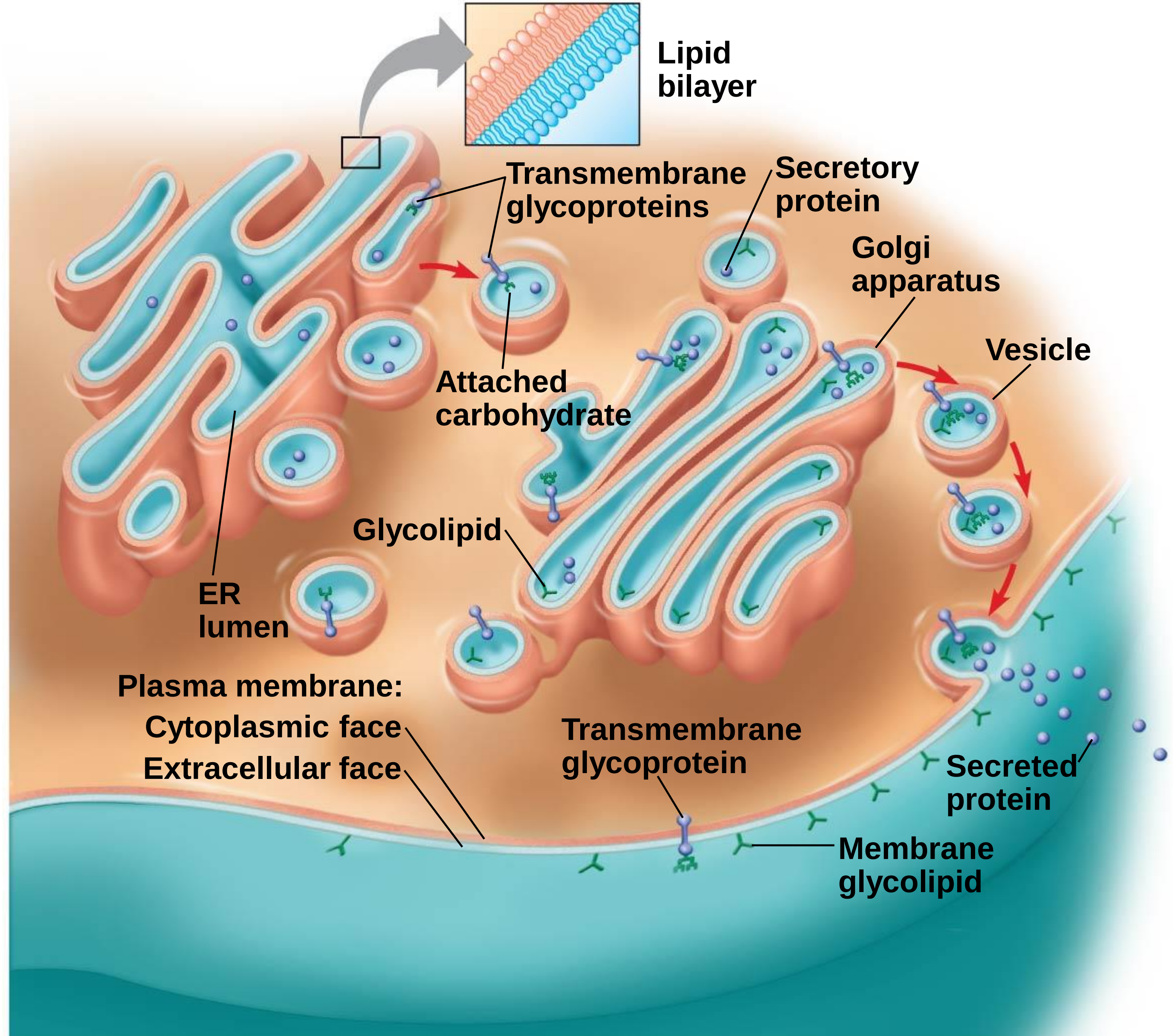
The Role of Membrane Carbohydrates in Cell-Cell Recognition

- Cells recognize each other by binding to molecules, often containing carbohydrates, on the extracellular surface of the plasma membrane
- Membrane carbohydrates may be covalently bonded to lipids (forming **glycolipids**) or, more commonly, to proteins (forming **glycoproteins**)
- Carbohydrates on the extracellular 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

Figure 8.9



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

Concept 8.2: 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
- Hydrophilic molecules including ions and polar molecules do not cross the membrane easily
- Proteins built into the membrane play key roles in regulating transport

Transport Proteins

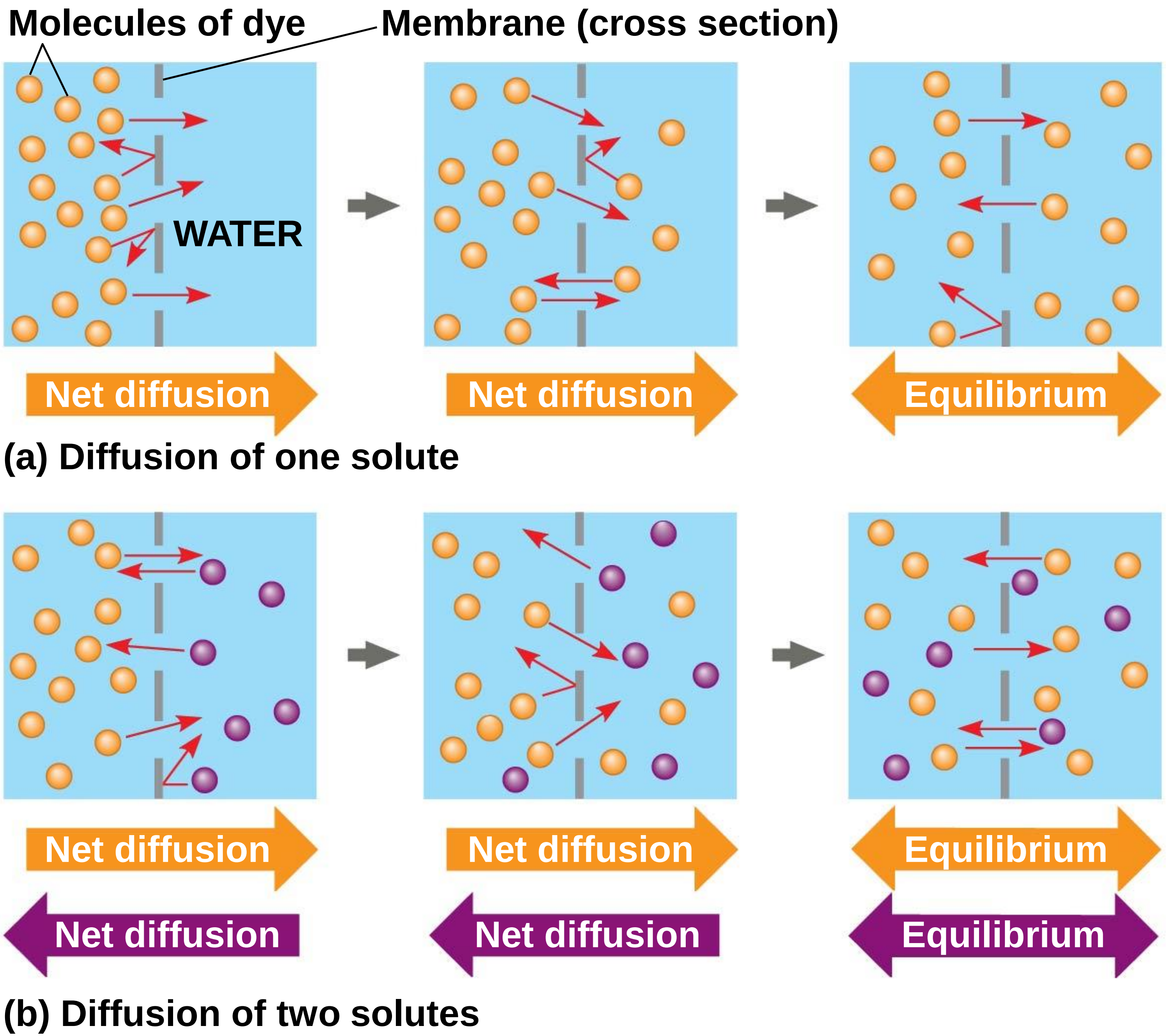
- **Transport proteins** allow passage of hydrophilic substances across the membrane
- Some transport proteins, called channel proteins, have a hydrophilic channel that certain molecules or ions can use as a tunnel
- Channel proteins called **aquaporins** greatly facilitate the passage of water molecules

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

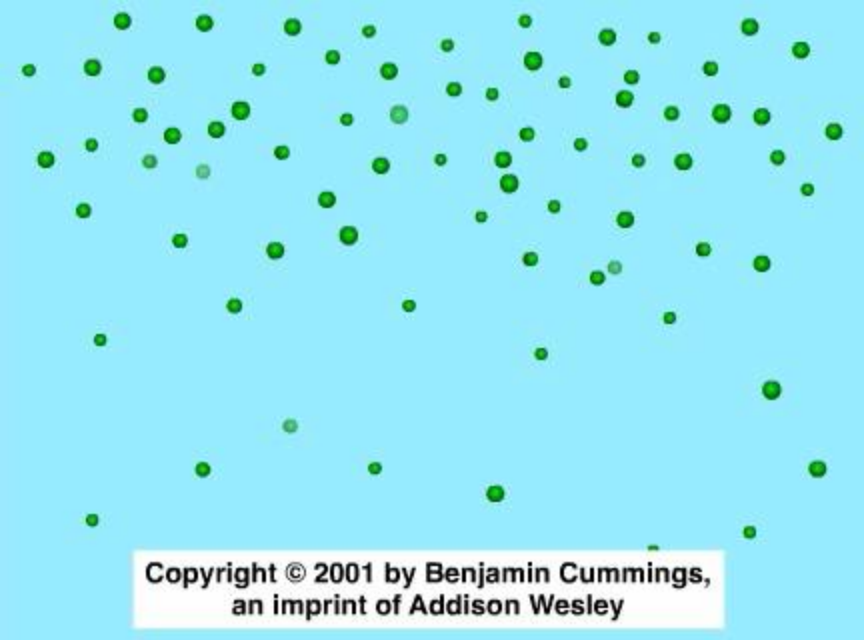
- **Diffusion** is the tendency for molecules to spread out evenly into the available space
- Although each molecule moves randomly, diffusion of a population of molecules may be directional
- At dynamic equilibrium, as many molecules cross the membrane in one direction as in the other

Figure 8.10

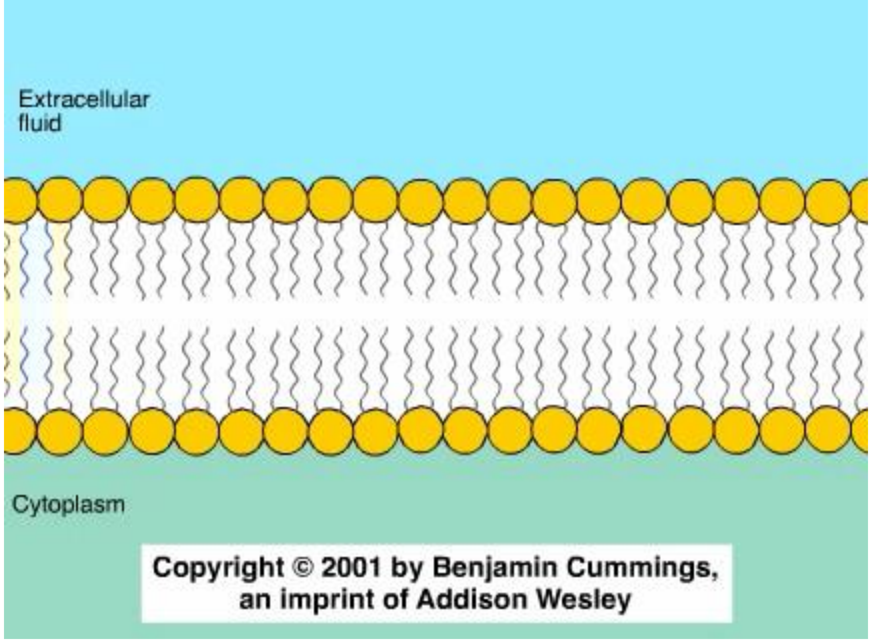


Molecules of dye
Membrane (cross section)
WATER
Net diffusion
Net diffusion
Equilibrium
(a) Diffusion of one solute
Net diffusion
Net diffusion
Equilibrium
Net diffusion
Net diffusion
Equilibrium
(b) Diffusion of two solutes

Animation: Diffusion



Animation: Membrane Selectivity

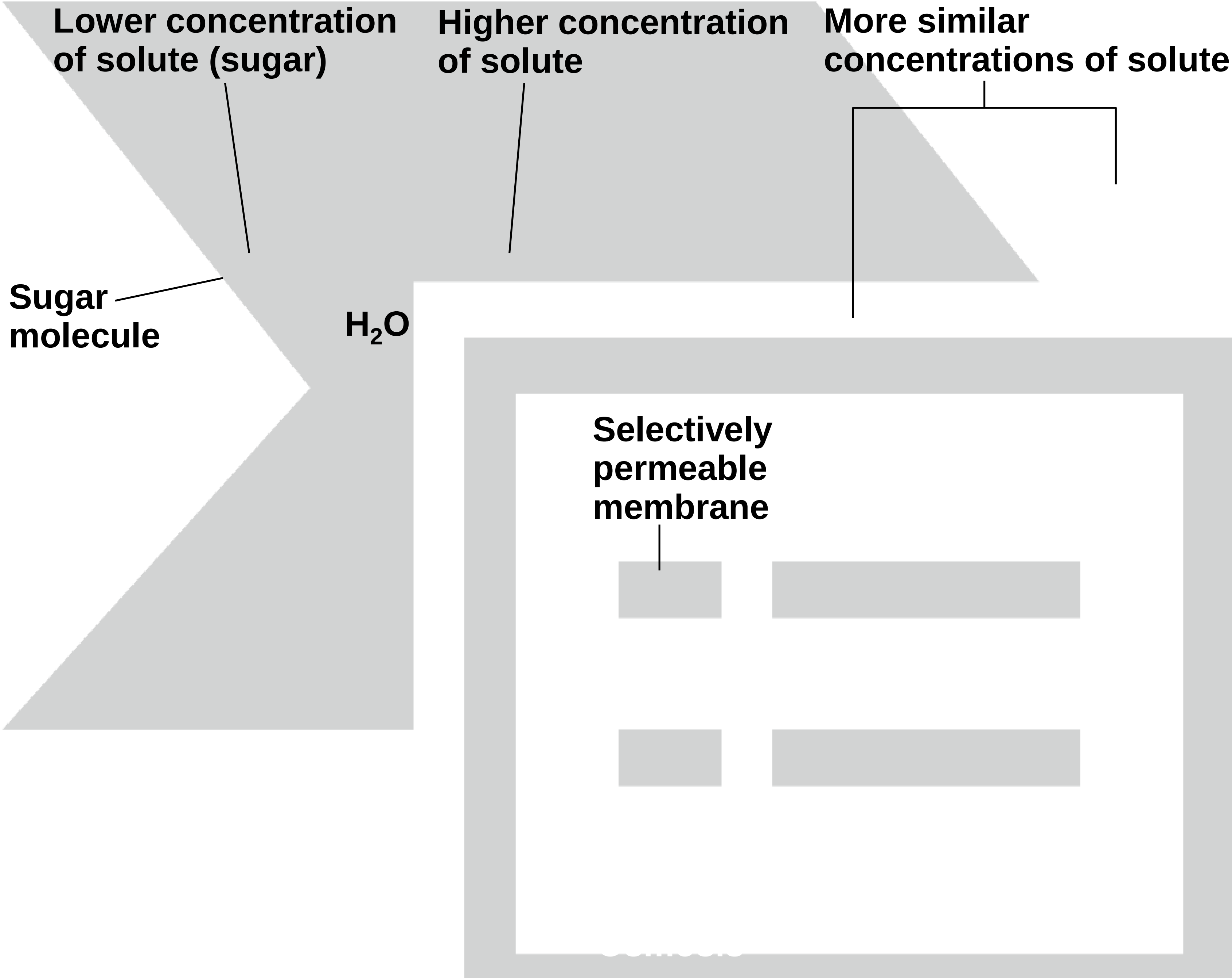


- Substances diffuse down their **concentration gradient**, the region along which the density of a chemical substance increases or decreases
- No work must be done to move substances down the concentration gradient
- The diffusion of a substance across a biological membrane is **passive transport** because no energy is expended by the cell to make it happen

Effects of Osmosis on Water Balance

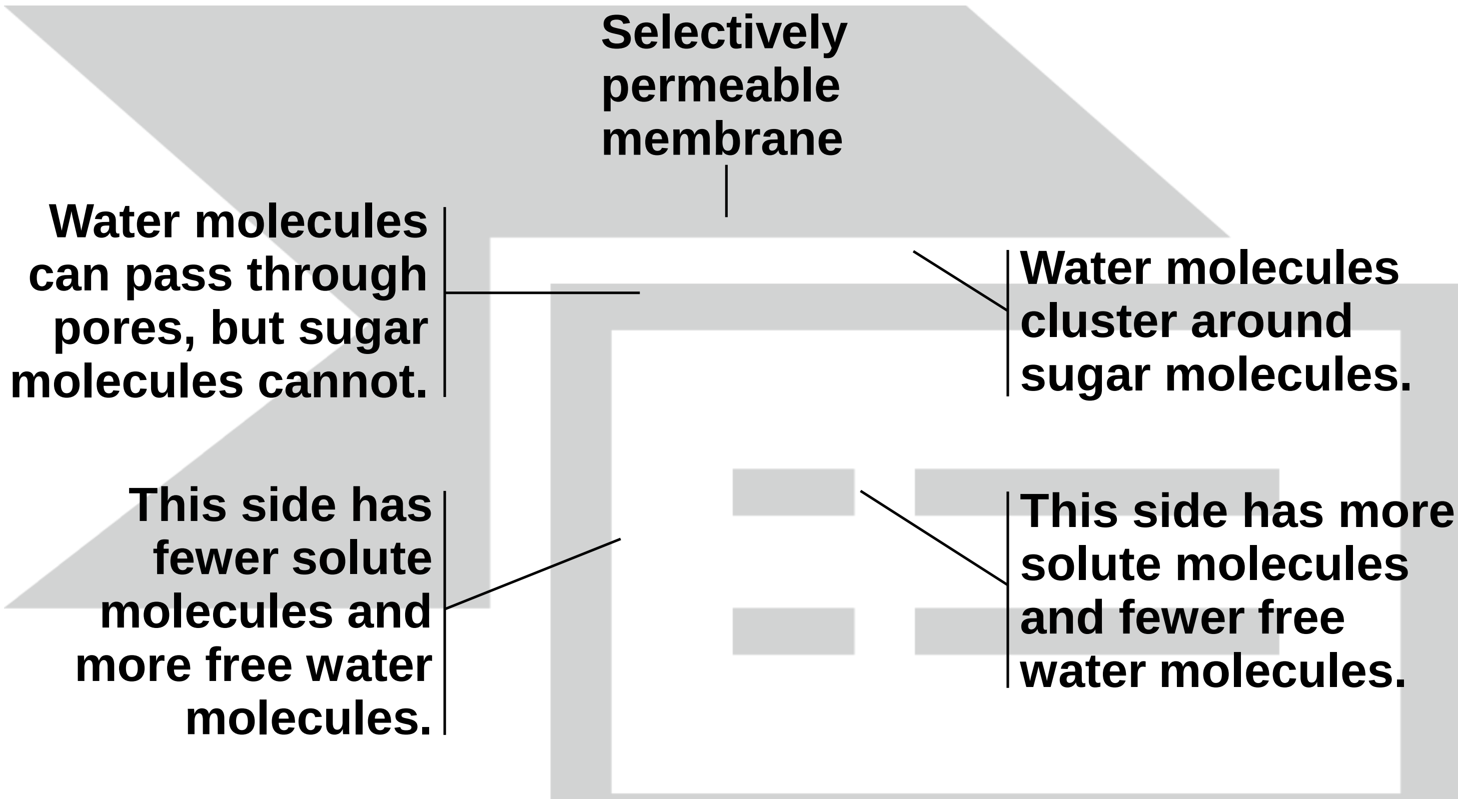
- **Osmosis** is the diffusion of water across a selectively permeable membrane
- Water diffuses across a membrane from the region of lower solute concentration to the region of higher solute concentration until the solute concentration is equal on both sides

Figure 8.11

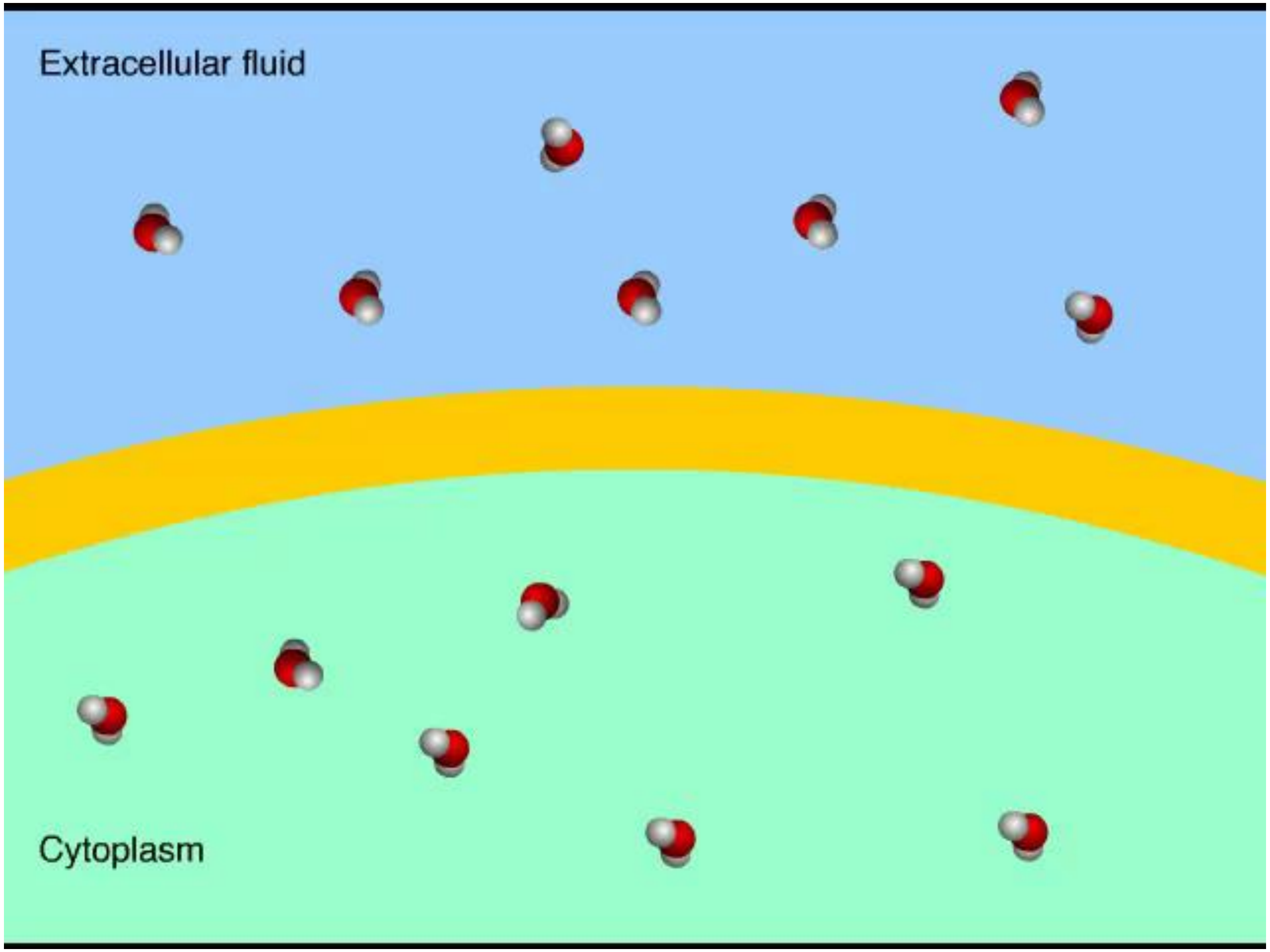


Lower concentration of solute (sugar)
Higher concentration of solute
More similar concentrations of solute
Sugar molecule
H_2O
Selectively permeable membrane

Figure 8.11a


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.

Animation: Osmosis

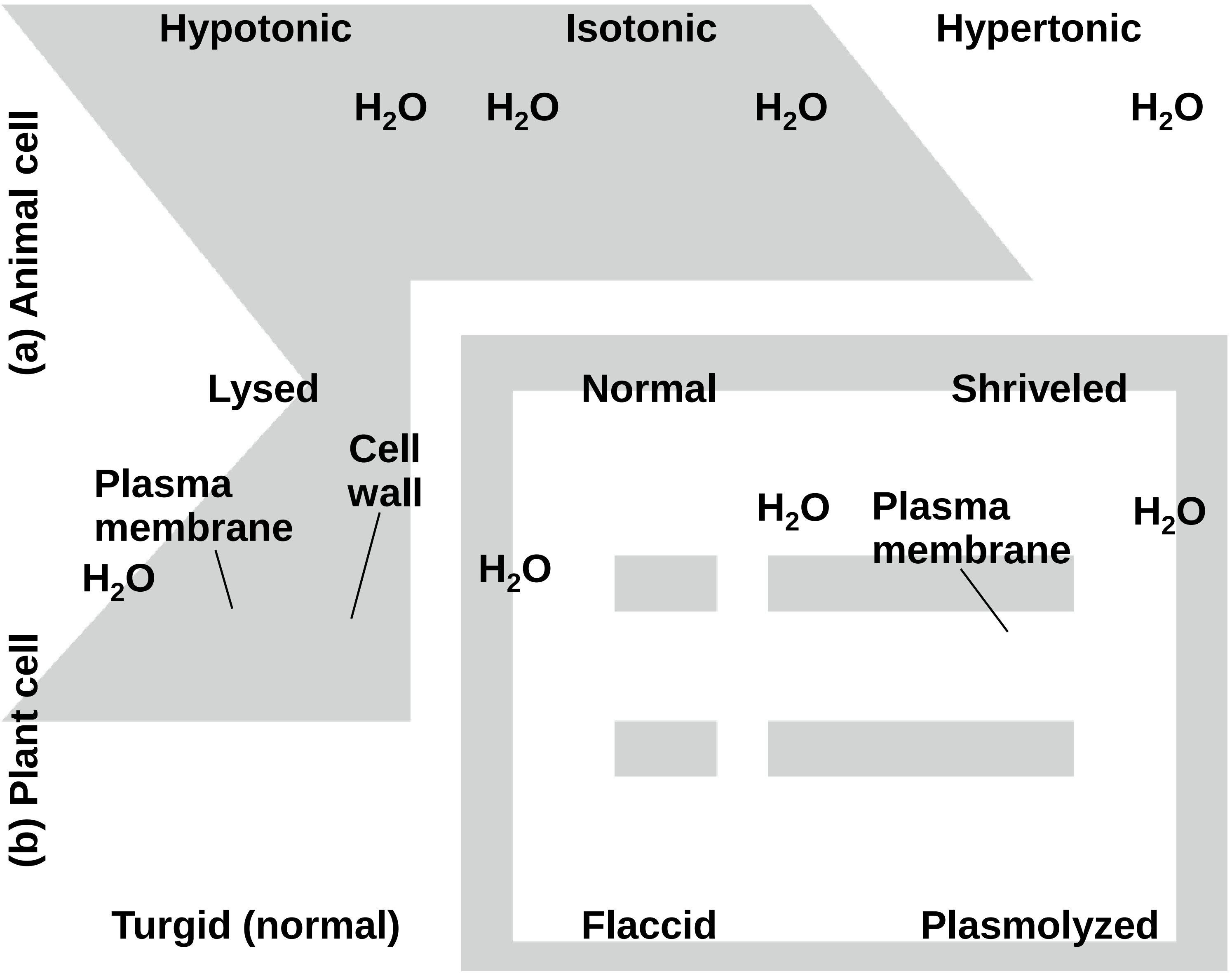


Water Balance of Cells Without Cell Walls

- **Tonicity** is the ability of a surrounding solution to cause a cell to gain or lose water
- The tonicity of a solution depends on its concentration of solutes that cannot cross the membrane relative to that inside the cell

- **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
- Cells without cell walls will shrivel in hypertonic solution and lyse (burst) in a hypotonic solution

Figure 8.12



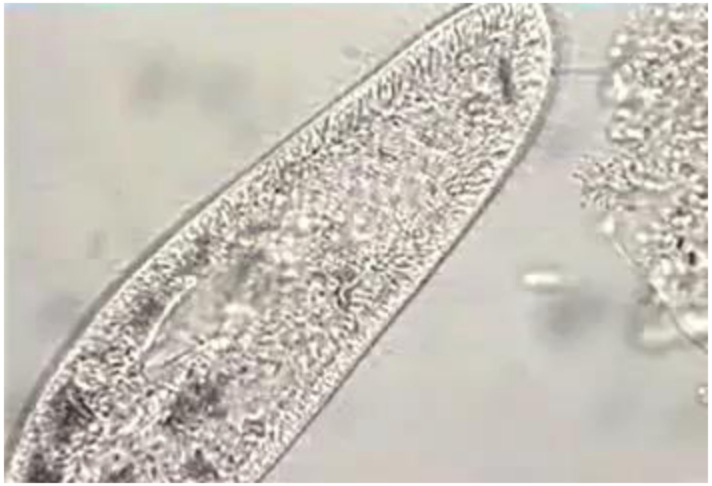
Hypotonic
Isotonic
Hypertonic
(a) Animal cell
H_2O
H_2O
H_2O
H_2O
Lysed
Normal
Shriveled
(b) Plant cell
Plasma membrane
Cell wall
H_2O
H_2O
H_2O
Plasma membrane
H_2O
Turgid (normal)
Flaccid
Plasmolyzed

- Hypertonic or hypotonic environments create osmotic problems for organisms that have cells without rigid walls
- **Osmoregulation**, the control of solute concentrations and water balance, is a necessary adaptation for life in such environments
  - For example, the unicellular eukaryote *Paramecium*, which is hypertonic to its pond water environment, has a contractile vacuole that acts as a pump

Figure 8.13

Video: *Chlamydomonas*

Video: *Paramecium* Vacuole



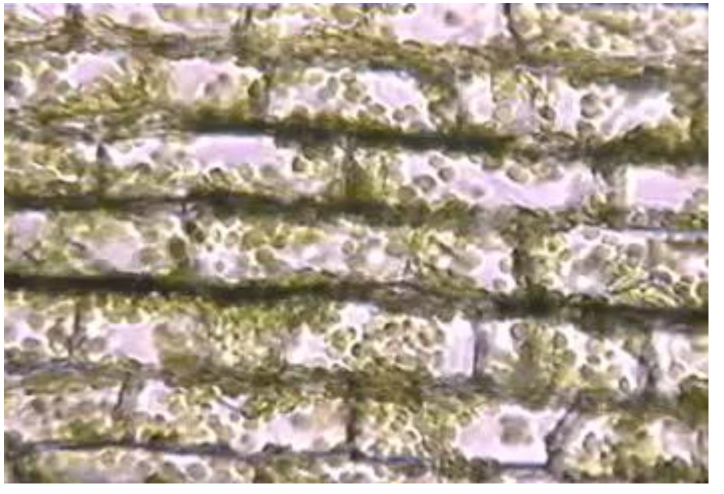
- Bacteria and archaea that live in hypersaline (excessively salty) environments have cellular mechanisms to balance internal and external solute concentrations

Water Balance of Cells with Cell Walls

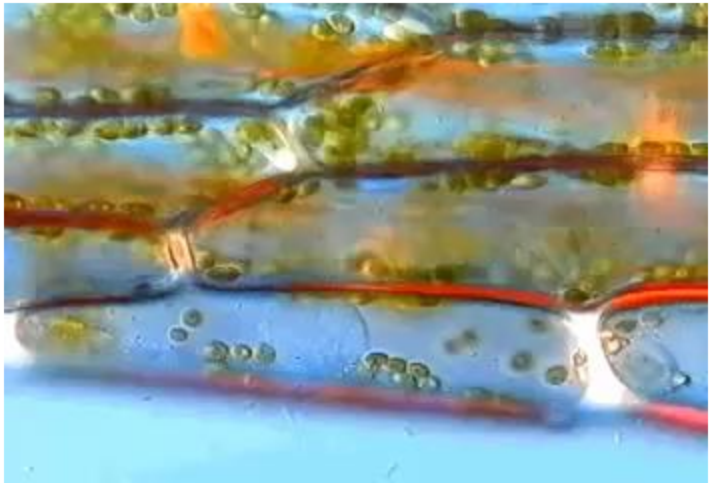
- Cell walls help maintain water balance
- A plant cell in a hypotonic solution swells until the wall opposes uptake; the cell is now **turgid** (firm)
- If a plant cell and its surroundings are isotonic, there is no net movement of water into the cell; the cell becomes **flaccid** (limp)

- In a hypertonic environment, plant cells lose water
- The membrane pulls away from the cell wall, causing the plant to wilt, a potentially lethal effect called **plasmolysis**

Video: Plasmolysis in *Elodea*



Video: Turgid *Elodea*

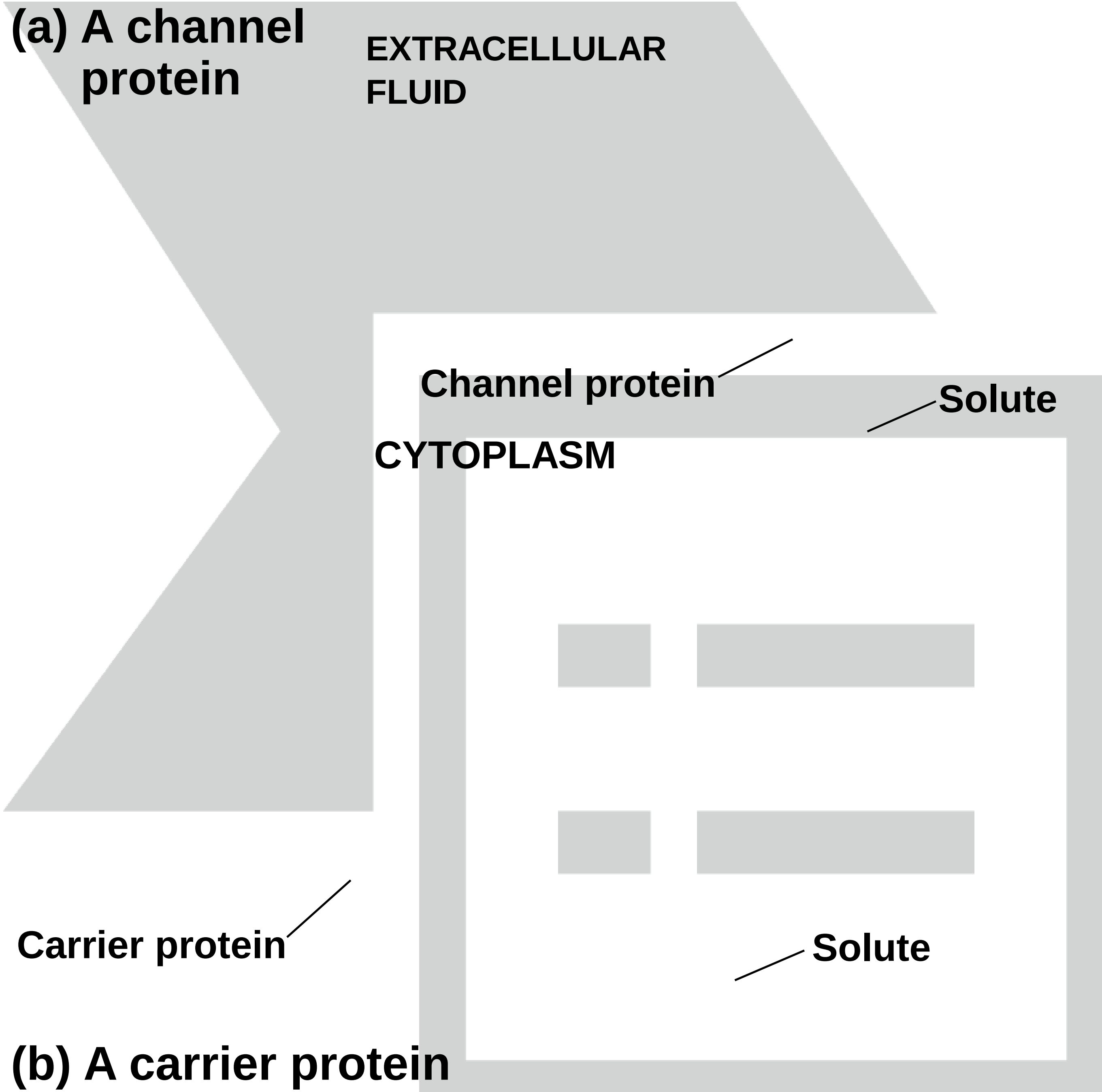


Facilitated Diffusion: Passive Transport Aided by Proteins

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

- 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
- Some ion channels, called **gated channels**, open or close in response to a stimulus
    - For example, in nerve cells, ion channels open in response to electrical stimulus

Figure 8.14



(a) A channel protein
EXTRACELLULAR FLUID
Channel protein
Solute
CYTOPLASM
Carrier protein
Solute
(b) A carrier protein

- Carrier proteins undergo a subtle change in shape that translocates the solute-binding site across the membrane
- This change in shape can be triggered by the binding and release of the transported molecule

Concept 8.4: Active transport uses energy to move solutes against their gradients

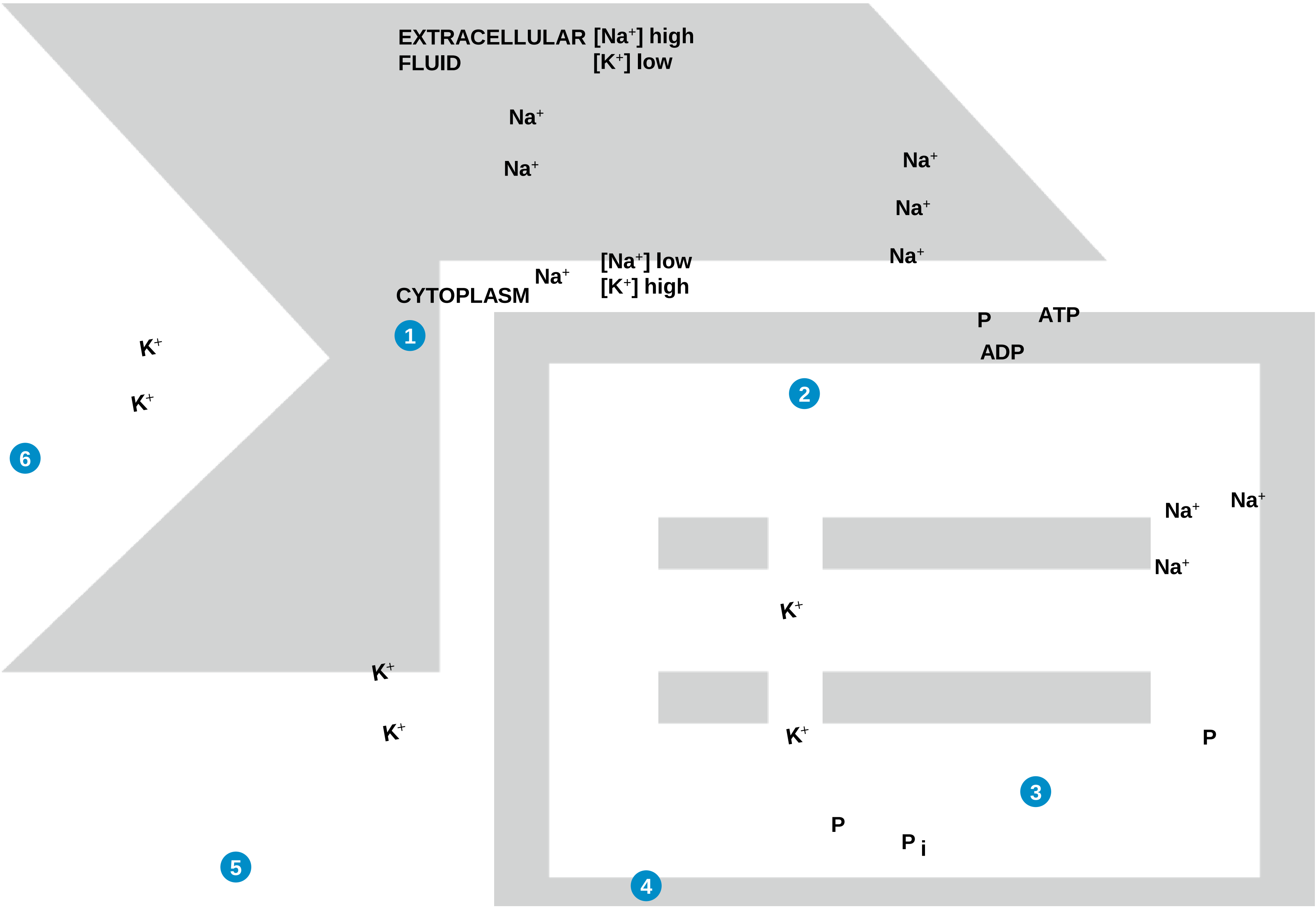
- Facilitated diffusion is still passive because the solute moves down its concentration gradient, and the transport requires no energy
- Some transport proteins, however, can move solutes against their concentration gradients

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

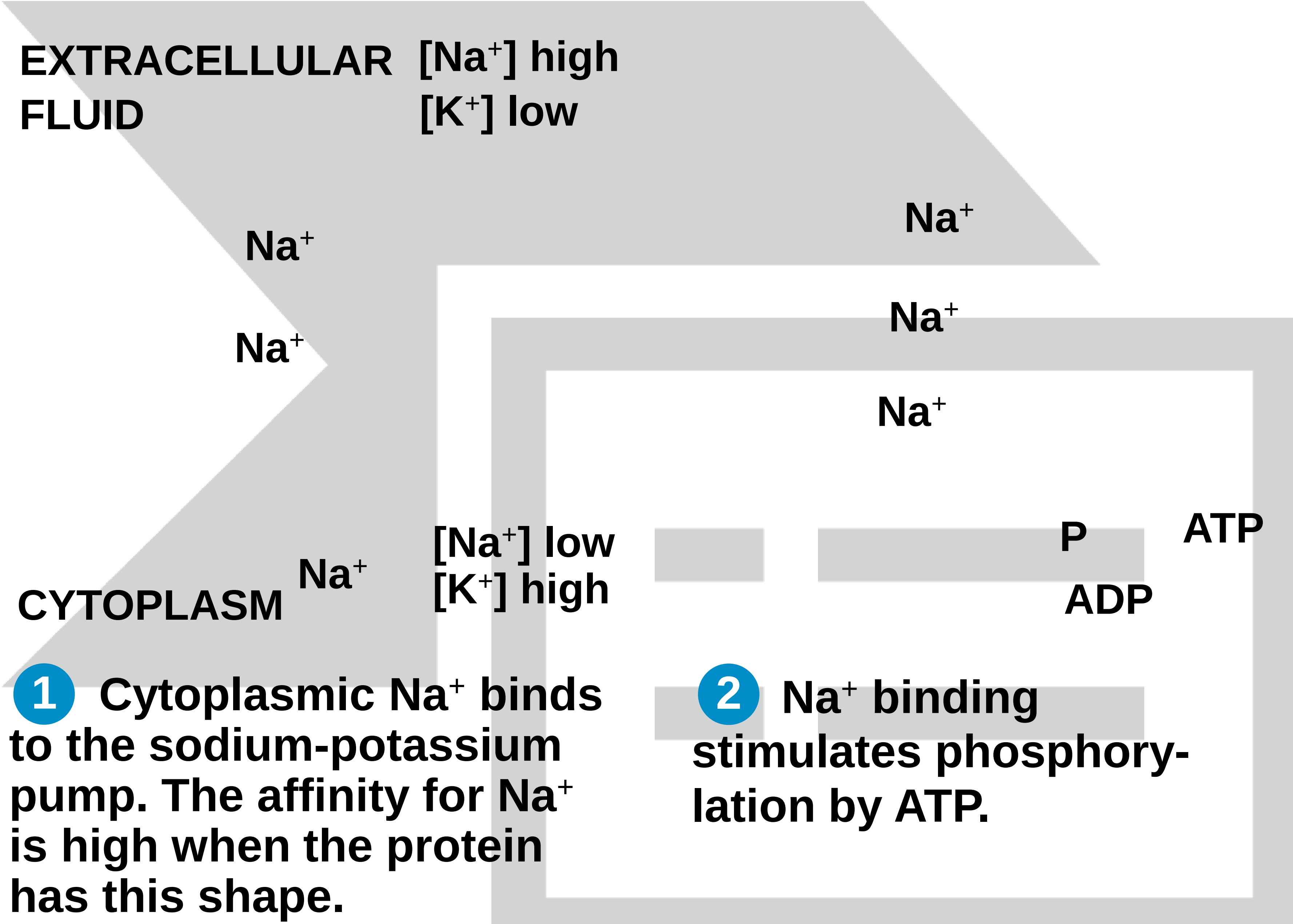
- Active transport allows cells to maintain concentration gradients that differ from their surroundings
  - For example, an animal cell has a much higher potassium (K^+) and a much lower sodium (Na^+) concentration compared to its surroundings
  - This is controlled by the **sodium-potassium pump**, a transport protein that is energized by transfer of a phosphate group from the hydrolysis of ATP

Figure 8.15



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

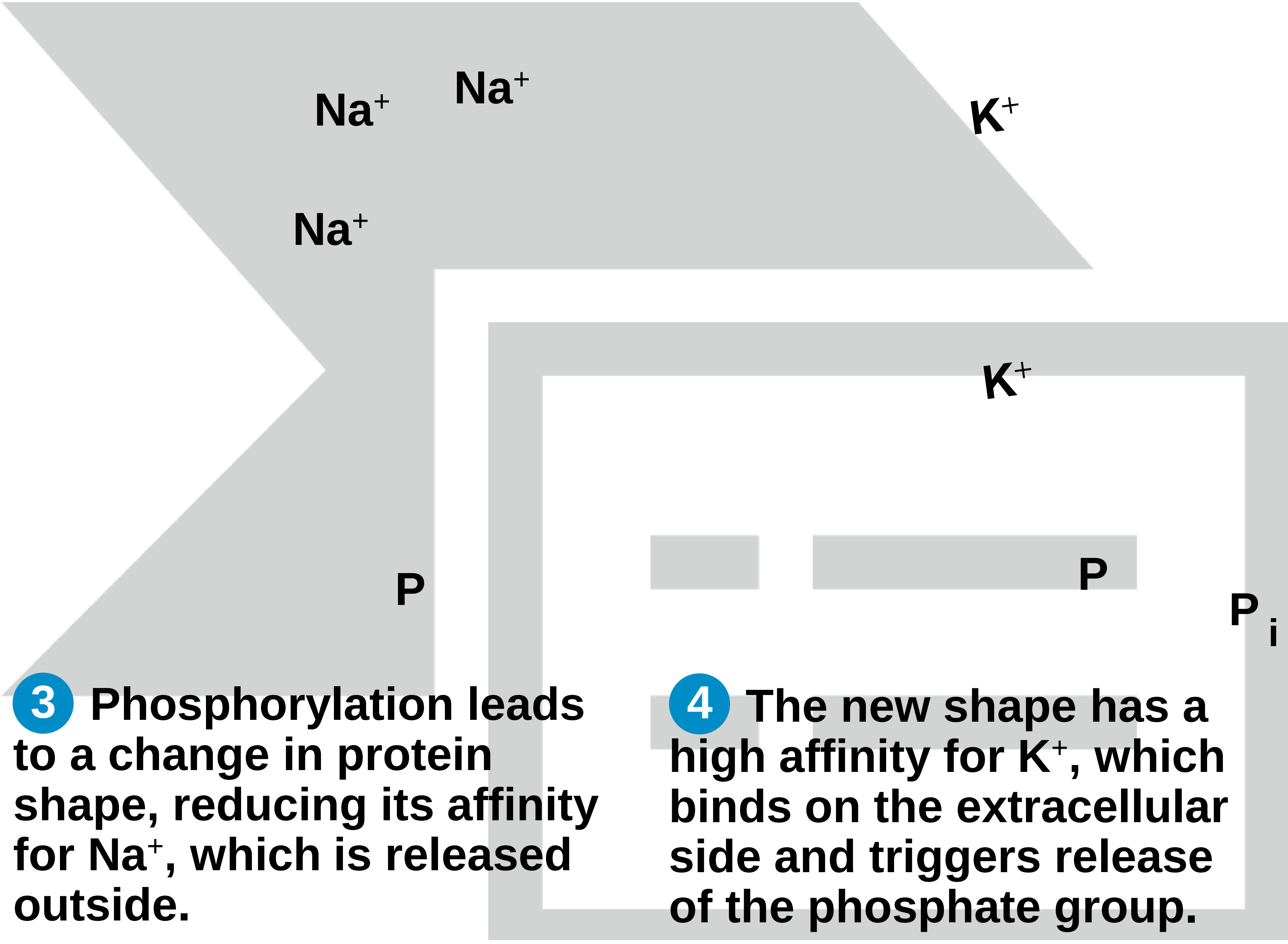
Figure 8.15a



1 Cytoplasmic Na^+ binds to the sodium-potassium pump. The affinity for Na^+ is high when the protein has this shape.

2 Na^+ binding stimulates phosphorylation by ATP.

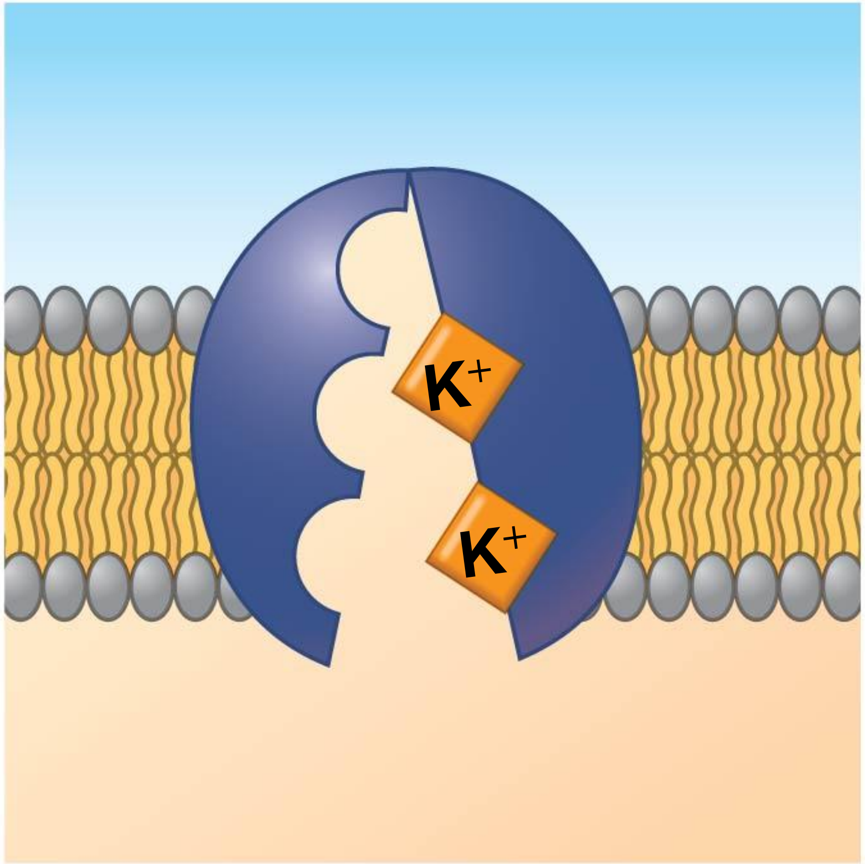
Figure 8.15b



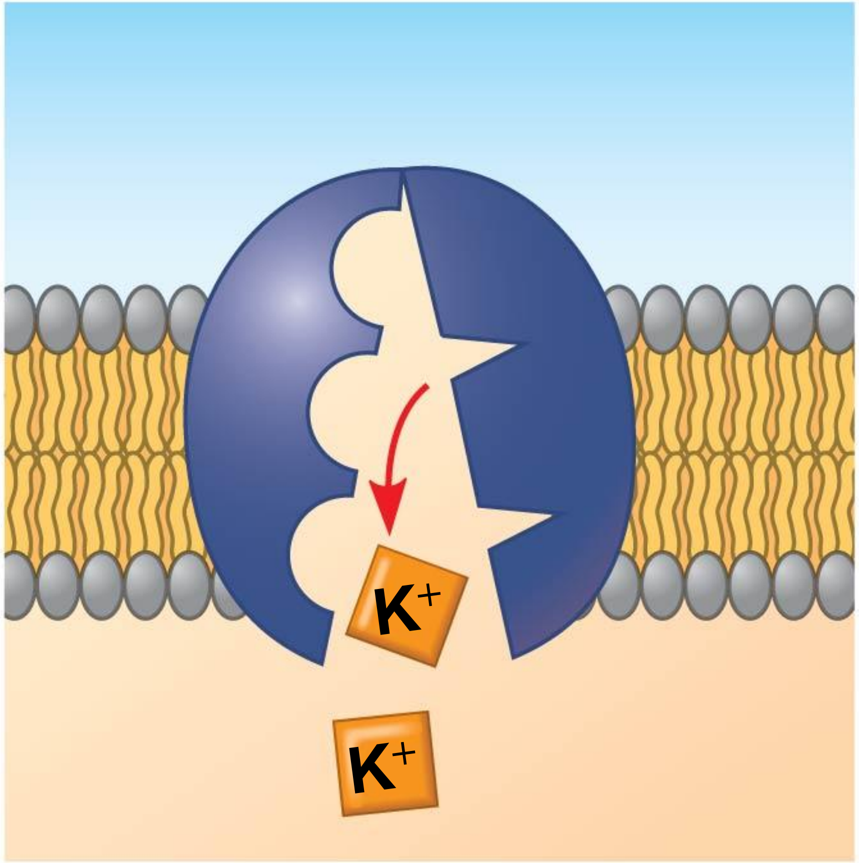
3 Phosphorylation leads to a change in protein shape, reducing its affinity for Na^+, which is released outside.

4 The new shape has a high affinity for K^+, which binds on the extracellular side and triggers release of the phosphate group.

Figure 8.15c

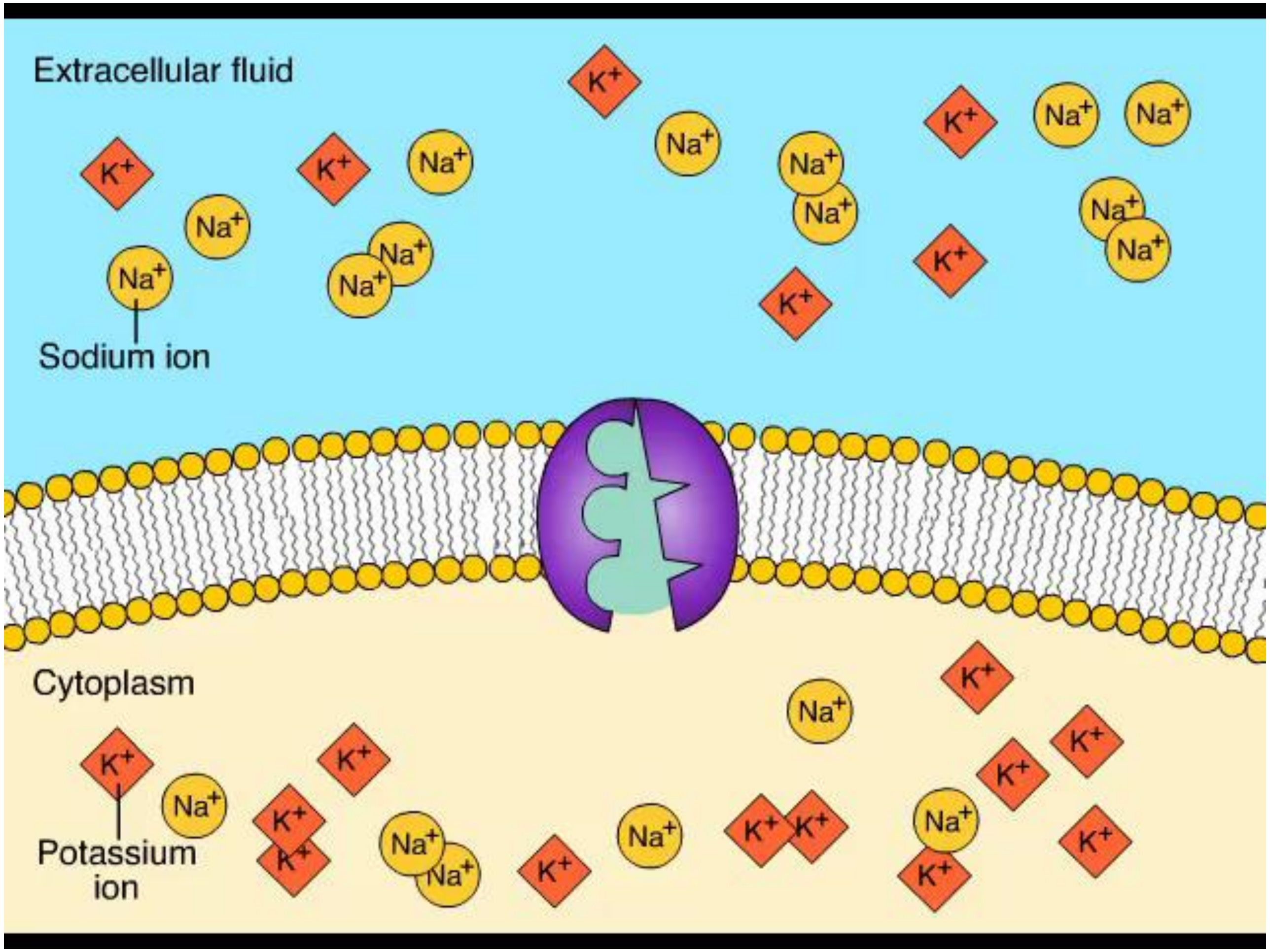


5 Loss of the phosphate group restores the protein's original shape, which has a lower affinity for K^+.



6 K^+ is released; affinity for Na^+ is high again, and the cycle repeats.

Animation: Active Transport



Video: Na^+/K^+ ATPase Cycle

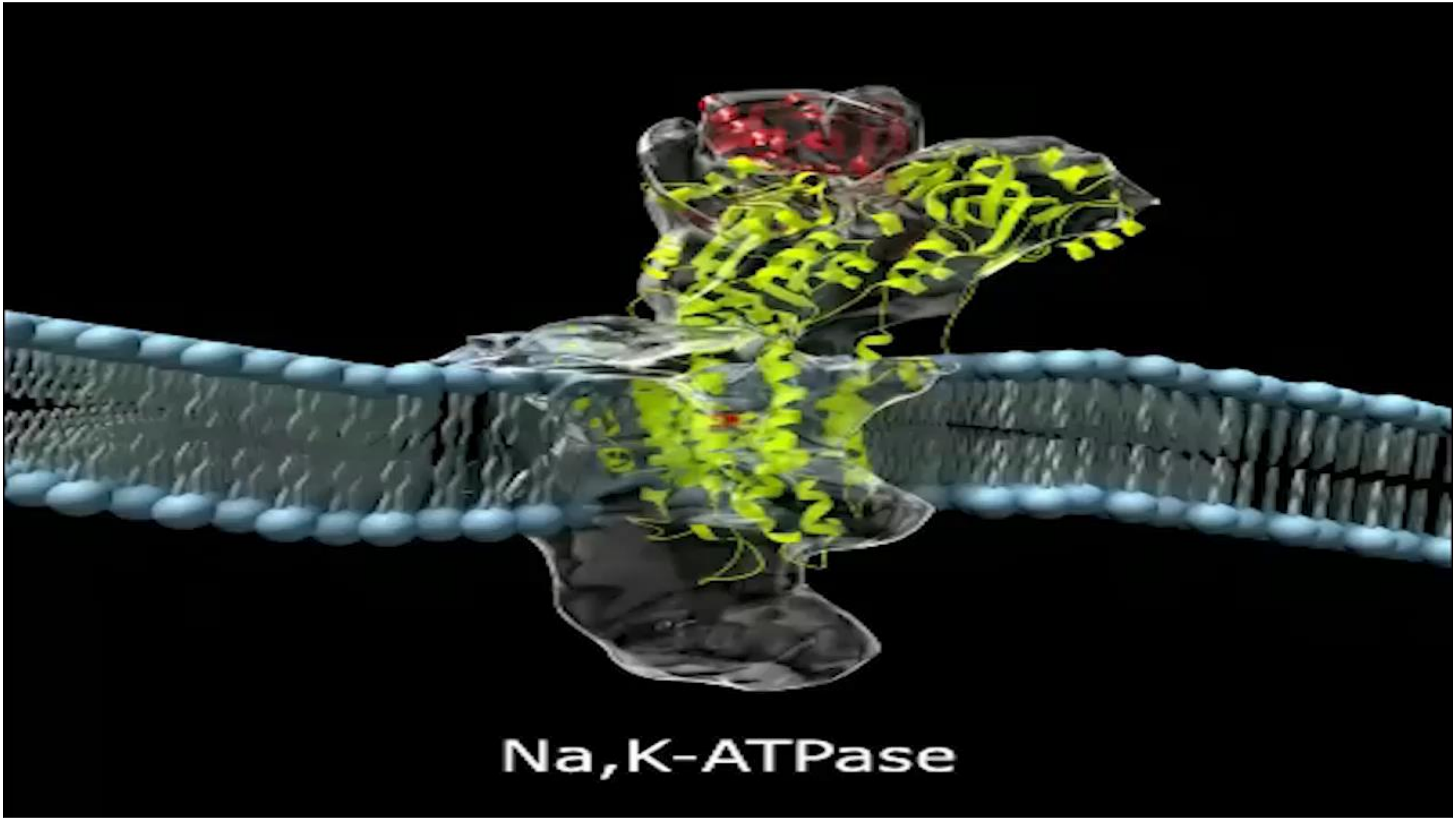
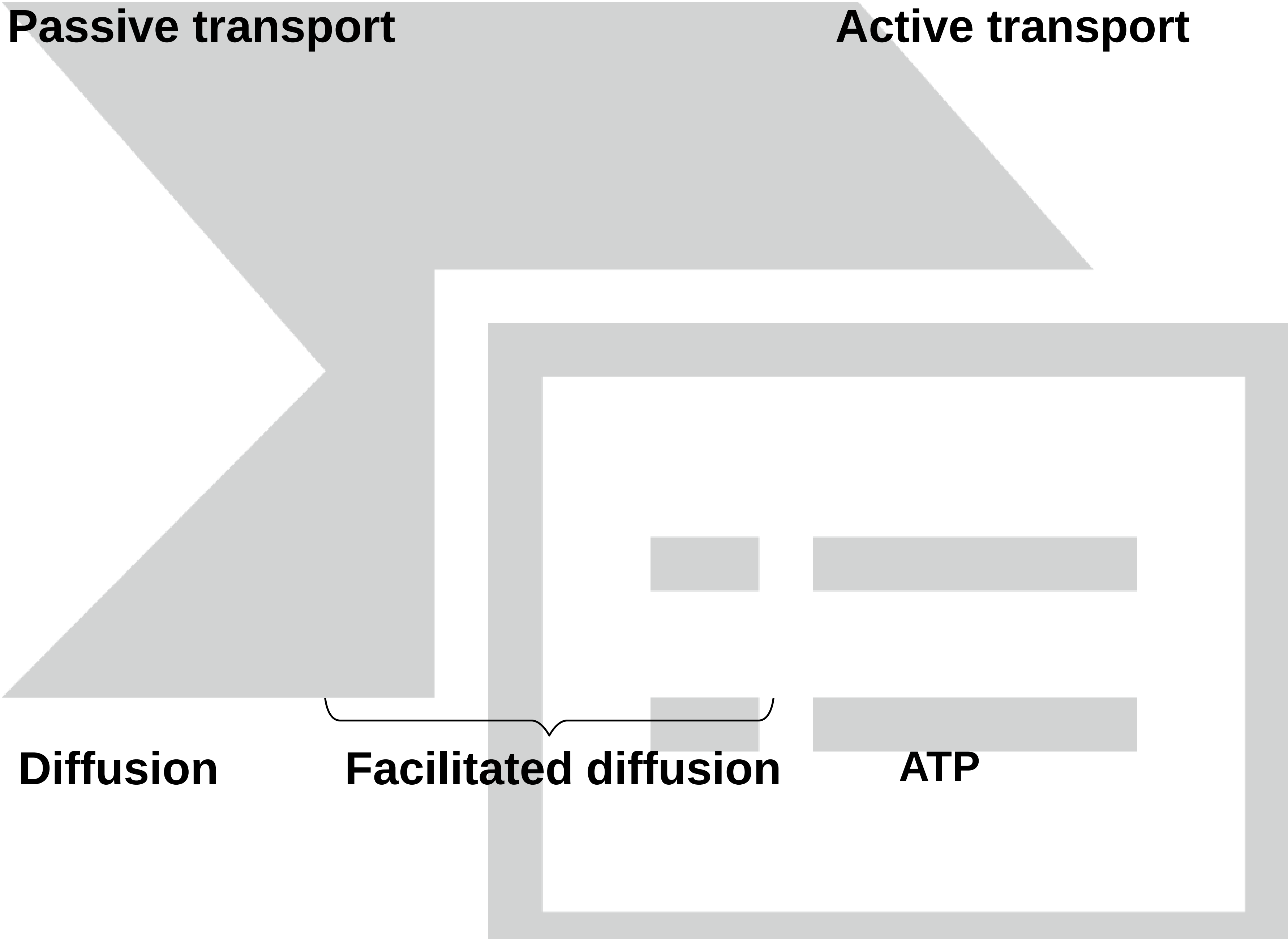
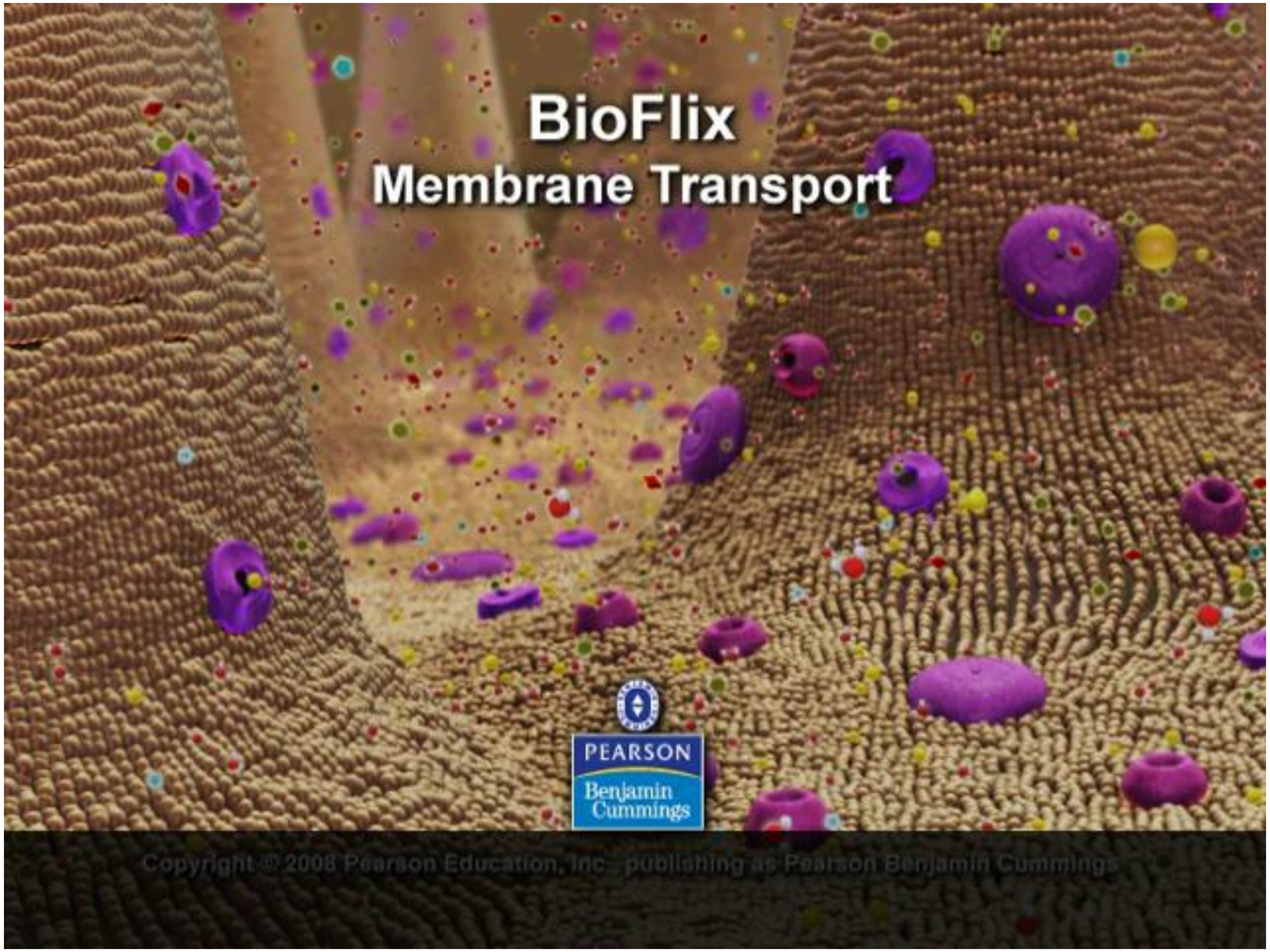


Figure 8.16


Passive transport
Active transport
Diffusion
Facilitated diffusion
ATP

BioFlix: Membrane Transport



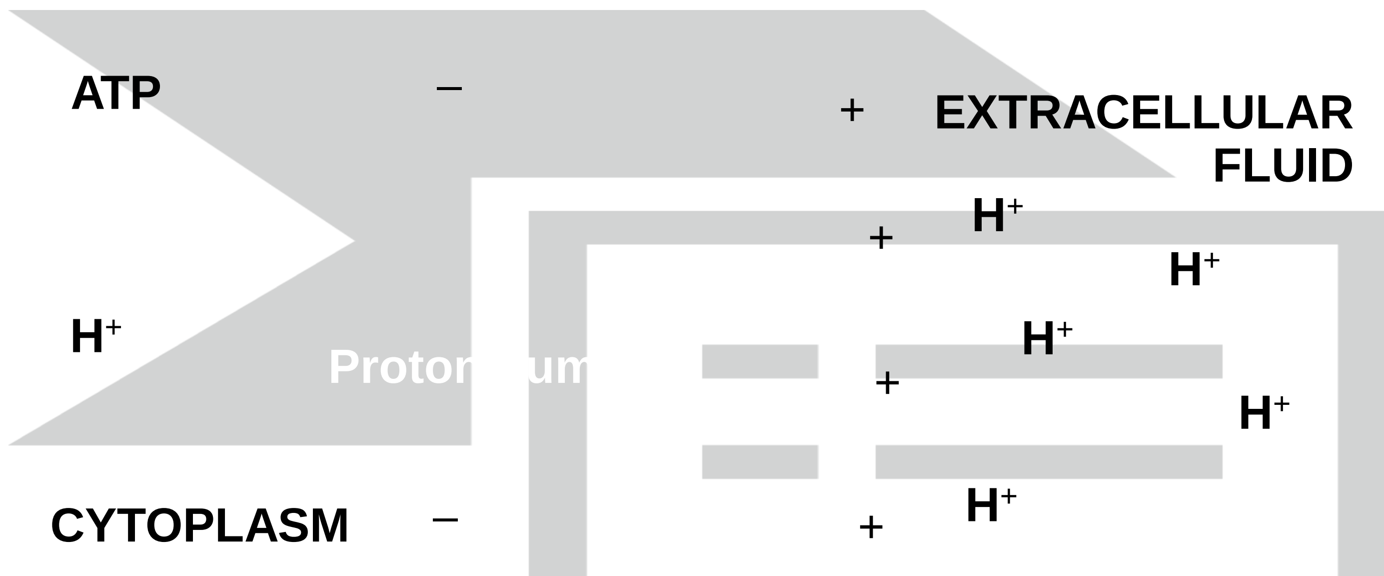
How Ion Pumps Maintain Membrane Potential

- **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 cytoplasmic side of the membrane is negative in charge relative to the extracellular side

- 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**, which actively transports hydrogen ions (H^+) out of the cell
- Electrogenic pumps help store energy that can be used for cellular work

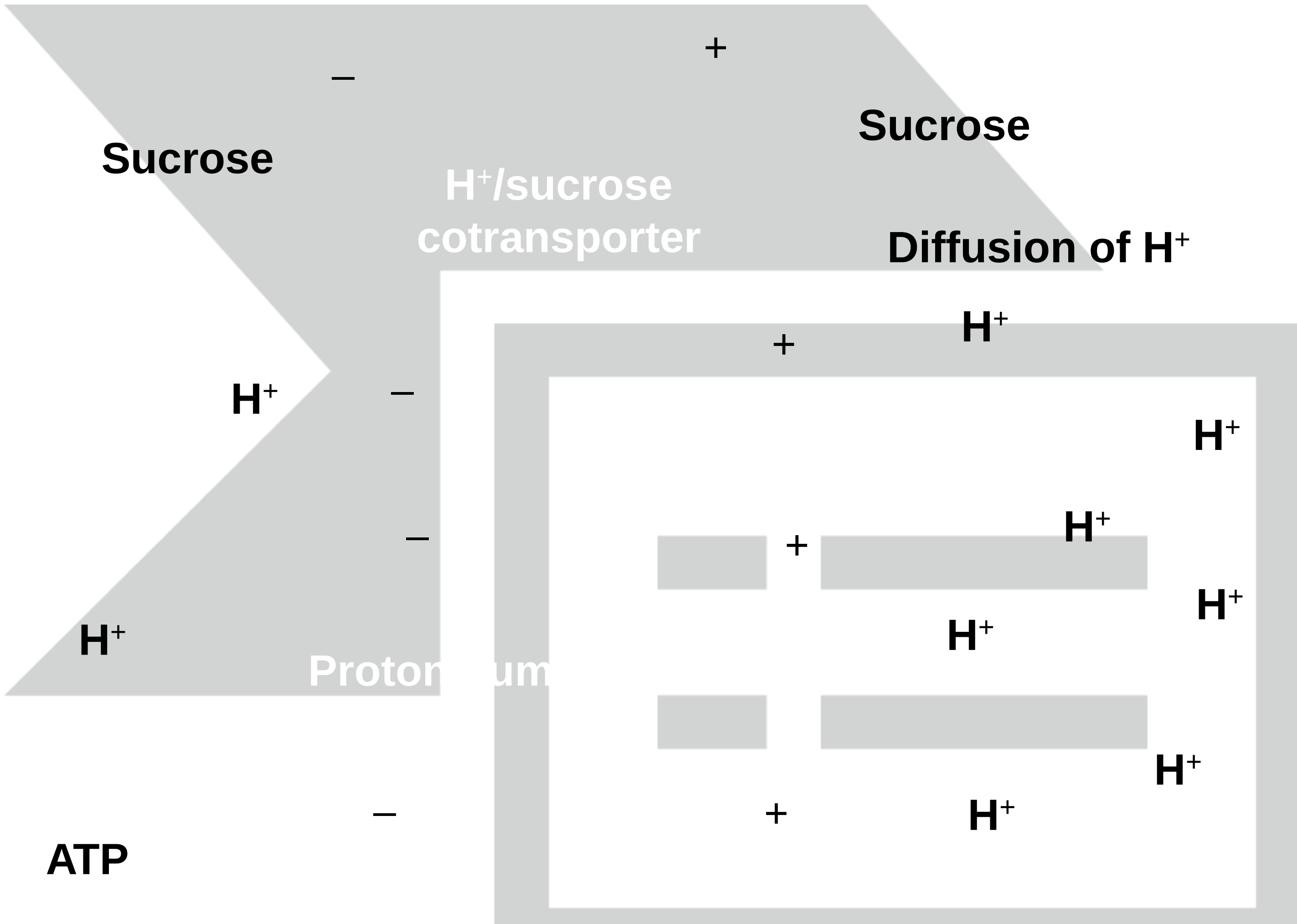
Figure 8.17



Cotransport: Coupled Transport by a Membrane Protein

- **Cotransport** occurs when active transport of a solute indirectly drives transport of other substances
- The diffusion of an actively transported solute down its concentration gradient is coupled with the transport of a second substance against its own concentration gradient

Figure 8.18

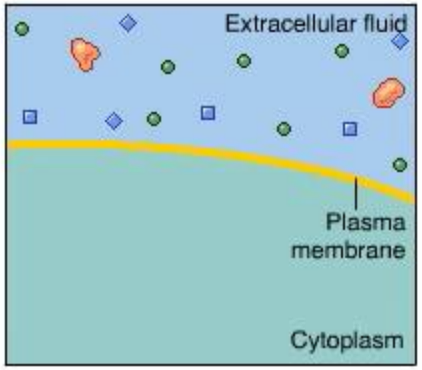


Sucrose
Sucrose
H+/sucrose
cotransporter
Diffusion of H+
H+
H+
H+
H+
H+
H+
H+
H+
H+
ATP

Concept 8.5: 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 via vesicles
- Bulk transport requires energy

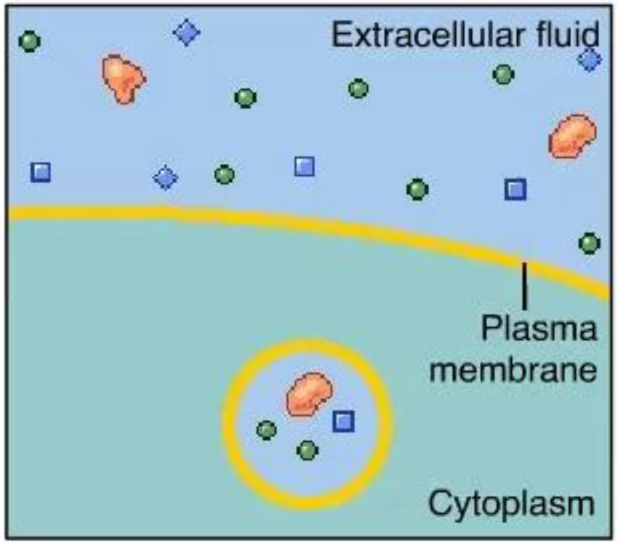
Animation: Exocytosis and Endocytosis Introduction



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

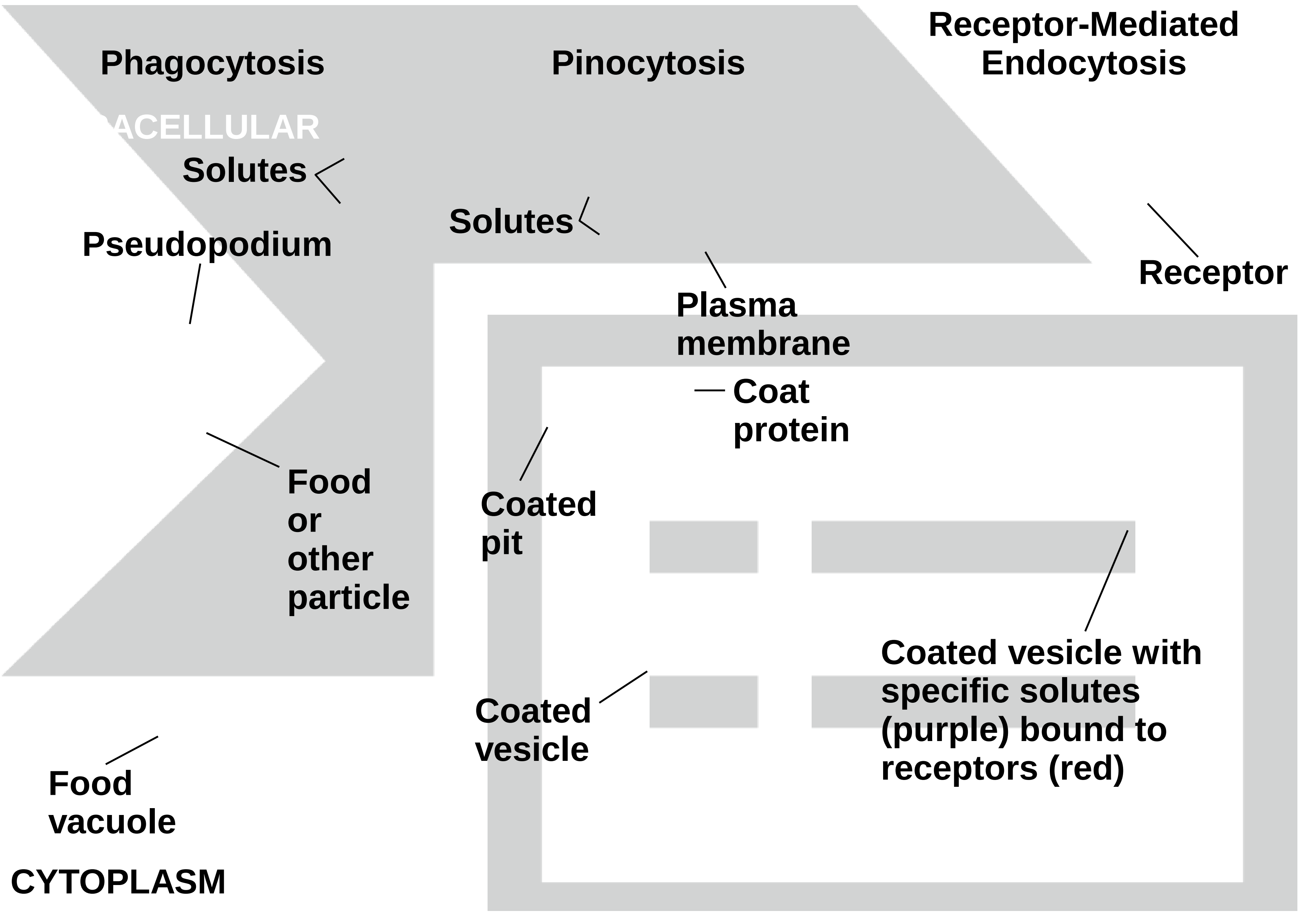
Animation: Exocytosis



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

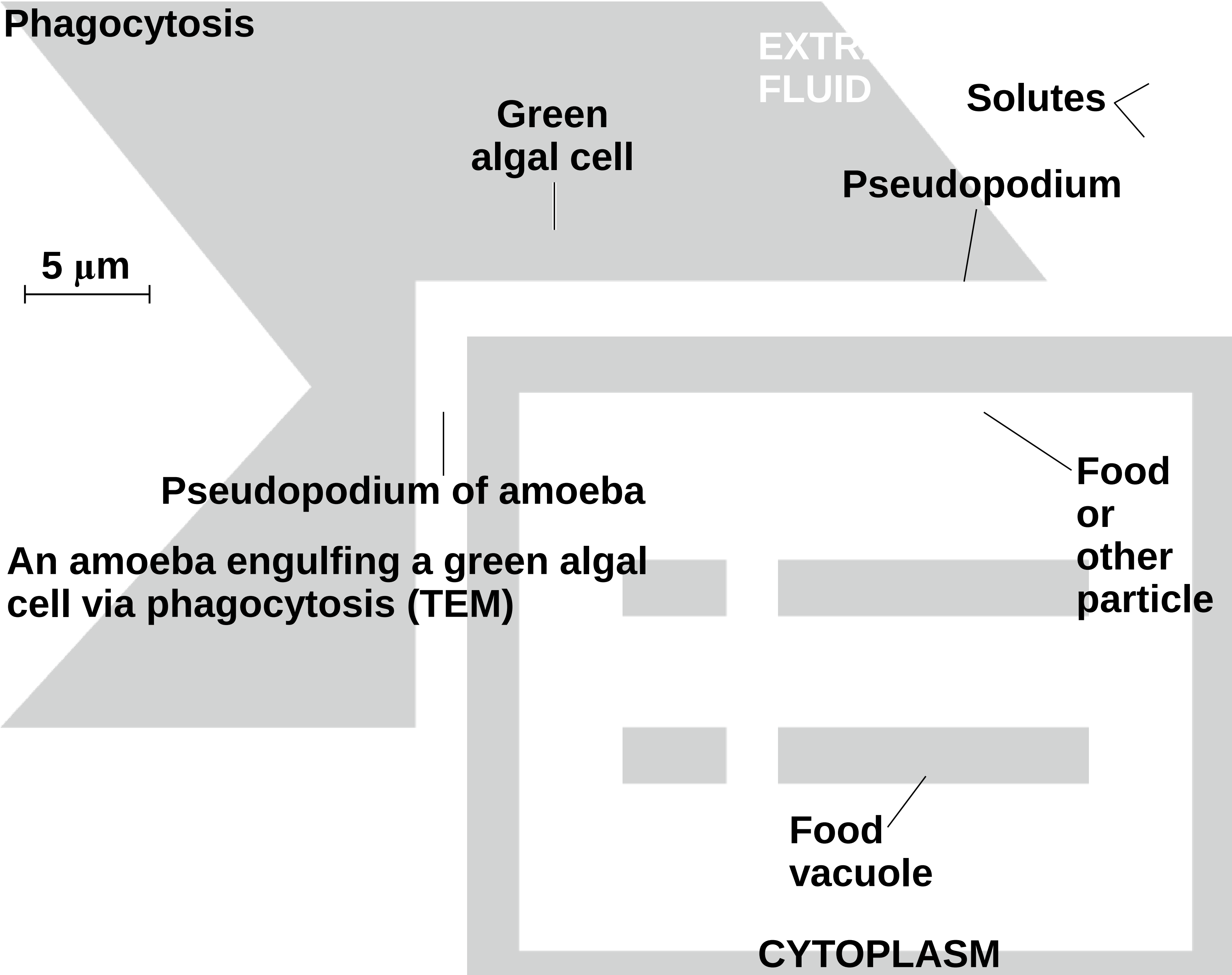
Figure 8.19


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

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

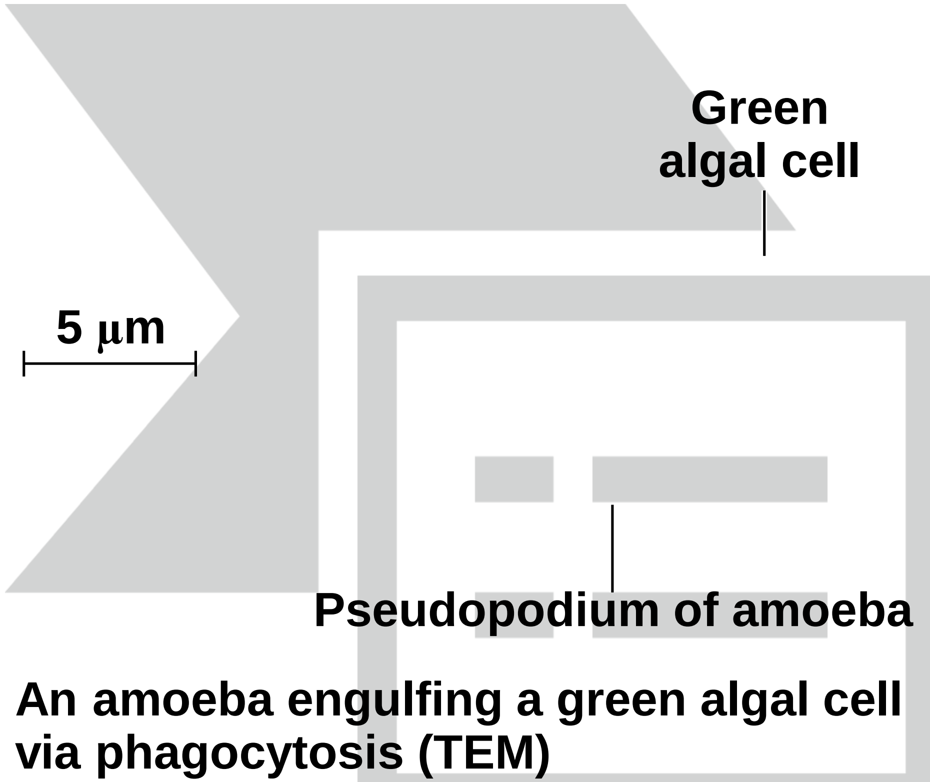
Figure 8.19a

Phagocytosis



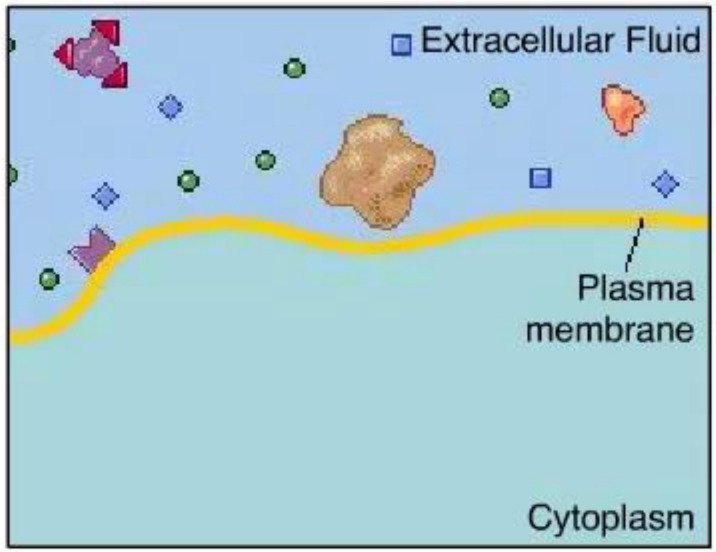
An amoeba engulfing a green algal cell via phagocytosis (TEM)

Figure 8.19aa

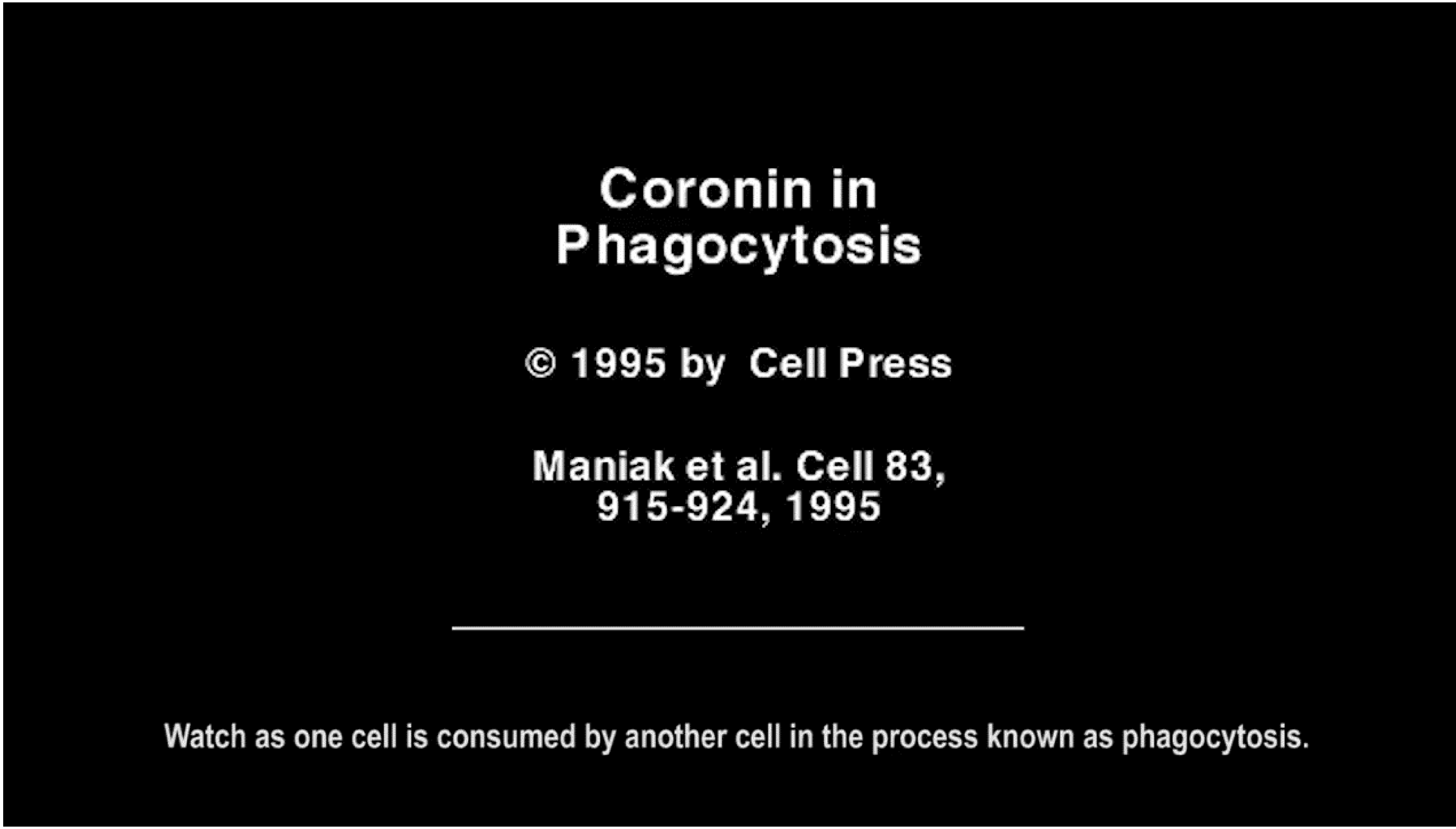


An amoeba engulfing a green algal cell via phagocytosis (TEM)

Animation: Phagocytosis



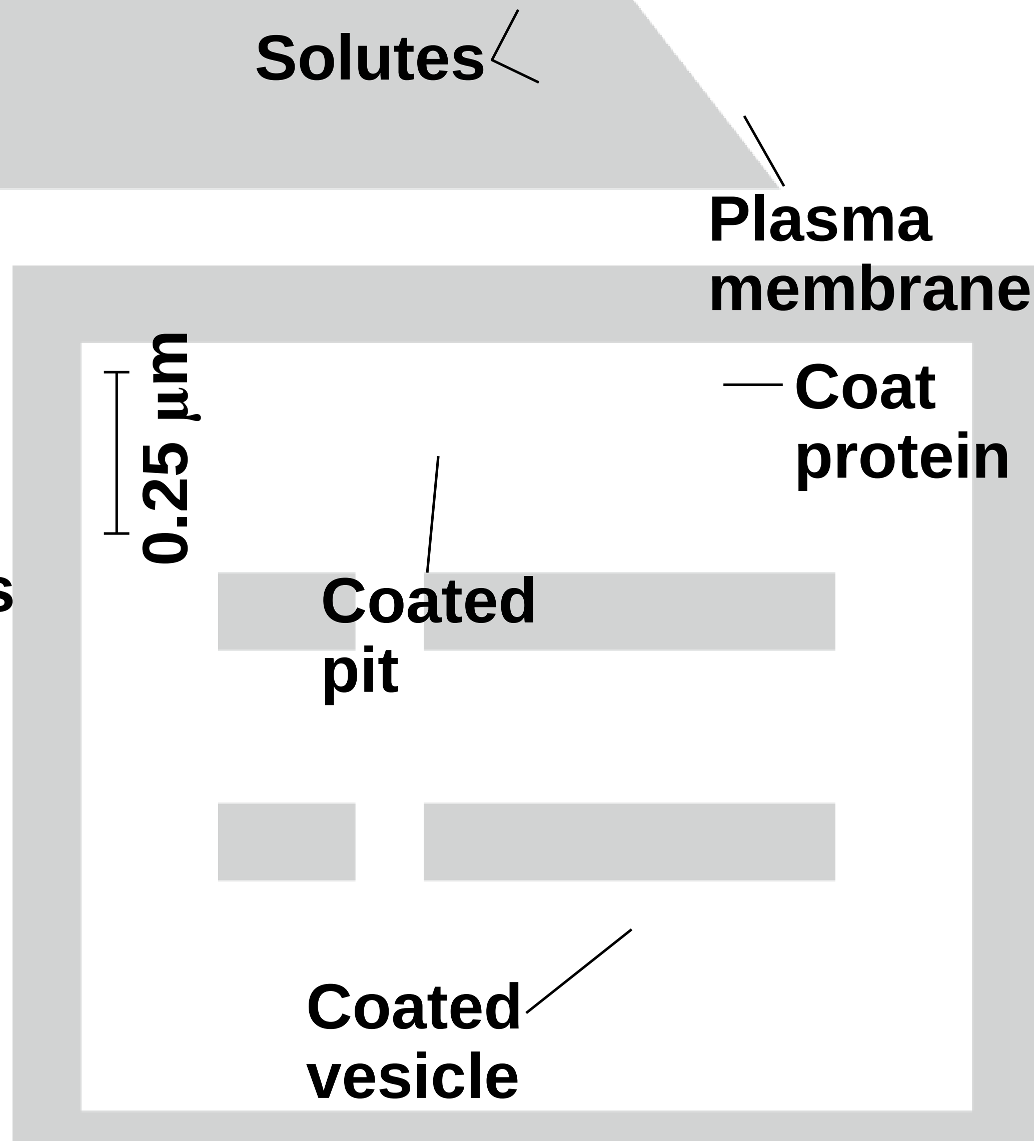
Video: Phagocytosis in Action



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

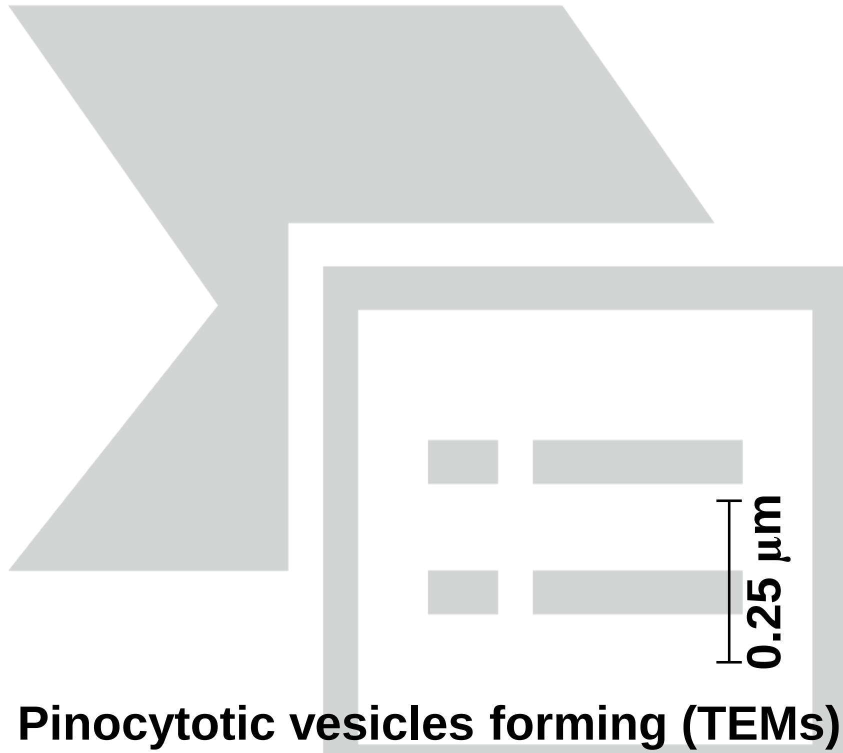
Figure 8.19b

Pinocytosis



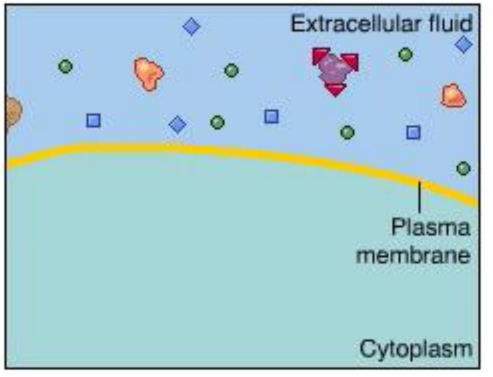
Pinocytotic vesicles forming (TEMs)

Figure 8.19ba



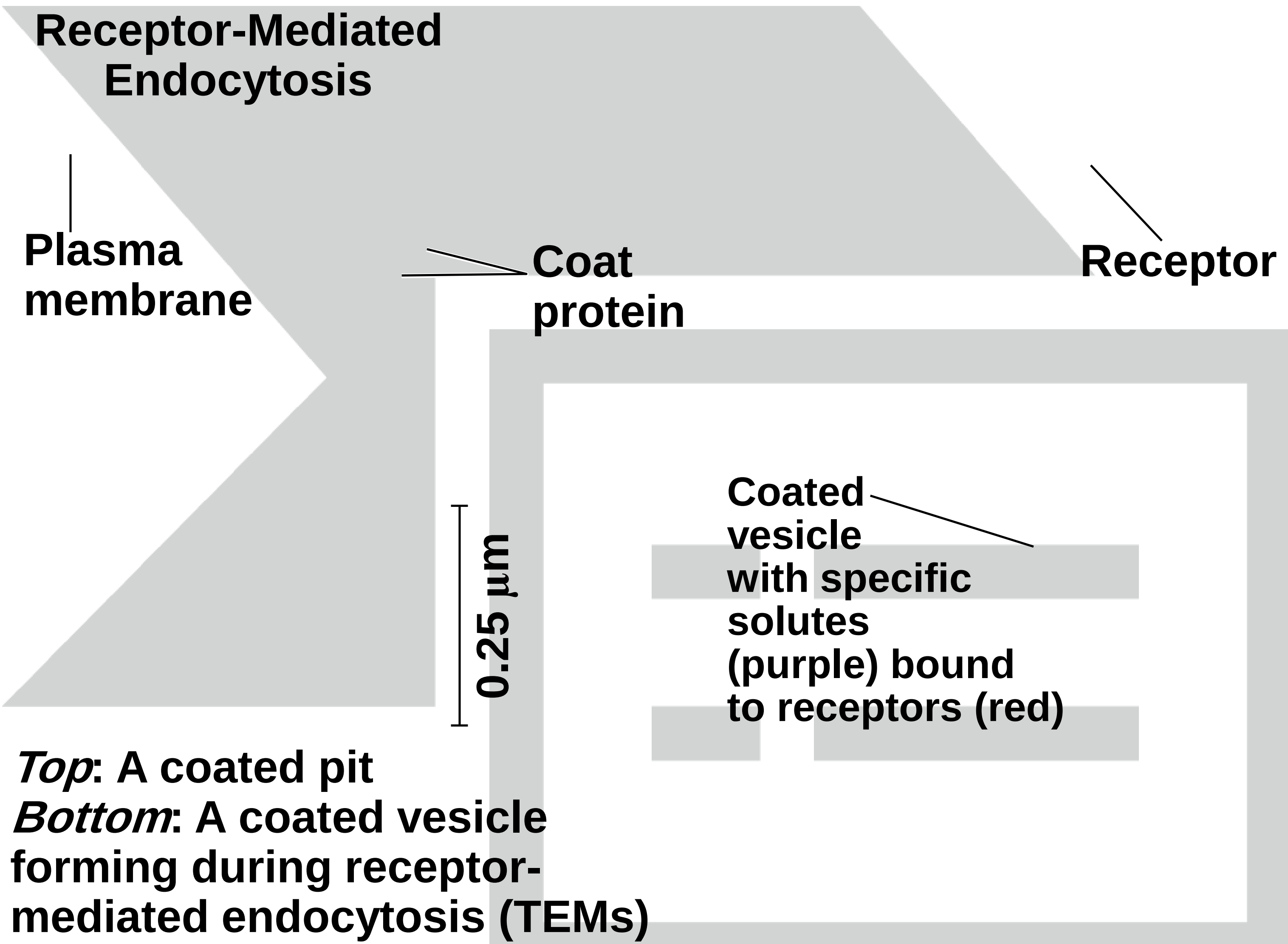
Pinocytotic vesicles forming (TEMs)

Animation: Pinocytosis



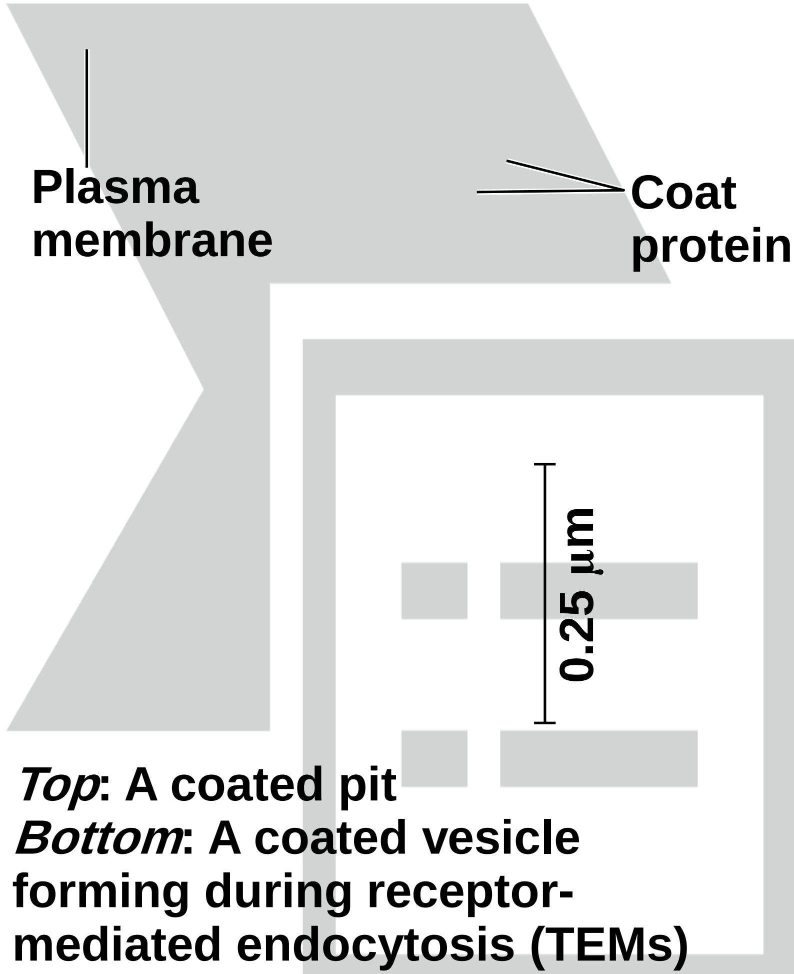
- In **receptor-mediated endocytosis**, binding of specific solutes to receptors triggers vesicle formation
- Receptor proteins, receptors, and other molecules from the extracellular fluid are transported in the vesicles
- Emptied receptors are recycled to the plasma membrane

Figure 8.19c



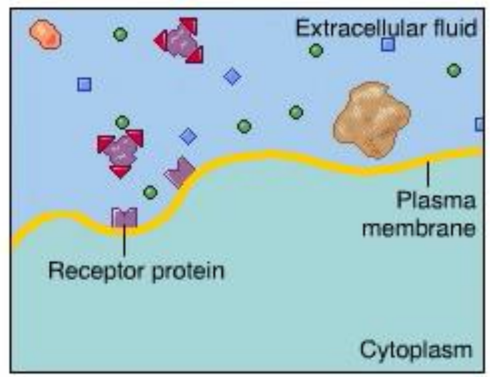
Top: A coated pit
Bottom: A coated vesicle forming during receptor-mediated endocytosis (TEMs)

Figure 8.19ca



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

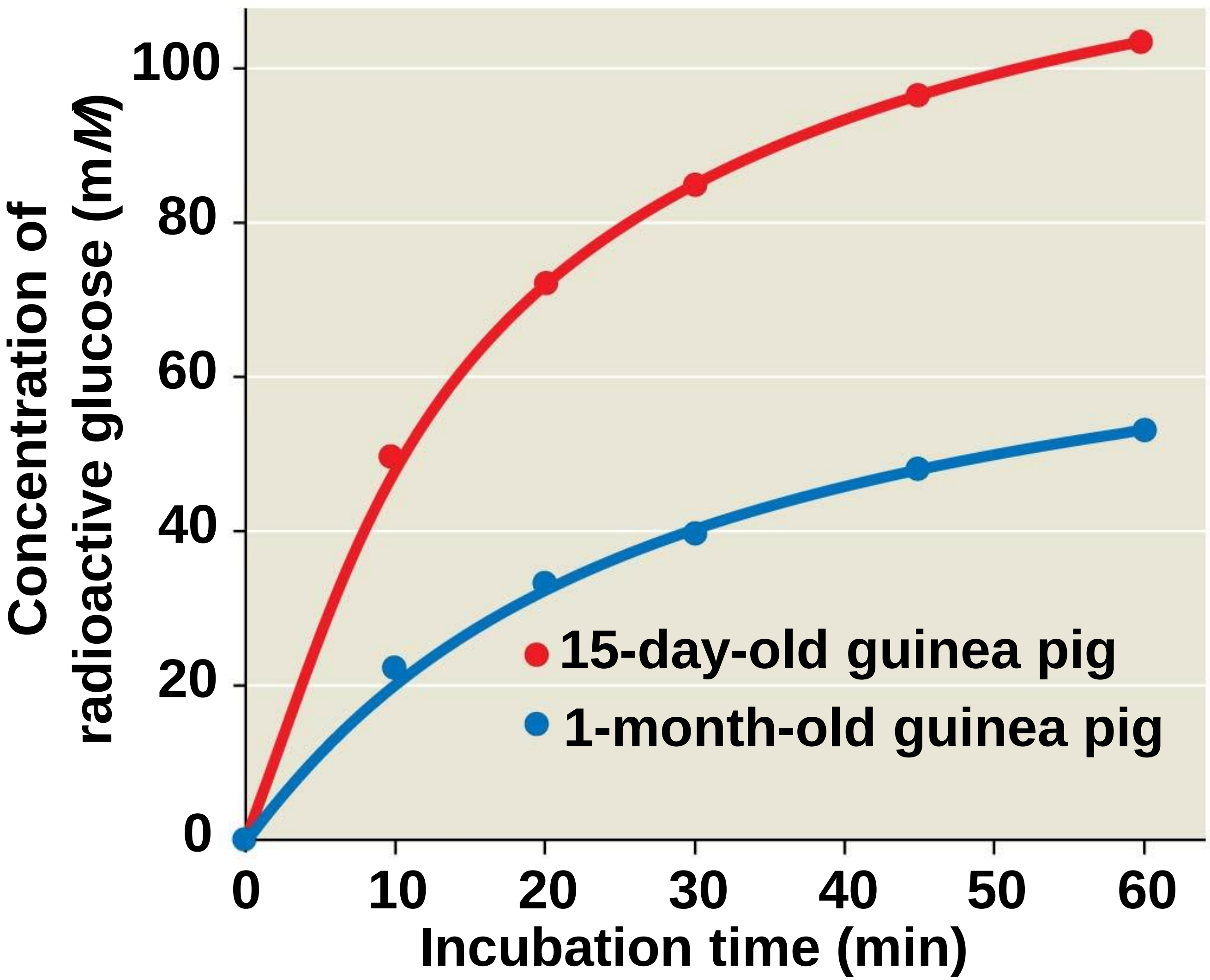
Animation: Receptor-Mediated Endocytosis



- Human cells use receptor-mediated endocytosis to take in cholesterol, which is carried in particles called low-density lipoproteins (LDLs)
- Individuals with the disease familial hypercholesterolemia have missing or defective LDL receptor proteins

Figure 8.UN02a

Glucose Uptake over Time in Guinea Pig Red Blood Cells



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 8.UN02b

Figure 8.UN03

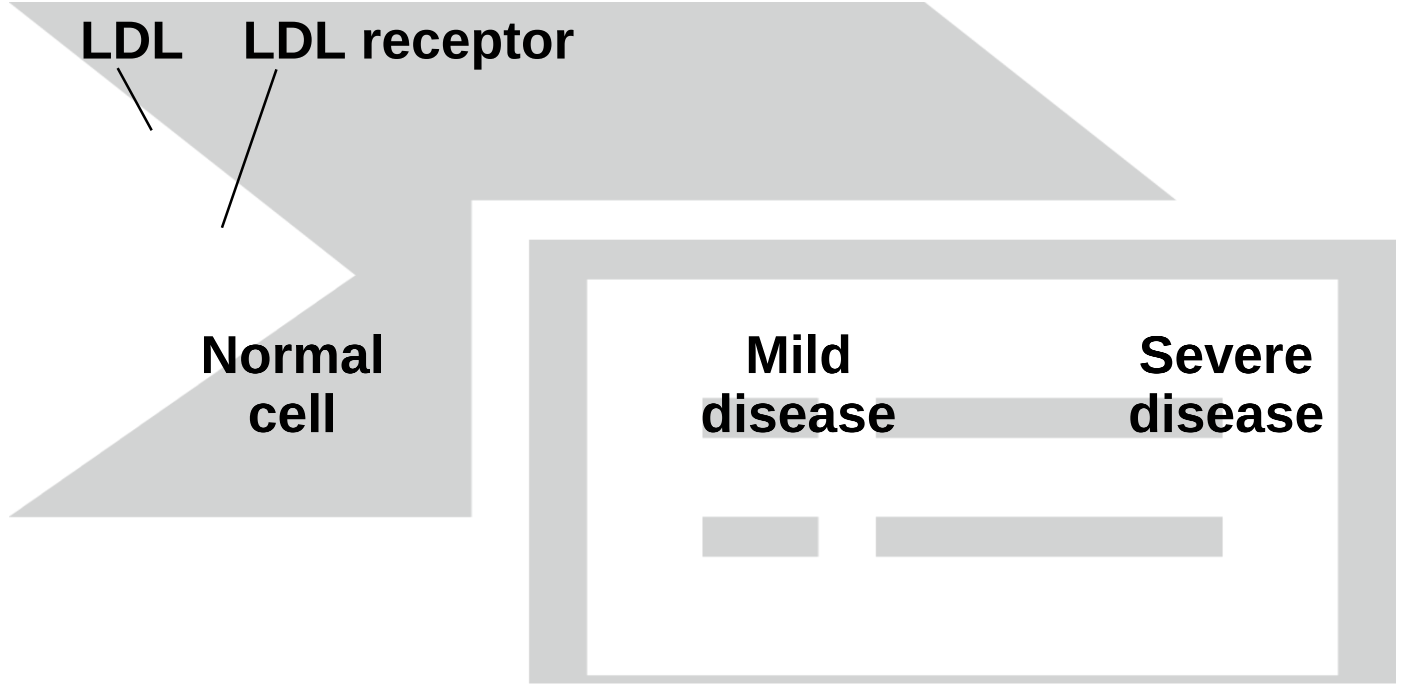


Figure 8.UN04

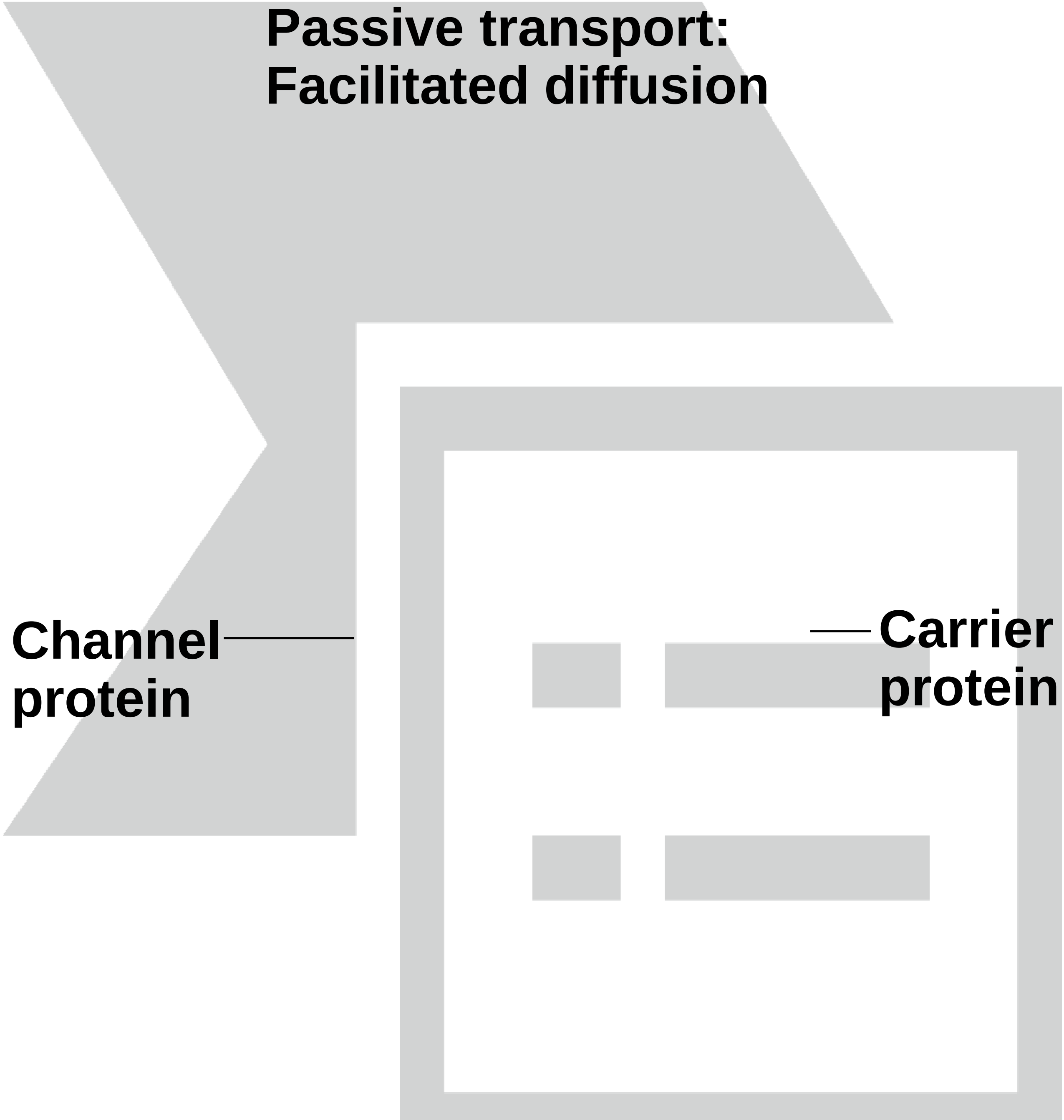


Figure 8.UN05

Figure 8.UN06

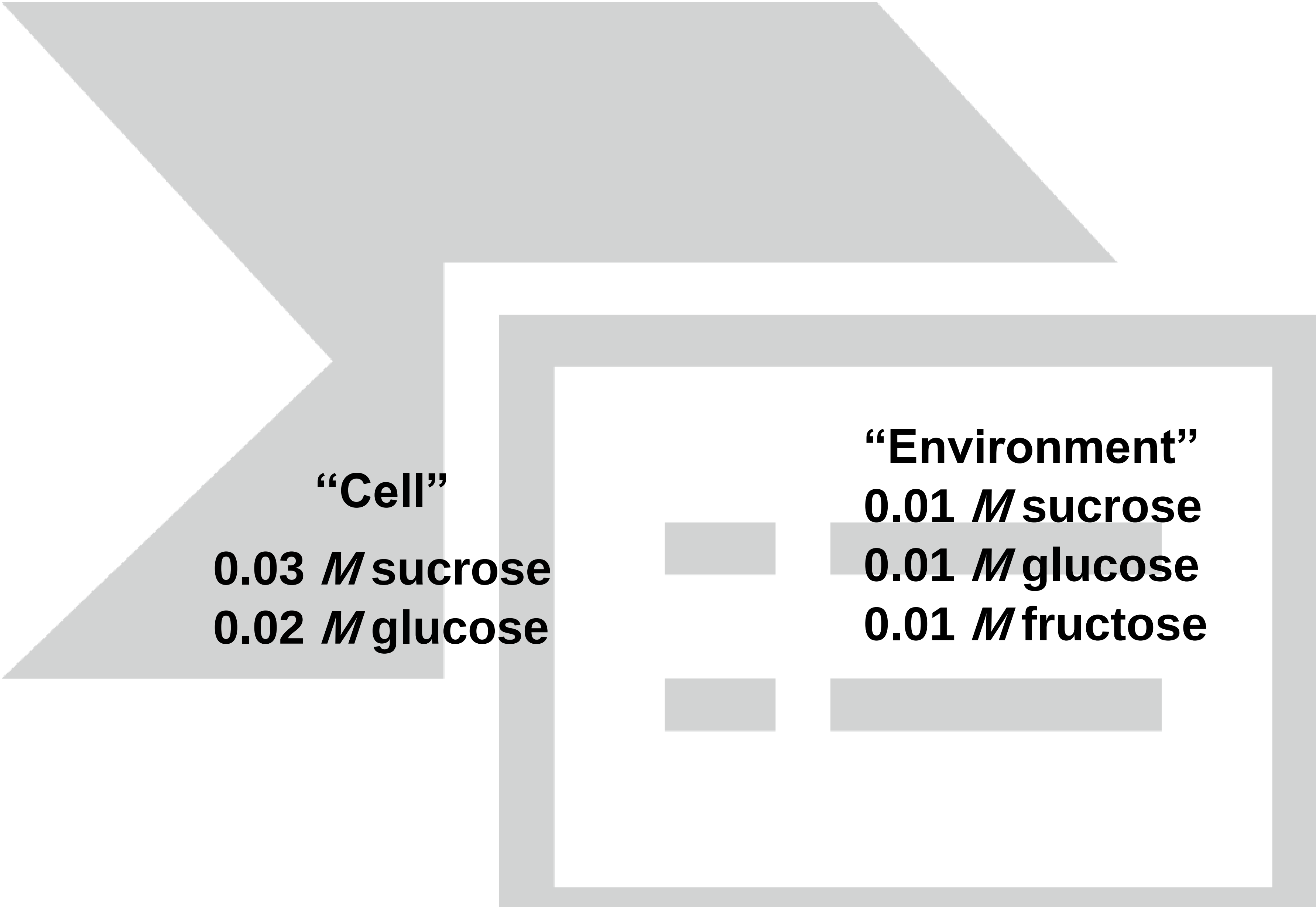


Figure 8.UN07