Membrane Structure and Function

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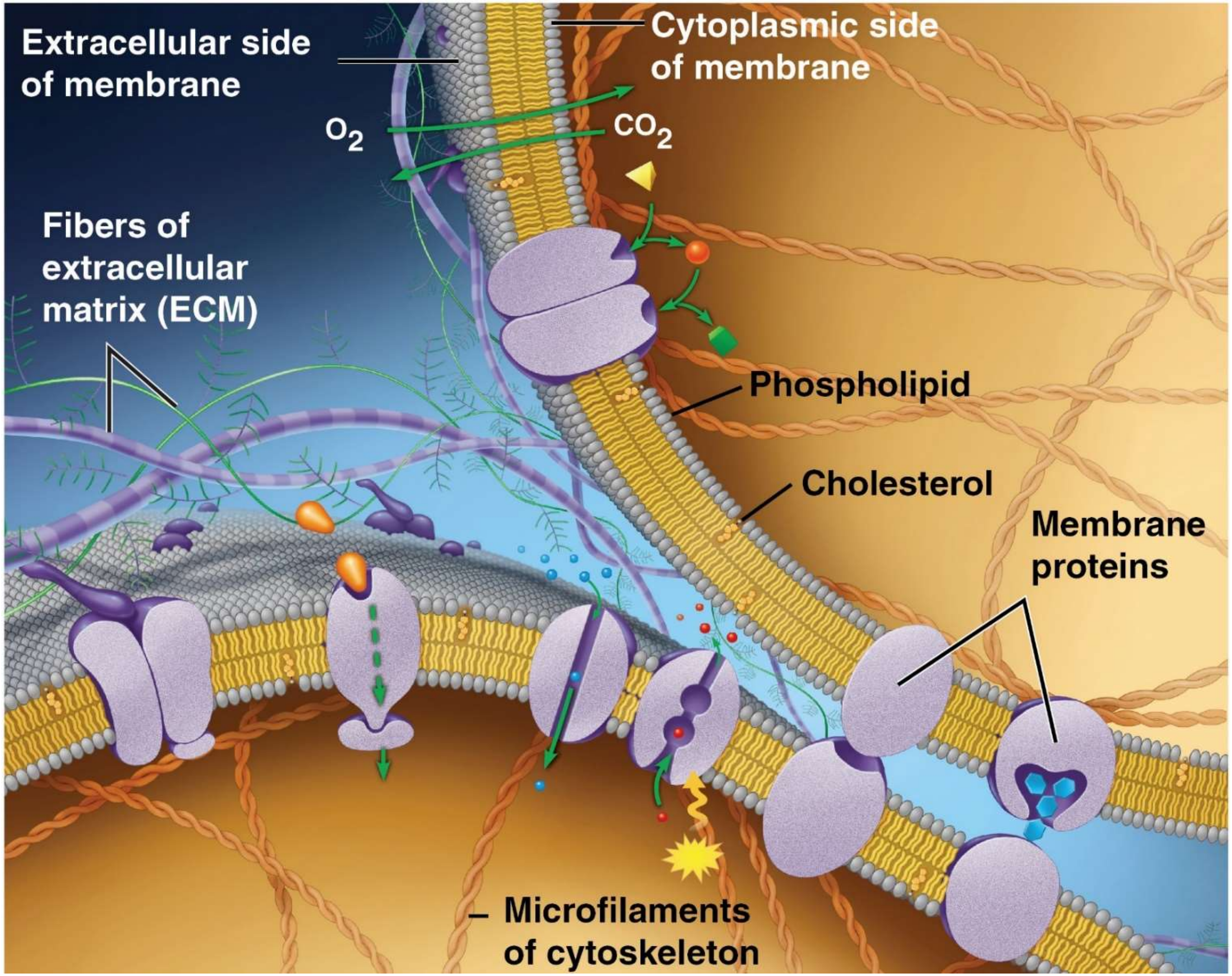
5.1 Visualizing The Concept: Membranes Are Fluid Mosaics of Lipids and Proteins with Many Functions

- Biologists use the **fluid mosaic model** to describe a membrane’s structure—diverse protein molecules suspended in a fluid phospholipid bilayer.
- The plasma membrane exhibits **selective permeability**.
- The proteins perform various functions.

Figure 5.1



Extracellular side
of membrane
Cytoplasmic side
of membrane
O_2
CO_2
Fibers of
extracellular
matrix (ECM)
Phospholipid
Cholesterol
Membrane
proteins
Microfilaments
of cytoskeleton

Figure 5.1_1

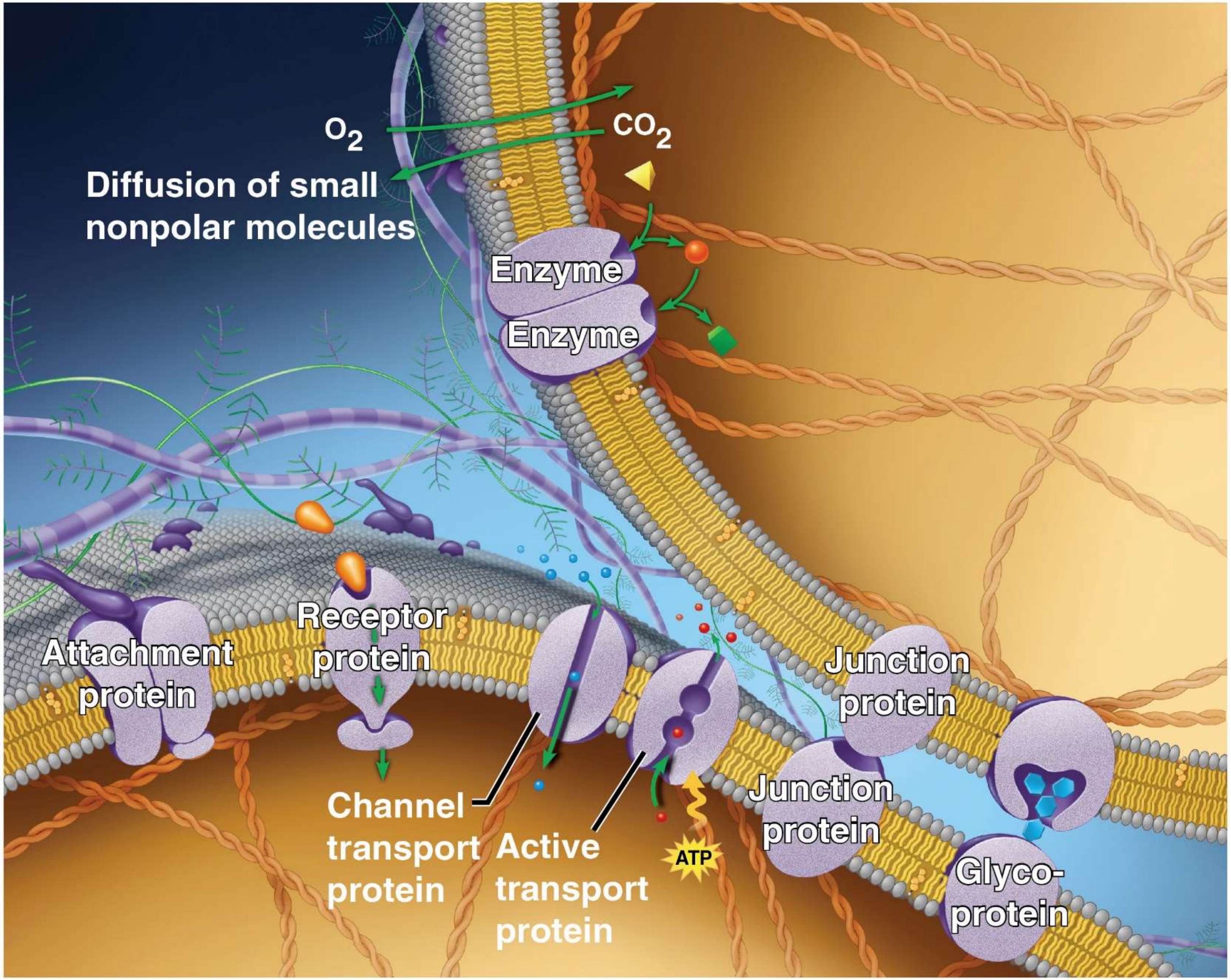


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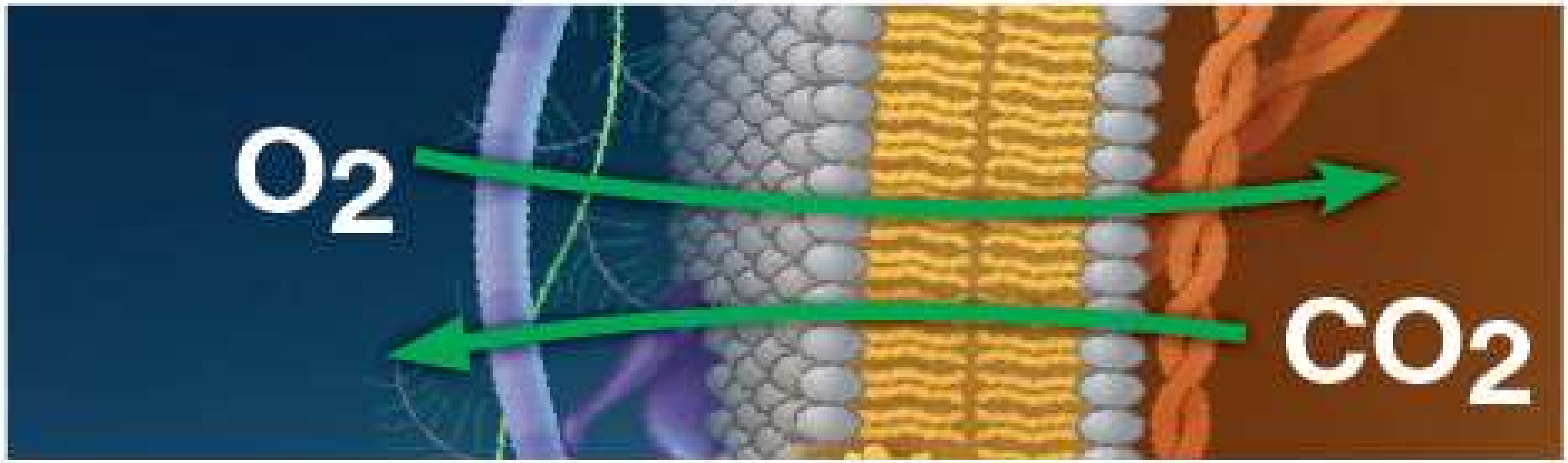
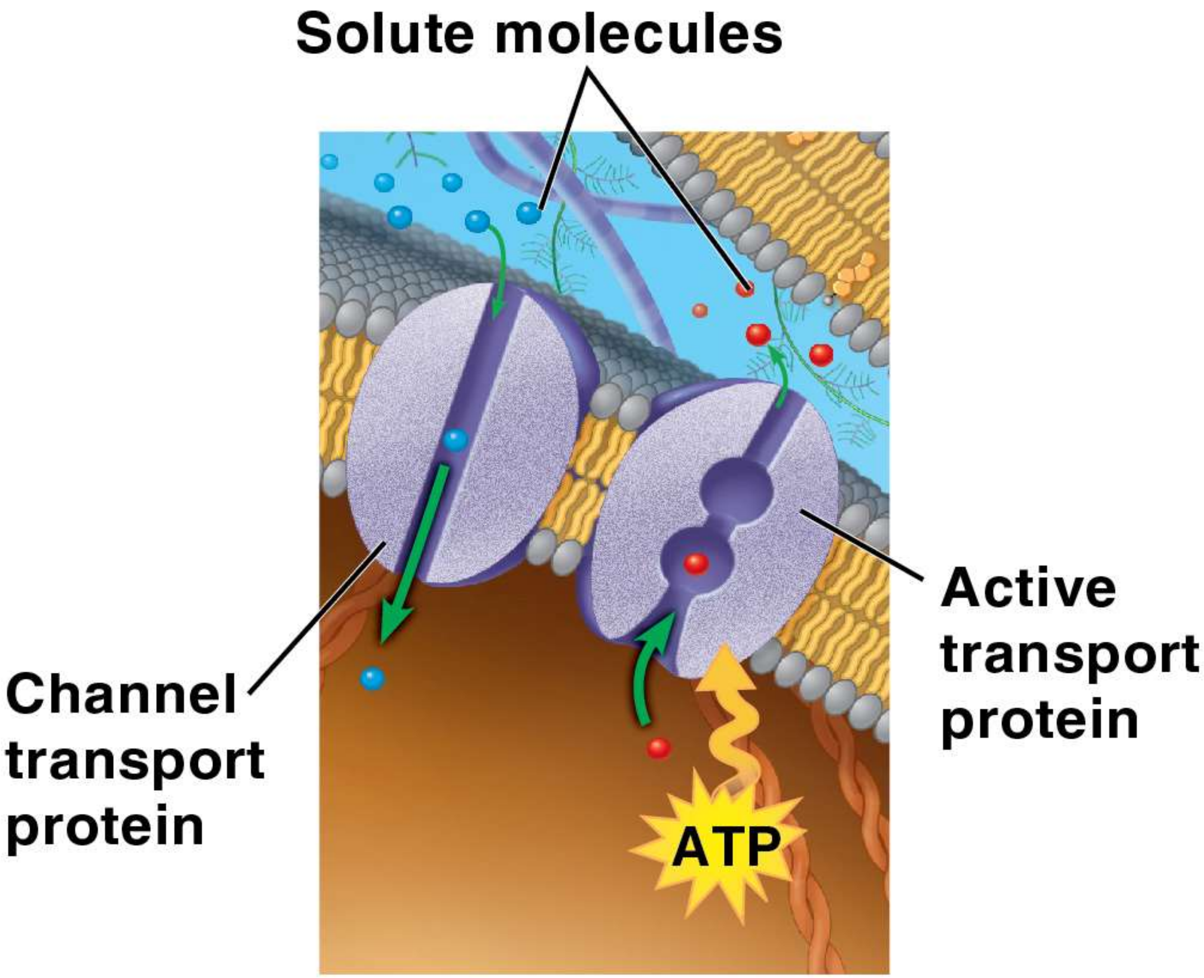
Figure 5.1_2



Diffusion of small nonpolar molecules

Figure 5.1_3



Transport proteins

- Allow specific ions or molecules to enter or exit the cell

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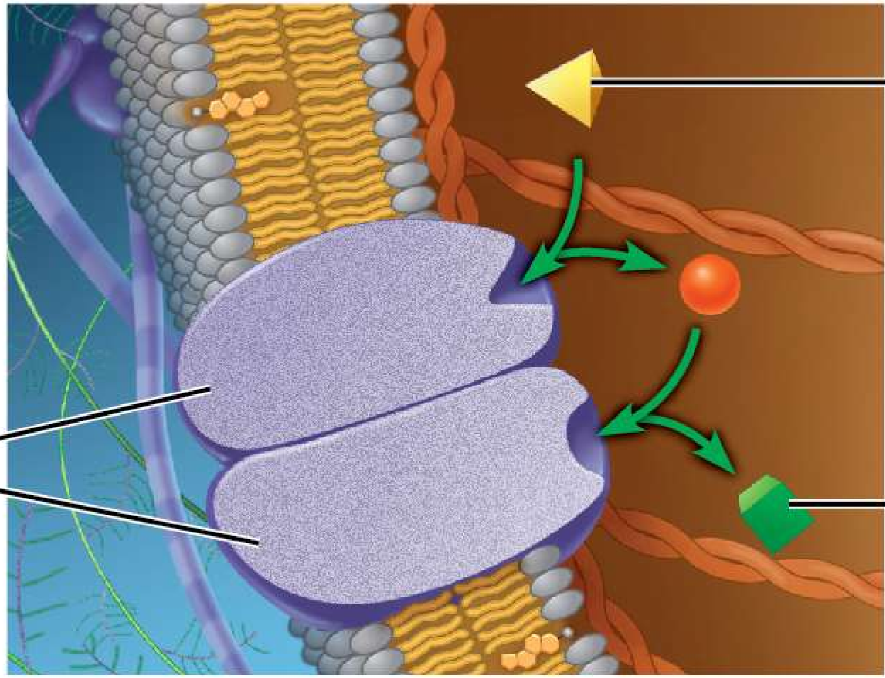
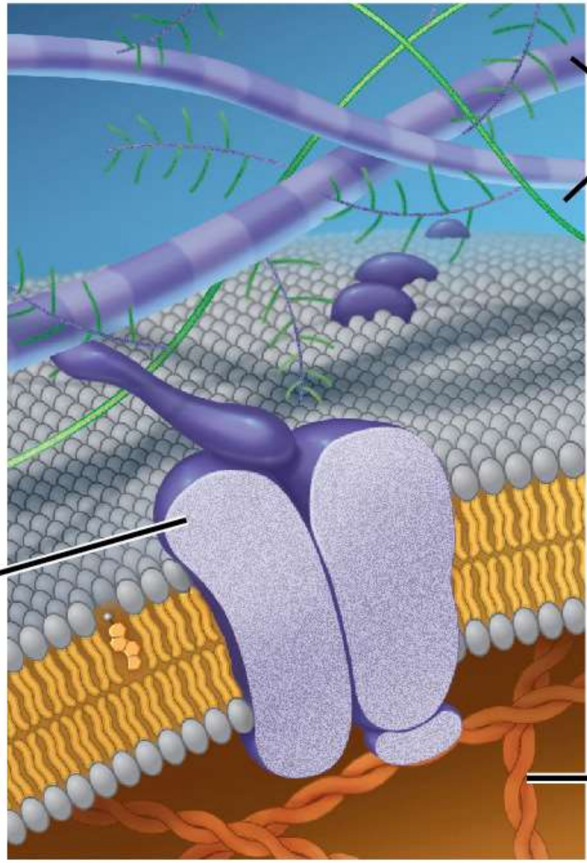
Figure 5.1_4



Enzymes

- Some membrane proteins are enzymes
- Enzymes may be grouped to carry out sequential reactions

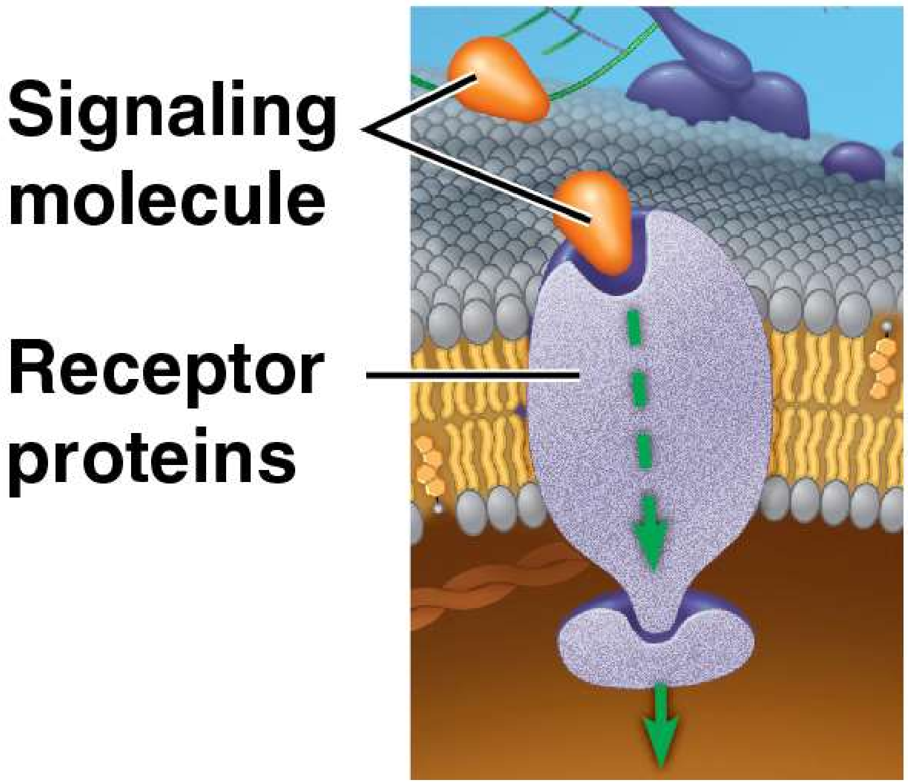
Figure 5.1_5



Attachment Proteins

- Attach to the extracellular matrix and cytoskeleton
- Help support the membrane
- Can coordinate external and internal changes

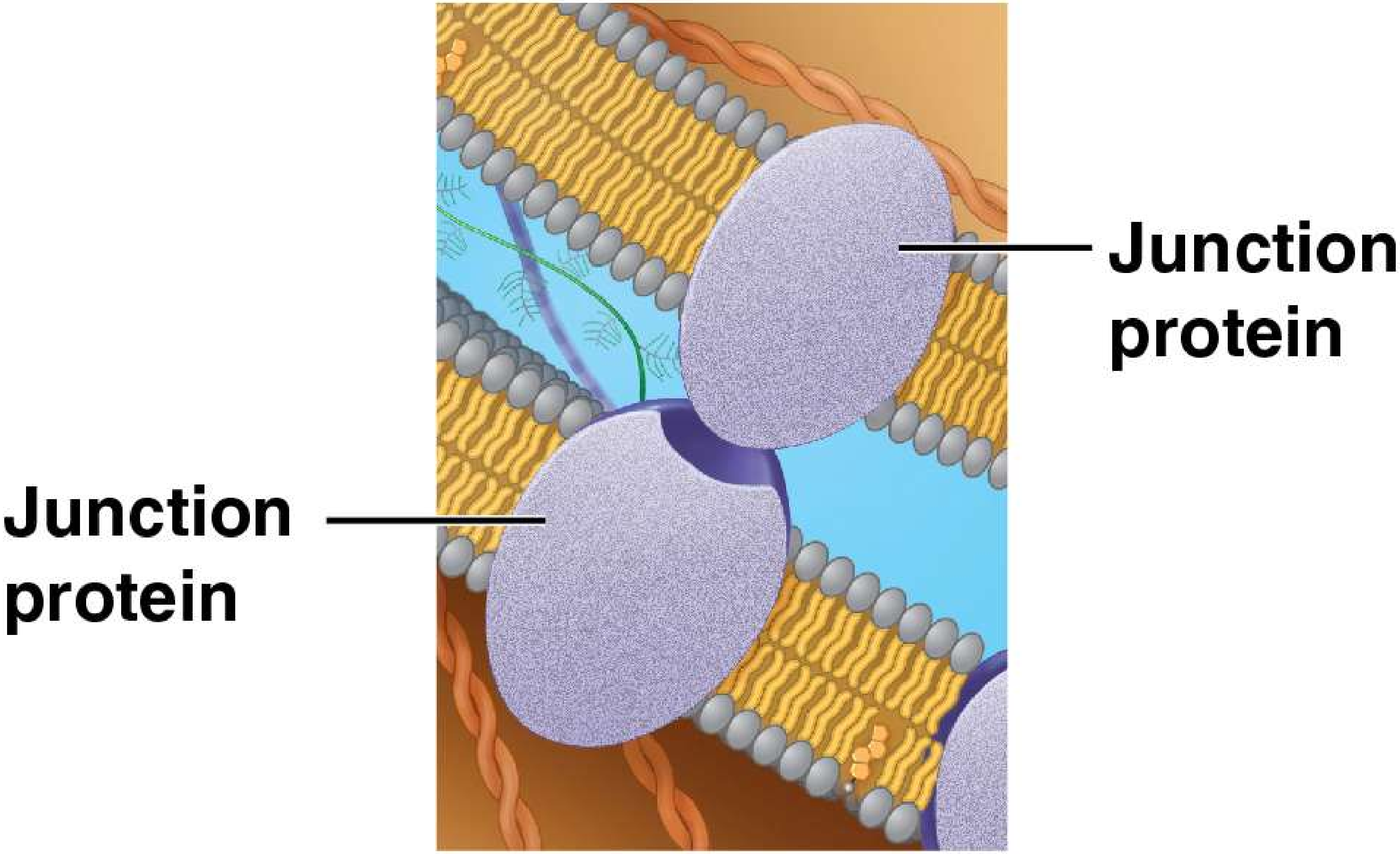
Figure 5.1_6



Receptor Proteins

- Signaling molecules bind to receptor proteins
- Receptor proteins relay the message by activating other molecules inside the cell

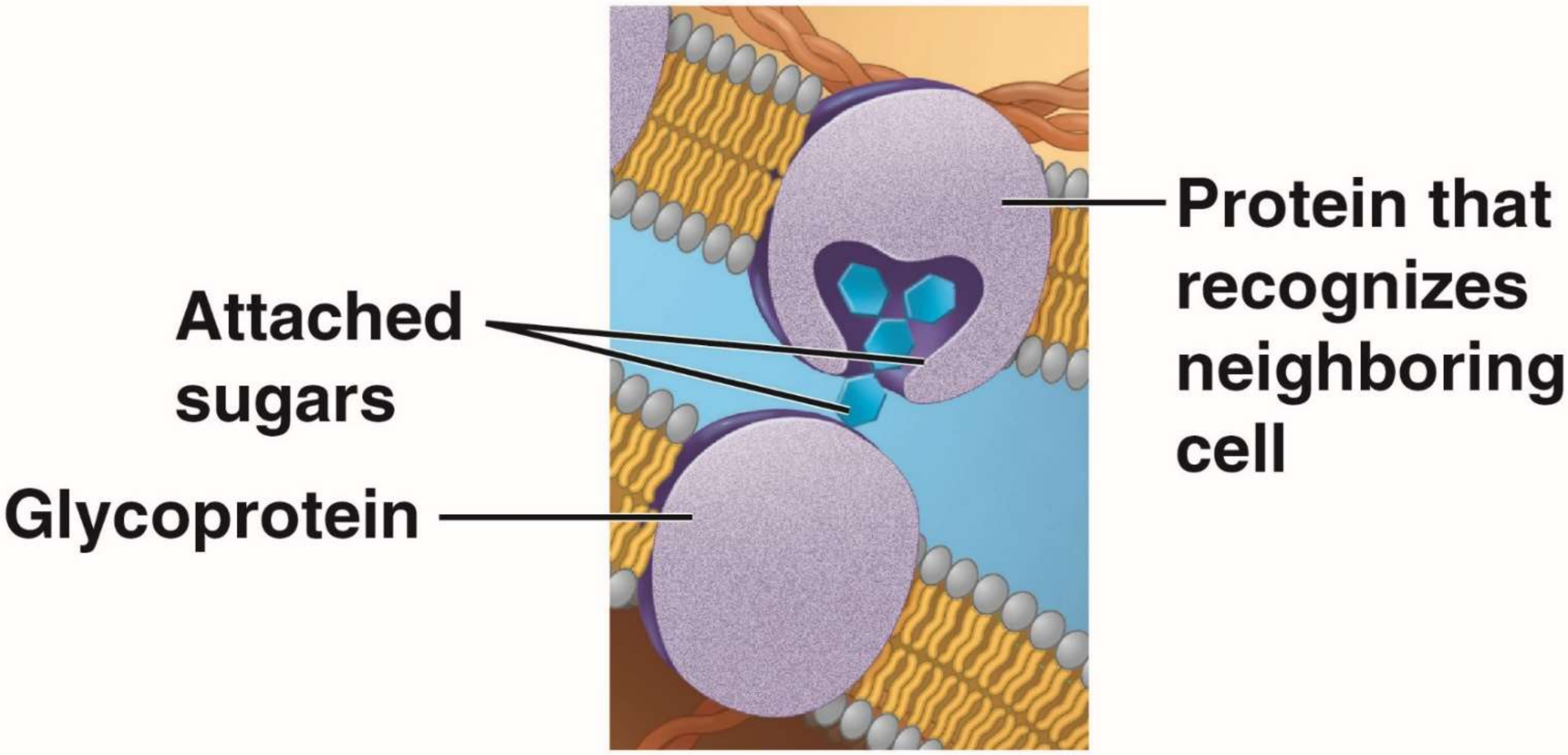
Figure 5.1_7



Junction Proteins

- Form intercelluluar junctions that attach adjacent cells

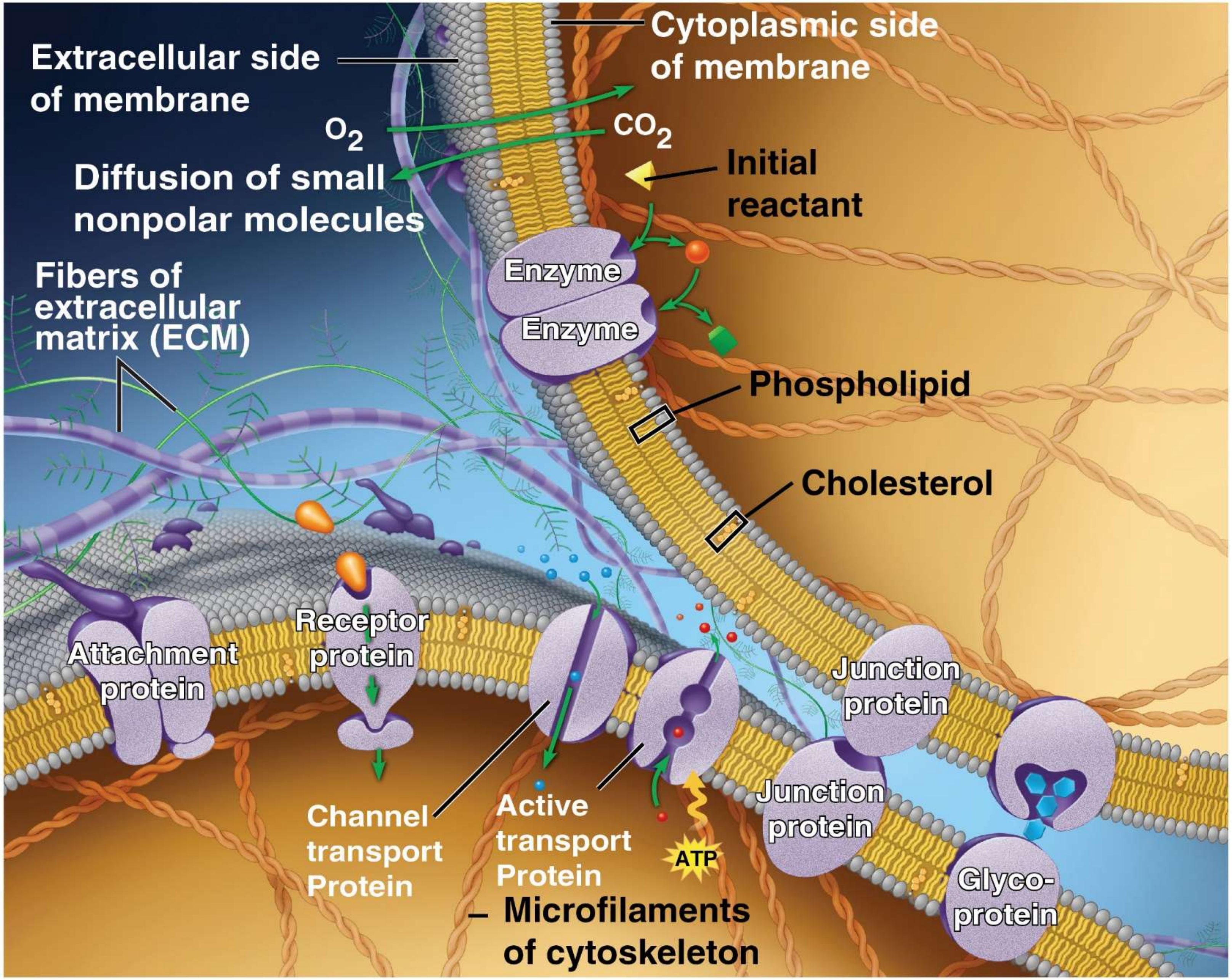
Figure 5.1_8



Glycoproteins

- Serve as ID tags
- May be recognized by membrane proteins of other cells

Figure 5.1_9



Extracellular side of membrane
Cytoplasmic side of membrane
O_2
CO_2
Diffusion of small nonpolar molecules
Initial reactant
Fibers of extracellular matrix (ECM)
Enzyme
Enzyme
Phospholipid
Cholesterol
Attachment protein
Receptor protein
Junction protein
Junction protein
Channel transport Protein
Active transport Protein
ATP
Glyco-protein
Microfilaments of cytoskeleton

5.2 Evolution Connection: The Spontaneous Formation of Membranes Was a Critical Step in the Origin of Life

- Phospholipids spontaneously self-assemble into simple membranes.
- The formation of membrane-enclosed collections of molecules was a critical step in the evolution of the first cells.

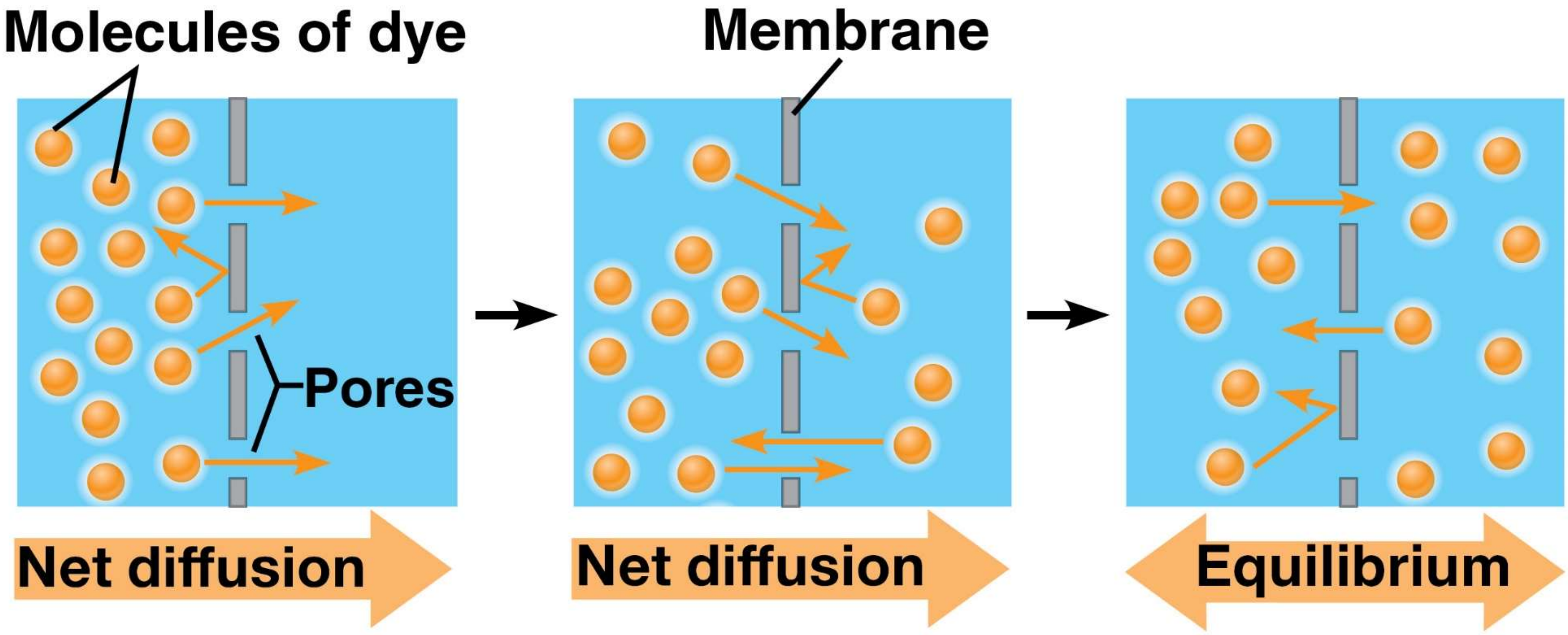
Checkpoint question In the origin of a cell, why would the formation of a simple lipid bilayer membrane not be sufficient? What else would have to be part of such a membrane? The membrane would need embedded proteins that could regulate the movement of substances into and out of the cell.

5.3 Passive Transport Is Diffusion Across a Membrane with No Energy Investment

- **Diffusion** is the tendency of particles to spread out evenly in an available space.
- Diffusion across a cell membrane does not require energy, so it is called passive **transport.**

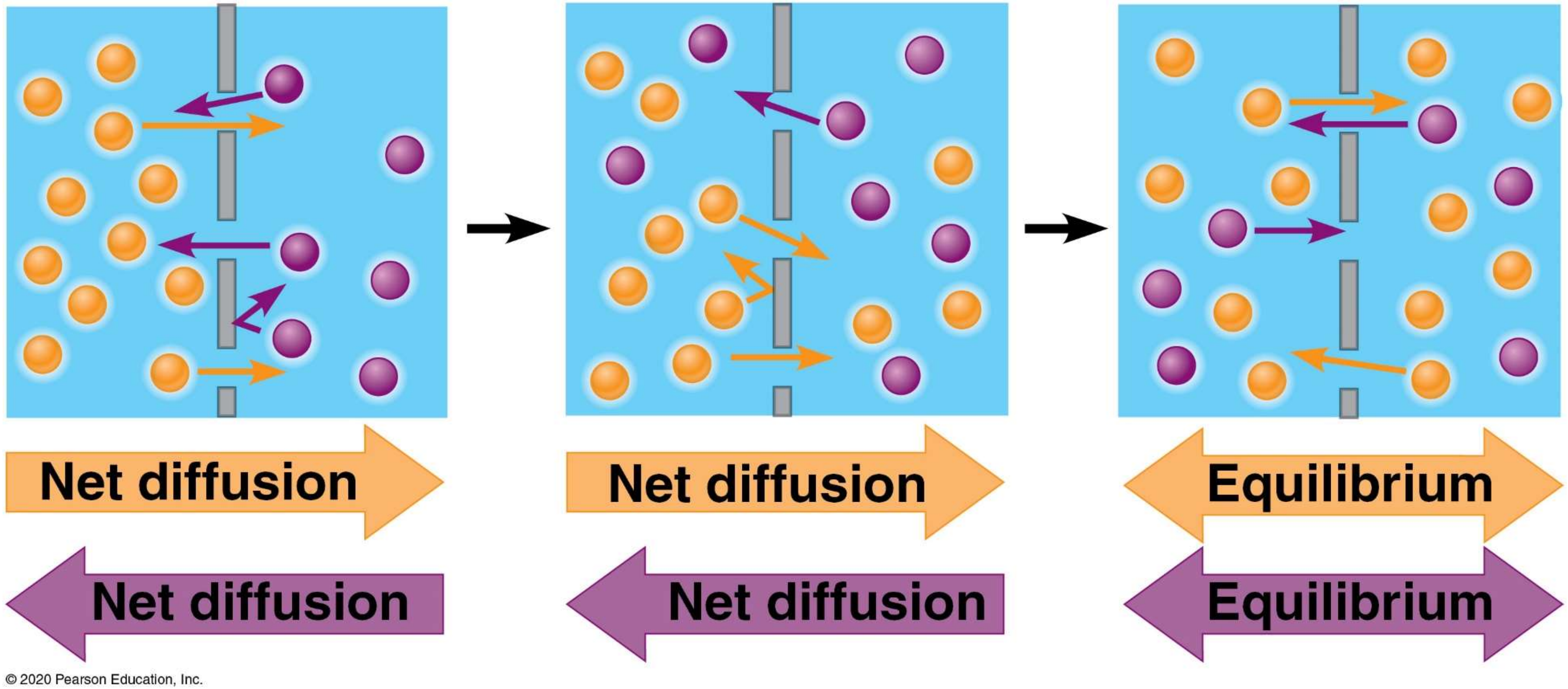
Checkpoint question Why is diffusion across a membrane called passive transport?

Figure 5.3a



Molecules of dye
Membrane
Pores
Net diffusion
Net diffusion
Equilibrium

Figure 5.3b


Net diffusion
Net diffusion
Net diffusion
Net diffusion
Equilibrium
Equilibrium
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5.4 Osmosis Is the Diffusion of Water Across a Membrane (1 of 2)

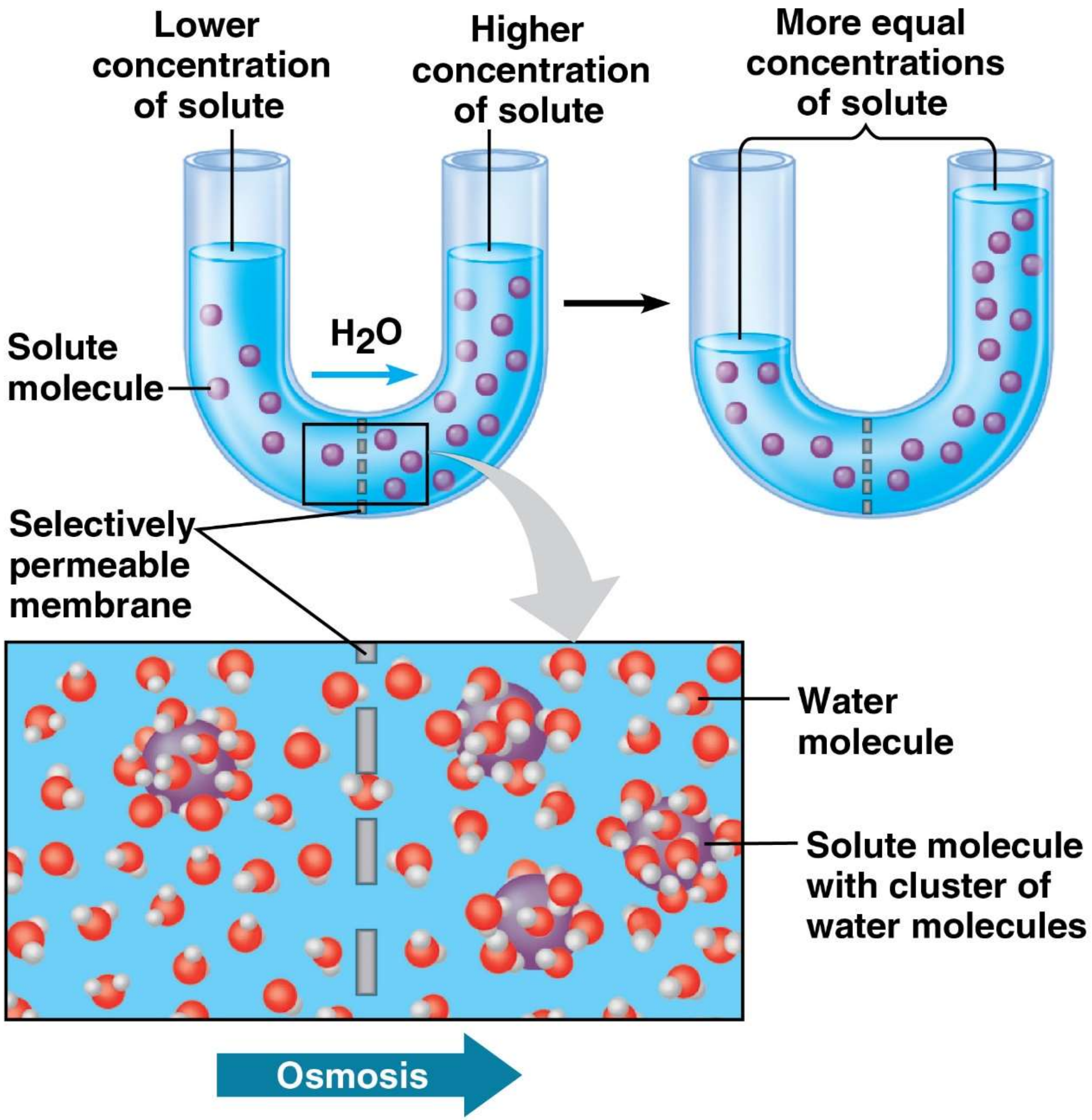
- The diffusion of water across a selectively permeable membrane is called **osmosis.**
- If a membrane, permeable to water but not to a solute, separates two solutions with different concentrations of solute, water will cross the membrane, moving down its own concentration gradient, until the solute concentration on both sides is equal.

5.4 Osmosis Is the Diffusion of Water Across a Membrane (2 of 2)

Checkpoint question Predict the net water movement between two solutions—a 0.5% sucrose solution and a 2% sucrose solution—separated by a membrane not permeable to sucrose.

Water will move from the 0.5% sucrose solution (lower solute concentration) to the 2% sucrose solution (higher solute concentration).

Figure 5.4



Lower concentration of solute
Higher concentration of solute
More equal concentrations of solute
Solute molecule
H_2O
Selectively permeable membrane
Water molecule
Solute molecule with cluster of water molecules
Osmosis

5.5 Water Balance Between Cells and Their Surroundings Is Crucial to Organisms (1 of 2)

- **Tonicity** is a term that describes the ability of a surrounding solution to cause a cell to gain or lose water.
- Cells shrink in a **hypertonic** solution.
- Cells swell in a **hypotonic** solution.
- In **isotonic** solutions, animal cells are normal, but plant cells are flaccid.

5.5 Water Balance Between Cells and Their Surroundings Is Crucial to Organisms (2 of 2)

Checkpoint question Explain the function of the contractile vacuoles in the freshwater *Paramecium* shown in Figure 4.11A in terms of what you have just learned about water balance in cells.

The pond water in which *Paramecium* lives is hypotonic to the cell. The contractile vacuoles expel the water that constantly enters the cell by osmosis.

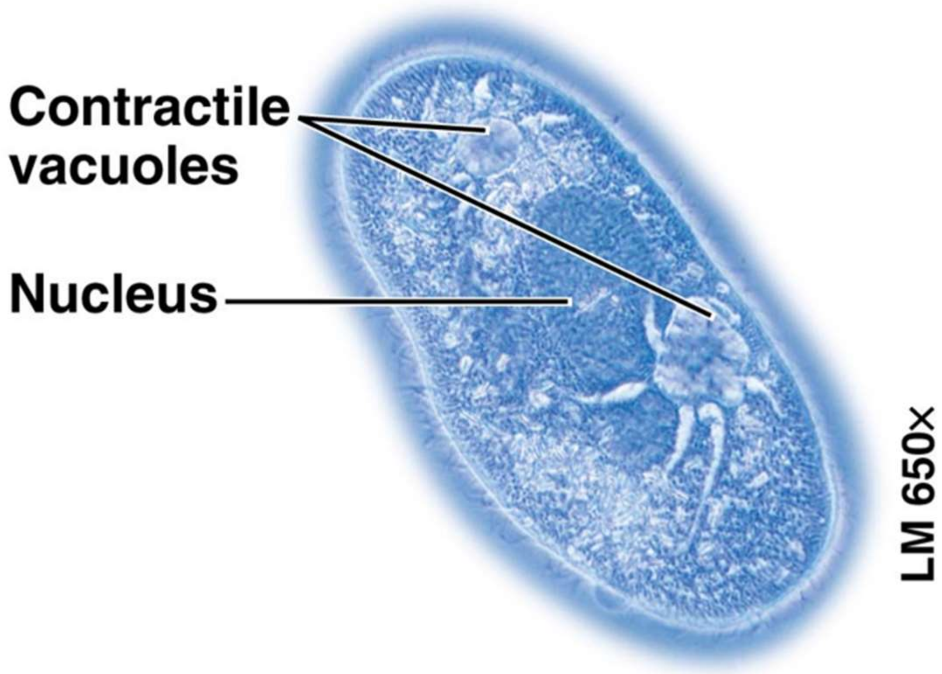
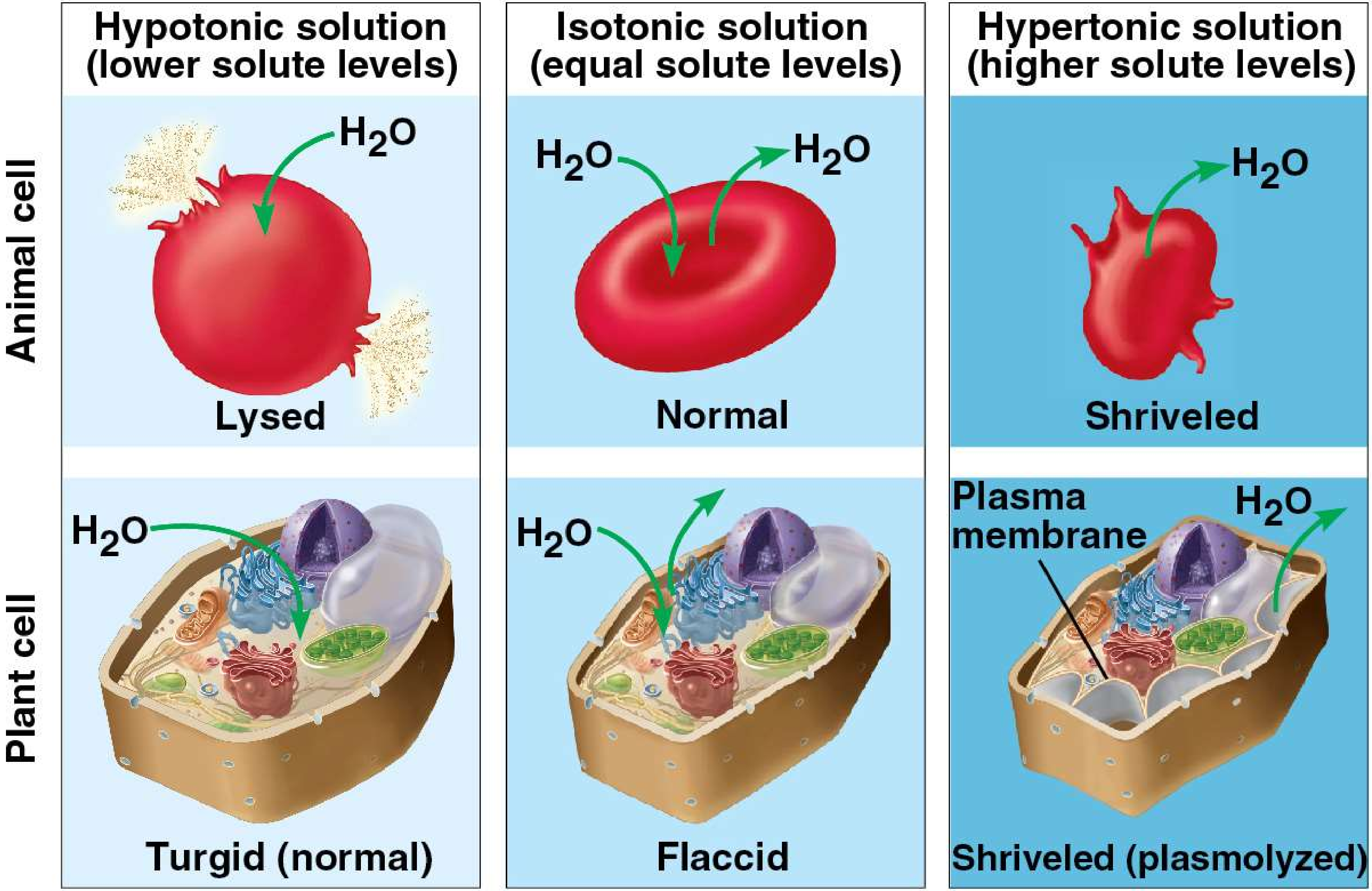


Figure 5.5



Hypotonic solution
(lower solute levels)
Isotonic solution
(equal solute levels)
Hypertonic solution
(higher solute levels)
Animal cell
H_2O
Lysed
H_2O
H_2O
Normal
H_2O
Shriveled
Plant cell
H_2O
Turgid (normal)
H_2O
Flaccid
Plasma
membrane
H_2O
Shriveled (plasmolyzed)

5.6 Transport Proteins Can Facilitate Diffusion Across Membranes (1 of 2)

- Hydrophobic substances easily diffuse across a cell membrane.
- However, polar or charged substances do not easily cross cell membranes.
- Instead, polar or charged substances move across membranes with the help of specific transport proteins, called **facilitated diffusion**, which
  - does not require energy and
  - relies on the concentration gradient.

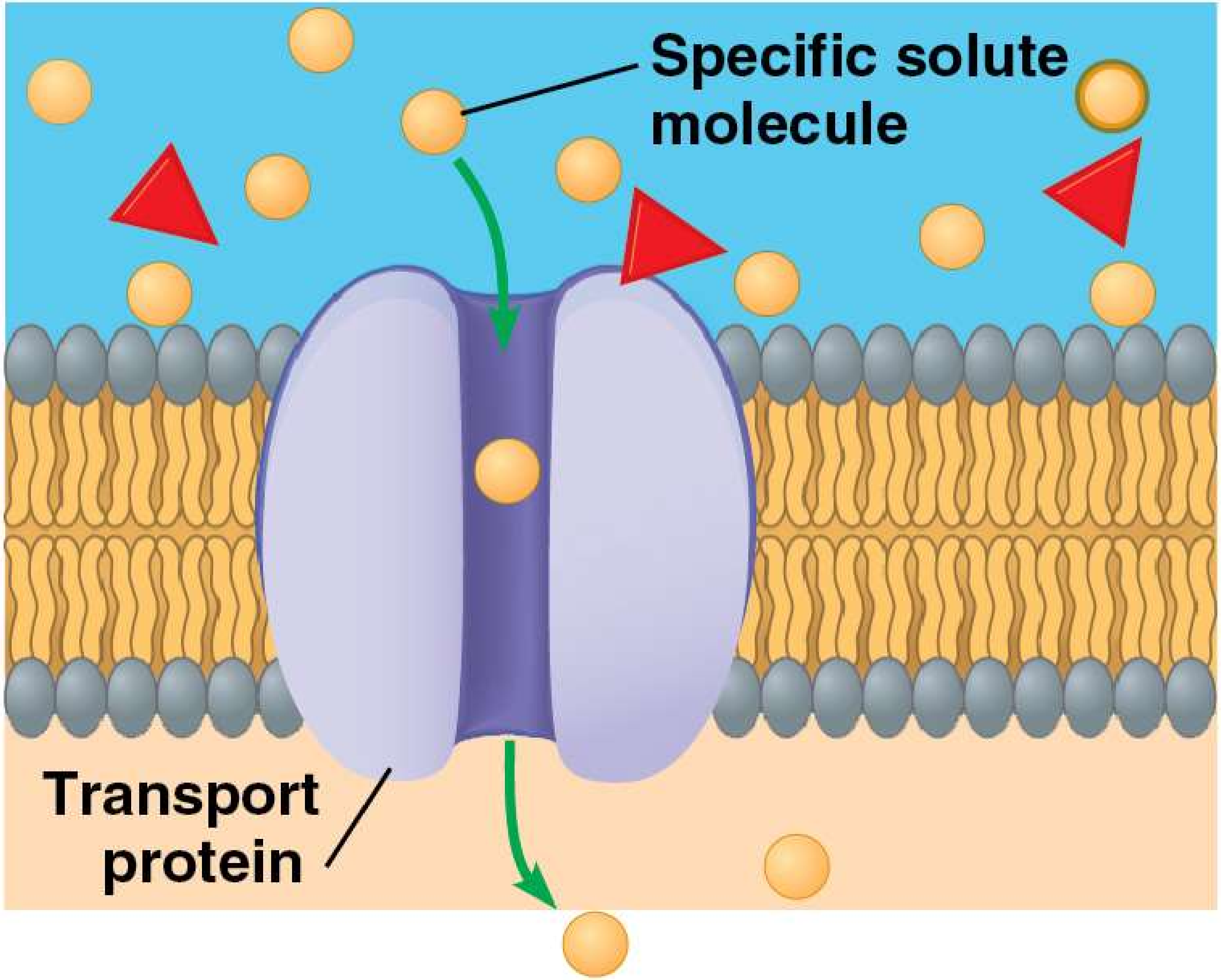
5.6 Transport Proteins Can Facilitate Diffusion Across Membranes (2 of 2)

- Transport proteins help specific substances diffuse across the membrane down their concentration gradients and thus requires no input of energy.
- The very rapid diffusion of water into and out of certain cells is made possible by a protein channel called an aquaporin.

Checkpoint question How do transport proteins contribute to a membrane's selective permeability?

Because they are specific for the solutes they transport, the numbers and kinds of transport proteins affect a membrane's permeability to various solutes.

Figure 5.6



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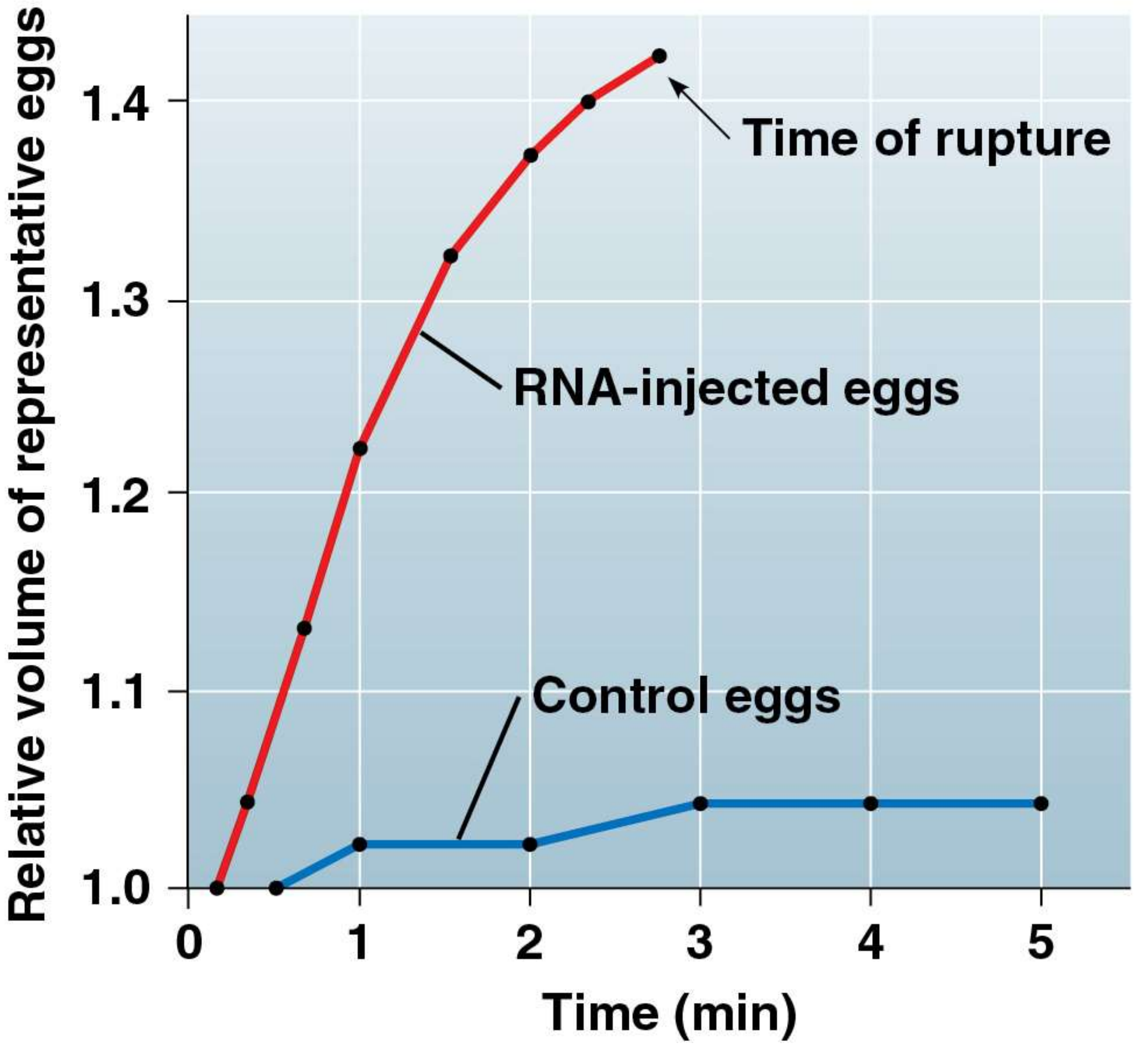
5.7 Scientific Thinking: Research on Another Membrane Protein Led to the Discovery of Aquaporins

- Dr. Peter Agre received the 2003 Nobel Prize in Chemistry for his discovery of aquaporins.
- His research on the Rh protein used in blood typing led to this discovery.

Checkpoint question Why did the researchers use frog eggs to test the function of this unknown protein? Why did they also monitor the behavior of control eggs in the hypotonic solution?

Frog eggs are quite impermeable to water. The control eggs confirmed this trait and provided a comparison to the bursting of the eggs that were making aquaporins.

Figure 5.7



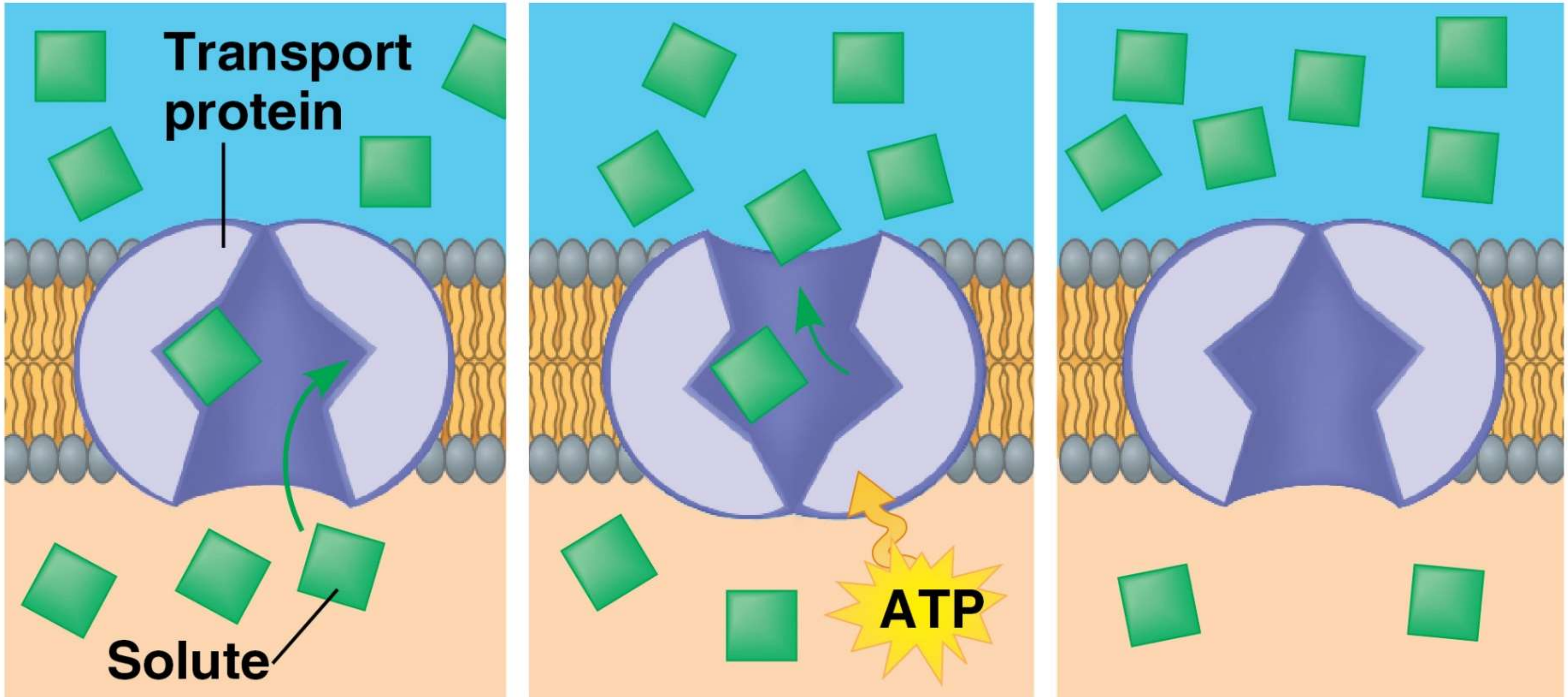
Source: Adaptation of Figure 2A from “Appearance of water channels in *Xenopus* oocytes expressing red cell C H I P28 protein” by Gregory Preston et al., from *Science*, April 1992, Volume 256(5055). Copyright © 1992 by A A A S. Reprinted with permission.

5.8 Cells Expend Energy in the Active Transport of a Solute

- In **active transport**, a cell must expend energy to move a solute *against* its concentration gradient.
- The energy molecule ATP supplies the energy for most active transport.
- The following figures show the four main stages of active transport.

Checkpoint question Cells actively transport Ca^{2+} out of the cell. Is calcium more concentrated inside or outside of the cell? Explain.

Figure 5.8_3



1 Solute binds to transport protein.

2 ATP provides energy for change in protein shape.

3 Protein returns to original shape; more solute can bind.

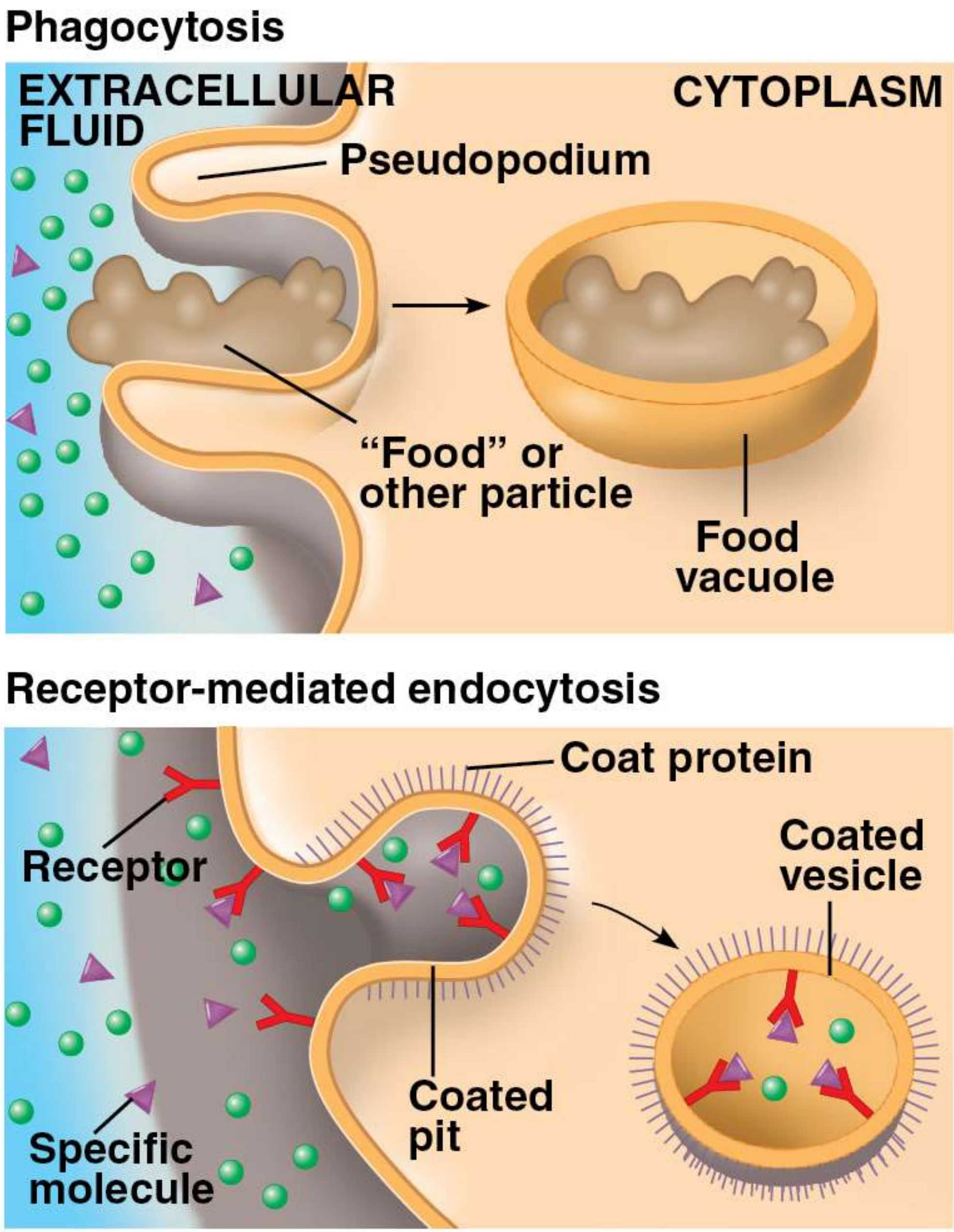
5.9 Exocytosis and Endocytosis Transport Large Molecules Across Membranes (1 of 2)

- A cell uses two mechanisms to move large molecules across membranes.
  1. **Exocytosis** is used to export bulky molecules, such as proteins or polysaccharides.
  2. **Endocytosis** is used to take in large molecules.
- In both cases, material to be transported is packaged within a vesicle that fuses with the membrane.

5.9 Exocytosis and Endocytosis Transport Large Molecules Across Membranes (2 of 2)

- There are two kinds of endocytosis.
  1. **Phagocytosis** is the engulfment of a particle by the cell wrapping cell membrane around it, forming a vacuole.
  2. **Receptor-mediated endocytosis** uses membrane receptors for specific solutes.
- In both cases, material to be transported is packaged within a vesicle that fuses with the membrane.

Figure 5.9


Phagocytosis
EXTRACELLULAR FLUID
CYTOPLASM
Pseudopodium
"Food" or other particle
Food vacuole
Receptor-mediated endocytosis
Coat protein
Receptor
Coated vesicle
Coated pit
Specific molecule

Energy and the Cell

5.10 Cells Transform Energy and Matter as They Perform Work (1 of 2)

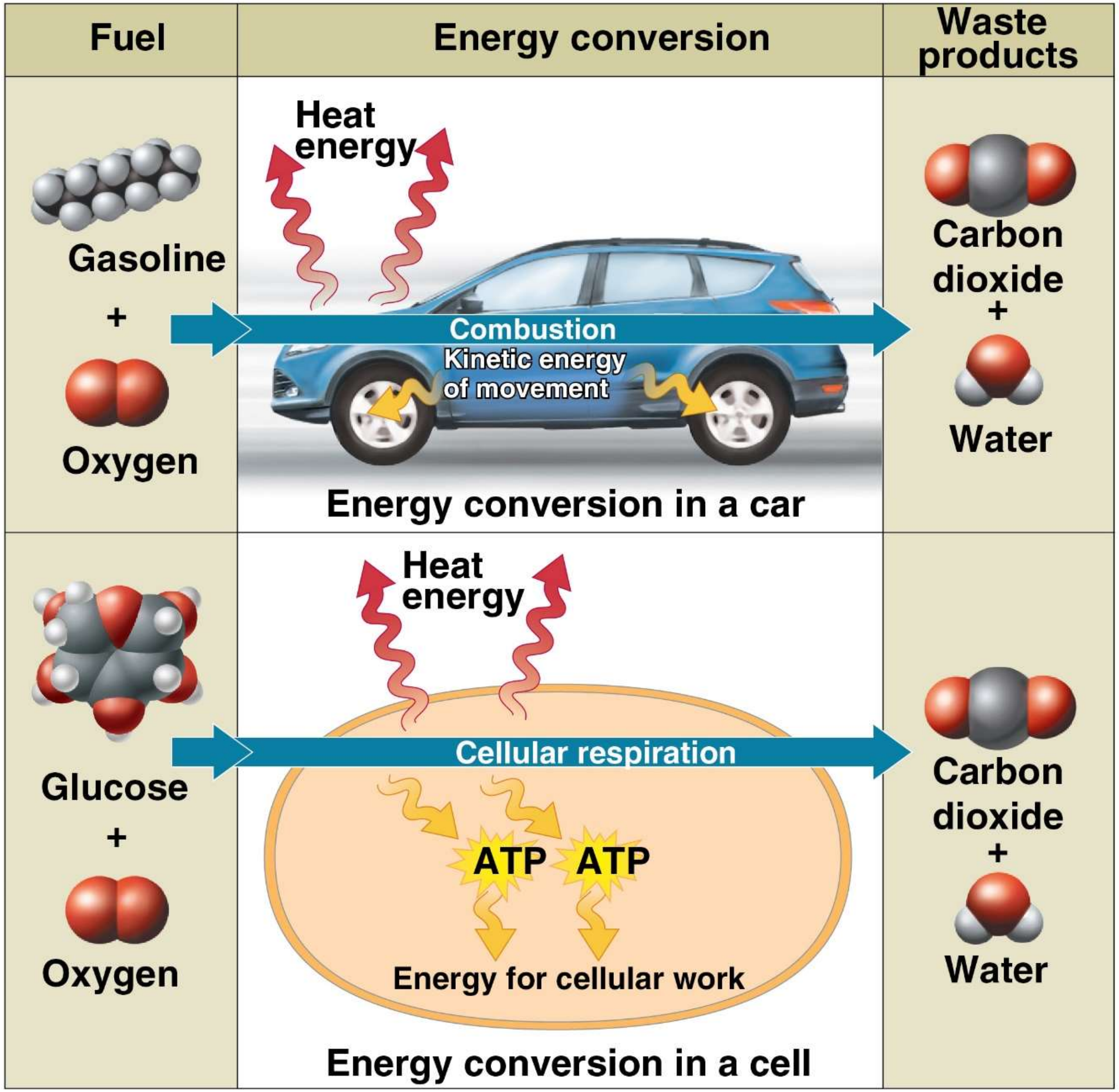
- **Energy** is the capacity to cause change.
- **Kinetic energy** is the energy of motion.
- **Potential energy** is energy stored in the location or structure of matter and includes **chemical energy**.
- According to the laws of **thermodynamics**,
  - energy can change form but cannot be created or destroyed, and
  - energy transfers or transformations increase disorder, or **entropy**, with some energy being lost as **heat**.

5.10 Cells Transform Energy and Matter as They Perform Work (2 of 2)

Checkpoint question How does the second law of thermodynamics explain the diffusion of a solute across a membrane?

- Diffusion across a membrane results in equal concentrations of solute, which is a more disordered arrangement (higher entropy) than a high concentration on one side and a low concentration on the other.

Figure 5.10


Fuel
Energy conversion
Waste products
Heat energy
Gasoline
+
Oxygen
Combustion
Kinetic energy of movement
Carbon dioxide
+
Water
Energy conversion in a car
Heat energy
Glucose
+
Oxygen
Cellular respiration
ATP
ATP
Energy for cellular work
Carbon dioxide
+
Water
Energy conversion in a cell

5.11 Chemical Reactions Either Release or Store Energy

- **Exergonic reactions** release energy.
- **Endergonic reactions** require energy and yield products rich in potential energy.
- Metabolism encompasses all of a cell's chemical reactions.

Checkpoint question Remembering that energy must be conserved, what do you think becomes of the energy extracted from food during cellular respiration?

5.12 ATP Drives Cellular Work by Coupling Exergonic and Endergonic Reactions

- **ATP** powers nearly all forms of cellular work.
- The transfer of a phosphate group from ATP is involved in chemical, transport, and mechanical work.

Checkpoint question Explain how ATP transfers energy from exergonic to endergonic processes in the cell.

Exergonic processes phosphorylate ADP to form ATP. ATP transfers energy to endergonic processes by phosphorylating other molecules.

Figure 5.12a_2

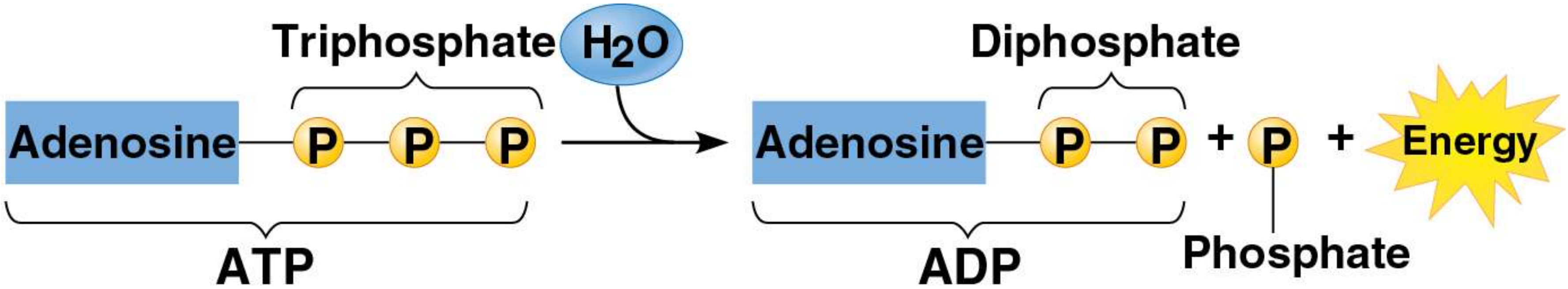


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Figure 5.12b

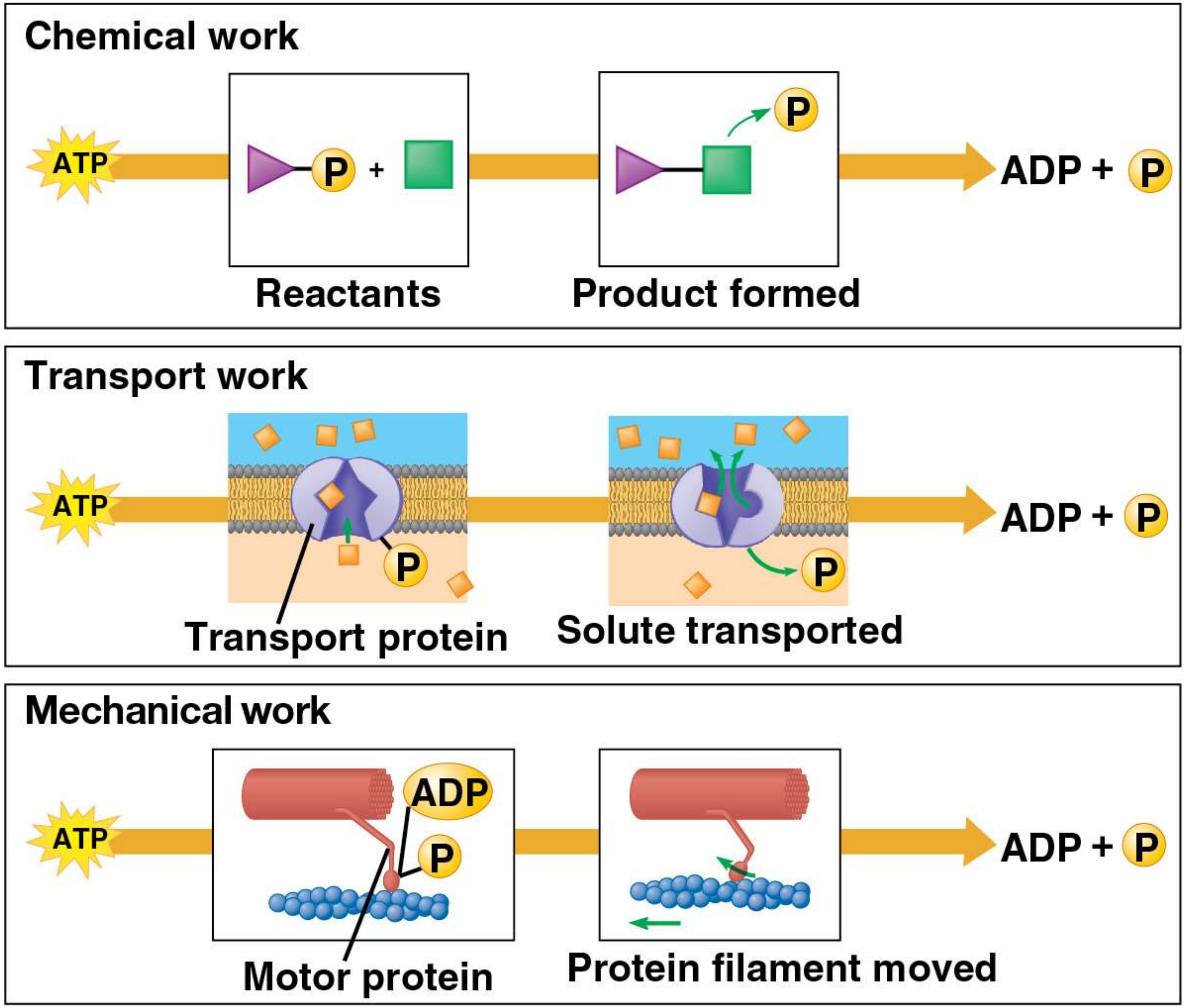
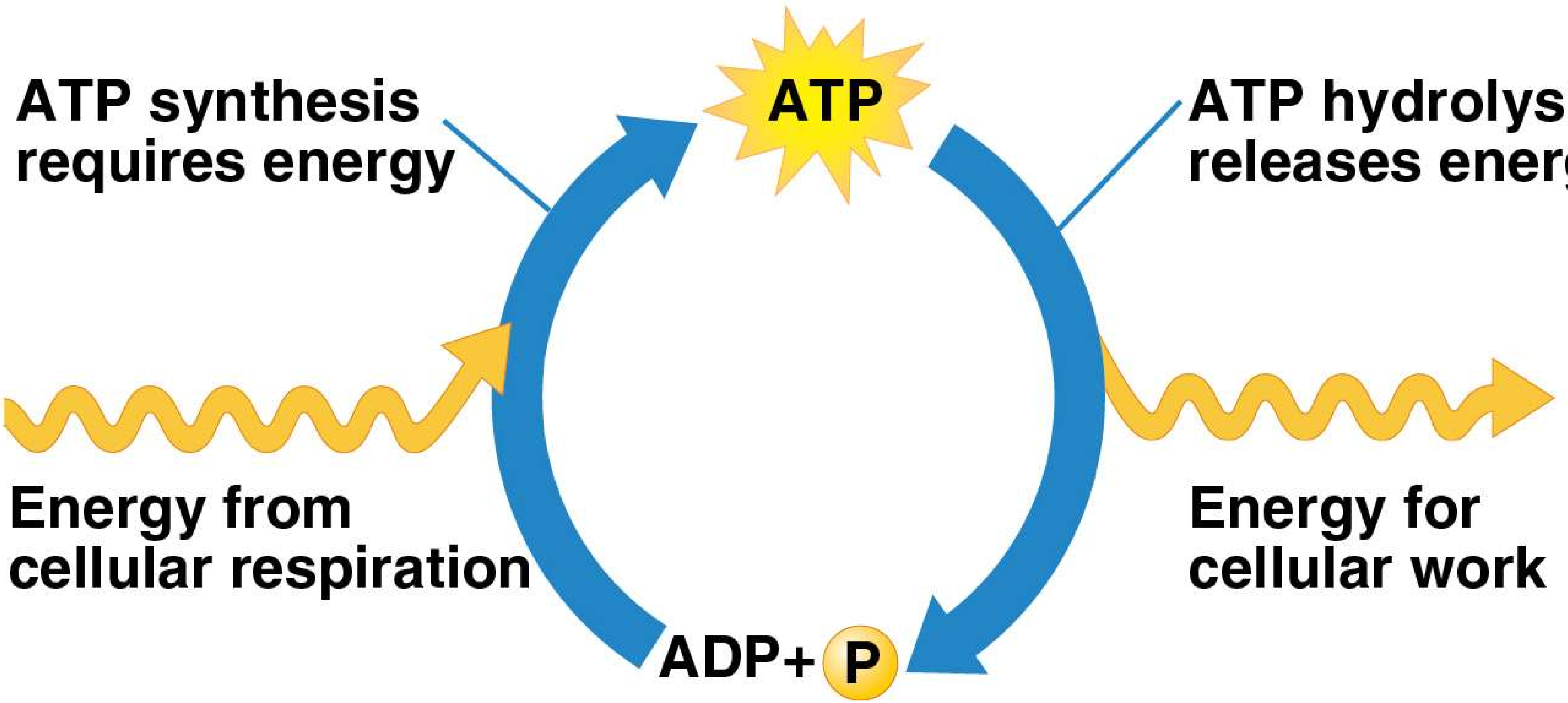

Chemical work
ATP
P
+
P
ADP + P
Reactants
Product formed
Transport work
ATP
P
P
ADP + P
Transport protein
Solute transported
Mechanical work
ATP
ADP
P
ADP + P
Motor protein
Protein filament moved

Figure 5.12c

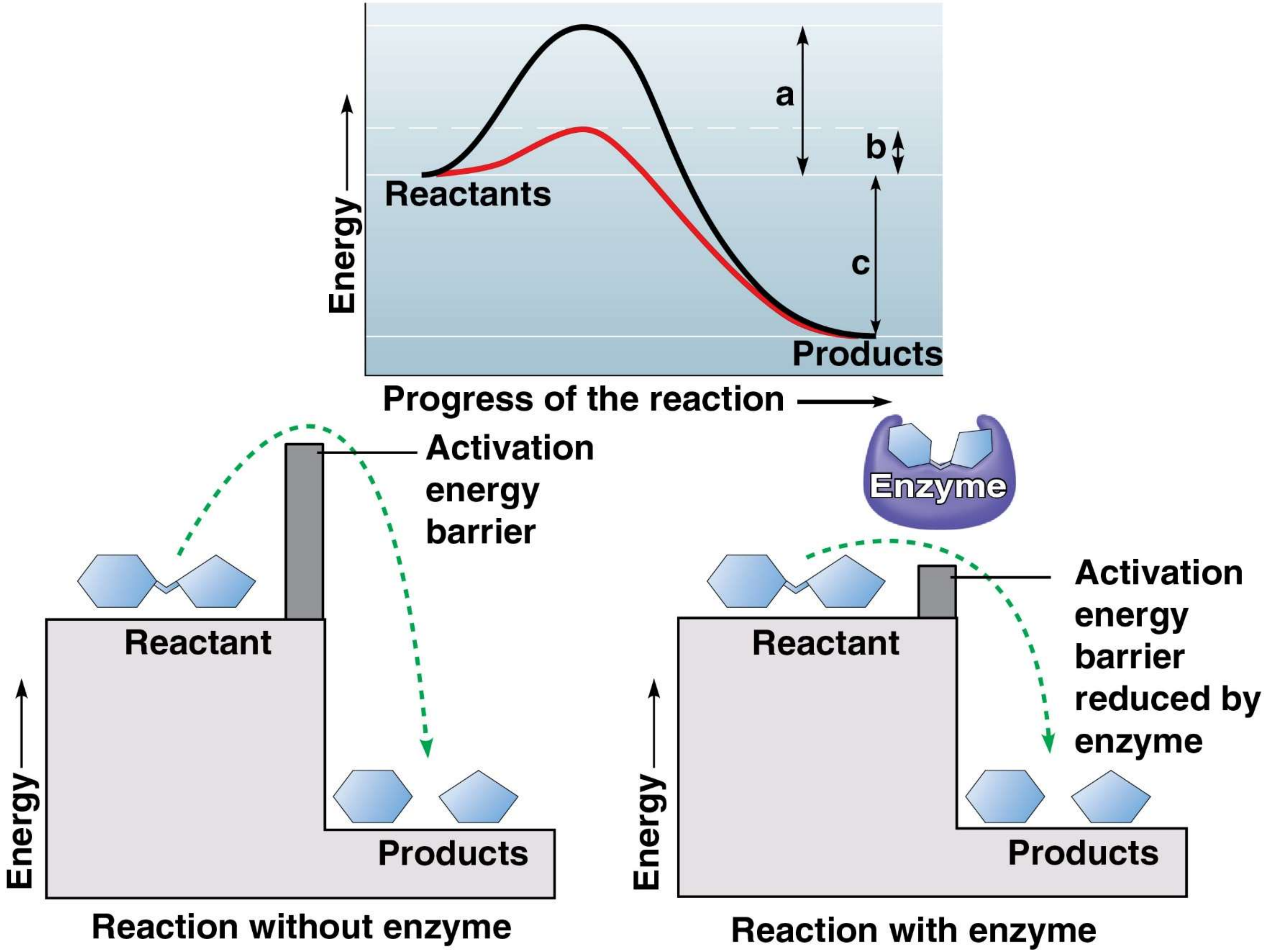

ATP synthesis requires energy
ATP
ATP hydrolysis releases energy
Energy from cellular respiration
Energy for cellular work
ADP+ P

How Enzymes Function

5.13 Enzymes Speed Up the Cell's Chemical Reactions by Lowering Energy Barriers (1 of 2)

- **Enzymes** are catalysts that decrease the activation energy needed for a reaction to begin, without being consumed by the reaction.

Figure 5.13



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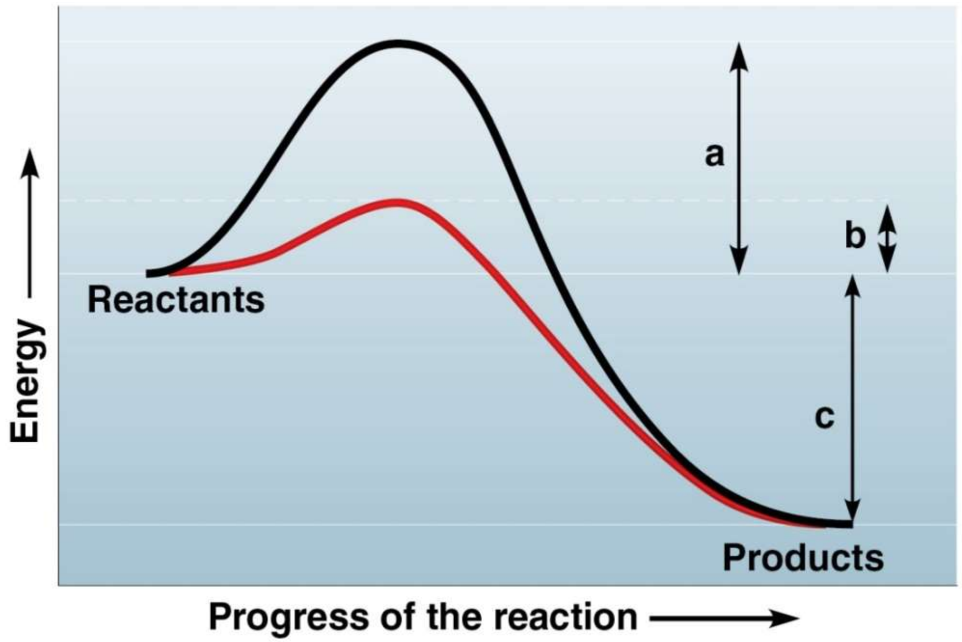
5.13 Enzymes Speed Up the Cell's Chemical Reactions by Lowering Energy Barriers (2 of 2)

Checkpoint question The graph below illustrates a reaction with and without an enzyme. Which curve represents the enzyme-catalyzed reaction? What do lines a, b, and c represent?0

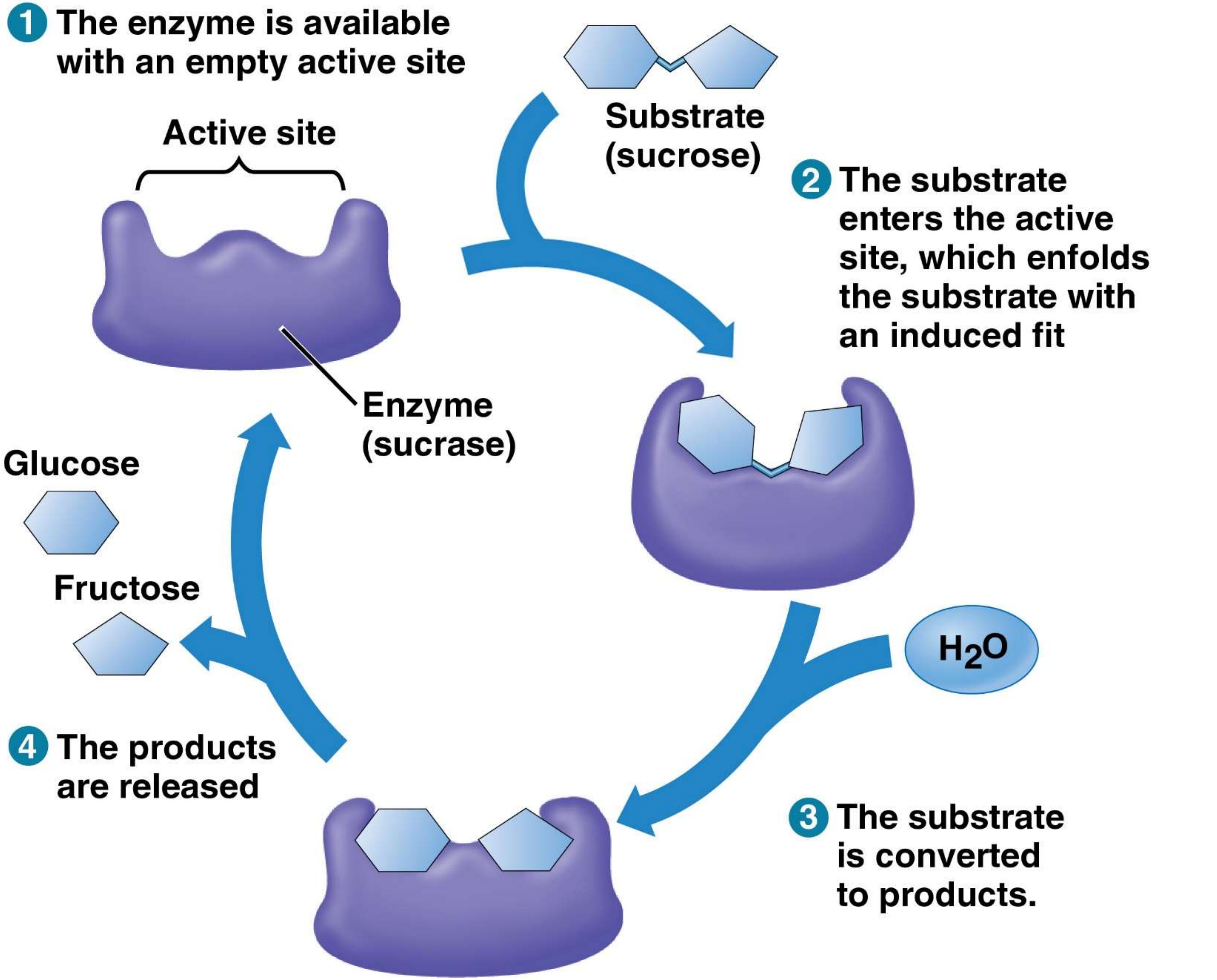


The red curve is the enzyme-catalyzed reaction. Line a is the activation energy without enzyme; b is the activation energy with enzyme; c is the change in energy between reactants and products, which is the same for both the catalyzed and uncatalyzed reactions.

5.14 A Specific Enzyme Catalyzes Each Cellular Reaction (1 of 2)

- An enzyme's **substrate** fits specifically in a region of the enzyme called the **active site**.
- The following figure illustrates the catalytic cycle of an enzyme.

Figure 5.14_4



1 The enzyme is available with an empty active site
Active site
Enzyme (sucrase)
Substrate (sucrose)
2 The substrate enters the active site, which enfolds the substrate with an induced fit
H_2O
3 The substrate is converted to products.
4 The products are released
Glucose
Fructose

5.14 A Specific Enzyme Catalyzes Each Cellular Reaction (2 of 2)

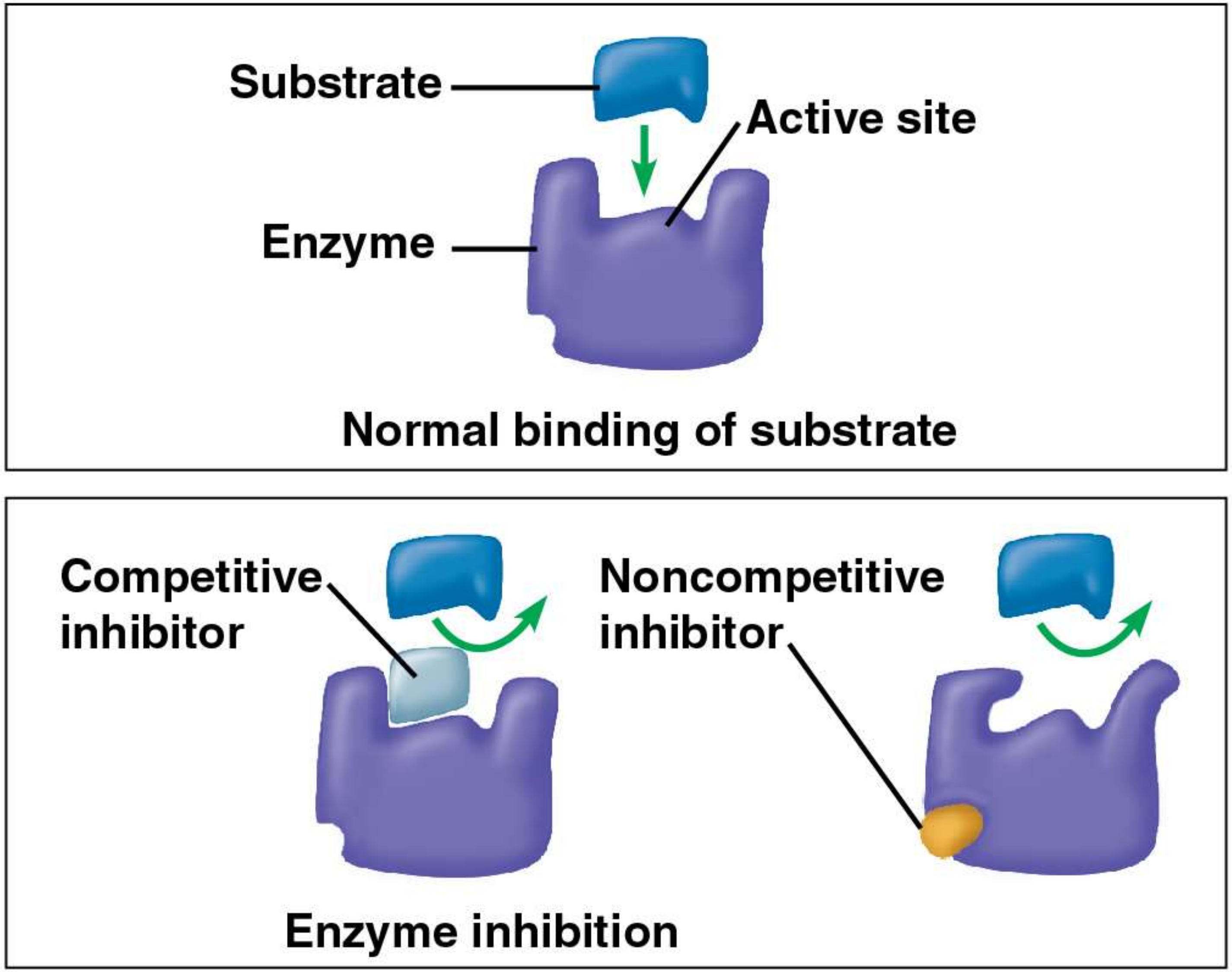
Checkpoint question Explain how an enzyme speeds up a specific reaction.

An enzyme lowers the activation energy needed for a reaction when its specific substrate enters its active site. With an induced fit, the enzyme strains bonds that need to break or positions substrates in an orientation that aids the conversion of reactants to products.

5.15 Enzyme Inhibition Can Regulate Enzyme Activity in a Cell (1 of 2)

- A **competitive inhibitor** reduces an enzyme's productivity by blocking substrate molecules from entering the active site.
- A **noncompetitive inhibitor** does not enter the active site. Instead, it binds to a site elsewhere on the enzyme, and its binding changes the enzyme's shape so that the active site no longer fits the substrate.
- **Feedback inhibition** helps regulate metabolism.

Figure 5.15a


Substrate
Active site
Enzyme
Normal binding of substrate
Competitive inhibitor
Noncompetitive inhibitor
Enzyme inhibition

5.15 Enzyme Inhibition Can Regulate Enzyme Activity in a Cell (2 of 2)

Checkpoint question Explain an advantage of feedback inhibition to a cell.

It prevents the cell from wasting valuable resources by synthesizing more of a particular product than is needed.

5.16 Connection: Many Drugs, Pesticides, and Poisons Are Enzyme Inhibitors (1 of 2)

- Many beneficial drugs act as enzyme inhibitors.

5.16 Connection: Many Drugs, Pesticides, and Poisons Are Enzyme Inhibitors (2 of 2)

- Many beneficial drugs act as enzyme inhibitors.
- Enzyme inhibitors have also been developed as
  - pesticides and
  - deadly poisons for use in warfare.

Checkpoint question What determines whether enzyme inhibition is reversible or irreversible?

If the inhibitor binds to the enzyme with covalent bonds, the inhibition is usually irreversible. When weak chemical interactions bind inhibitor and enzyme, the inhibition is reversible.