Chapter 7

Membrane Structure and Function

PowerPoint® Lecture Presentations for

Biology

Eighth Edition

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

Overview: Life at the Edge

- The plasma membrane is the boundary that separates the living cell from its surroundings
- The plasma membrane exhibits **selective permeability**, allowing some substances to cross it more easily than others
- http://www.teachersdomain.org/resource/tdc02.sci.life.cell.membraneweb/

Concept 7.1: 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 and hydrophilic regions
- The **fluid mosaic model** states that a membrane is a fluid structure with a “mosaic” of various proteins embedded in it

Membrane Models: *Scientific Inquiry*

- Membranes have been chemically analyzed and found to be made of proteins and lipids
- Scientists studying the plasma membrane reasoned that it must be a phospholipid bilayer

Fig. 7-2

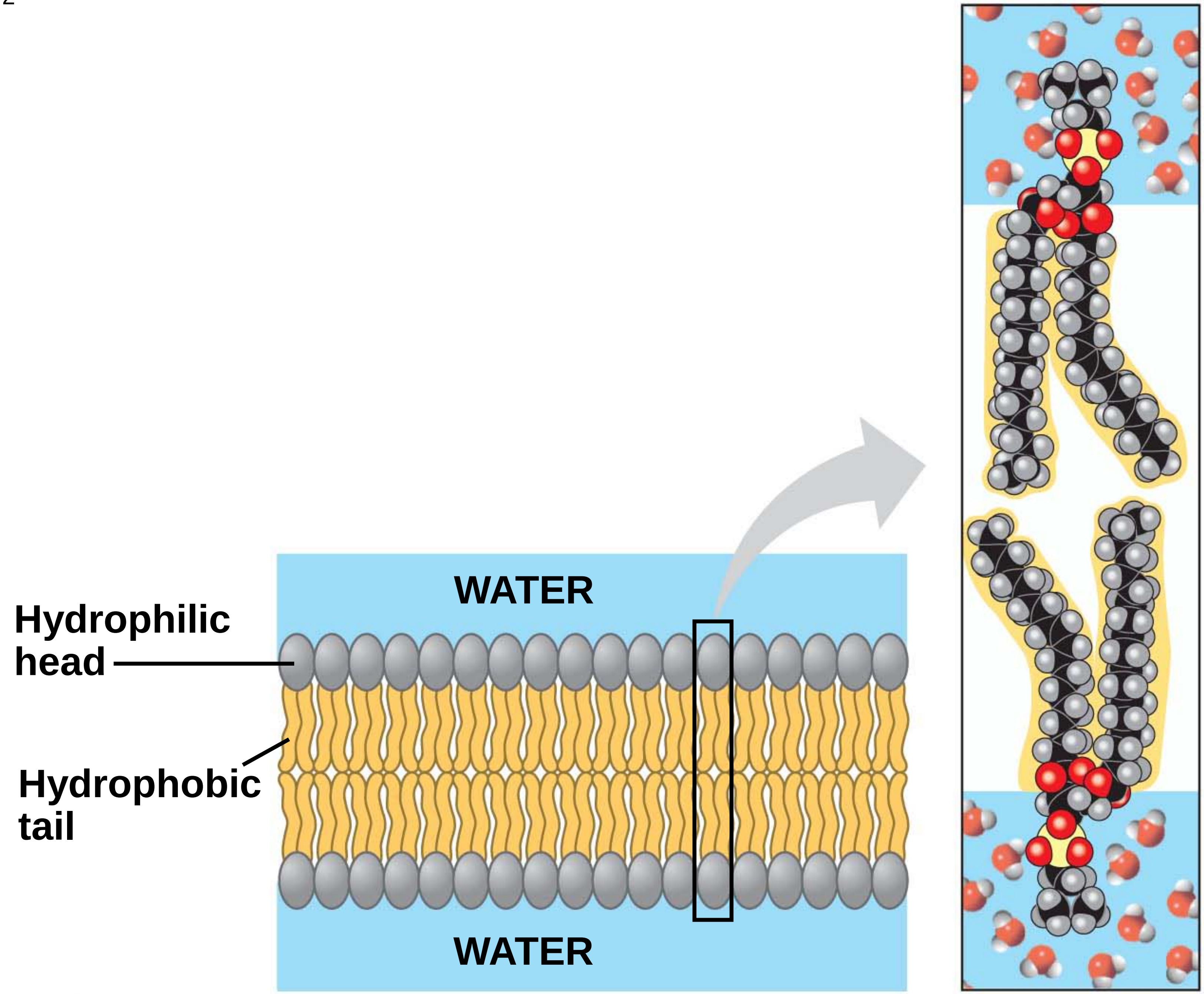
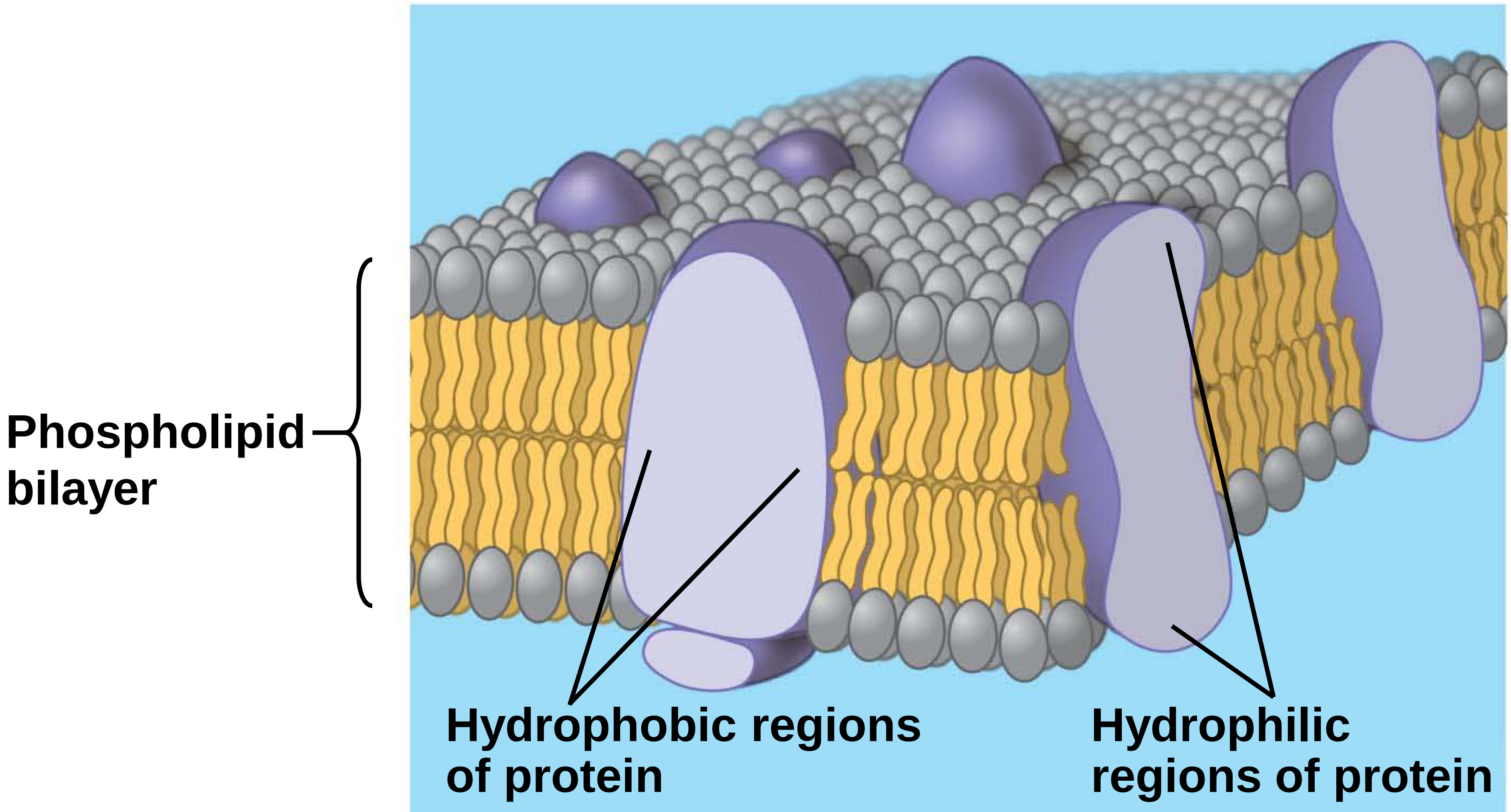


Fig. 7-3

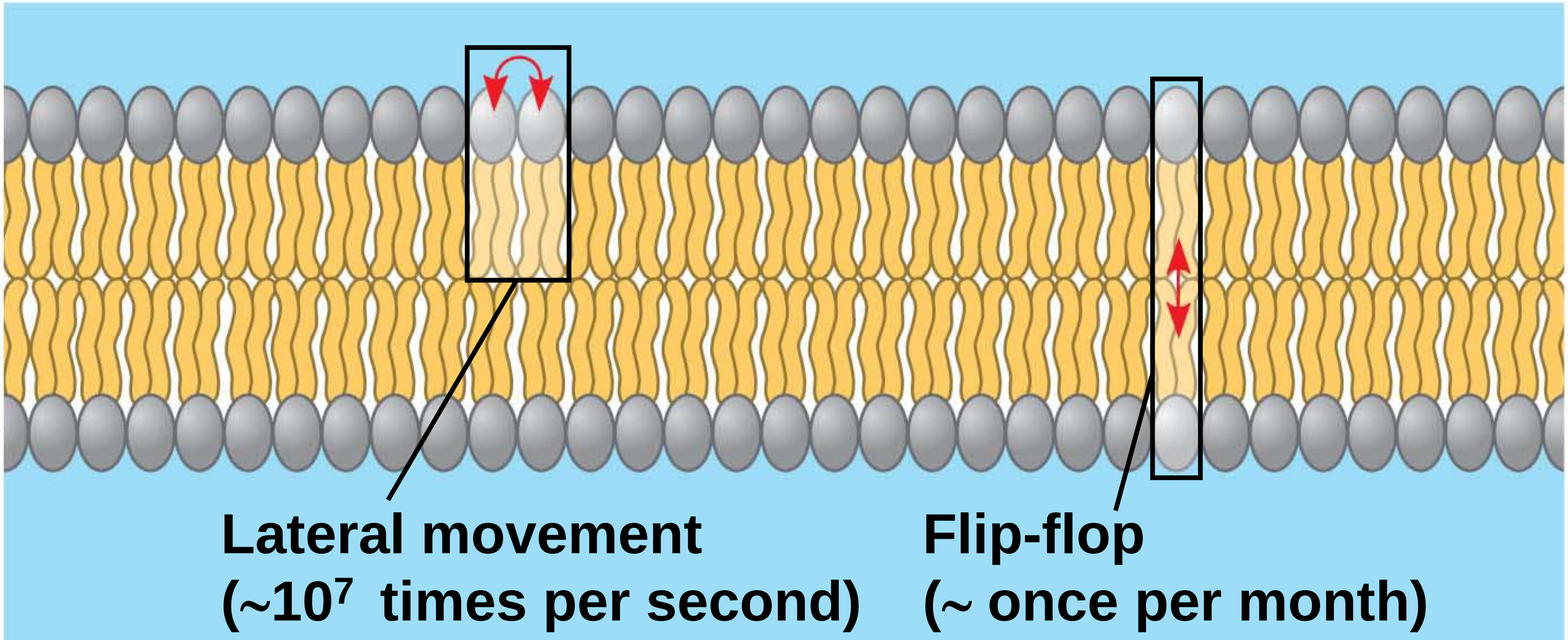


Phospholipid bilayer
Hydrophobic regions of protein
Hydrophilic regions of protein

The Fluidity of Membranes

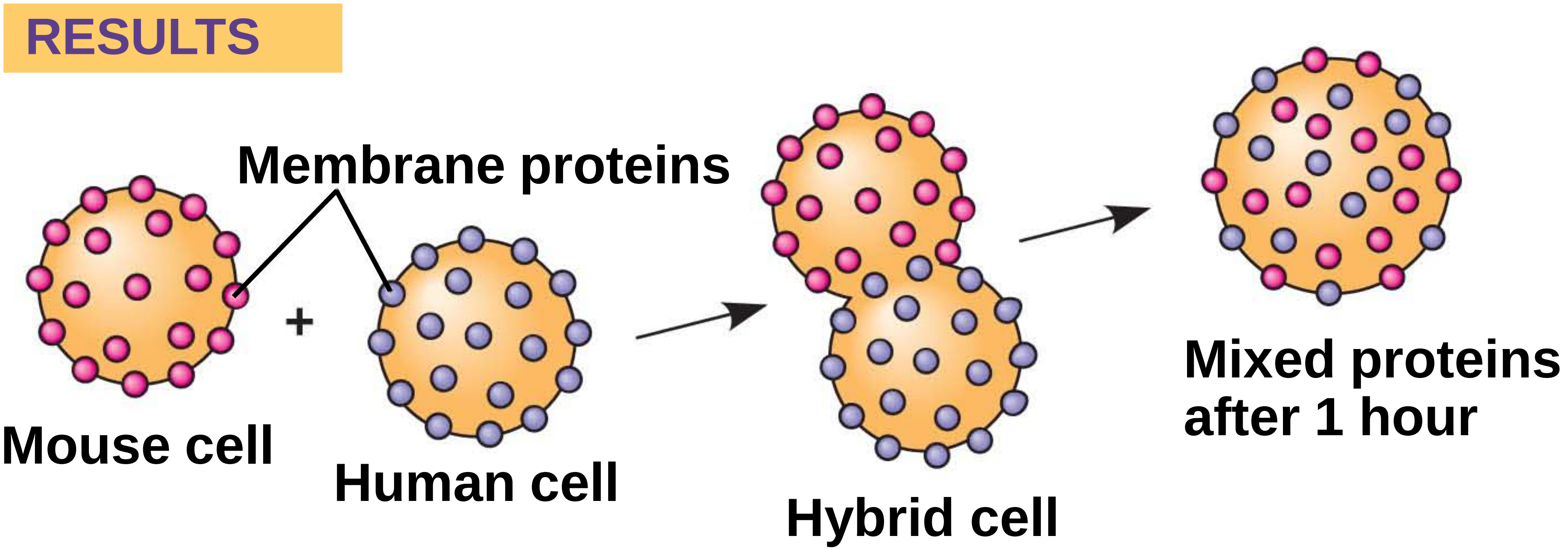
- Phospholipids in the plasma membrane can move within the bilayer
- Most of the lipids, and some proteins, drift laterally
- Rarely does a molecule flip-flop transversely across the membrane

Fig. 7-5a



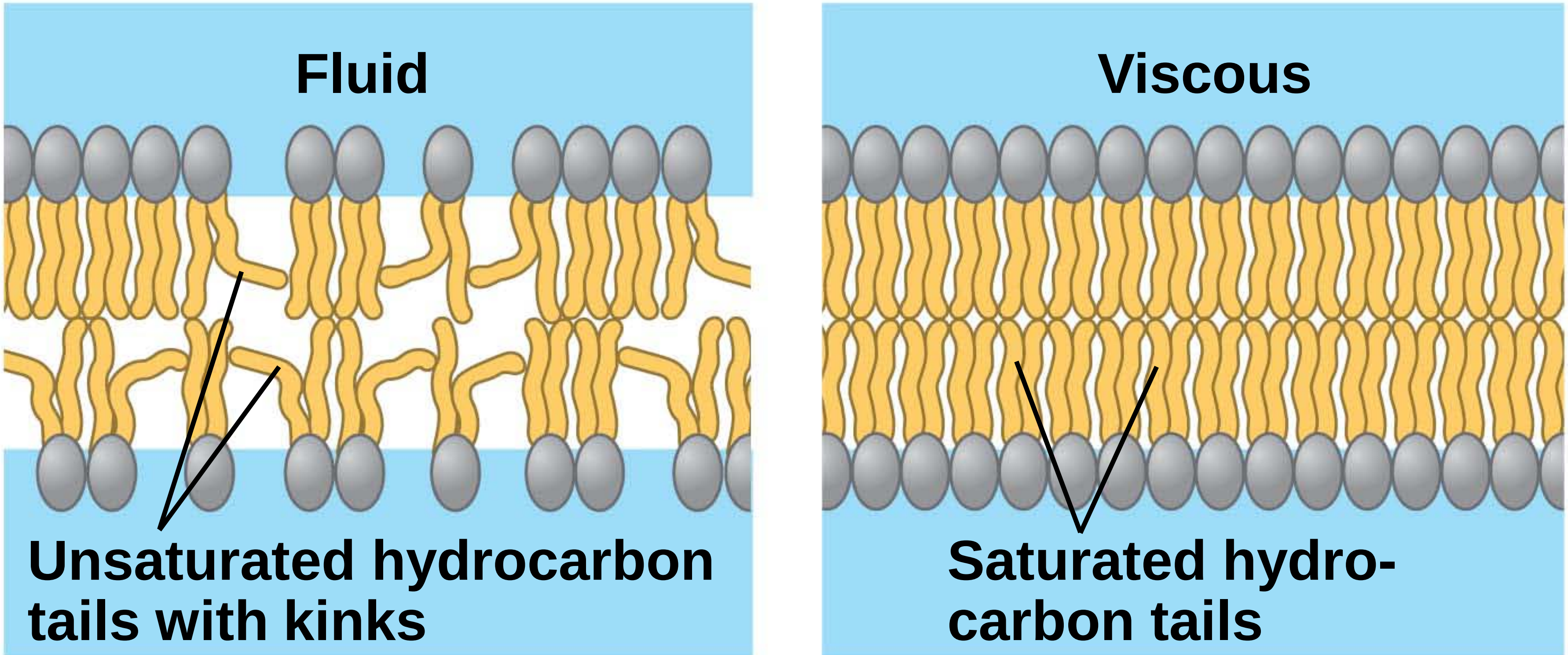
(a) Movement of phospholipids

Fig. 7-6


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

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

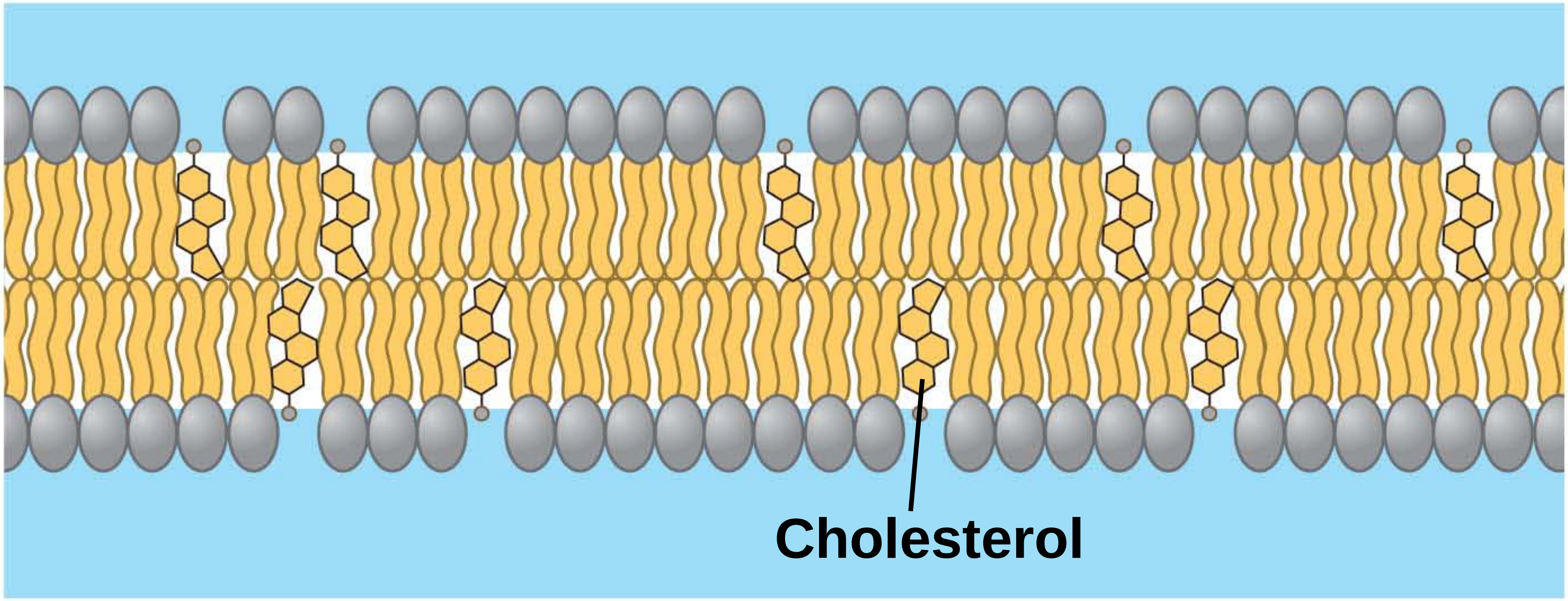
Fig. 7-5b



(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

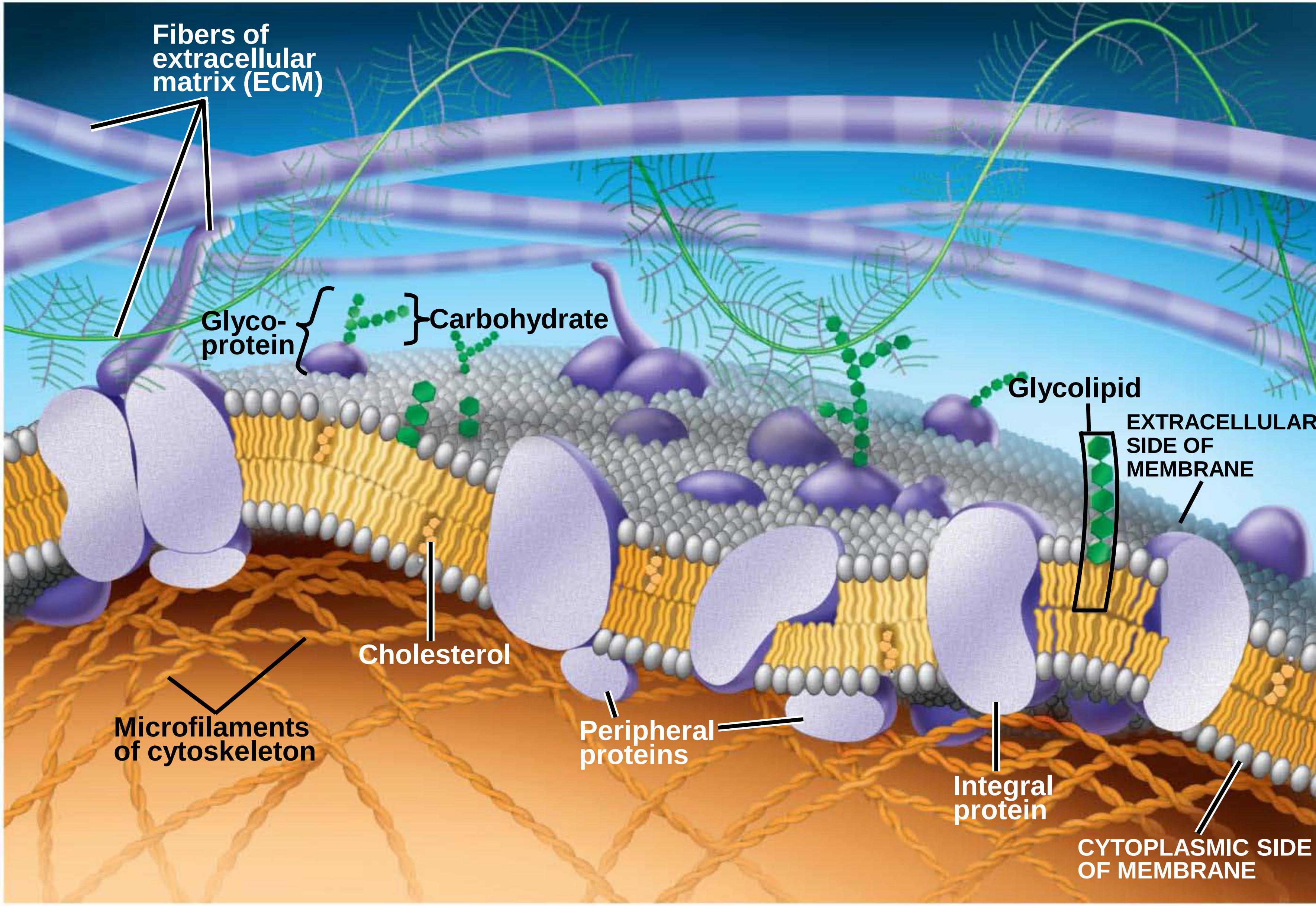
Fig. 7-5c



(c) Cholesterol within the animal cell membrane

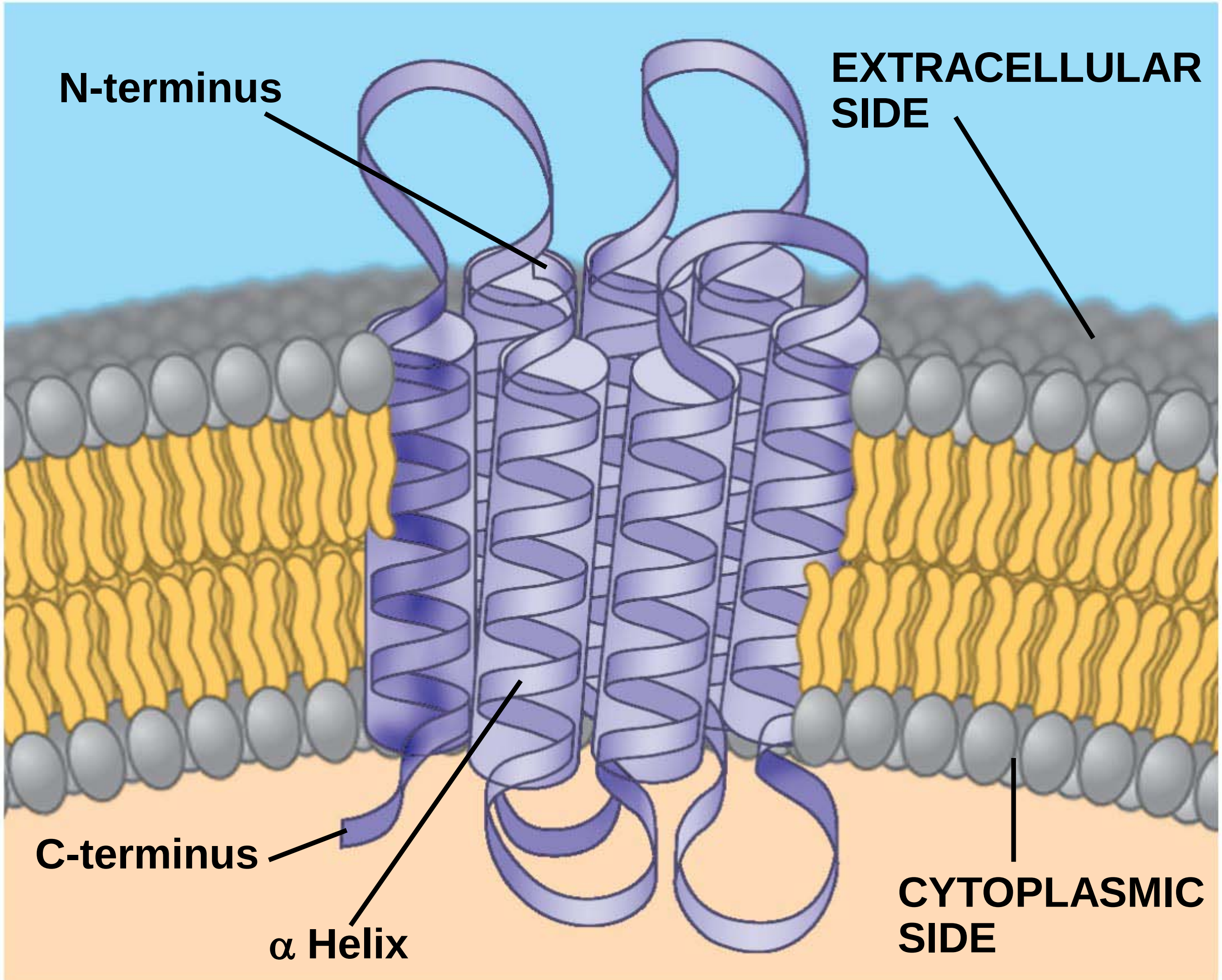
Membrane Proteins and Their Functions

- A membrane is a collage of different proteins embedded in the fluid matrix of the lipid bilayer
- Proteins determine most of the membrane's specific functions


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

- **Peripheral proteins** are bound to the surface of the membrane
- **Integral proteins** penetrate the hydrophobic core
- Integral proteins that span the membrane are called transmembrane proteins
- The hydrophobic regions of an integral protein consist of one or more stretches of nonpolar amino acids, often coiled into alpha helices

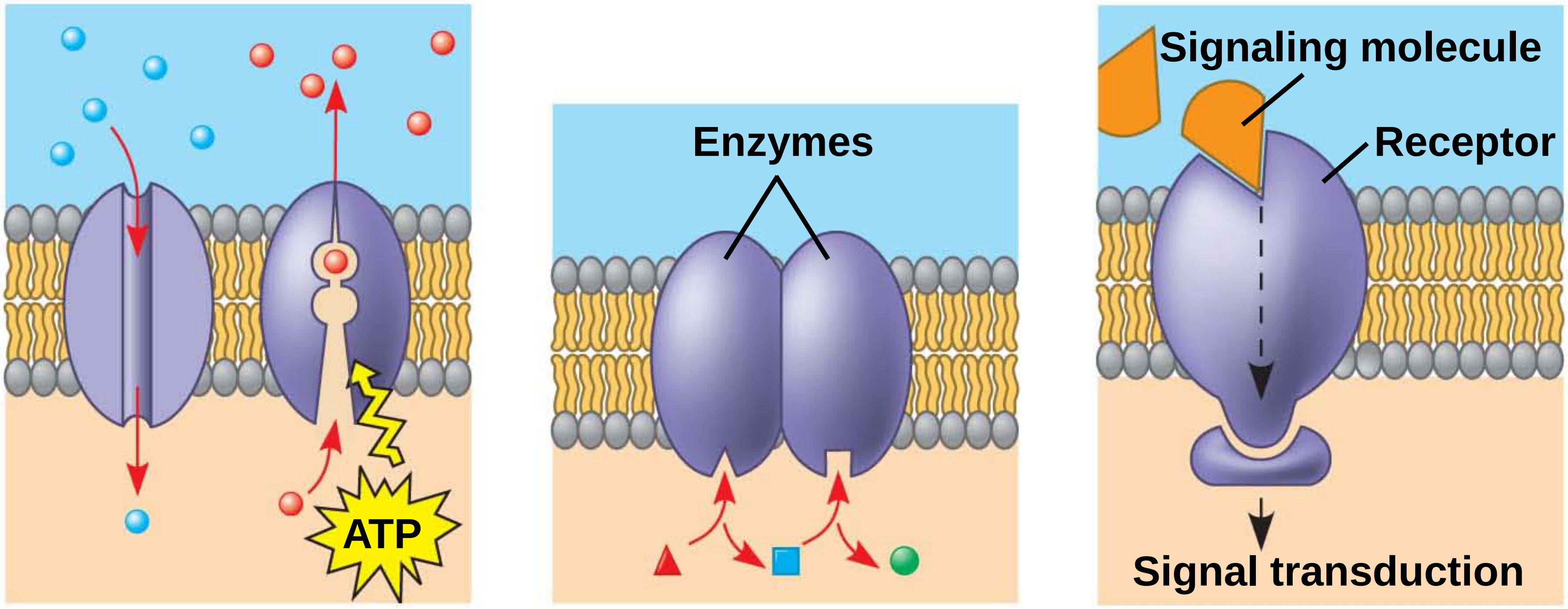
Fig. 7-8



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

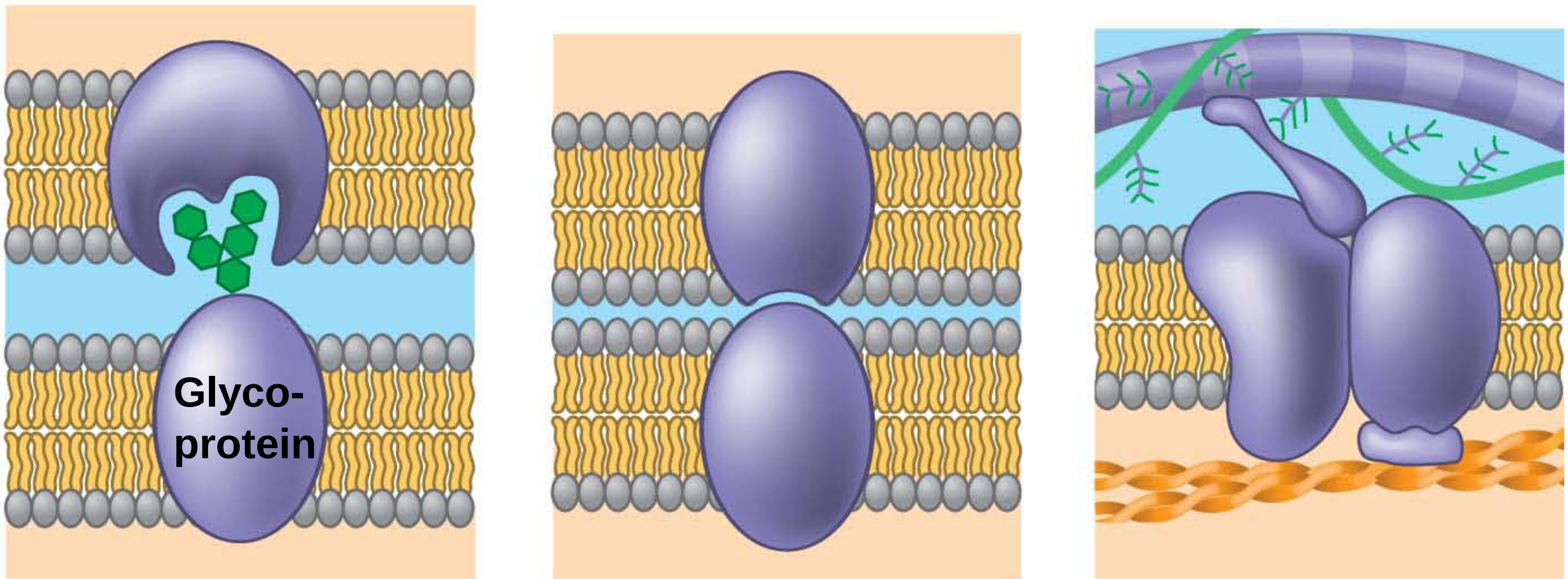
- Six major functions of membrane proteins:
  - Transport
  - Enzymatic activity
  - Signal transduction
  - Cell-cell recognition
  - Intercellular joining
  - Attachment to the cytoskeleton and extracellular matrix (ECM)

Fig. 7-9ac



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

Fig. 7-9df



(d) Cell-cell recognition

(e) Intercellular joining

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

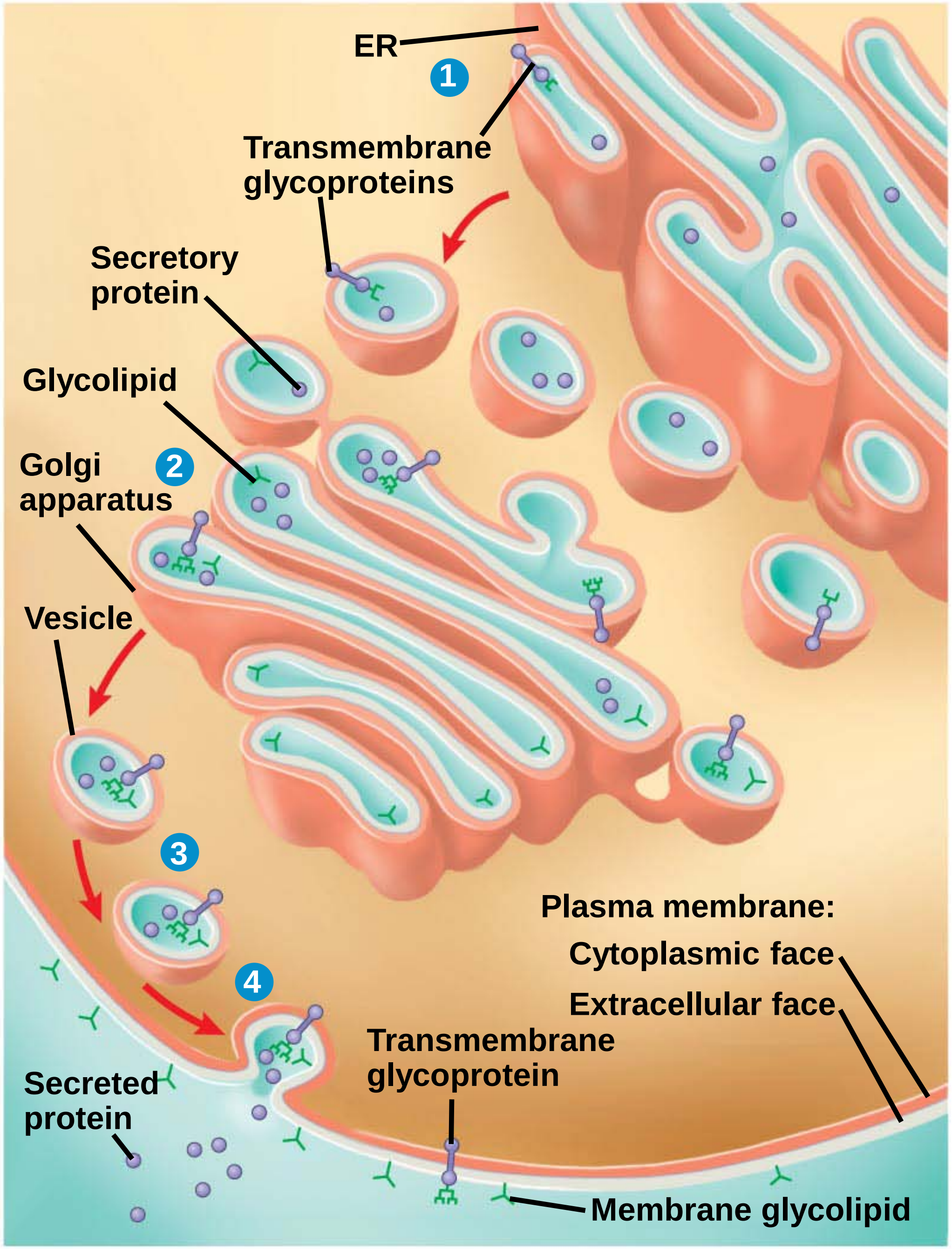
The Role of Membrane Carbohydrates in Cell-Cell Recognition

- 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

Fig. 7-10



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

AQ#1: You add a drop of blue dye to a container of water and after several hours the entire container turns light blue. Which statement is correct regarding this process?

A. **The high concentration of dye particles repelled each other causing the dye to spread out.**
B. **The particles moved until they were evenly dispersed, then they stopped moving.**
C. **There were too many particles crowded into one area, so they move to an area with more room.**
D. **By random chance, dye particles moved from areas of higher concentration to areas of lower concentration.**
E. **The dye molecules were broken into smaller pieces.**

Answer: D

AQ#2: If you continued to watch the container in the previous question for several more hours, what would you expect to happen?

A. The dye molecules will stop moving.
B. The dye molecules will settle to the bottom of the container.
C. The dye molecules will continue to move around randomly.
D. The dye molecules will continue to move such that the container will become different shades of blue.
E. The dye molecules will continue to move but in a non-random manner.

Answer: C

Agony and Ecstasy

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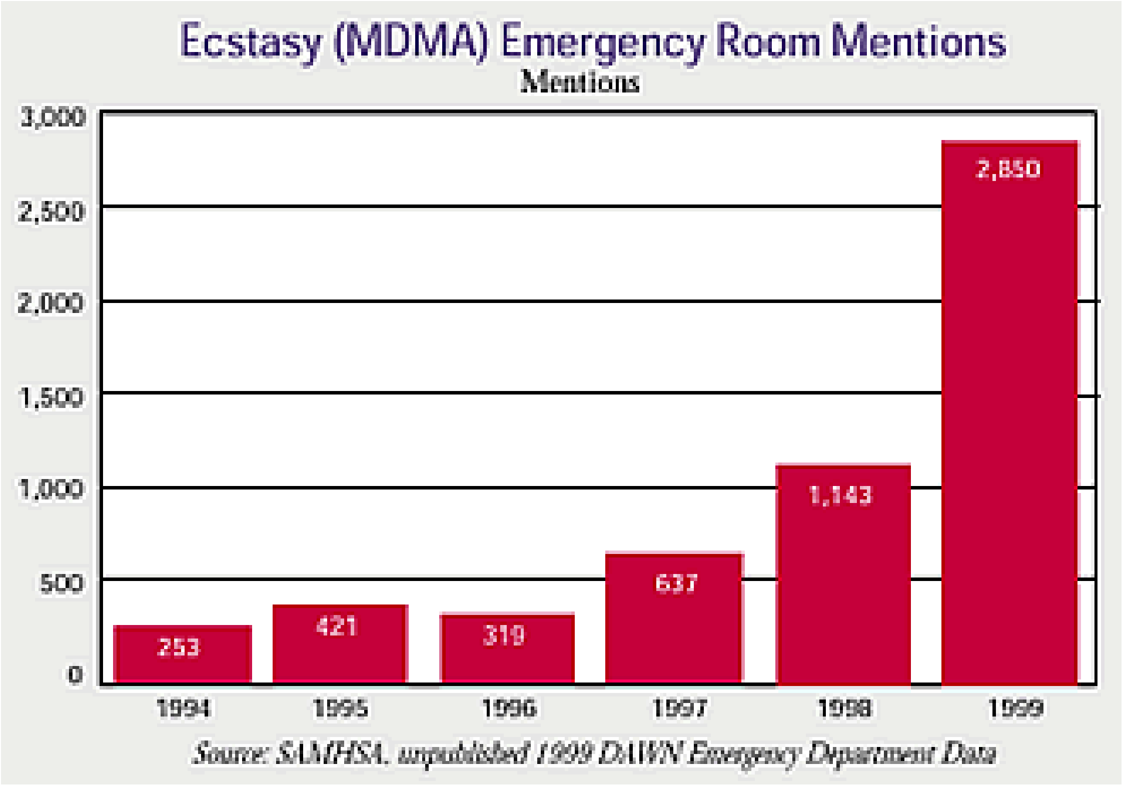
Susan, a new intern at the local hospital, was working the admissions desk one Monday morning. A man and a woman rushed through the doors, carrying a second woman. “Help! Can you help us?” one called. Susan and a nurse rushed them into an exam room.

“What happened?” Susan asked while examining the patient. “We don’t know!” the female student sobbed. “Brittany started feeling sick at a party last night. She came home and went to sleep, but then couldn’t wake up this morning. She was acting so weird we decided to bring her here.”

Susan carefully observed the woman lying on the table. She was rolling her head and clearly seemed confused. However, there were no obvious signs of trauma. “Has Brittany taken any drugs recently?” Susan asked. The two students hesitated and looked at each other. Finally one of them nodded. “I think she took some Ecstasy last night.”

Susan thought for a moment. Ecstasy had been fairly popular on the party scene for several years now. She had seen people on the drug become somewhat confused, but not delirious. Maybe Brittany was having an adverse reaction to the drug. It was a start. To be safe, Susan ordered a series of blood tests. In the meantime, she checked her medical references to find out as much as she could about how Ecstasy affected the body.



Ecstasy (MDMA) Fact Sheet

- **MDMA (3,4 methylenedioxymethamphetamine) is a synthetic, psychoactive drug chemically similar to the stimulant methamphetamine and the hallucinogen mescaline. MDMA acts as both a stimulant and psychedelic. It produces an energizing effect, distorts both physical and cognitive sensations, and may impair memory.**

- **MDMA affects a neuron's ability to use the chemical serotonin. Serotonin plays an important role in regulating mood, aggression, sexual activity, sleep, and sensitivity to pain. Research in animals indicates that MDMA is a neurotoxin. MDMA is potentially harmful to health and, on rare occasions, may be lethal.**

Ideas why Brittany is ill?

MDMA may affect:

- Blood pressure
- Pulse rate
- Body temperature
    - Hyperthermia
    - Hypothermia
- Water Balance
    - Dehydration
    - Excess water
- Blood sugar level
- Vision

Brittany's Test Results

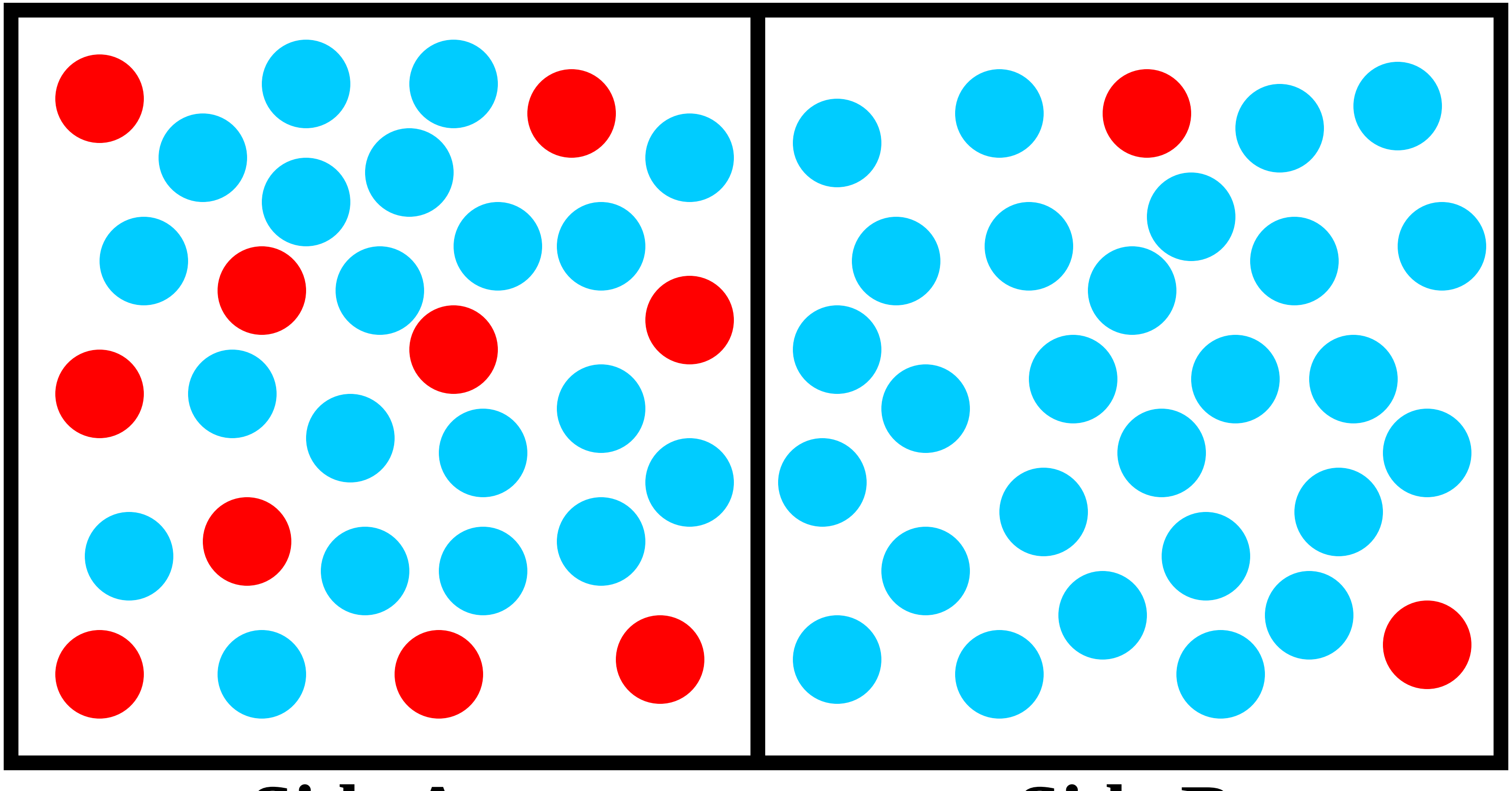
Item and measure	Normal	Brittany
Heart Rate (beats/min)	60-100	90
Blood Pressure (mmHg)	90/50 - 140/90	135/87
Temperature (°F)	98.6	100.2
Glucose (mg/dl)	60-109	72
Sodium-Na^+ (mM/L)	135-146	115
Potassium-K^+ (mM/L)	3.5-5.5	2.9
Chloride-Cl^- (mM/L)	95-109	88
O_2 (mmHg)	80-100	93
CO_2 (mM/L)	22-32	24

CQ#1: What do the test results suggest is causing Brittany's illness?

A. High blood pressure or rapid heart rate
B. Hypoglycemia (too little blood sugar water)
C. Hyperthermia (too hot)
D. Hypothermia (too cold)
E. Excess water (too much water)
F. Dehydration (too little water)

Answer: E

Concentration: Amount of one substance (solute, ●) dissolved in given volume of another substance (solvent, ●).



Ecstasy Case Continued

Susan spoke to the students in the waiting area. "Did Brittany have much to drink last evening?" "Just one beer," replied one. "She had a test today and wanted to study. She did drink a lot of water. You're supposed to do that to prevent a hangover aren't you? She seemed really thirsty."

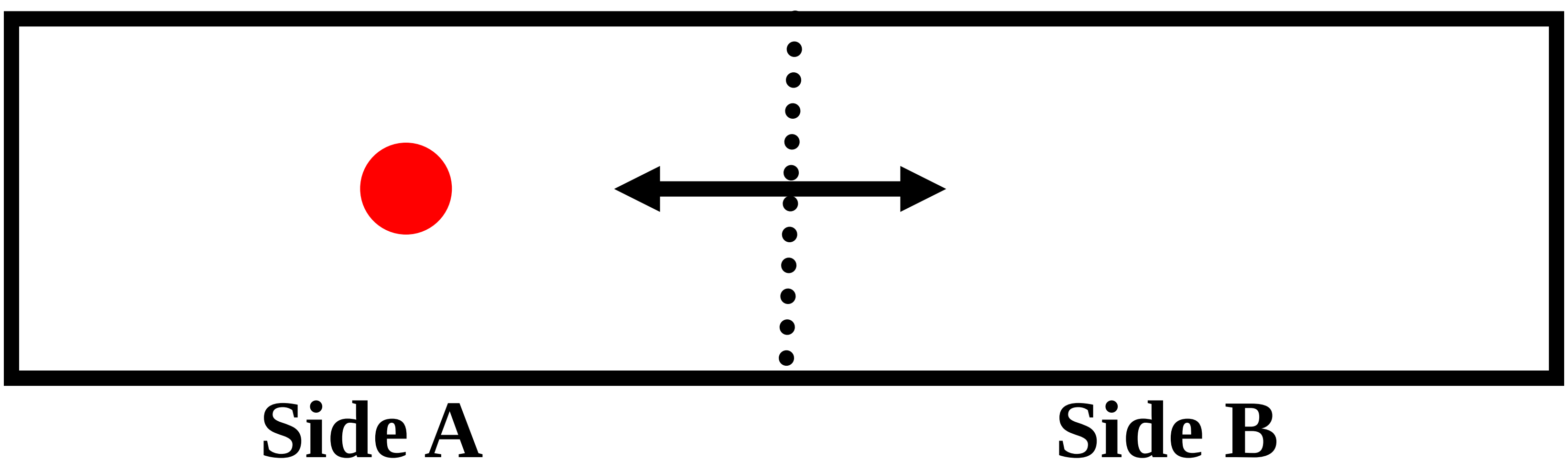
Susan thought for a minute. Normally, Brittany's kidneys would respond to drinking a lot of water by producing large amounts of dilute urine. However, Ecstasy acts as an anti-diuretic and forces the kidneys to make concentrated urine instead. This would prevent Brittany's body from getting rid of excess water and could cause her electrolytes to fall. Could this be causing her symptoms?

- Diffusion Model

http://molo.concord.org/database/activities/223.htm

CQ#2: Assume movement of a molecule is limited. It can move to the opposite side of a container or stay where it is. If movement is random, what is the probability (0-100%) that the molecule will move to the opposite side?

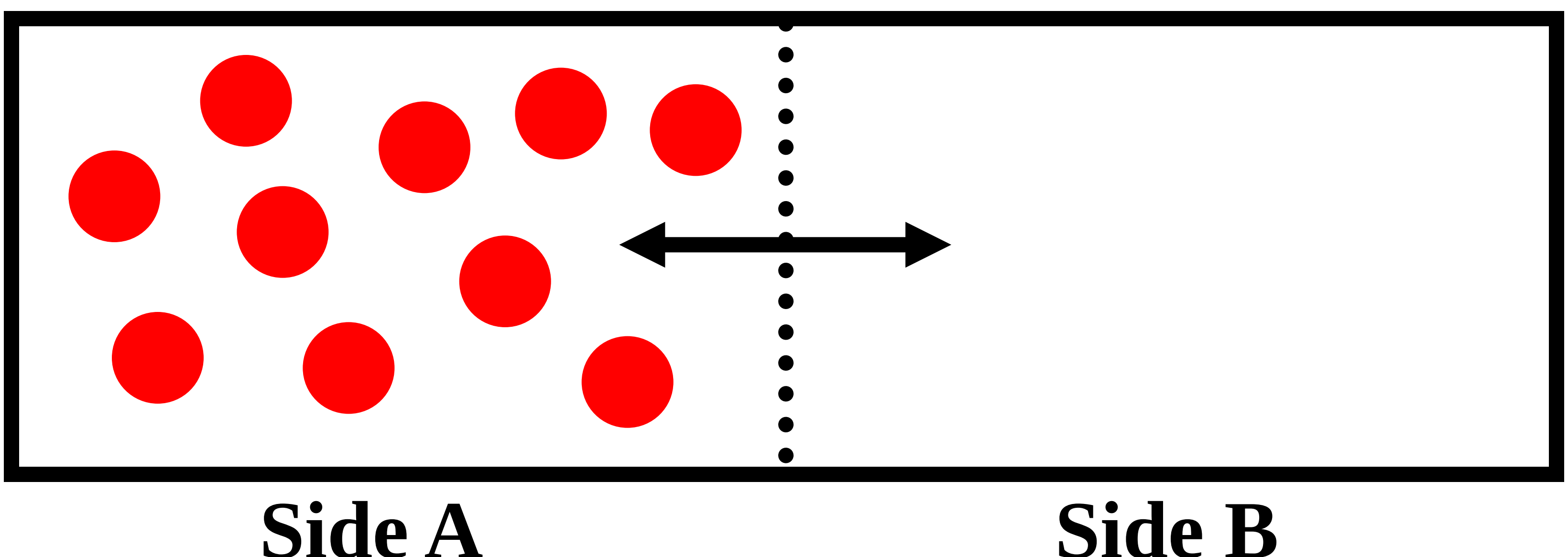
Answer: 50%



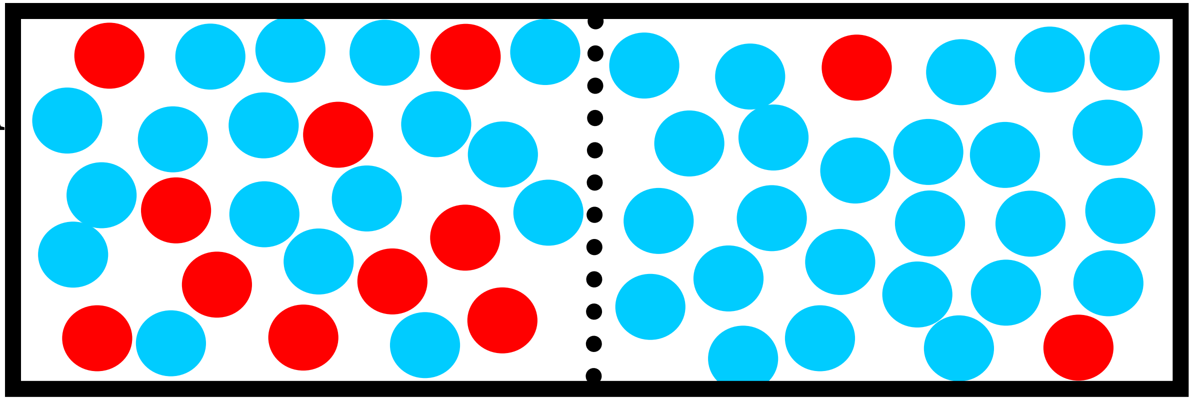
CQ#3: Assume there are 10 molecules on one side of a container. How many would you expect to move to the opposite side?

A. 10
B. 5
C. 0
D. It is impossible to predict

Answer: B



CQ#4: Which statement best describes how these molecules will behave over time due to random movement?



A. Red molecules will move from side A to B.
B. Blue molecules will move from side B to A.
C. All of the molecules will move so that red and blue will become equal on both sides.
D. More molecules will move from side A to B than from side B to A.

Answer: C

Diffusion / Osmosis Animations

Good practice site

http://physioweb.med.uvm.edu/diffusion/

http://molo.concord.org/database/activities/223.htm

CQ#5: Which of the following molecules could move through a phospholipid membrane with the *least* difficulty?

A. H_2O
B. Glucose
C. Na+
D. O_2
E. An amino acid

Answer: D

Concept 7.3: 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 exhibit a net movement in one direction
- At dynamic equilibrium, as many molecules cross one way as cross in the other direction

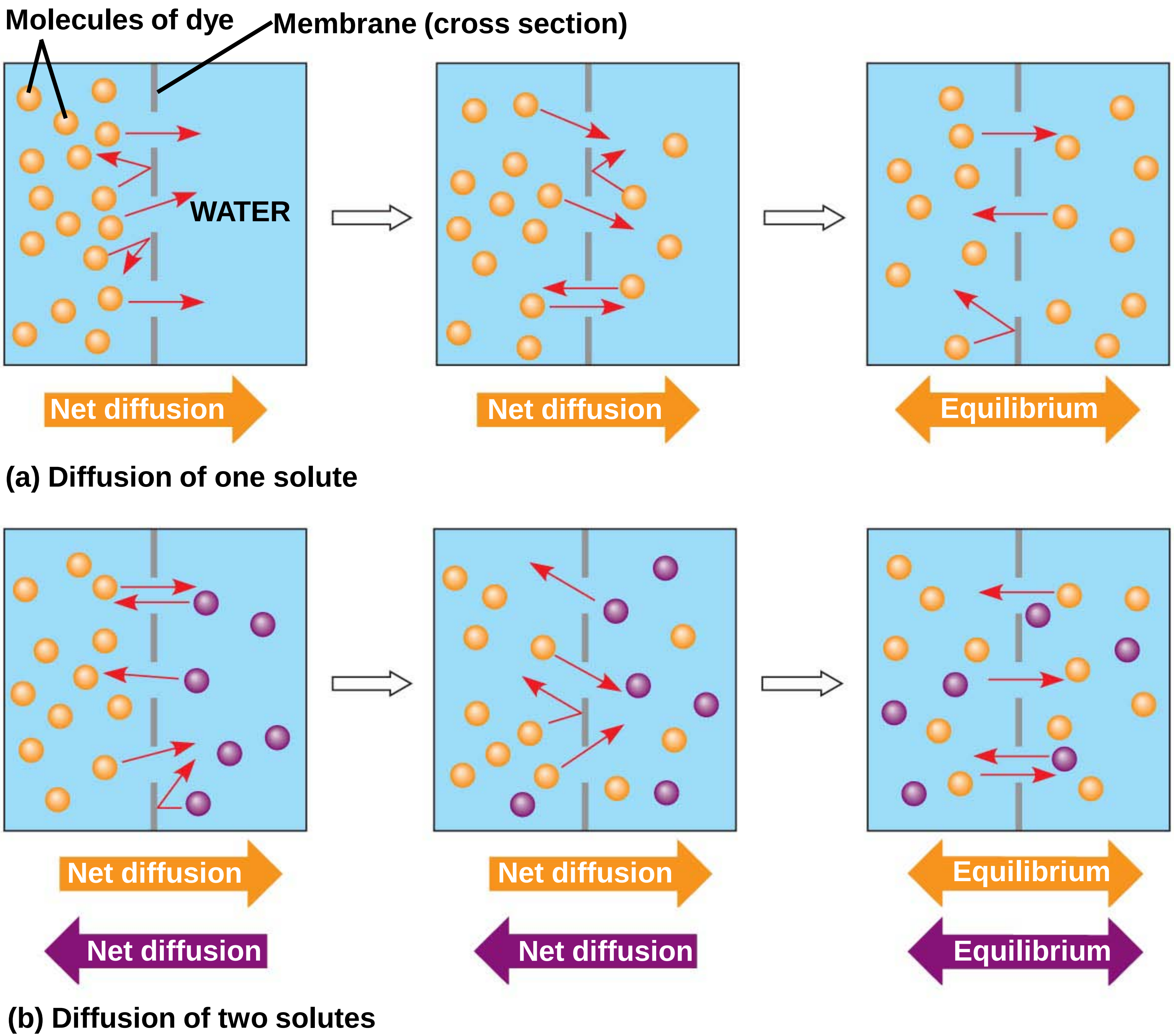
PLAY Animation: Membrane Selectivity

PLAY Animation: Diffusion

Concept 7.2: 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

Fig. 7-11

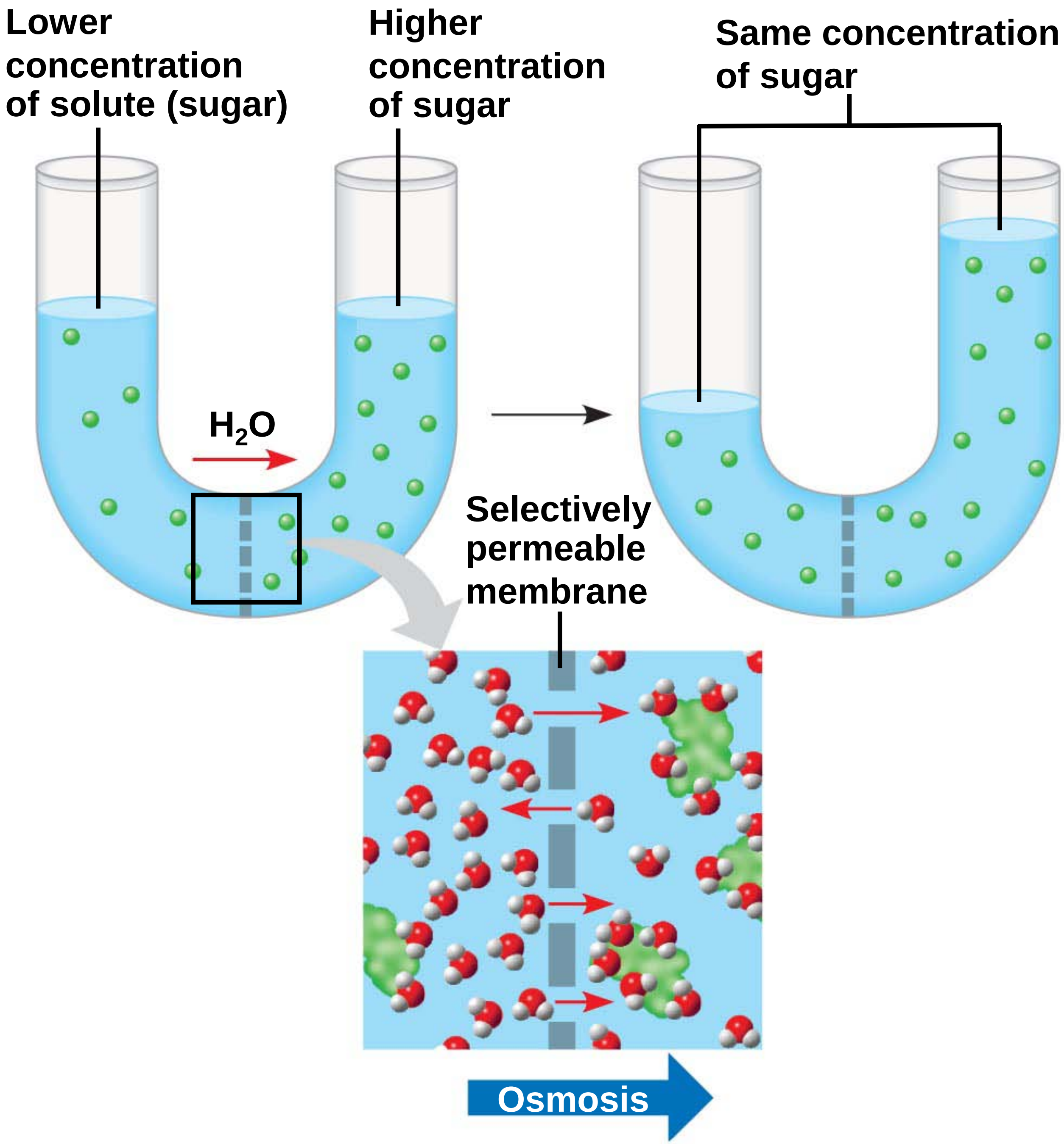

Molecules of dye
Membrane (cross section)
WATER
Net diffusion
Net diffusion
Equilibrium
(a) Diffusion of one solute
Net diffusion
Net diffusion
Equilibrium
Net diffusion
Net diffusion
Equilibrium
(b) Diffusion of two solutes

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

- http://molo.concord.org/database/activities/233.htm

Fig. 7-12

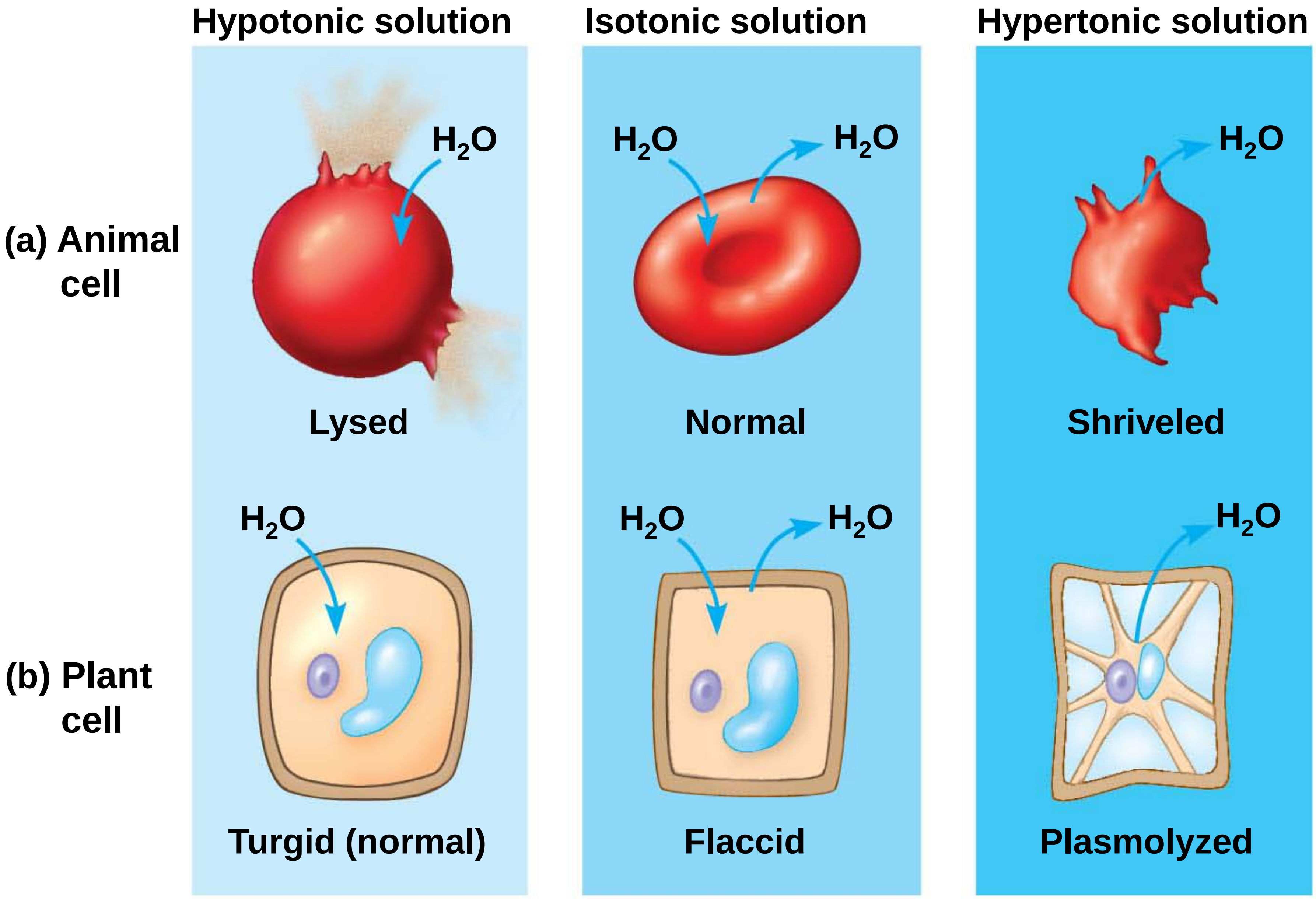

Lower concentration of solute (sugar)
Higher concentration of sugar
Same concentration of sugar
H_2O
Selectively permeable membrane
Osmosis

- http://arbl.cvmbs.colostate.edu/hbooks/cmb/cells/pmemb/osmosis_eg.html

Water Balance of Cells Without Walls

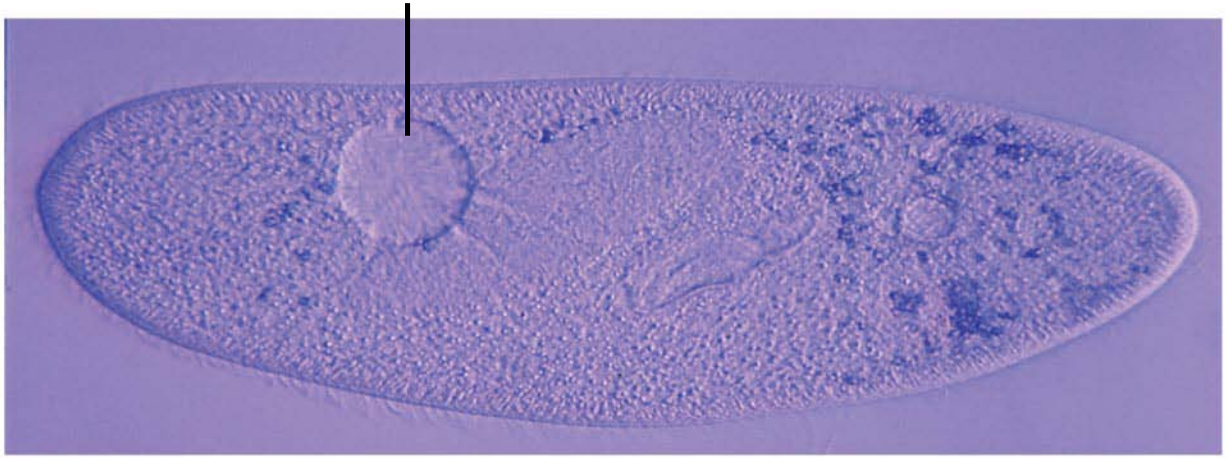
- **Tonicity** is the ability of a solution to cause a cell to gain or lose water
- **Isotonic** solution: Solute concentration is the same as that inside the cell; no net water movement across the plasma membrane
- http://www.youtube.com/watch?v=pIen79Fgmz0&feature=related
- **Hypertonic** solution: Solute concentration is greater than that inside the cell; cell loses water
  http://www.youtube.com/watch?v=IRQLRO3dIp8&NR=1
- **Hypotonic** solution: Solute concentration is less than that inside the cell; cell gains water
- http://www.youtube.com/watch?v=EA_ss8ZkjAM

Fig. 7-13

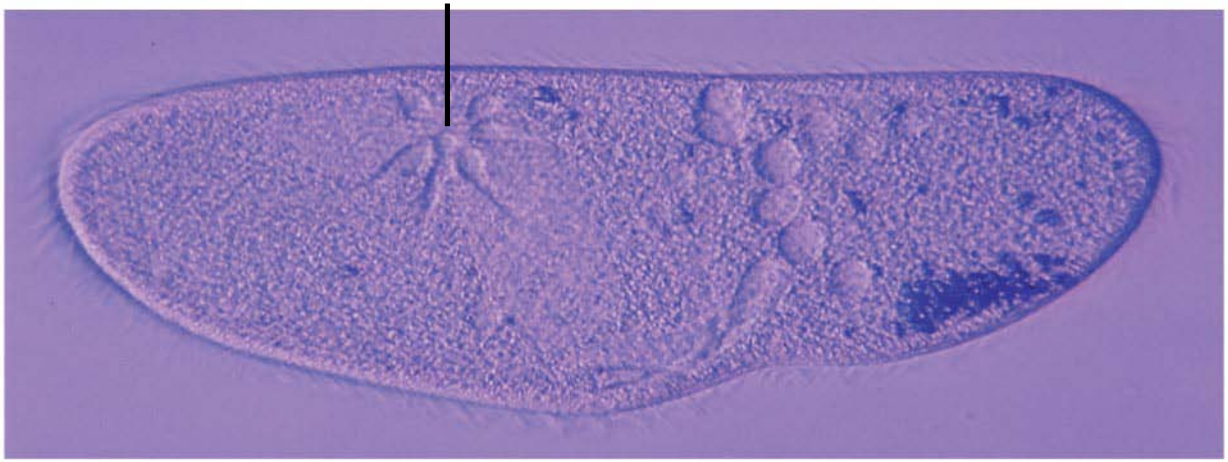

Hypotonic solution
Isotonic solution
Hypertonic solution
(a) Animal cell
H_2O
H_2O
H_2O
H_2O
Lysed
Normal
Shriveled
(b) Plant cell
H_2O
H_2O
H_2O
H_2O
Turgid (normal)
Flaccid
Plasmolyzed

- http://www2.nl.edu/jste/osmosis.htm#Osmosis

Fig. 7-14



(a) A contractile vacuole fills with fluid that enters from a system of canals radiating throughout the cytoplasm.



(b) When full, the vacuole and canals contract, expelling fluid from the cell.

- http://arbl.cvmbs.colostate.edu/hbooks/cmb/cells/pmemb/osmosis_eg.html

CQ#6: What do you expect to happen over time in Brittany's cells?

Inside Cells	Outside Cells
300 mM Salt	250 mM Salt

A. Water will move from inside to outside ONLY.

B. Water will move from outside to inside ONLY.

C. Water will move in both directions, but more water will move inside.

D. Water will move in both directions, but more water will move outside.

E. Water will not move.

Answer: C

So what happened to Brittany?

Brittany was treated for hyponatremia. The treatment included giving her an IV of fluids with normal or slightly higher sodium concentrations to correct the salt imbalance in her tissues.

A problem associated with acute (sudden) hyponatremia, or water intoxication, is swelling of tissues due to osmotic uptake of water by cells. Fortunately, because she received treatment, they were able to reverse the swelling effects before her brain stem was damaged.

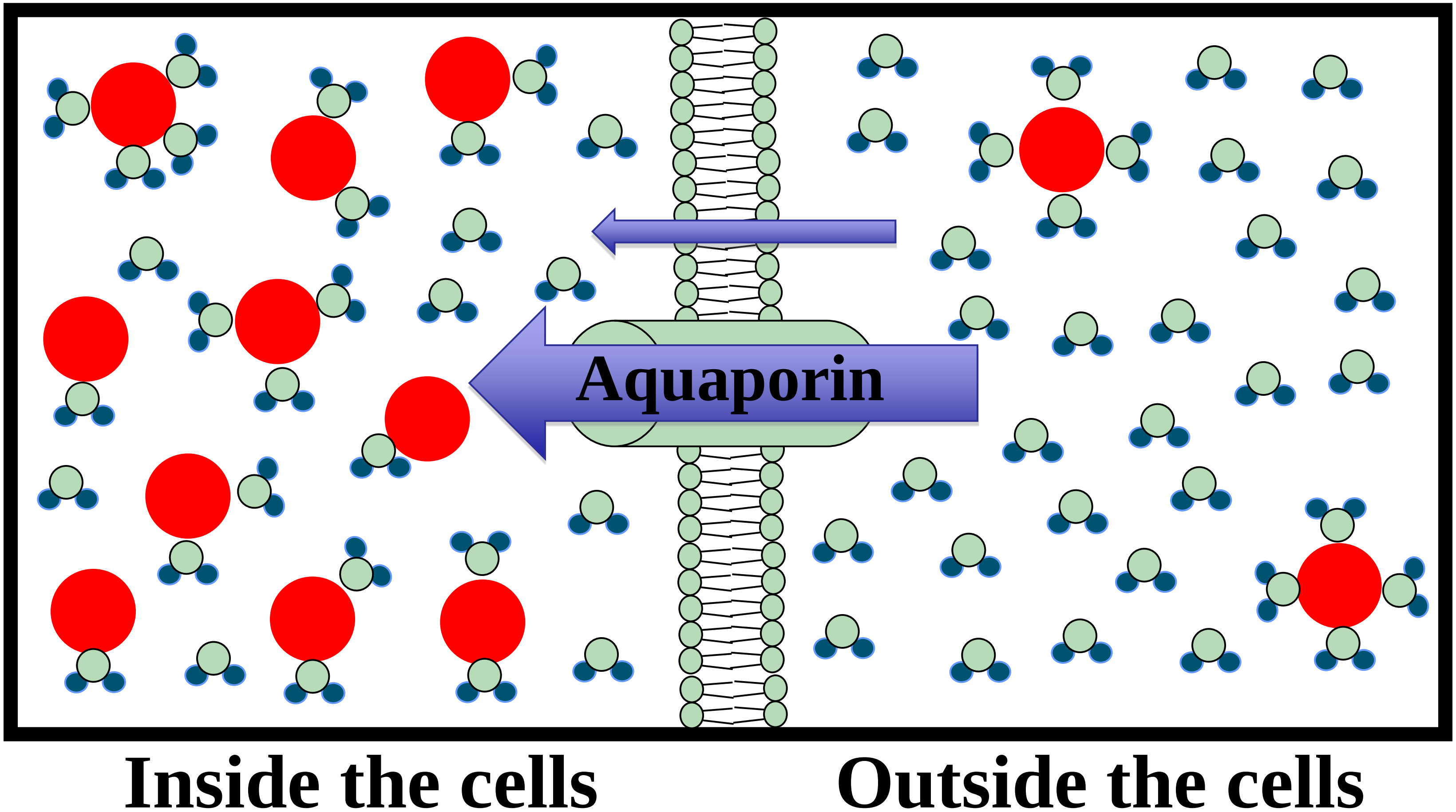
Hyponatremia can be very serious because of the possibility of brain damage.

- http://molo.concord.org/database/activities/233.htm

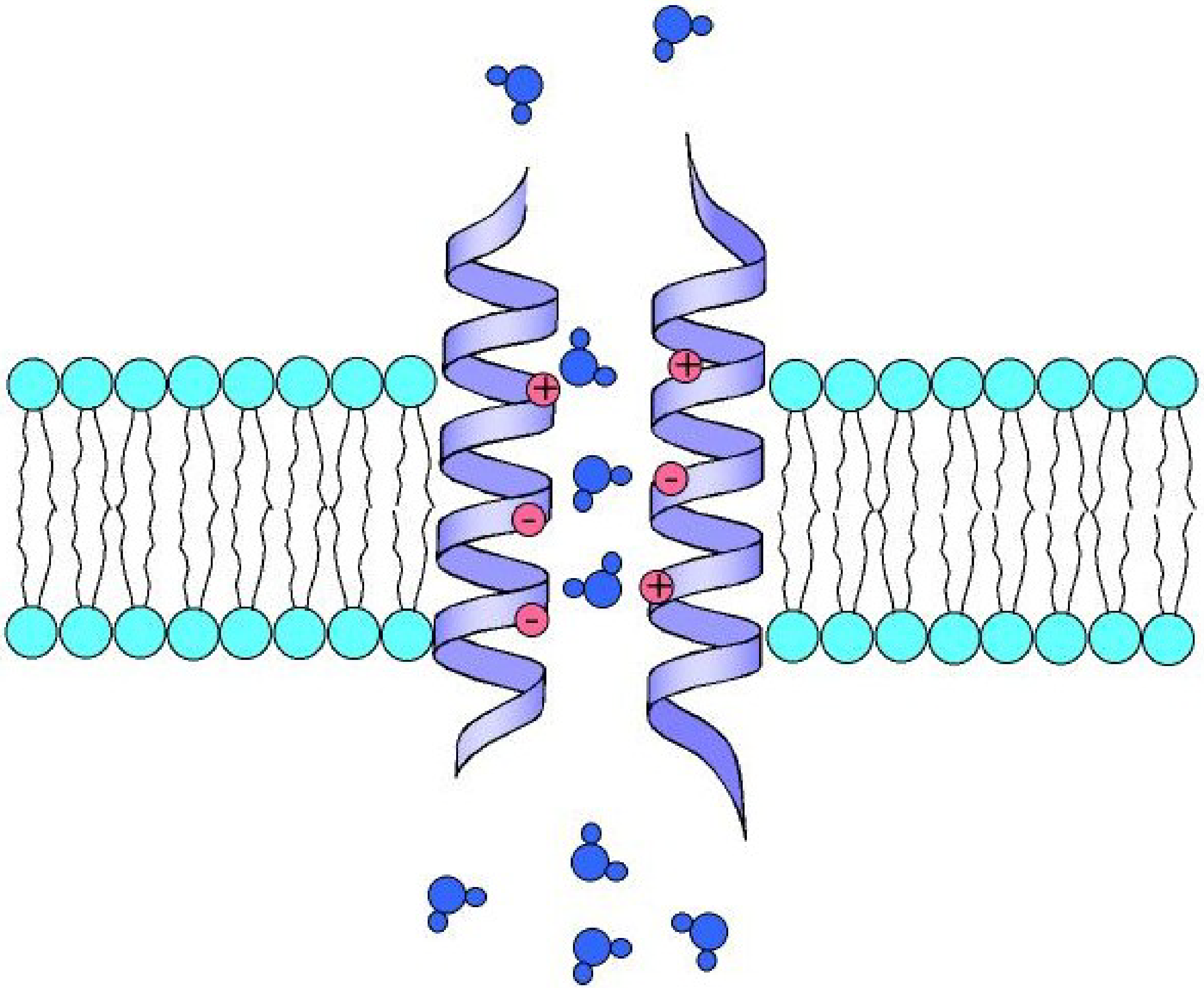
Problems with Hyponatremia

- Brittney Chambers of Colorado (2001), Leah Betts of Great Britain (1995), and Anna Wood of Australia (1995) died after reportedly taking Ecstasy and drinking large amounts of water.
- Fraternity hazing killed Matthew Carrington, a student at California State Chico February 2005.
- In Sacramento, Jennifer Strange died after a water-drinking contest "Hold your wee for a Wii" sponsored by a local radio station, January 2007.
- A 28-year-old female Boston marathoner died in 2002.
- Artist Andy Warhol died after hospital staff accidentally administered excess water after gall bladder surgery (1987).
- Infants fed diluted formula for extended periods of time can suffer from hyponatremia.

Brittany's Tissues



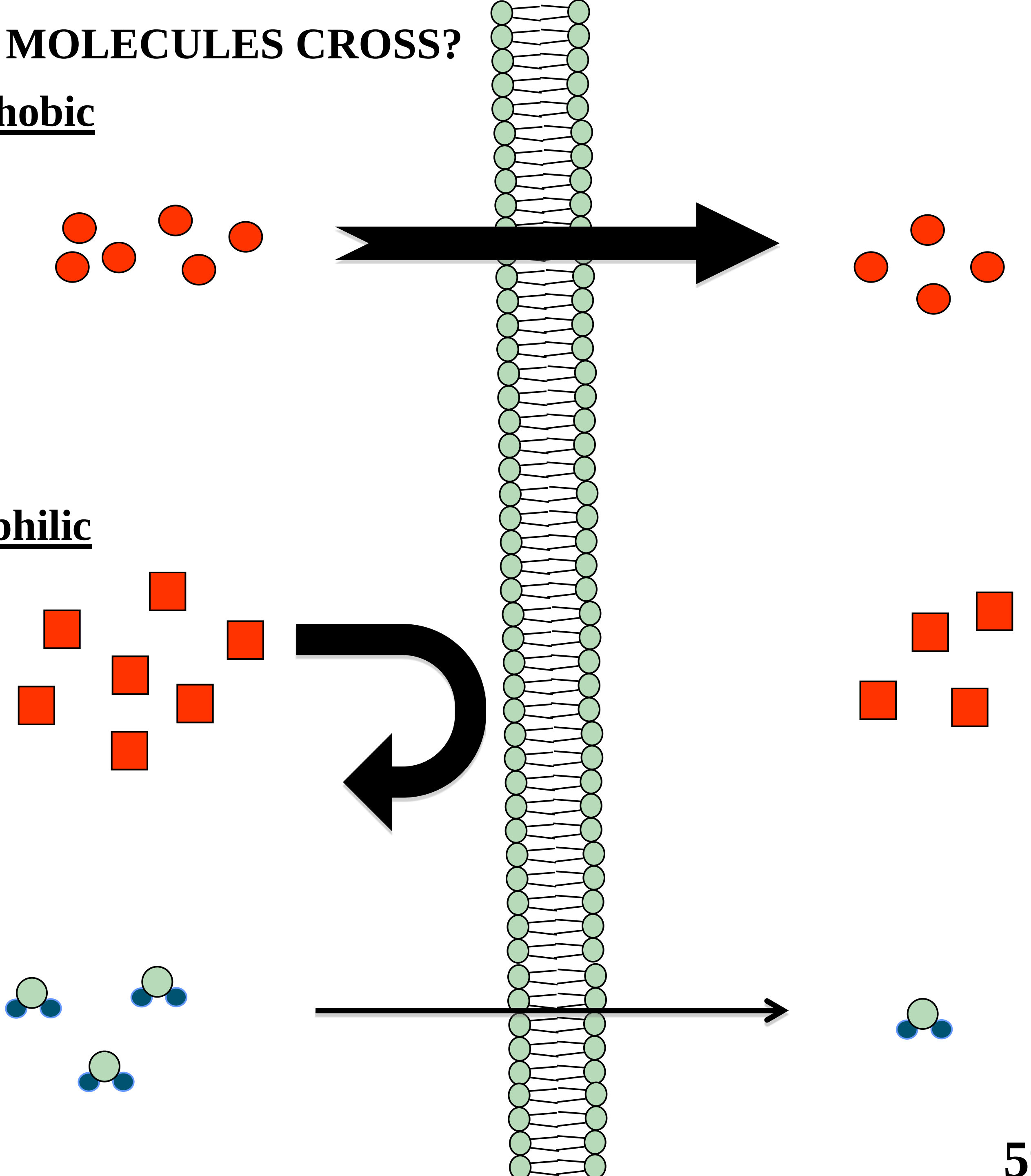
Aquaporins

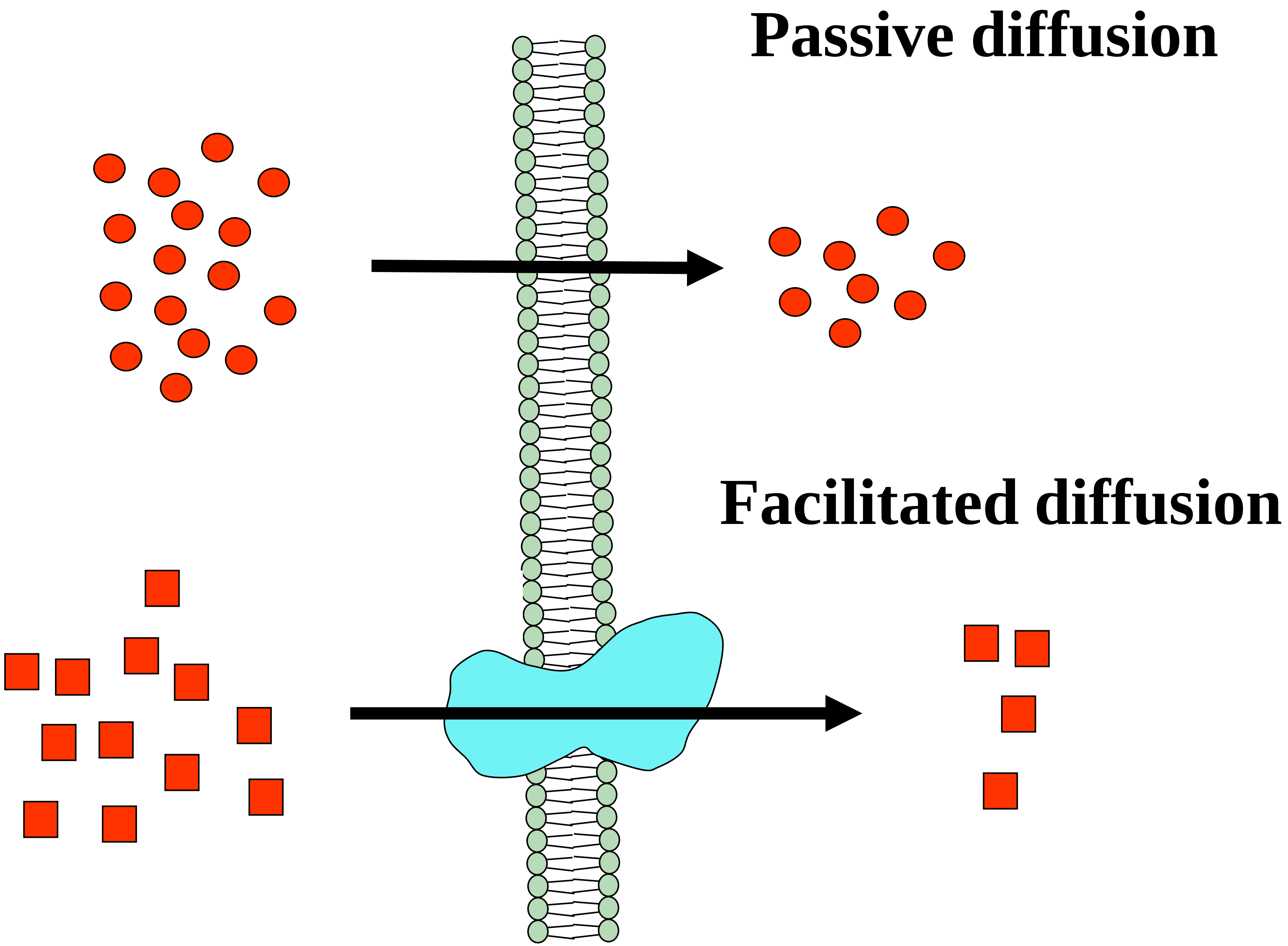


HOW DO MOLECULES CROSS?

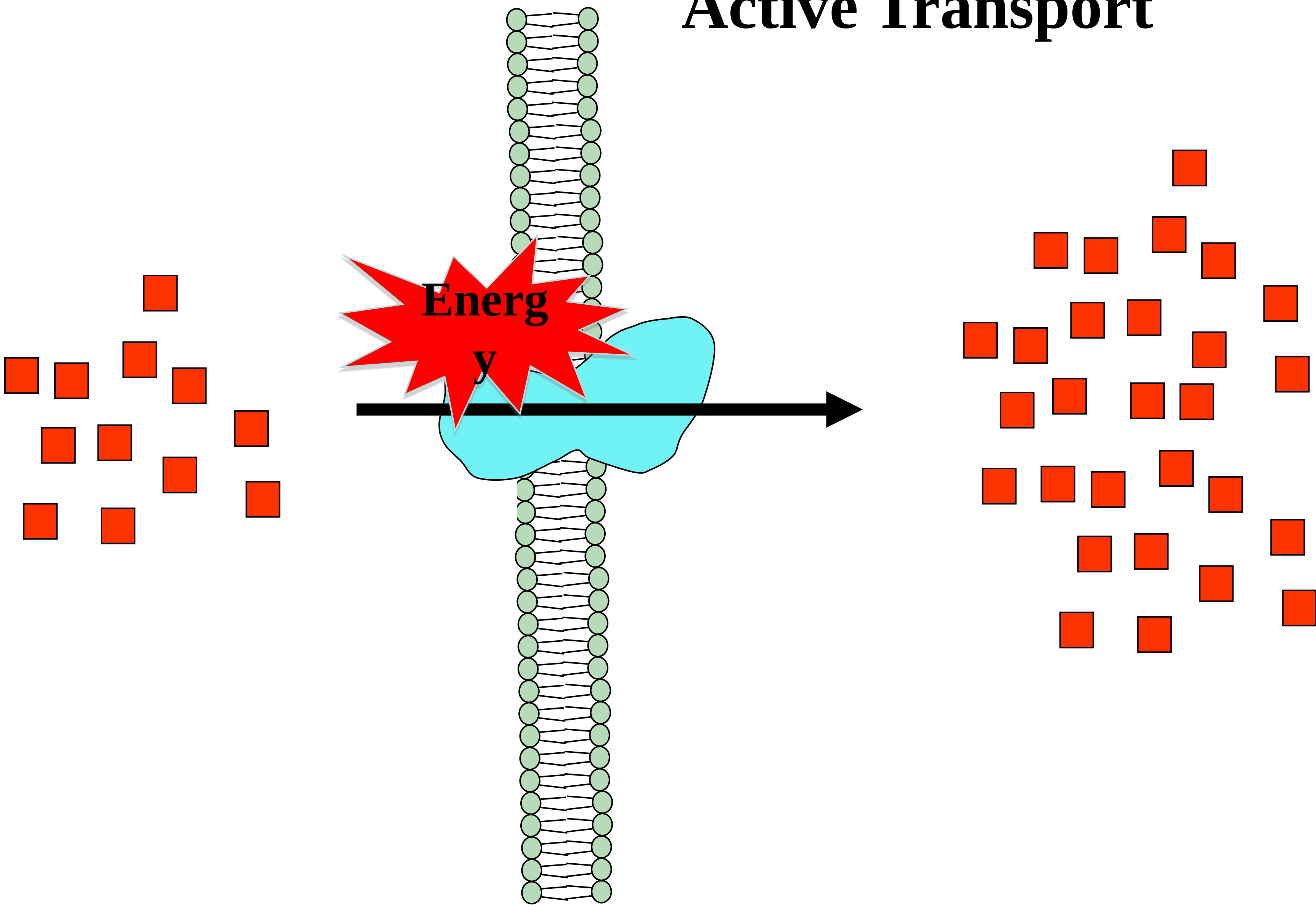
Hydrophobic

Hydrophilic

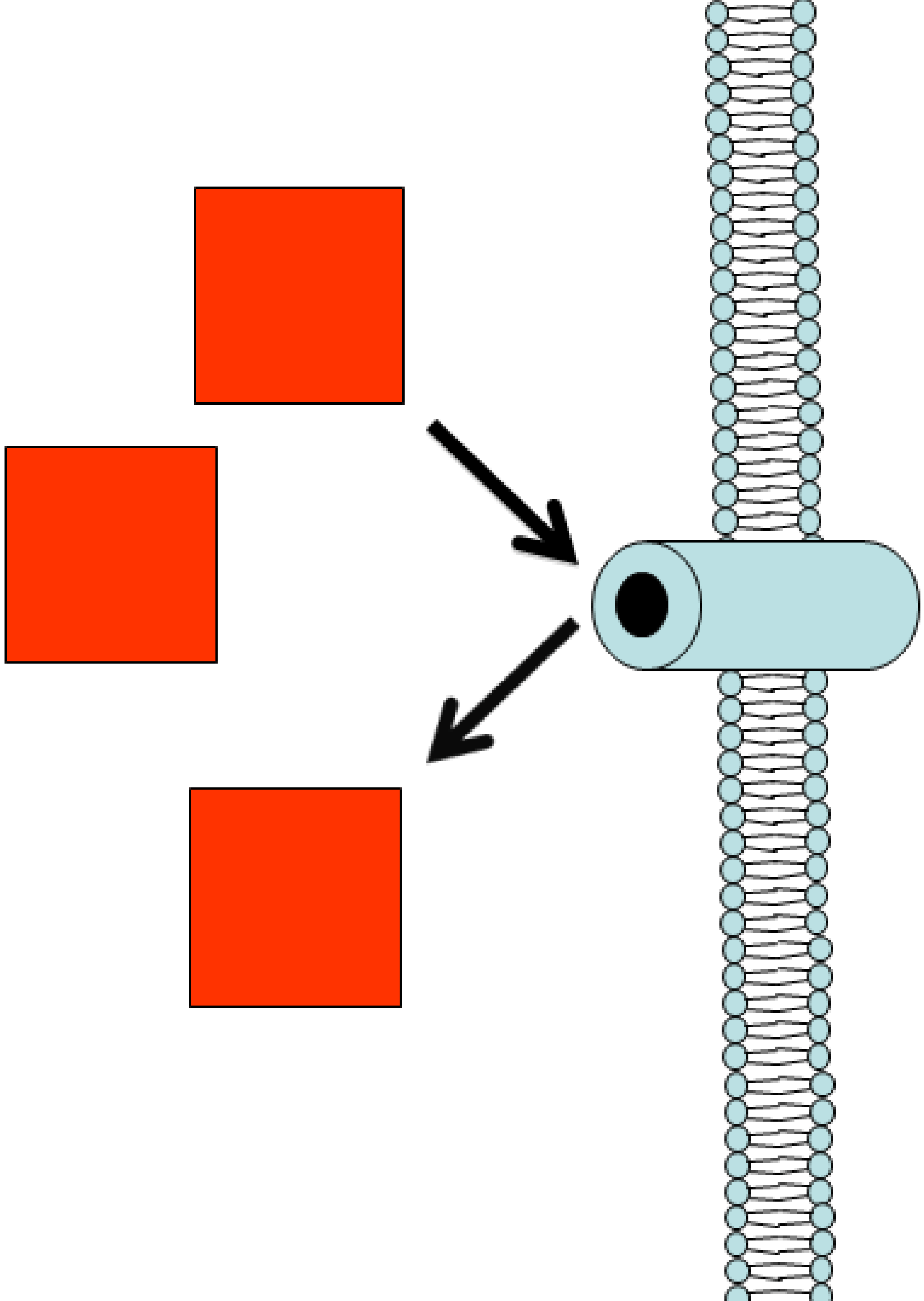



Passive diffusion
Facilitated diffusion

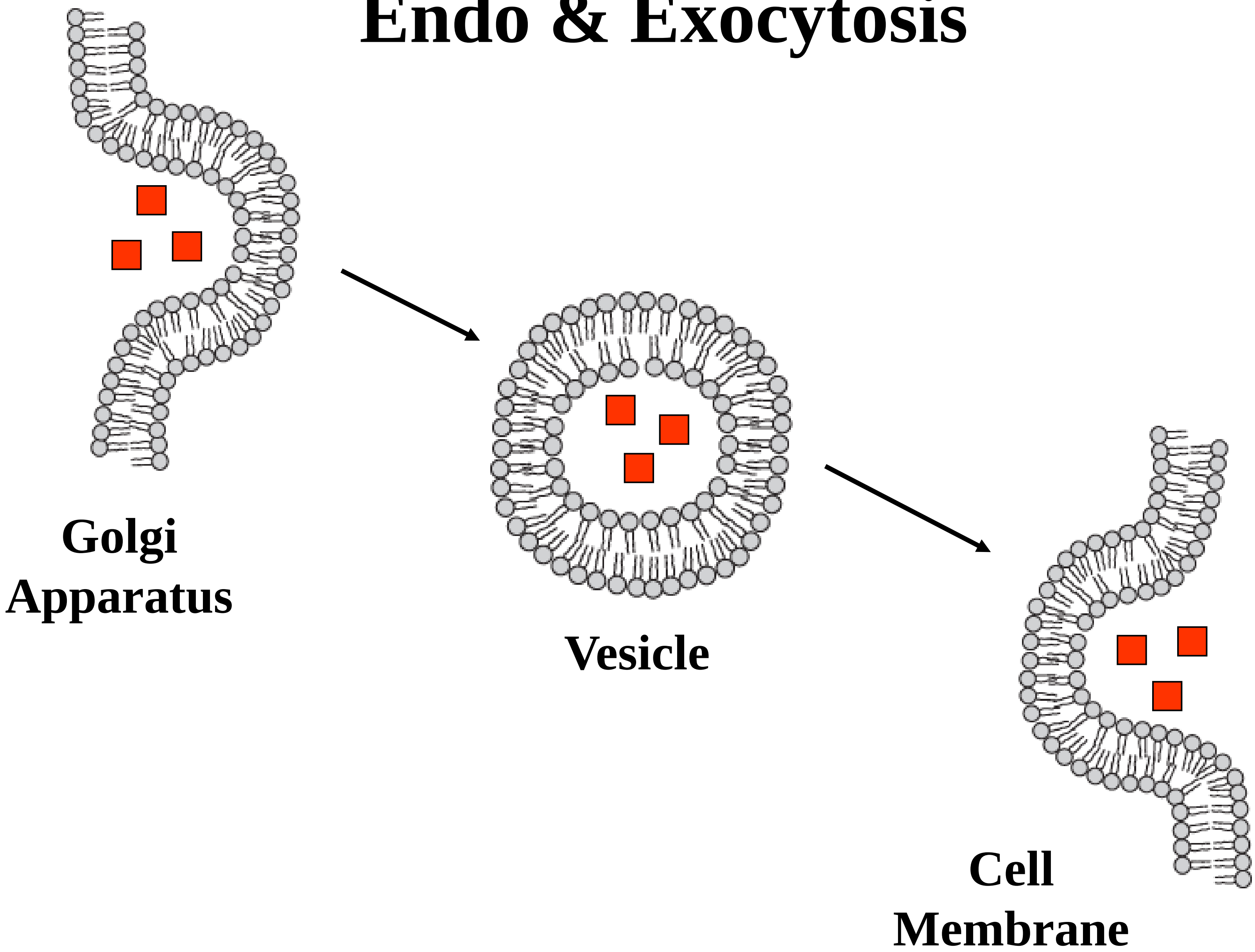
Active Transport



How do big molecules cross?



Endo & Exocytosis



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

AQ#3: When we want to know whether a specific molecule will pass through a biological membrane, we need to consider ...

A. The specific types of lipids present in the membrane.
B. The degree to which the molecule is water soluble.
C. Whether the molecule is actively repelled by the lipid layer.
D. Whether the molecule is harmful to the cell.

Answer: B

- 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

- Hypertonic or hypotonic environments create osmotic problems for organisms
- **Osmoregulation**, the control of water balance, is a necessary adaptation for life in such environments
- The protist *Paramecium,* which is hypertonic to its pond water environment, has a contractile vacuole that acts as a pump

PLAY Video: *Chlamydomonas*

PLAY Video: *Paramecium* Vacuole

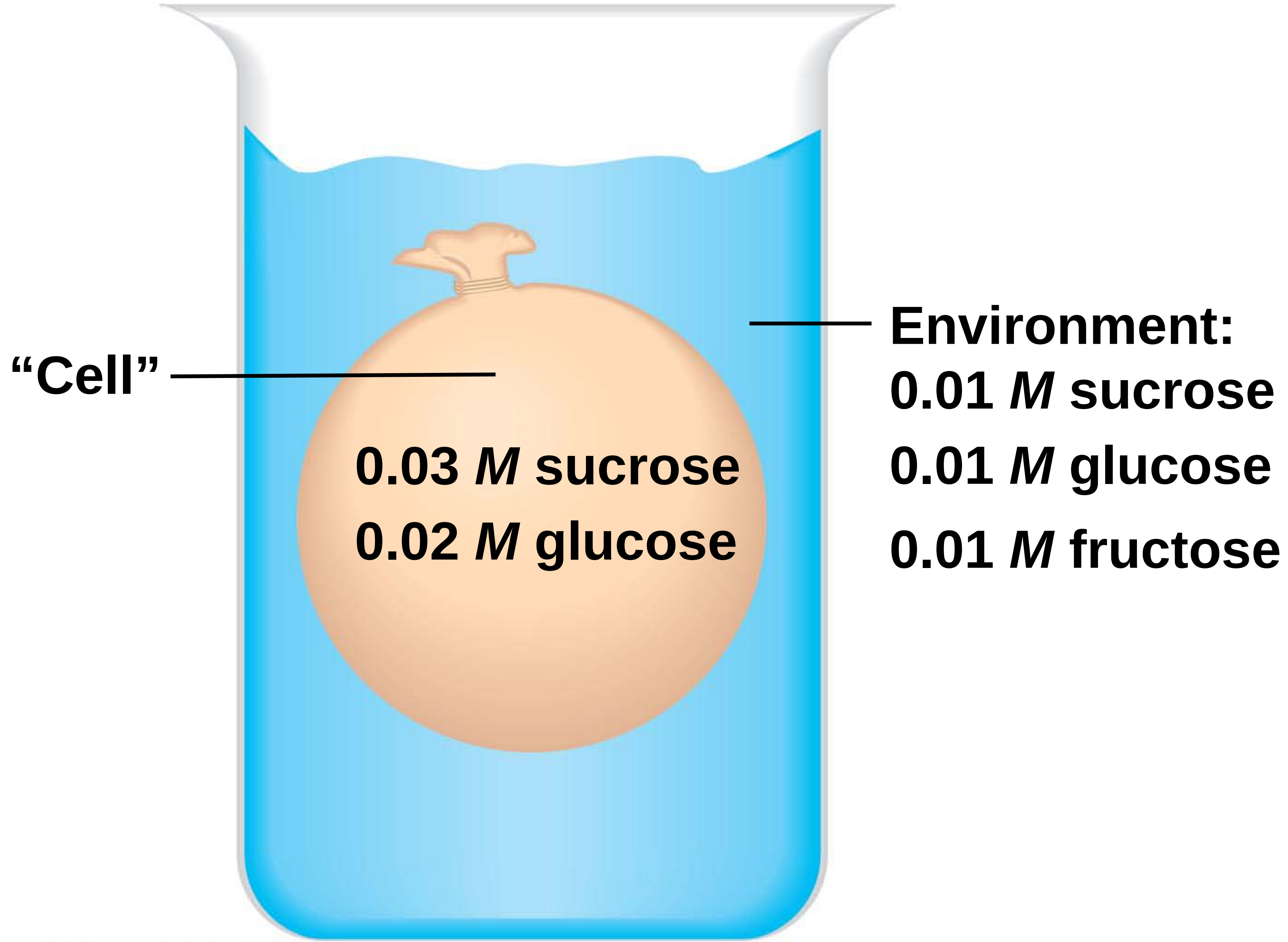
Water Balance of Cells with Walls

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

- In a hypertonic environment, plant cells lose water; eventually, the membrane pulls away from the wall, a usually lethal effect called **plasmolysis**

PLAY Animation: Osmosis

Fig. 7-UN3


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

AQ#5: Swimming in the ocean, you cut yourself on a seashell. The seawater has a solute concentration of 0.3 M. The fluid in your body has a solute concentration of 0.27 M. When one of your red blood cells (RBCs) enters the water, what would you expect to happen?

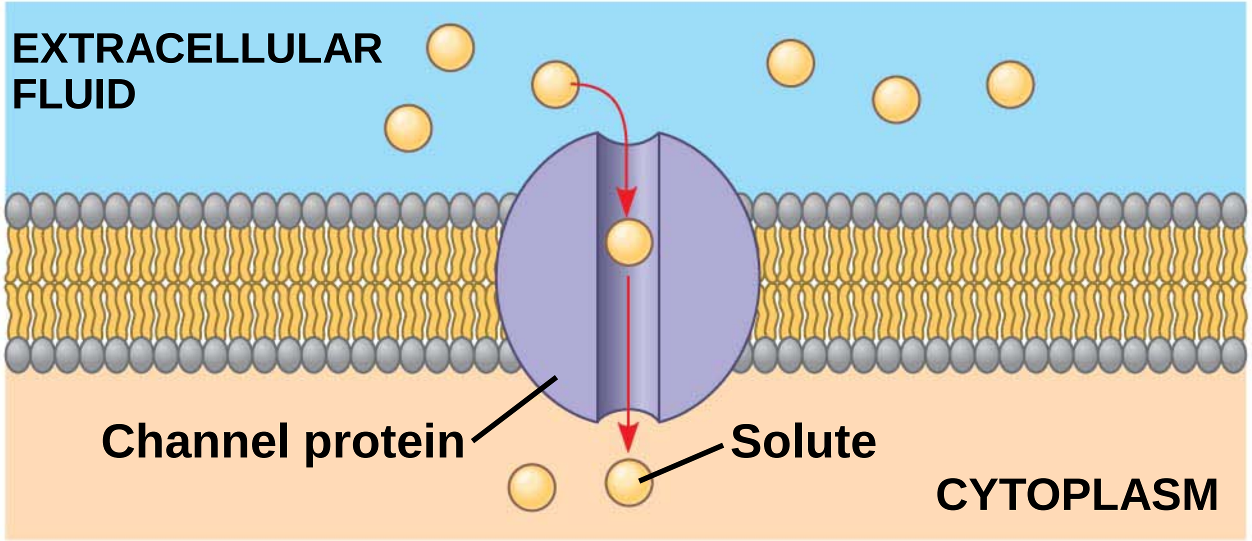
A. Nothing, the RBCs membranes do not allow salt or water to pass.
B. Water and salt will enter the cell.
C. Water will enter and leave the cell but more will enter.
D. Water will enter and leave the cell but more will leave.
E. Water and salt will leave the cell.

Answer: D

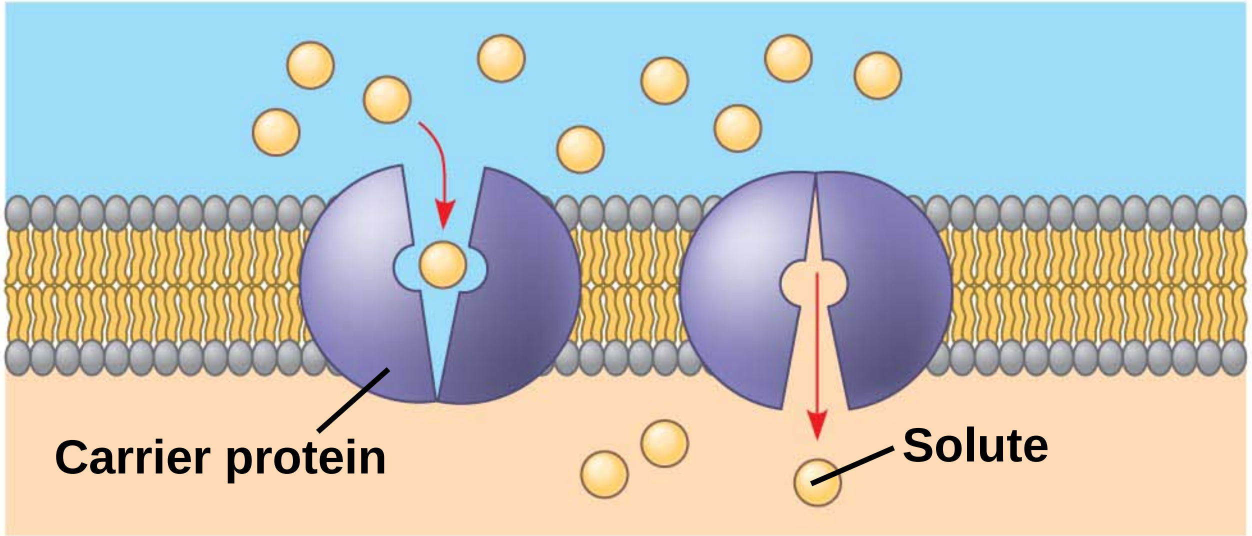
Facilitated Diffusion: Passive Transport Aided by Proteins

- In **facilitated diffusion**, transport proteins speed the passive movement of molecules across the plasma membrane
- Channel proteins provide corridors that allow a specific molecule or ion to cross the membrane
- http://www.youtube.com/watch?v=s0p1ztrbXPY&NR=1
- Channel proteins include
  - Aquaporins, for facilitated diffusion of water
  - **Ion channels** that open or close in response to a stimulus (**gated channels**)

Fig. 7-15



(a) A channel protein



(b) A carrier protein

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

- Some diseases are caused by malfunctions in specific transport systems, for example the kidney disease cystinuria https://health.google.com/health/ref/Cystinuria

Concept 7.4: 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

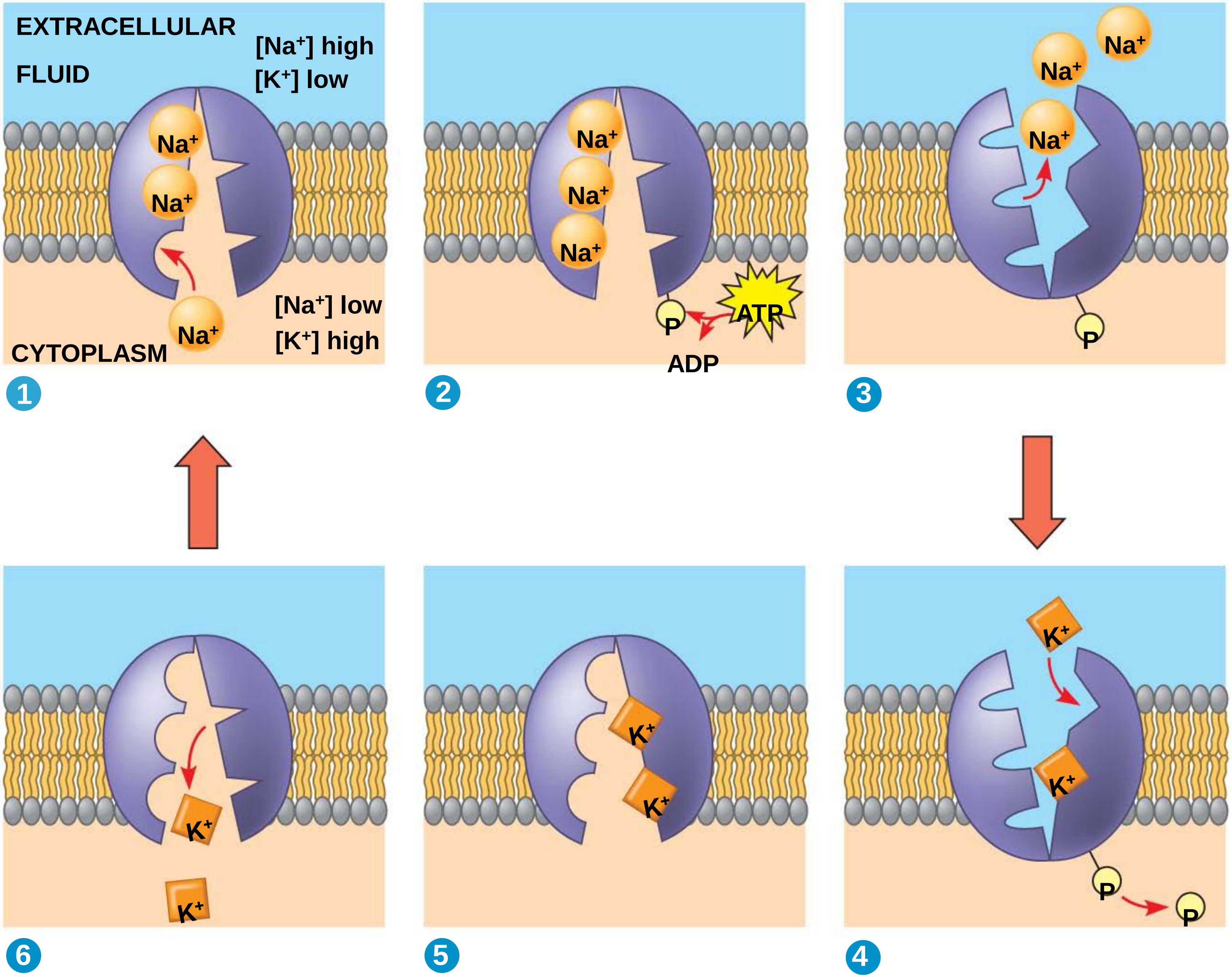
The Need for Energy in Active Transport

- **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
- http://www.youtube.com/watch?v=STzOiRqzzL4&feature=related

PLAY Animation: Active Transport

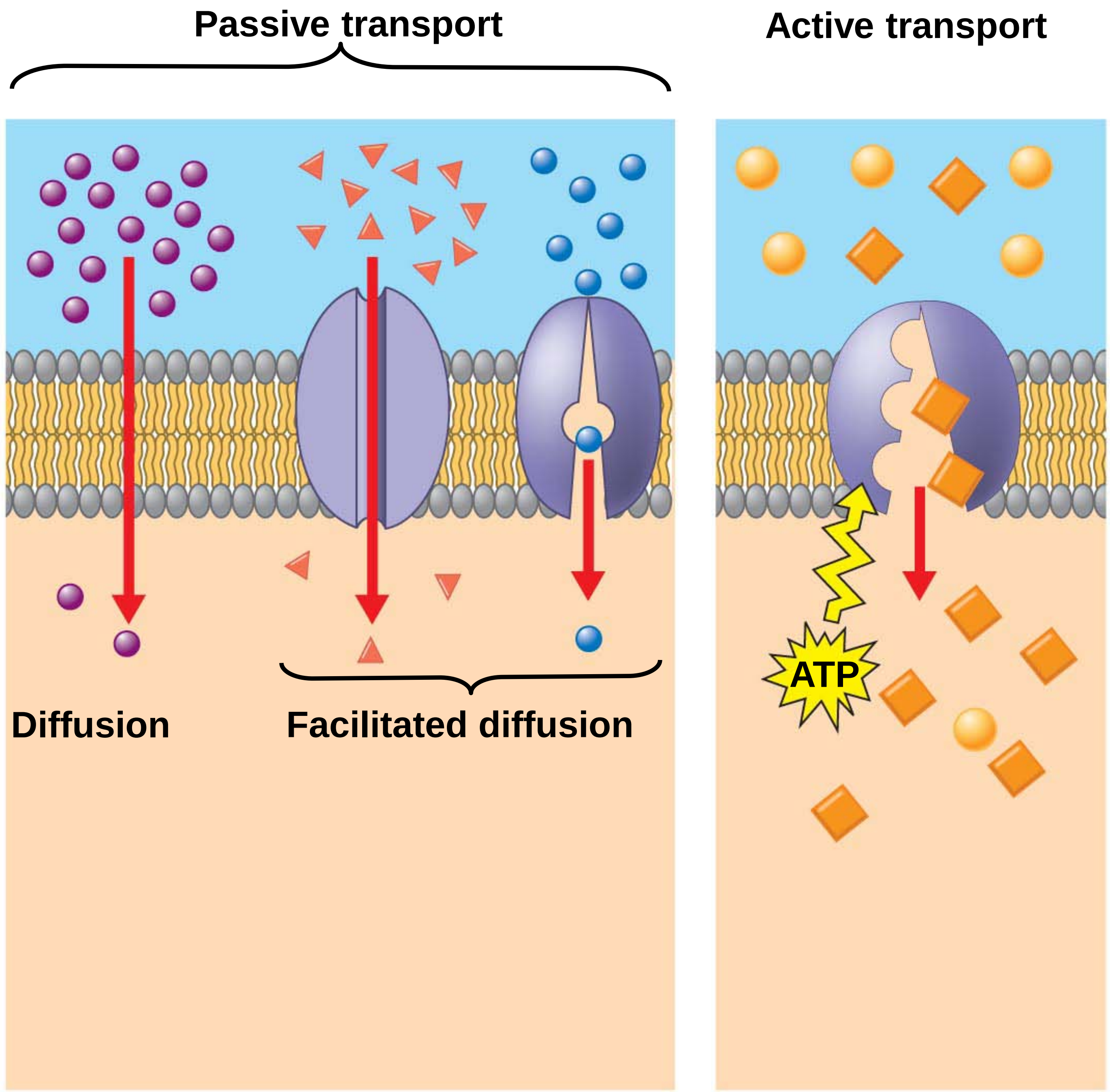
- Active transport allows cells to maintain concentration gradients that differ from their surroundings
- The **sodium-potassium pump** is one type of active transport system

Fig. 7-16-7


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

- http://highered.mcgraw-hill.com/sites/0072437316/student_view0/chapter6/animations.html#

Fig. 7-17


Passive transport
Active transport
ATP
Diffusion
Facilitated diffusion

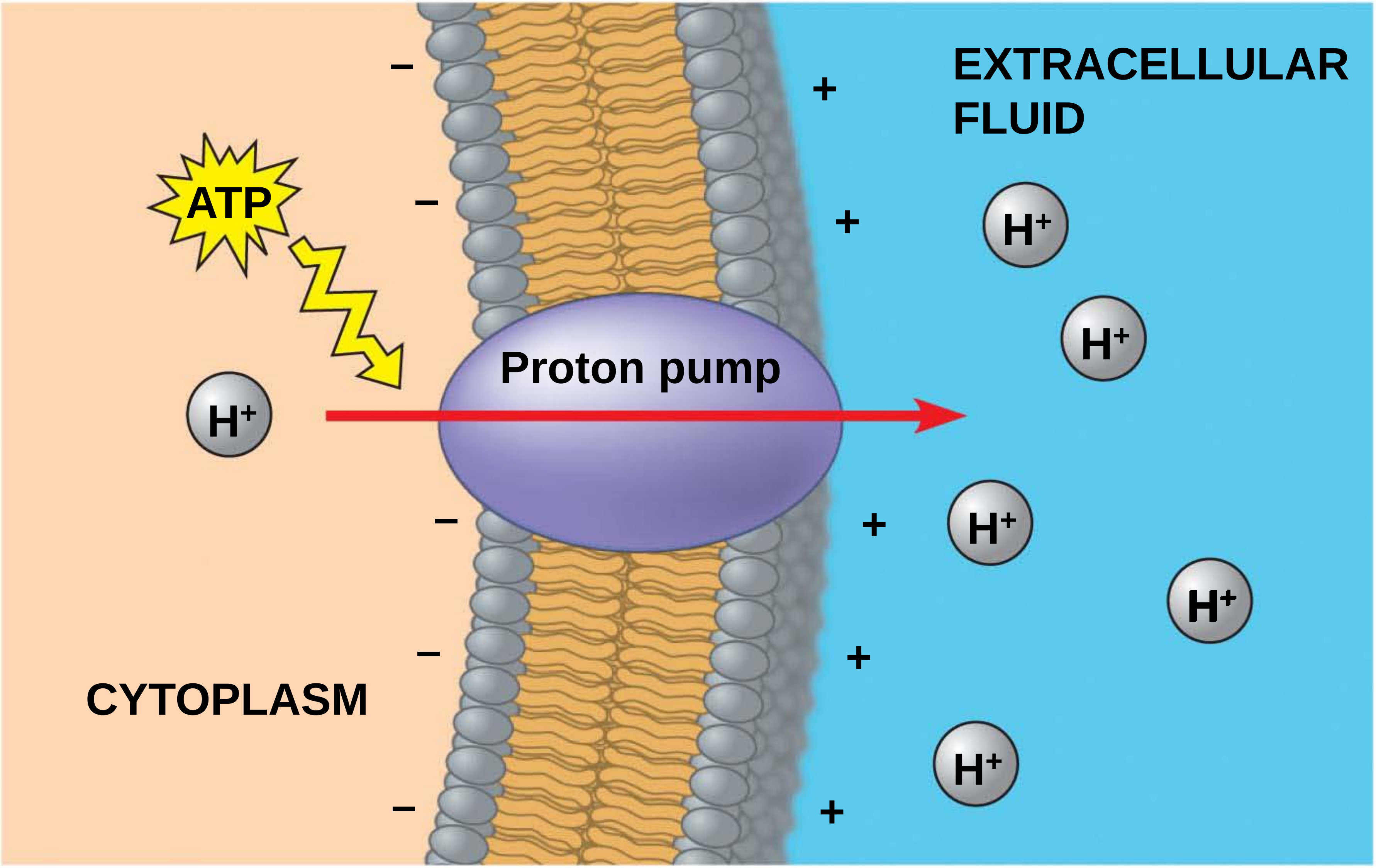
How Ion Pumps Maintain Membrane Potential

- **Membrane potential** is the voltage difference across a membrane
- Voltage is created by differences in the distribution of positive and negative ions

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

- An **electrogenic pump** is a transport protein that generates voltage across a membrane
- The sodium-potassium pump is the major electrogenic pump of animal cells
- The main electrogenic pump of plants, fungi, and bacteria is a **proton pump**

Fig. 7-18

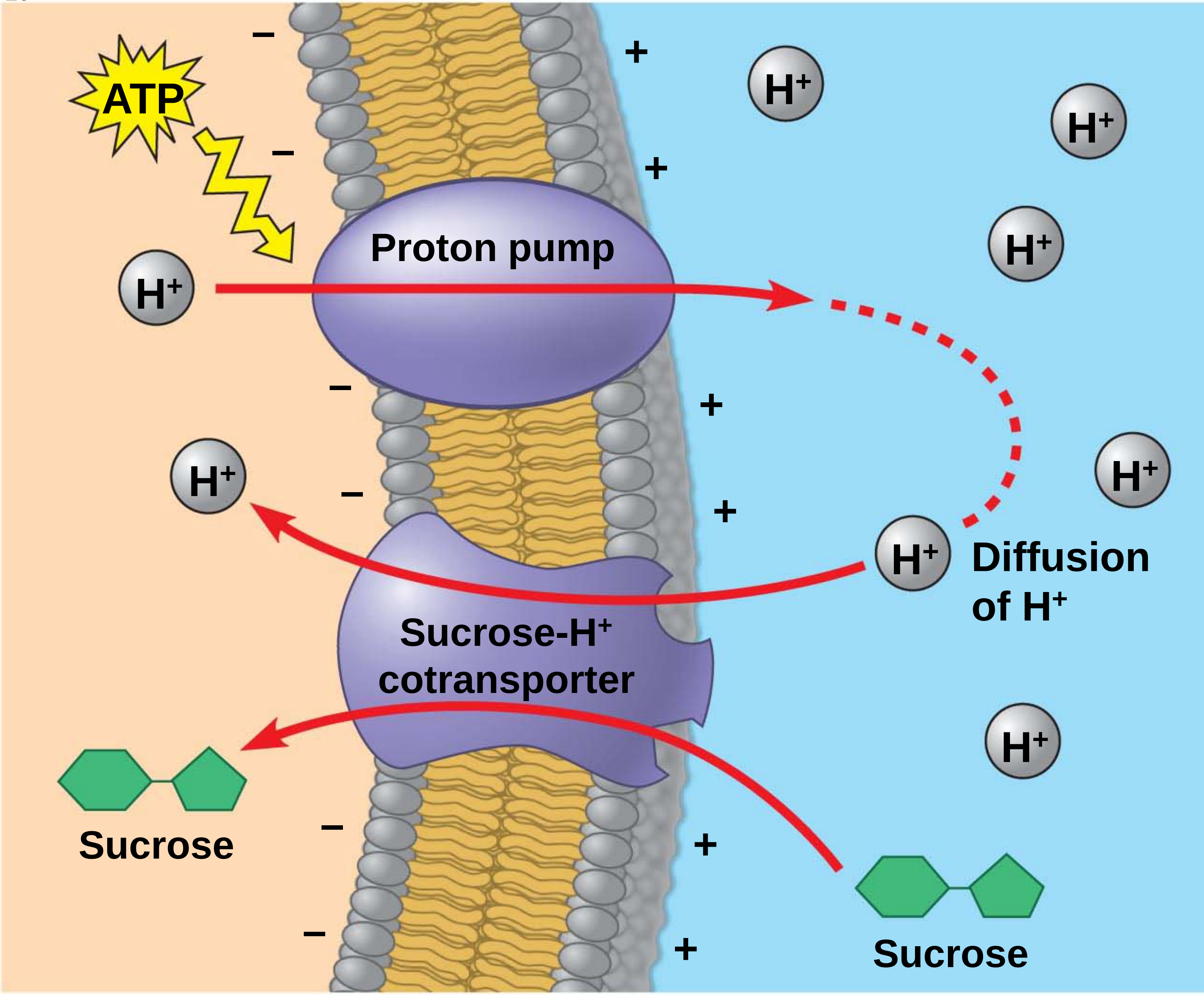


- http://highered.mcgraw-hill.com/sites/0072437316/student_view0/chapter6/animations.html#

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

Fig. 7-19


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

- Movie

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 by transport proteins
- Large molecules, such as polysaccharides and proteins, cross the membrane in bulk via vesicles
- Bulk transport requires energy

Exocytosis

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

PLAY Animation: Exocytosis

Endocytosis

- In **endocytosis**, the cell takes in macromolecules by forming vesicles from the plasma membrane
- Endocytosis is a reversal of exocytosis, involving different proteins
- There are three types of endocytosis:
  - Phagocytosis (“cellular eating”)
  - Pinocytosis (“cellular drinking”)
  - Receptor-mediated endocytosis
  - Movie

PLAY

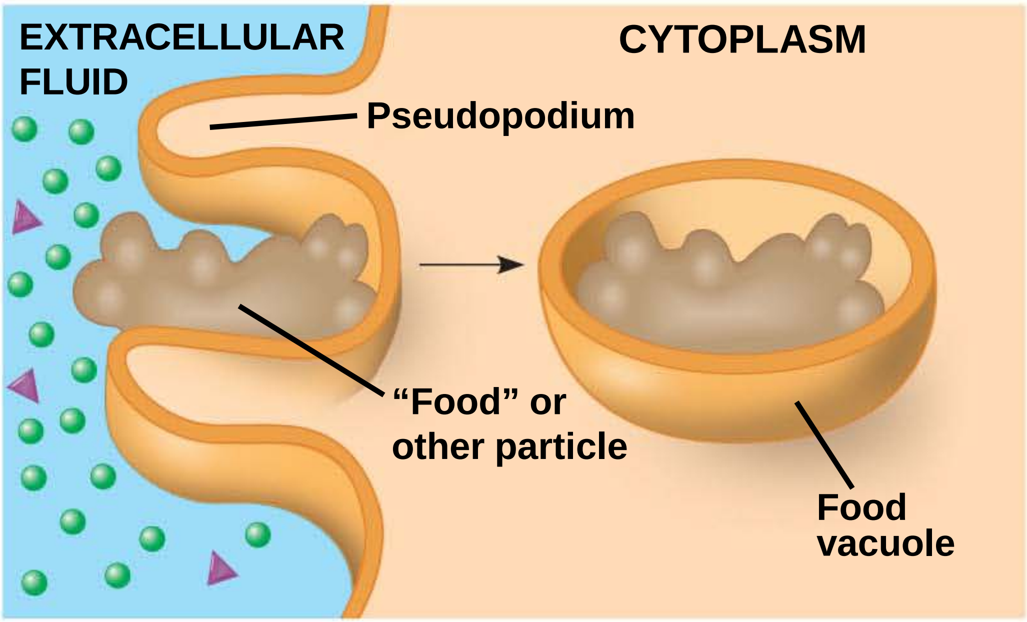
Animation: Exocytosis and Endocytosis Introduction

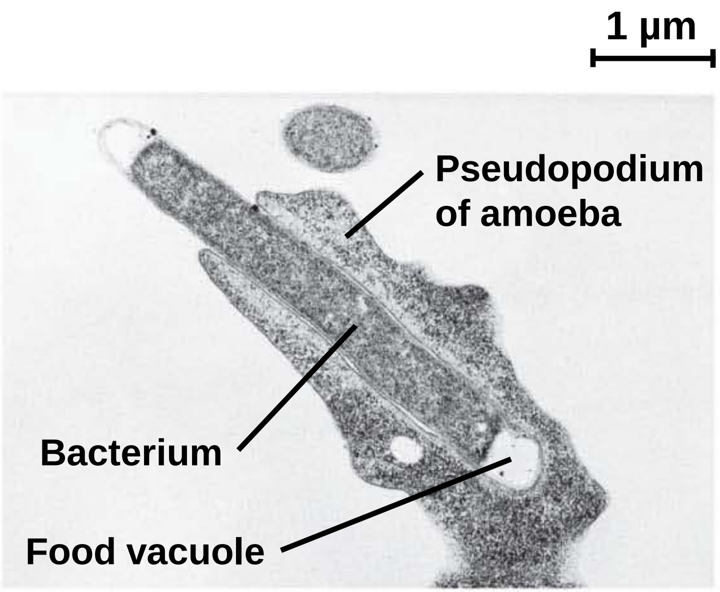
- In **phagocytosis** a cell engulfs a particle in a vacuole
- The vacuole fuses with a lysosome to digest the particle
- http://www.youtube.com/watch?v=JnlULOjUhSQ&feature=related

PLAY Animation: Phagocytosis

Fig. 7-20a

PHAGOCYTOSIS





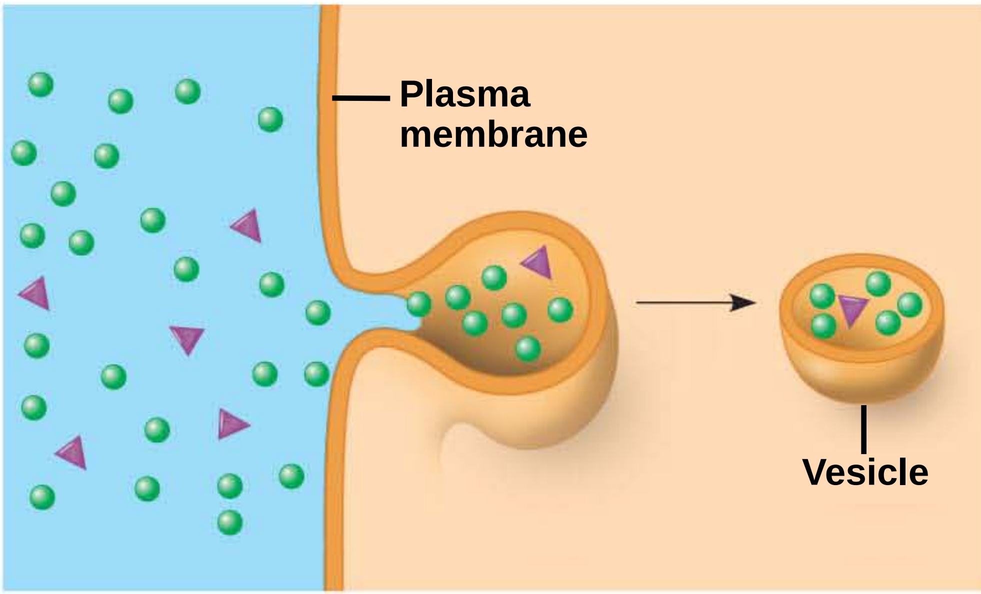
An amoeba engulfing a bacterium via phagocytosis (TEM)

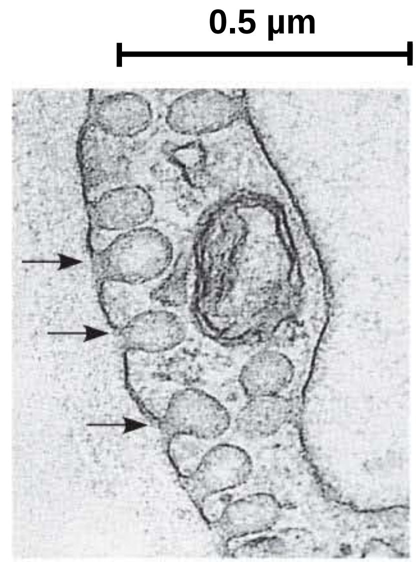
- In **pinocytosis**, molecules are taken up when extracellular fluid is "gulped" into tiny vesicles

PLAY Animation: Pinocytosis

Fig. 7-20b

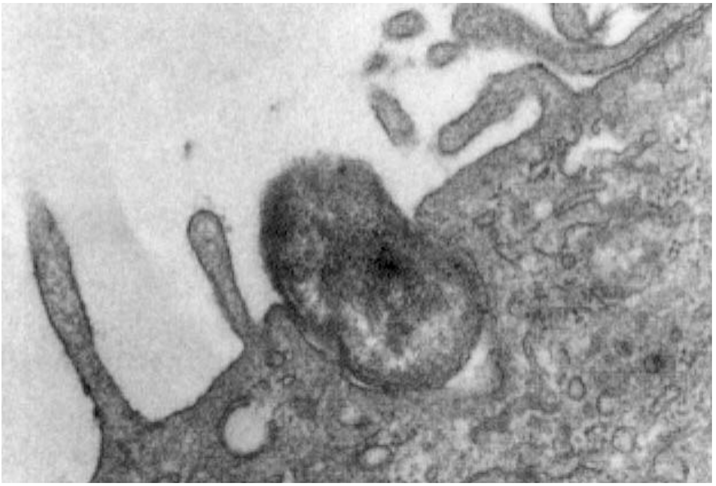
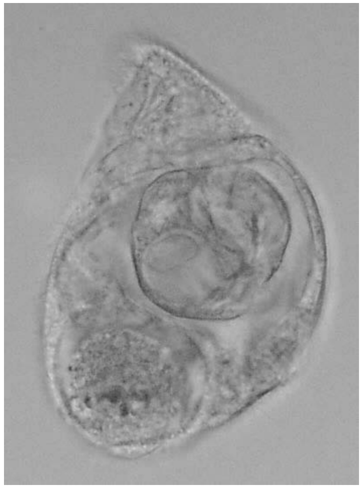
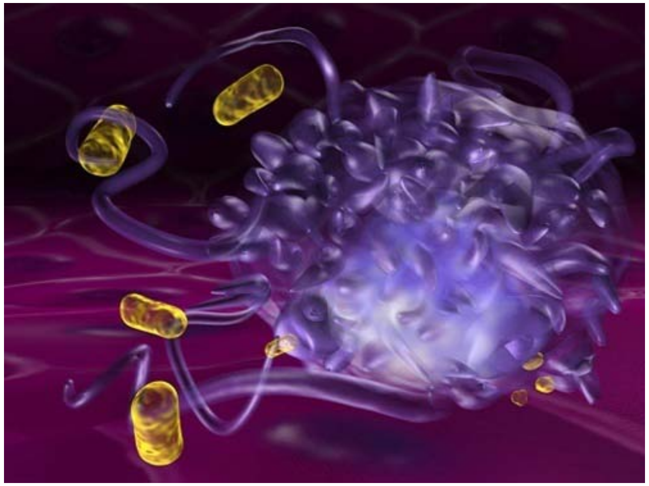
PINOCYTOSIS

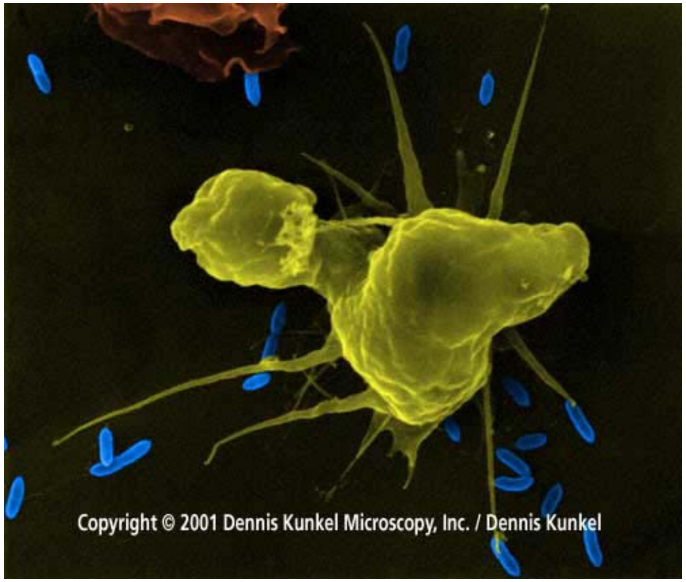


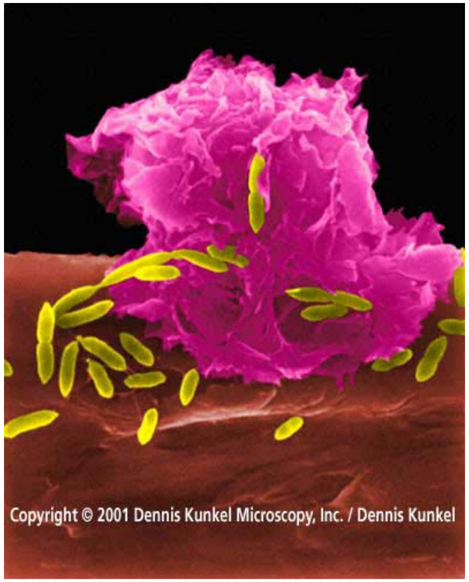


Pinocytosis vesicles forming (arrows) in a cell lining a small blood vessel (TEM)

Phagocytosis: Examples



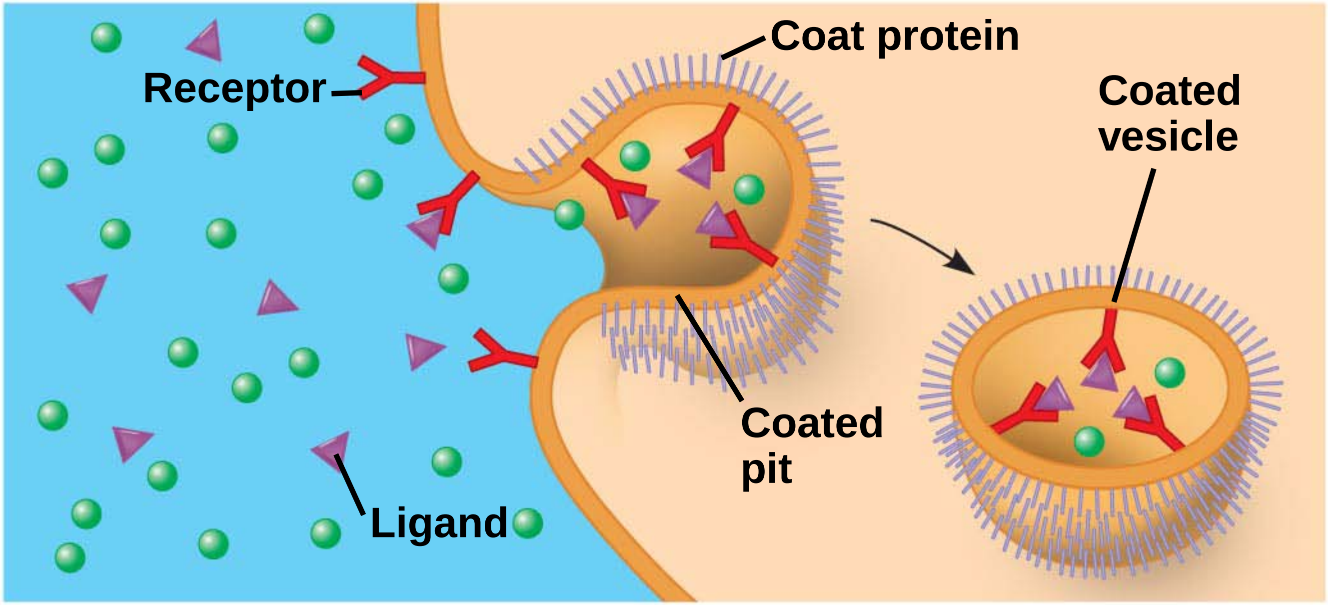


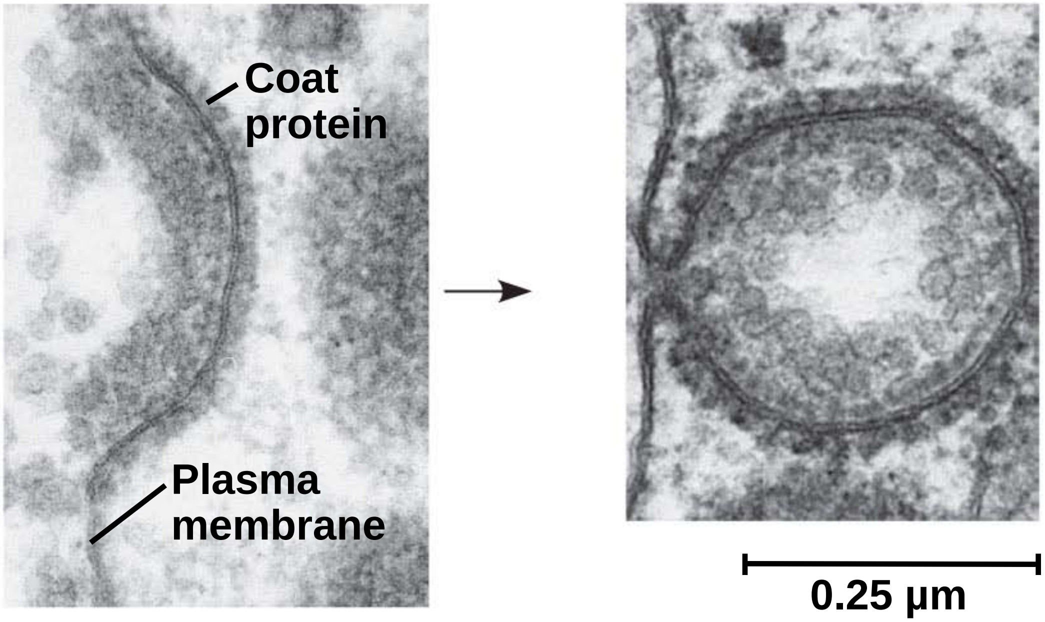
- In **receptor-mediated endocytosis**, binding of ligands to receptors triggers vesicle formation
- A **ligand** is any molecule that binds specifically to a receptor site of another molecule

PLAY **Animation: Receptor-Mediated Endocytosis**

Fig. 7-20c

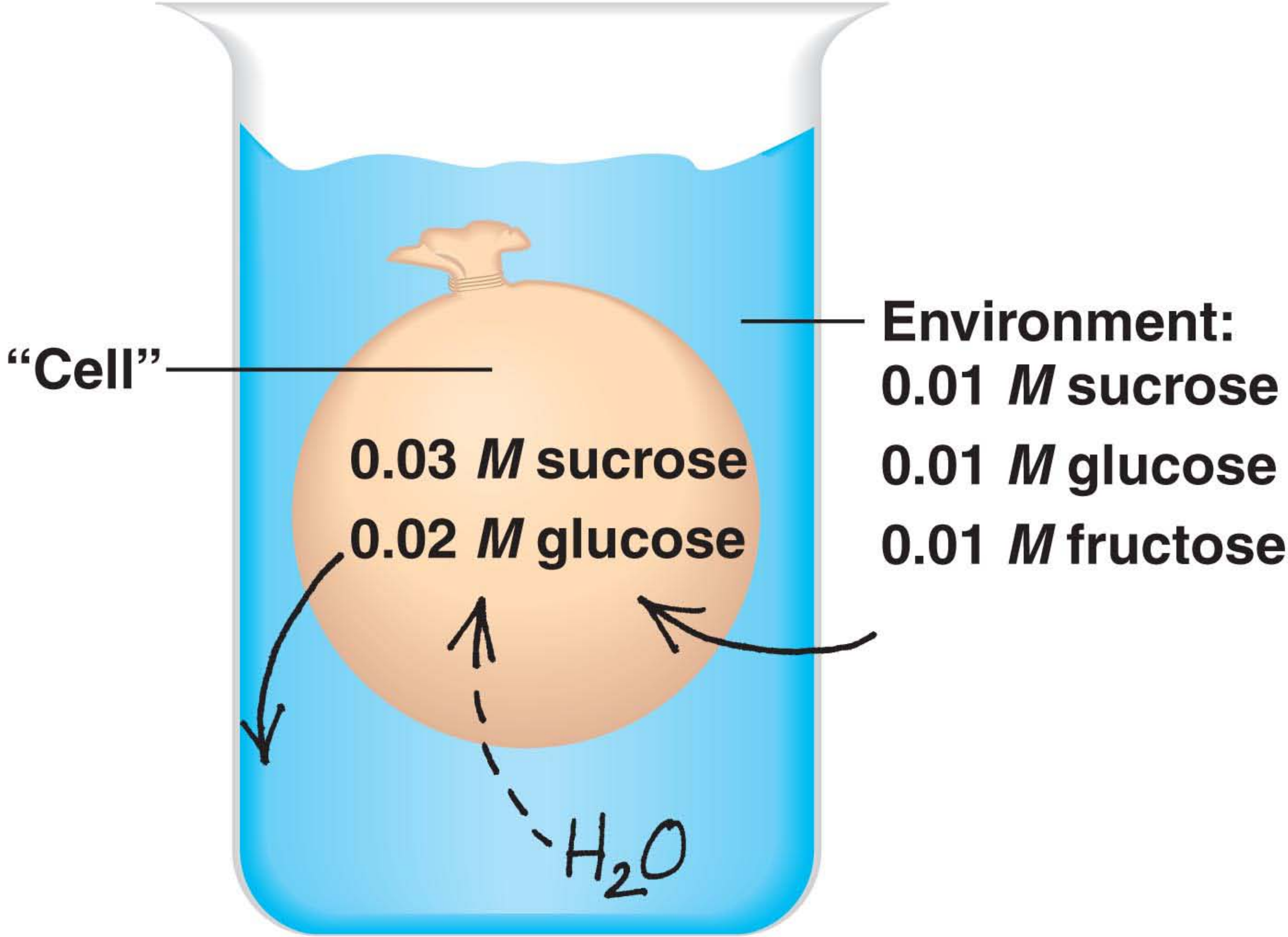
RECEPTOR-MEDIATED ENDOCYTOSIS





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

Fig. 7-UN4



"Cell"
0.03 M sucrose
0.02 M glucose
Environment:
0.01 M sucrose
0.01 M glucose
0.01 M fructose
H2O

AQ#4: When sodium ions cross a membrane:

A. They must move down its concentration gradient.

B. They diffuse across the bilayer without any help.

C. They are helped across by proteins.

D. Sodium ions can never cross membranes.

Answer: C