Cell Membrane Structure and Function

PREFACE

- The plasma membrane is the edge of life.
- All cells have a plasma membrane.
- It enables and maintains an internal environment of the cell that is different from its surrounding external environment.
- The plasma membrane is **selectively permeable**, it controls the traffic of molecules into and out from the cell.

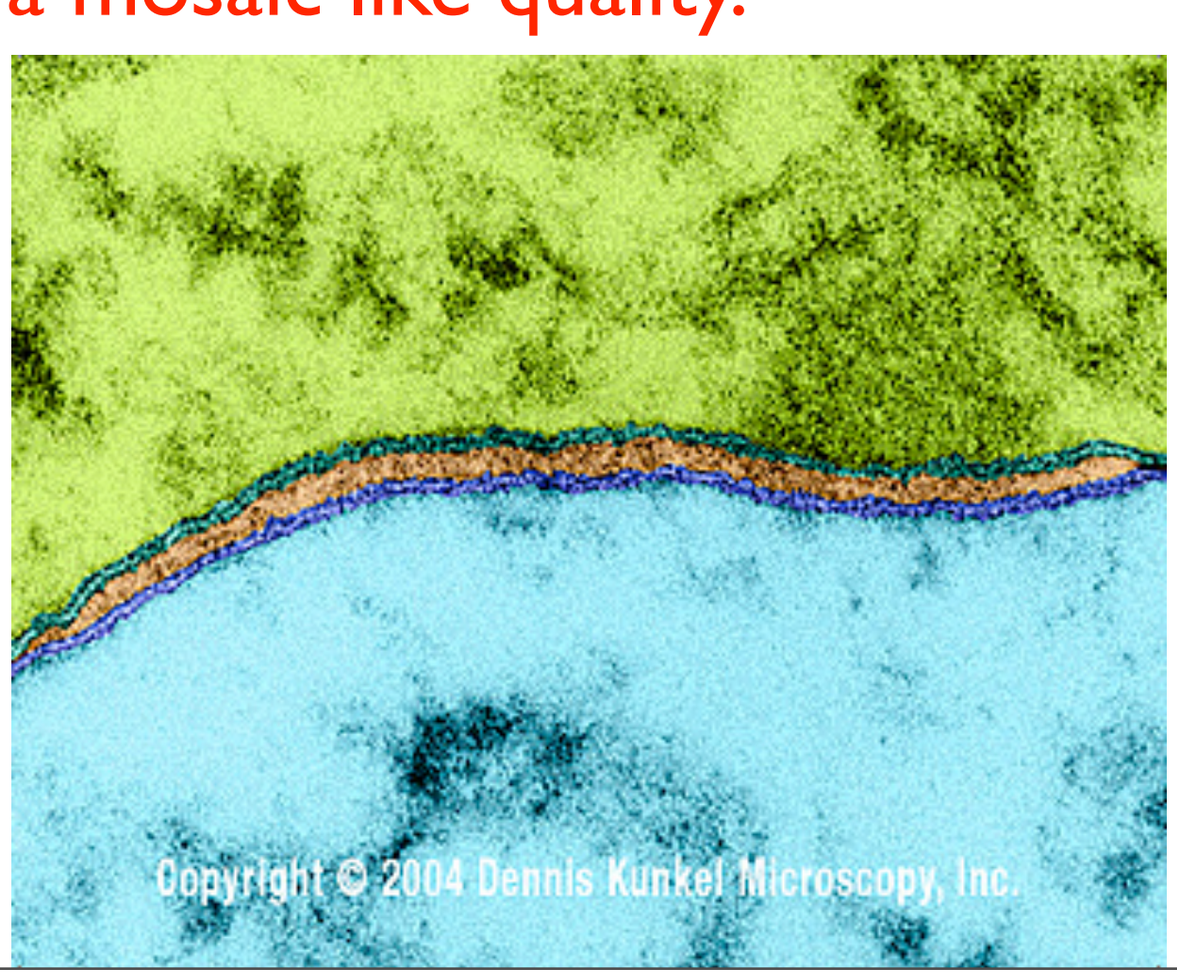
All told, each one of us has enough membranes in our body to cover about 75 soccer fields!

Cell Membranes

I.

Main Idea: Membranes are composed of primarily phospholipids which give the membrane a fluid like quality.

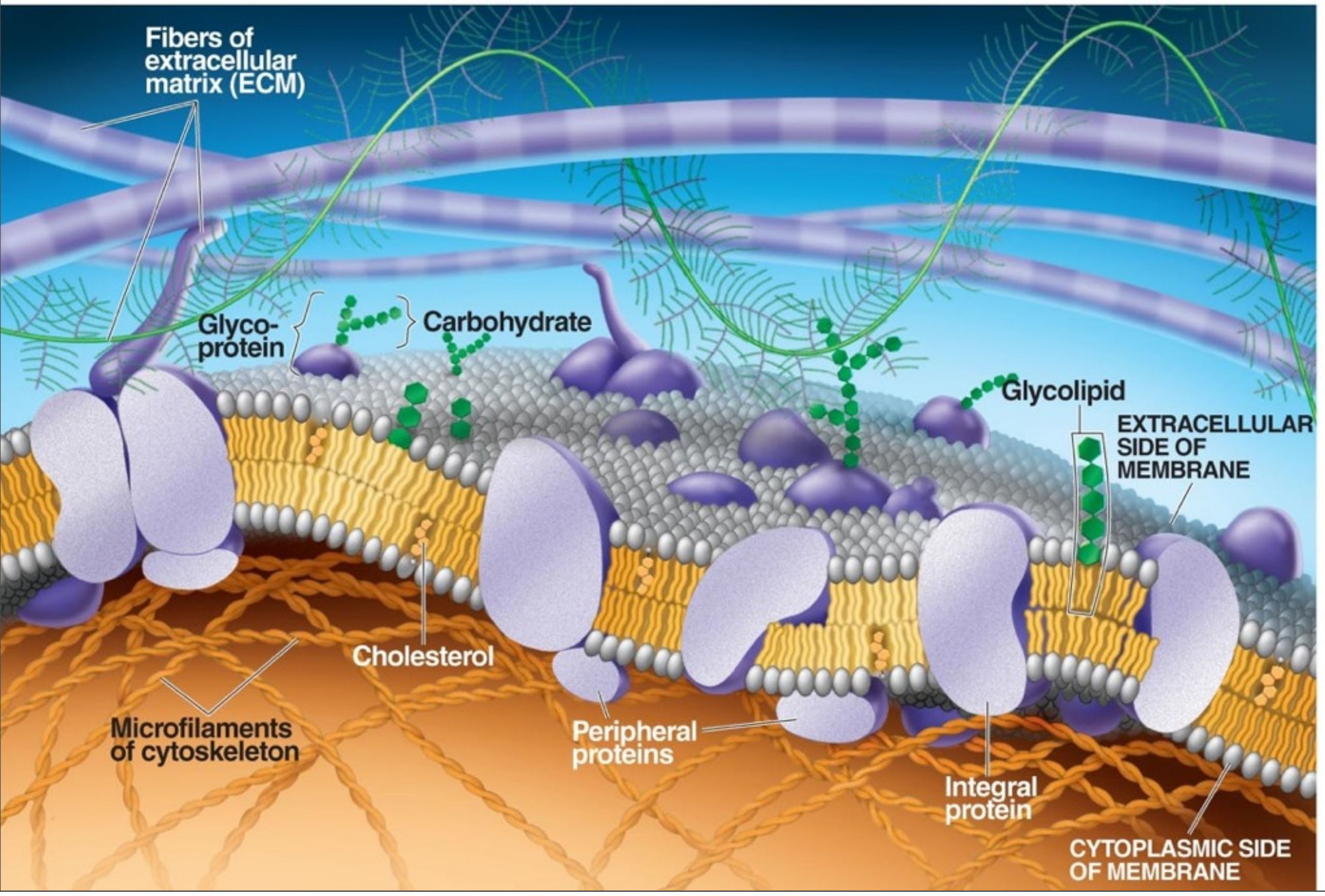
Main Idea: Membranes are embedded with proteins and sugars which give them a mosaic like quality.



CELLULAR MEMBRANES ARE FLUID MOSAICS OF LIPIDS AND PROTEINS

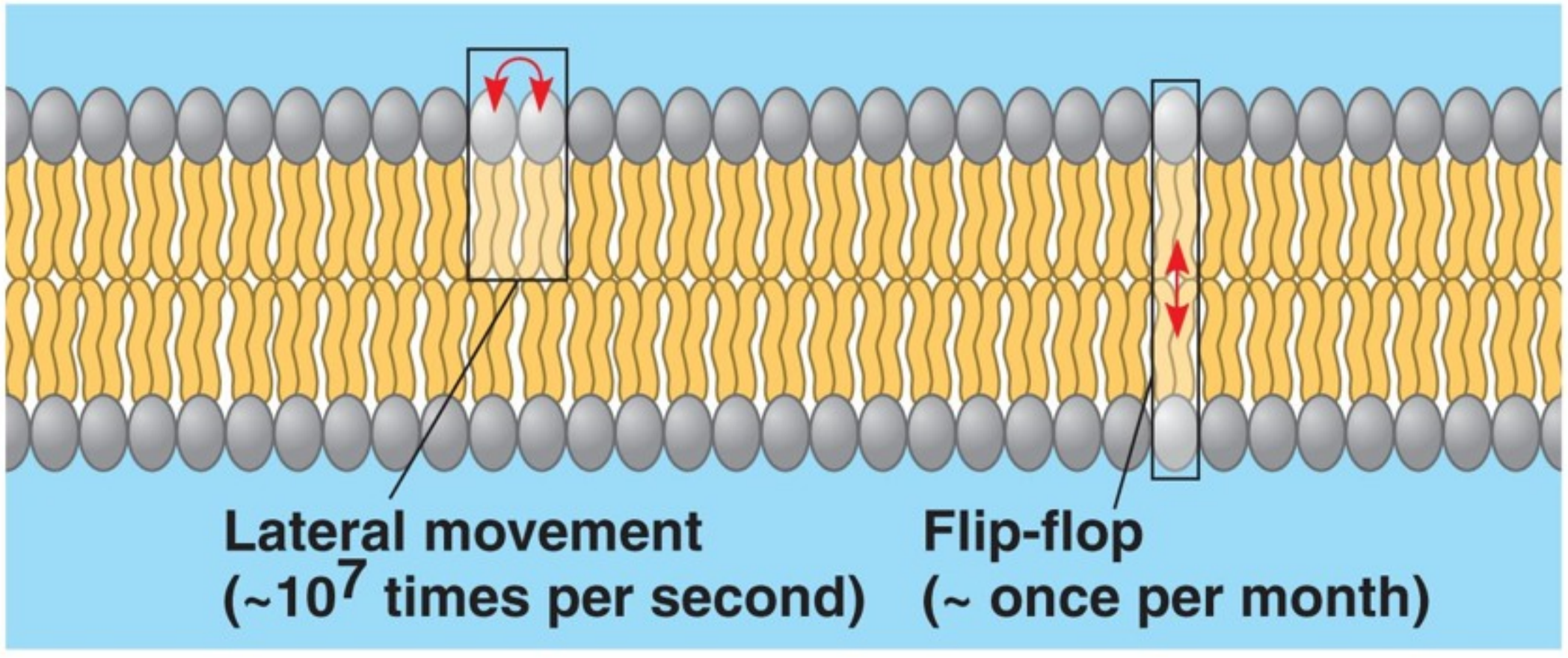
- The foundation of the membrane is the phospholipid.
- Phospholipids are **amphipathic** meaning that have a hydrophilic region and a hydrophobic region.
  - They will inherently form membranes when they come together.
- The remainder of the membrane is littered with proteins and sugars.
  - Many of the proteins are themselves amphipathic
- The **fluid mosaic model** describes the structure of membranes.

A. Membrane Models



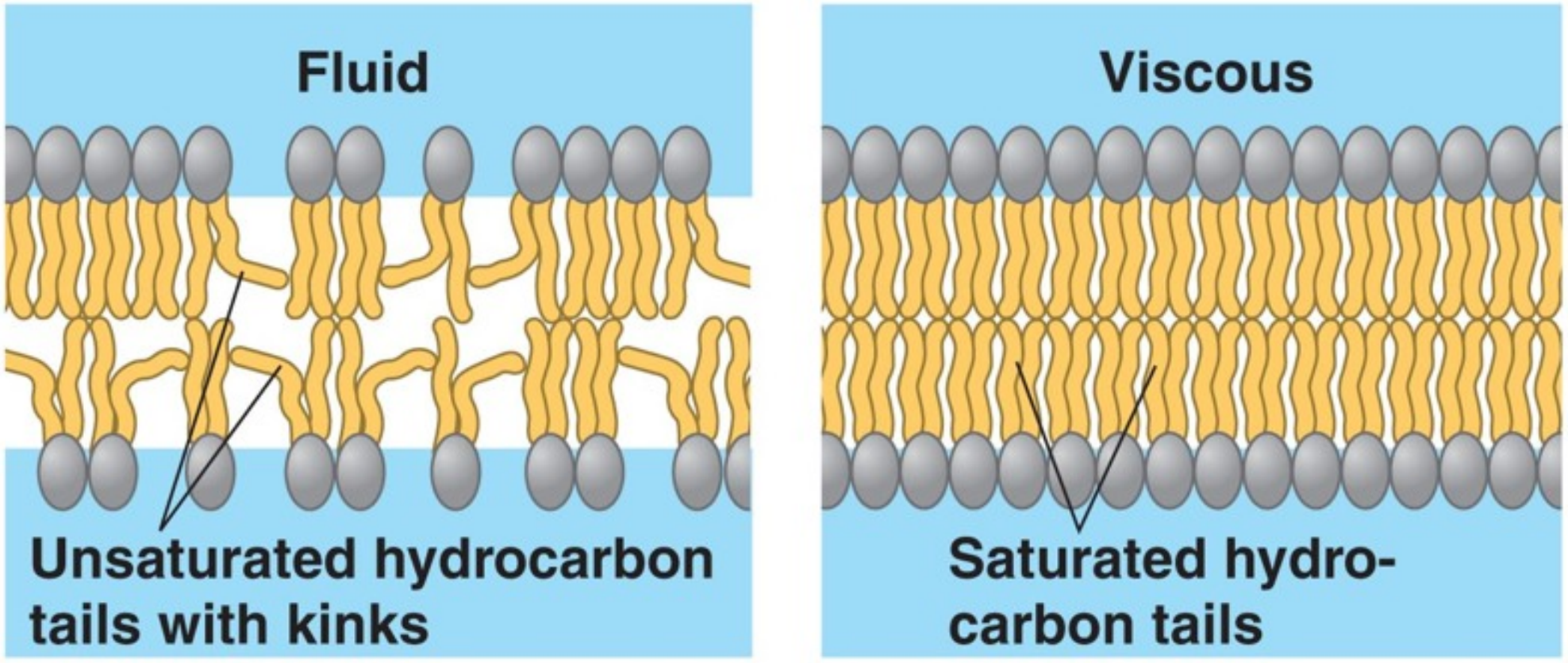
B. The Fluidity of Membranes

- Membranes are static sheets, they are held together by weak hydrophobic interactions.
- The lipids and proteins both move laterally although the lipids move much more freely.
  - Furthermore some proteins do not move at all because they locked into place by the ECM and cytoskeleton.



The Fluidity of Membranes

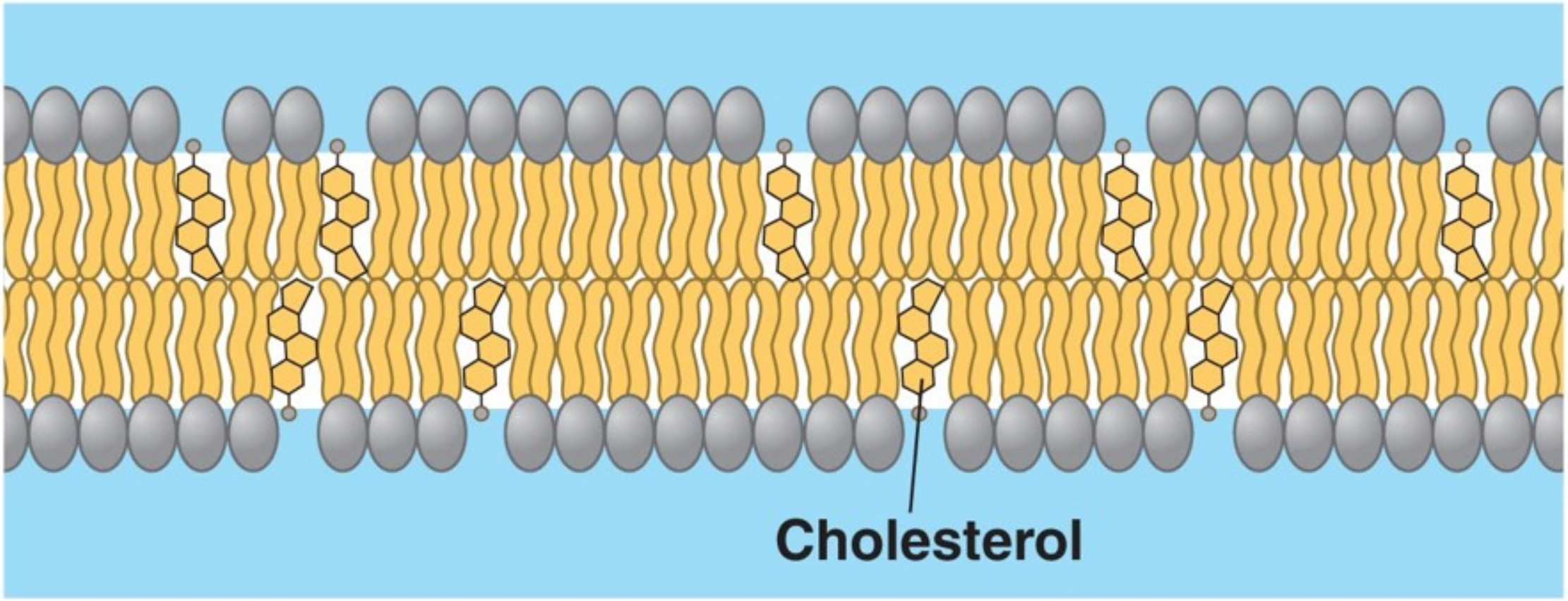
- Membrane fluidity is directly correlated with temperature.
  - The higher the temperature the more fluid the membrane
- The type of fatty acid tails in the phospholipids also effect fluidity
- Membrane fluidity is important because it effects membrane permeability



(b) Membrane fluidity

The Fluidity of Membranes

- Cholesterol acts like a membrane "fluidity buffer".
  - At higher temperatures cholesterol decreases the membrane fluidity, by restraining lipid movement.
  - At lower temperatures cholesterol increases the membrane fluidity, by hindering the close packing.



(c) Cholesterol within the animal cell membrane

C. The Evolution of Different Membrane Lipid Composition

- Variations in lipid composition appears to be an evolutionary adaptation.
  - *Fish that live in cold water have a high proportion of unsaturated fatty acids.*
  - *Bacteria living in thermal hot springs show a high proportion of saturated fatty acids.*

The Evolution of Different Membrane Lipid Composition

- The ability to adjust lipid composition appears to be an evolutionary adaptation.
  - *Winter wheat* can change its percentage of unsaturated fatty acids that make up its membrane as the seasons change.
- **Natural selection has favored organisms who have a mixture of fatty acid types and or those organisms that can adjust their membrane's permeability as necessary.**

The Speed of Life

- In general, larger the beast, the slower its metabolism and the longer its life and vice versa.
  - The explanation to this observation may reside in the plasma membrane.
- "Gunky" watertight membranes are found in elephants and whales with slow metabolisms and long lifespans.
  - *The most common unsaturated fatty acid accounts for 0.2% of an elephant's membrane.*
- "Runny" leaky membranes allow mice and hummingbirds to live fast but these organisms have short lifespans.
  - *The most common unsaturated fatty acid accounts for 20% of an mouse's membrane.*

Can you generate hypothesis for membrane permeability and lifespan?

D. Membrane Proteins and Their Functions

- A membrane is a collage of different proteins.
  - More than 50 kinds of have been found so far in the plasma membrane.
- Proteins determine most of the membrane'd functions .
  - Different types of cells contain different sets of membrane proteins.
- However all membrane proteins fall into one of two groups

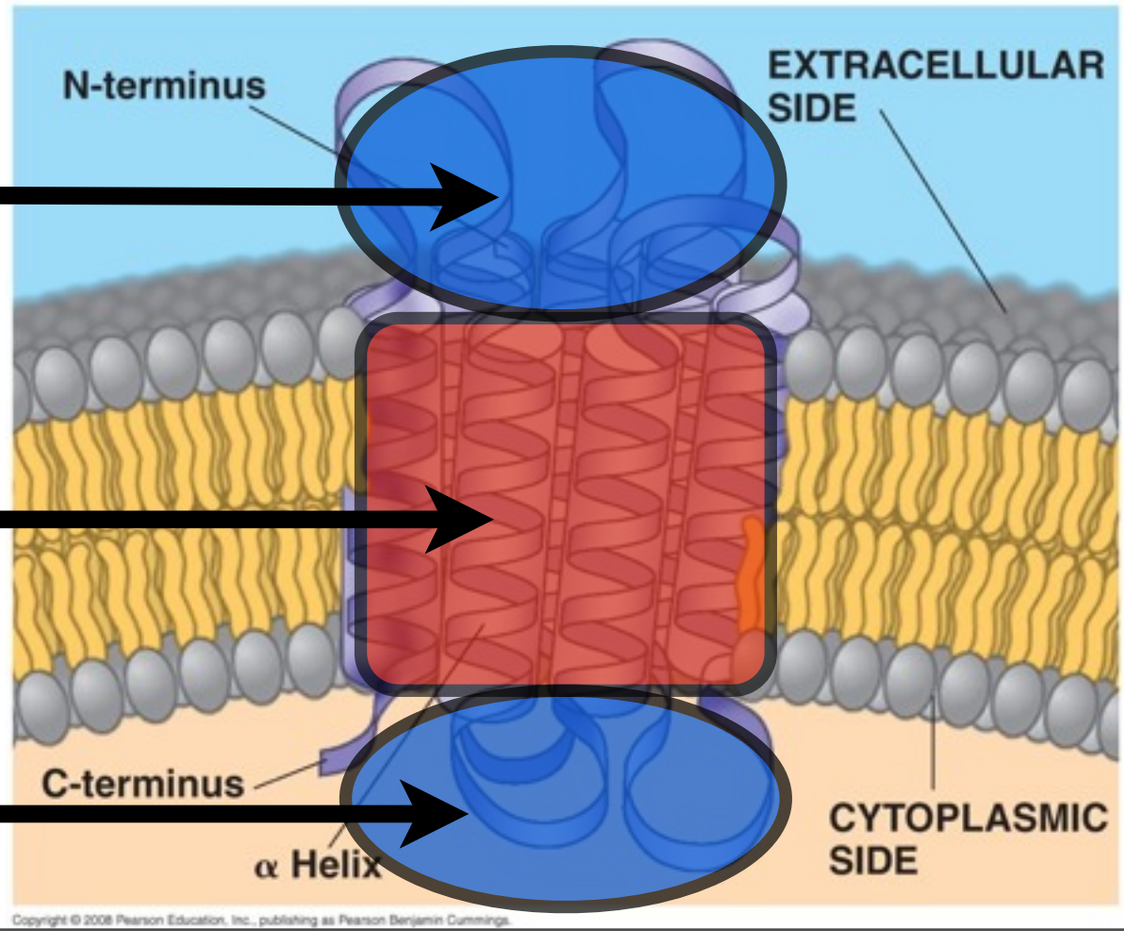
Membrane Proteins and Their Functions

- However all membrane proteins fall into one of two groups
  - **Integral proteins**, penetrate the lipid bilayer and most span the entire membrane
  - **Peripheral proteins**, do not penetrate the lipid bilayer, they are loosely bound to the surface of other proteins
- Many membrane proteins are held in place by the cytoskeleton or the fibers of the ECM

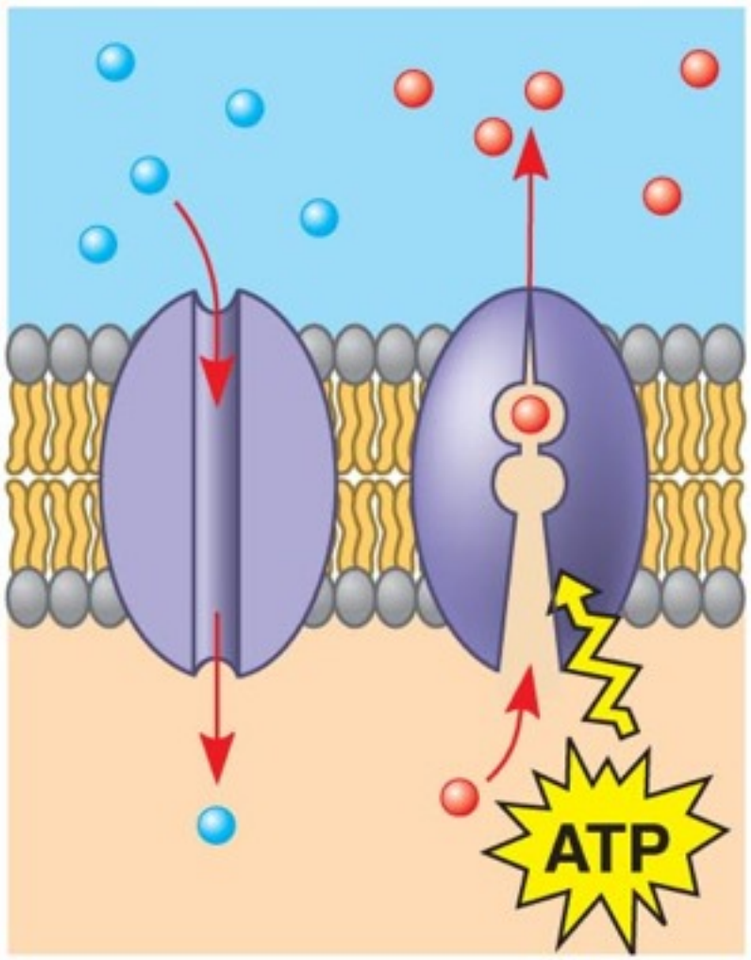
Hydrophilic

Hydrophobic

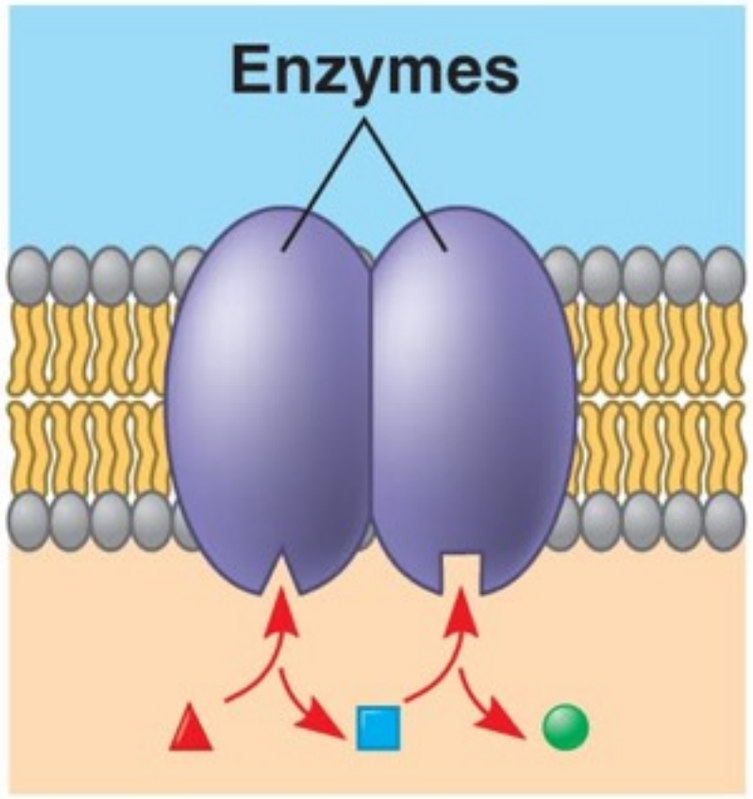
Hydrophilic



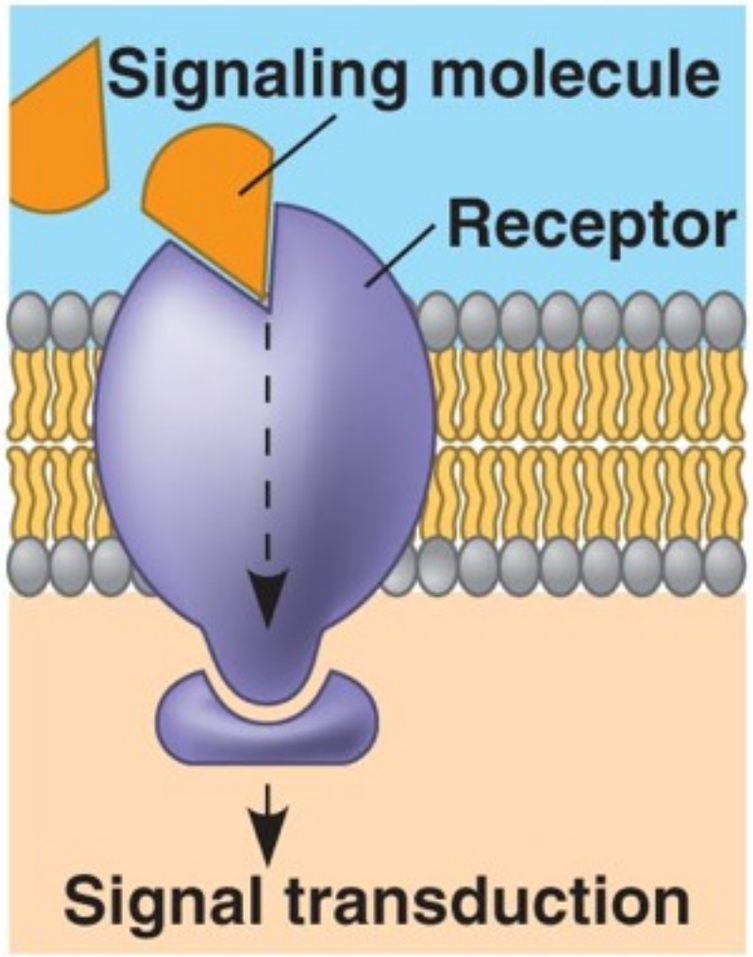
Membrane Proteins and Their Functions



(a) Transport

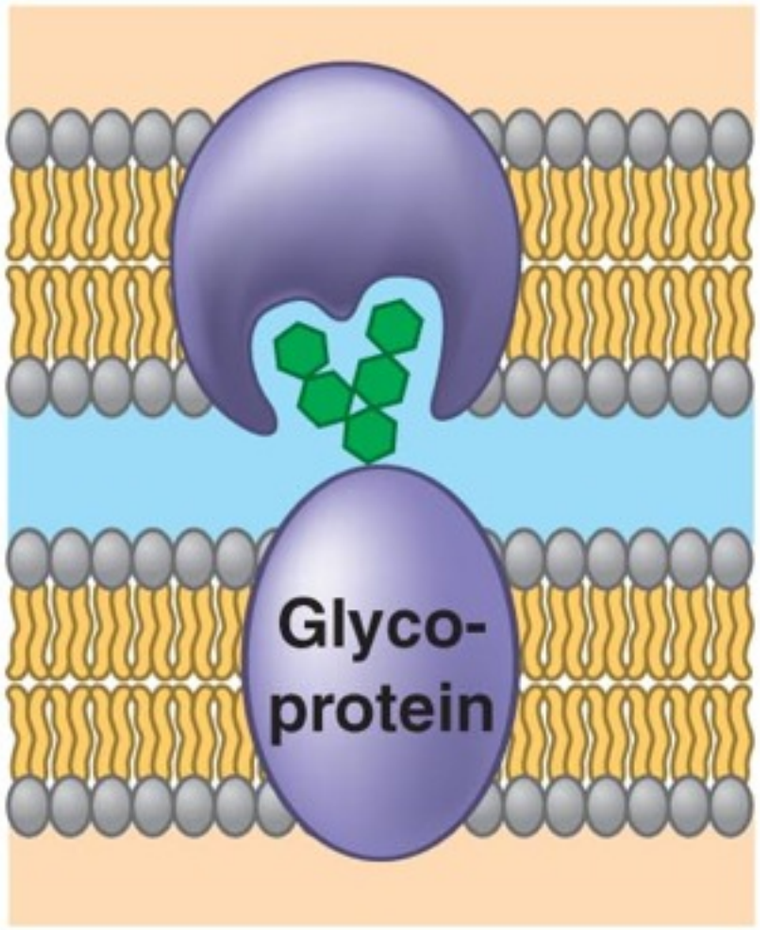


(b) Enzymatic activity

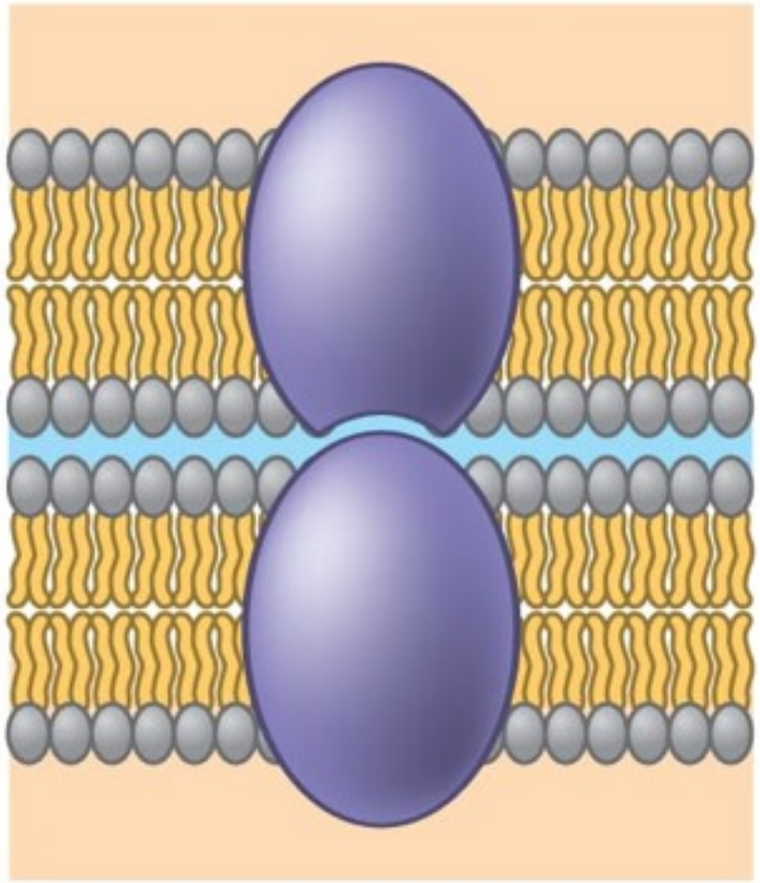


(c) Signal transduction

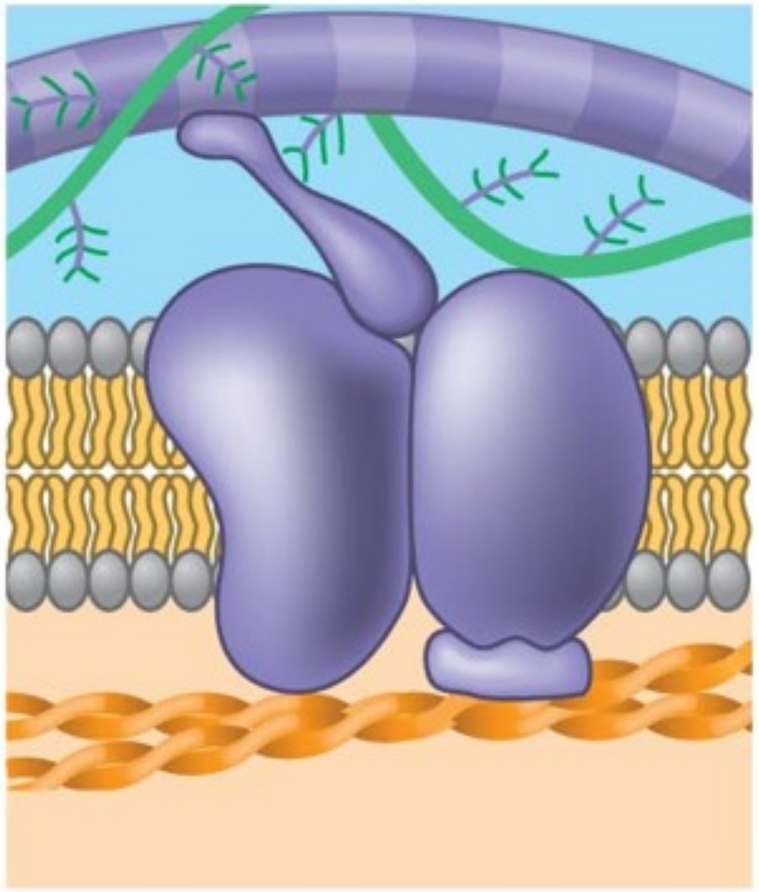
Membrane Proteins and Their Functions



(d) Cell-cell recognition



(e) Intercellular joining



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

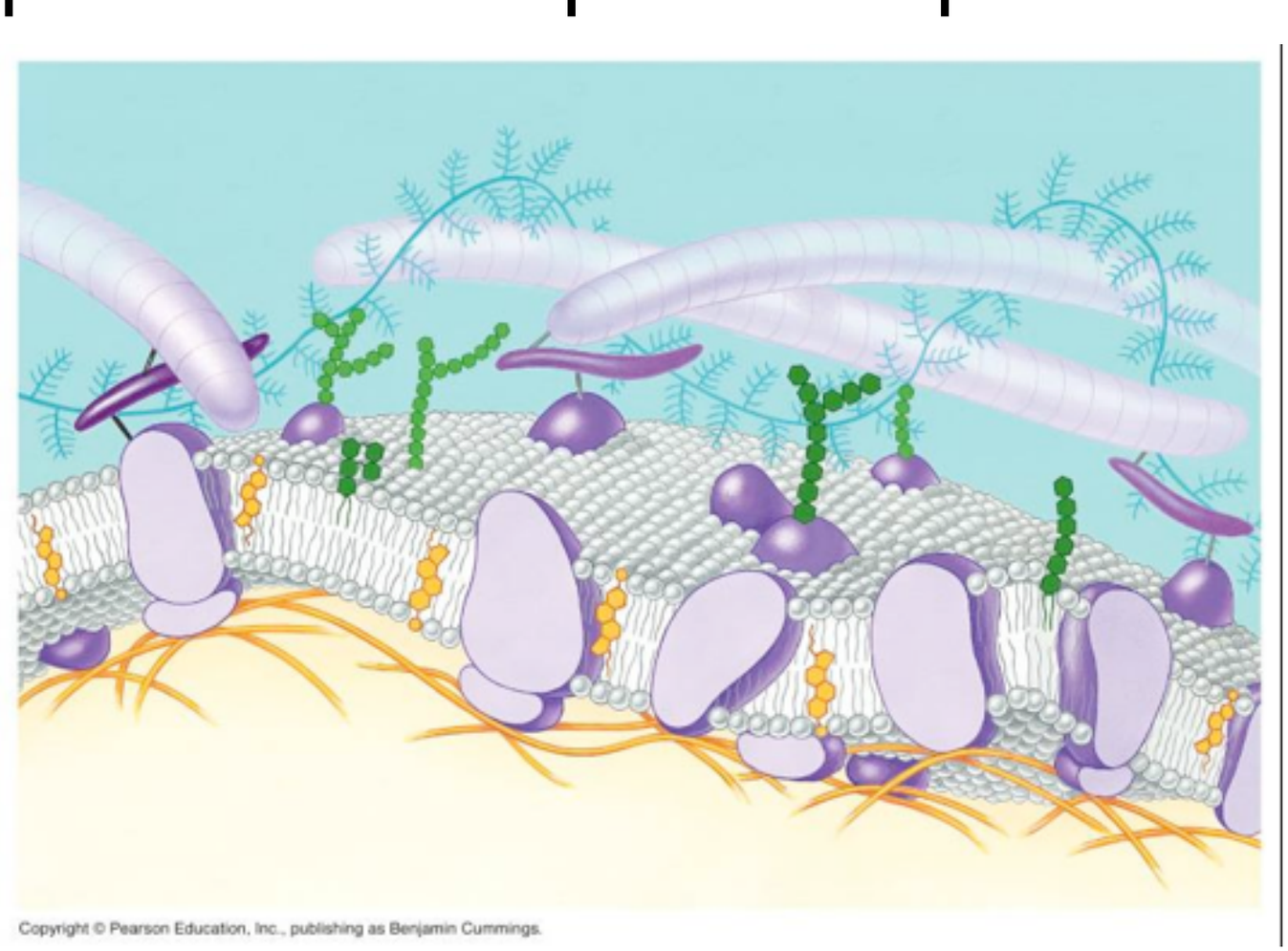
The Role of Membrane Carbohydrates in Cell to Cell Recognition

- Carbohydrates play a critical role in cellular identification.
  - Very short (~15 units) sugars serve as cellular "ID tags".
  - **Glycolipids** are sugars bound to lipids
  - **Glycoproteins** are sugars bound to proteins

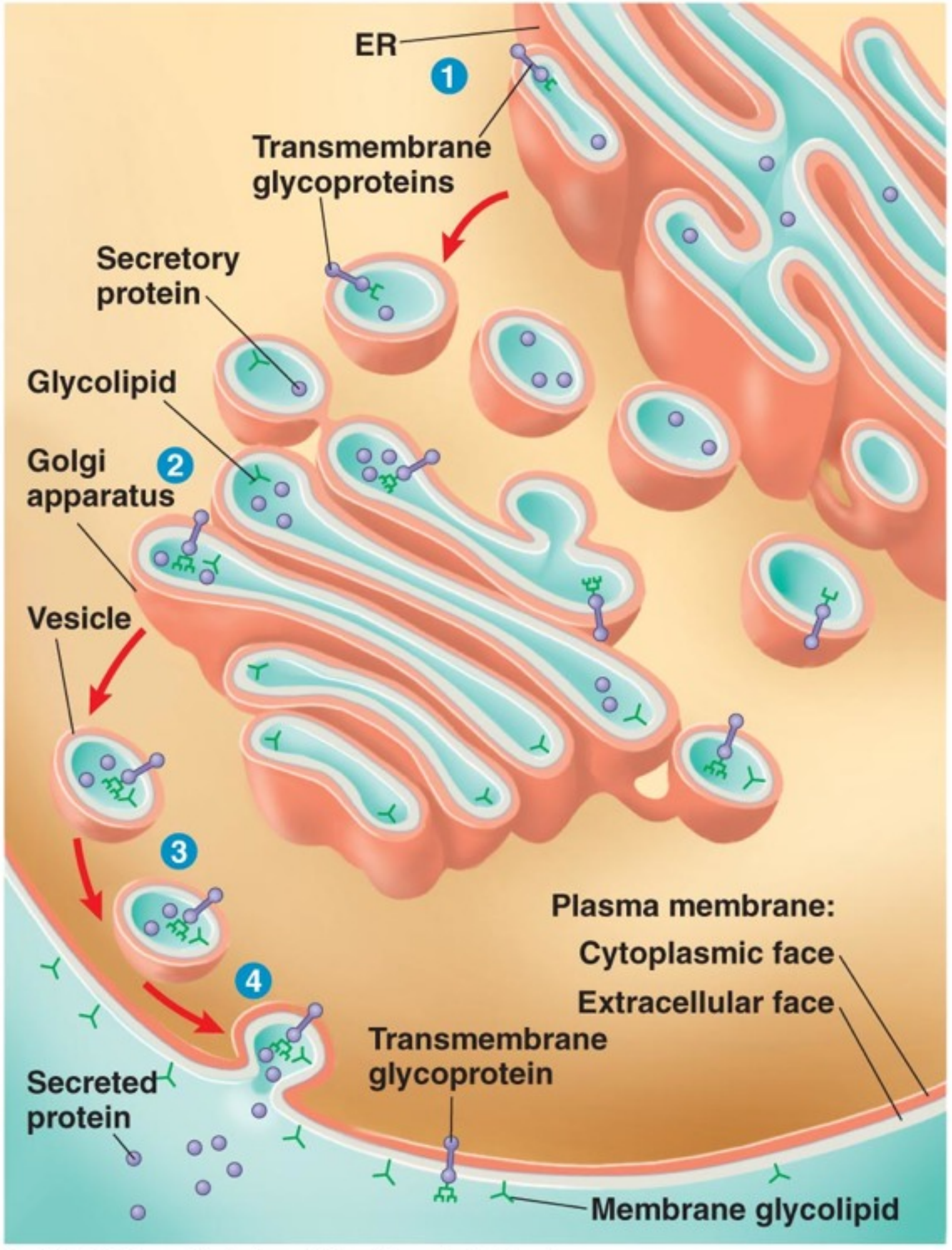
- These carbs are located on the extracelluar side.
  - *They vary from species to species*
  - *They vary among individuals of the same species*
  - *They vary among the cells of the same individual.*

E. Synthesis and Sidedness of Membranes

- **Membranes have distinct inside and outside surfaces.**
- The proportion and percentage of lipids and proteins is fairly consistent even among different species
- However the types lipids and the shapes of the proteins can vary greatly



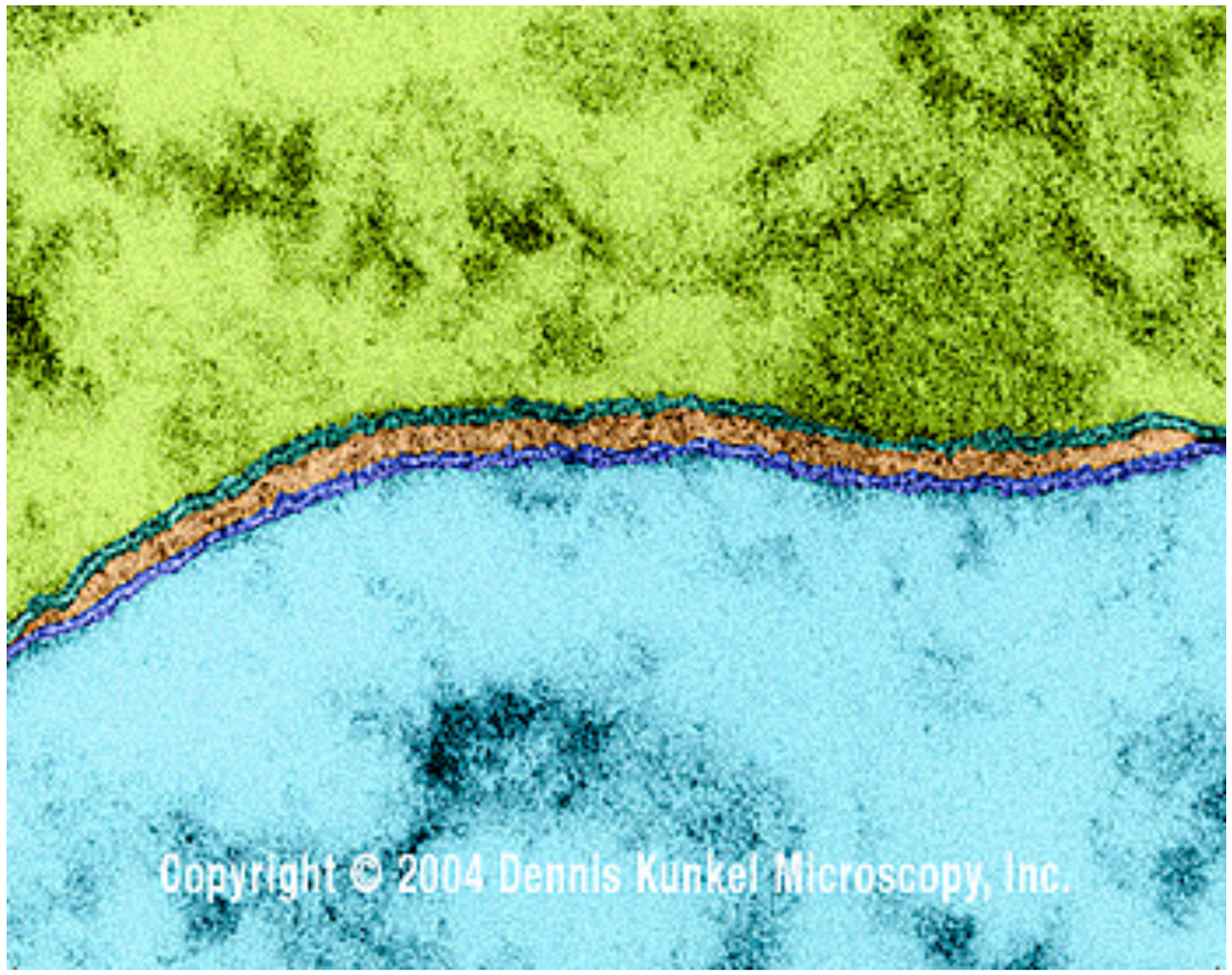
Synthesis of Membranes



Cell Membranes

II.

Main Idea:The structure and composition of the plasma membrane allows it to regulate the transport of substances across the membrane.

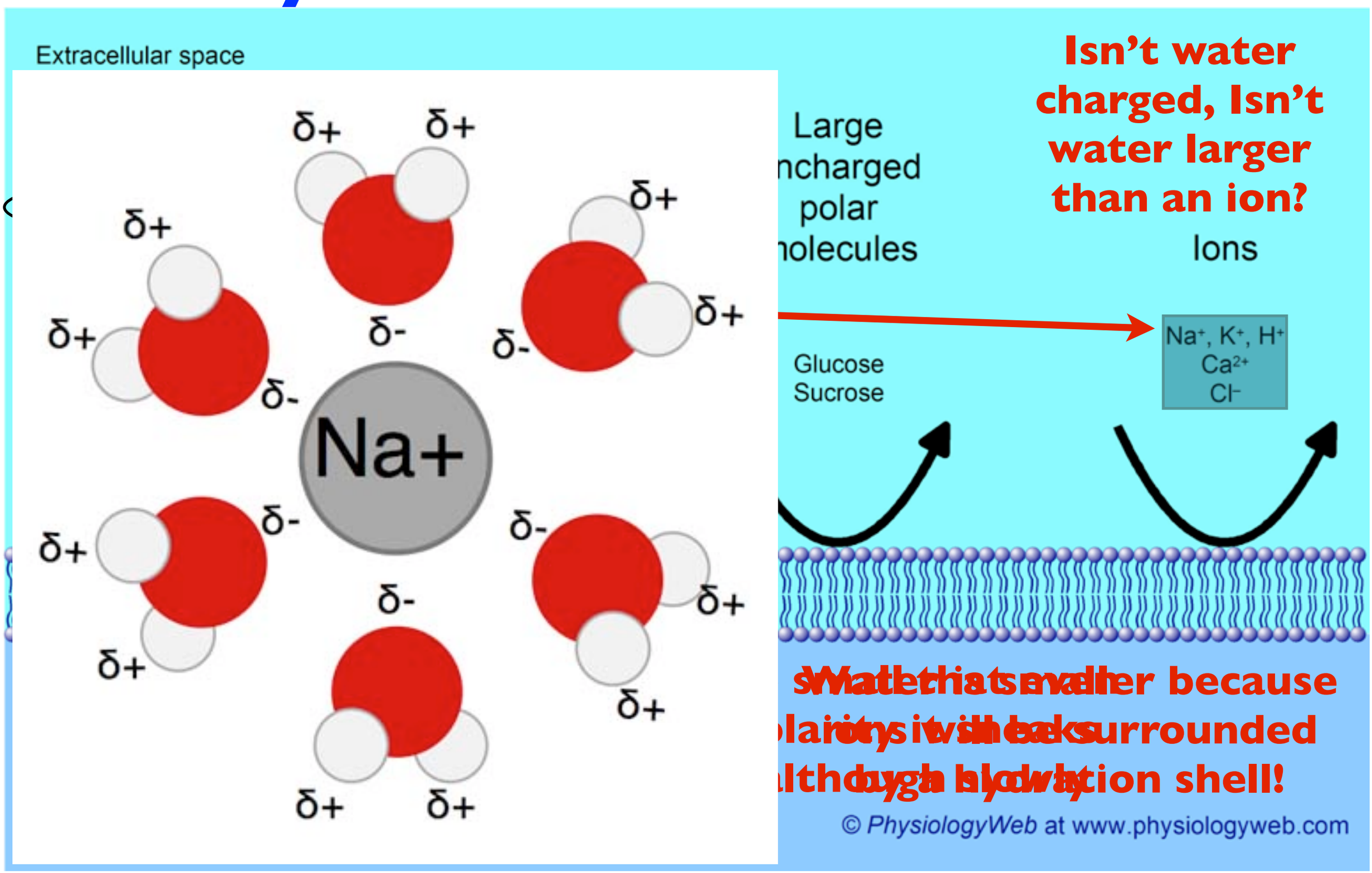


MEMBRANE STRUCTURE RESULTS IN SELECTIVE PERMEABILITY

- Substances do not pass through the membrane indiscriminately
- The cell is able to take up some molecules while excluding others.
    - Nutrients need to enter the cell and wastes need to leave the cell
- Also, substances move through the membrane at different rates

A. The permeability of the Lipid Bilayer

A. The permeability of the Lipid Bilayer



The Lipid bilayer is just one aspect of the "gatekeeper" system

Small Molecules

Fat Soluble Molecules

Molecules with no electrical charge

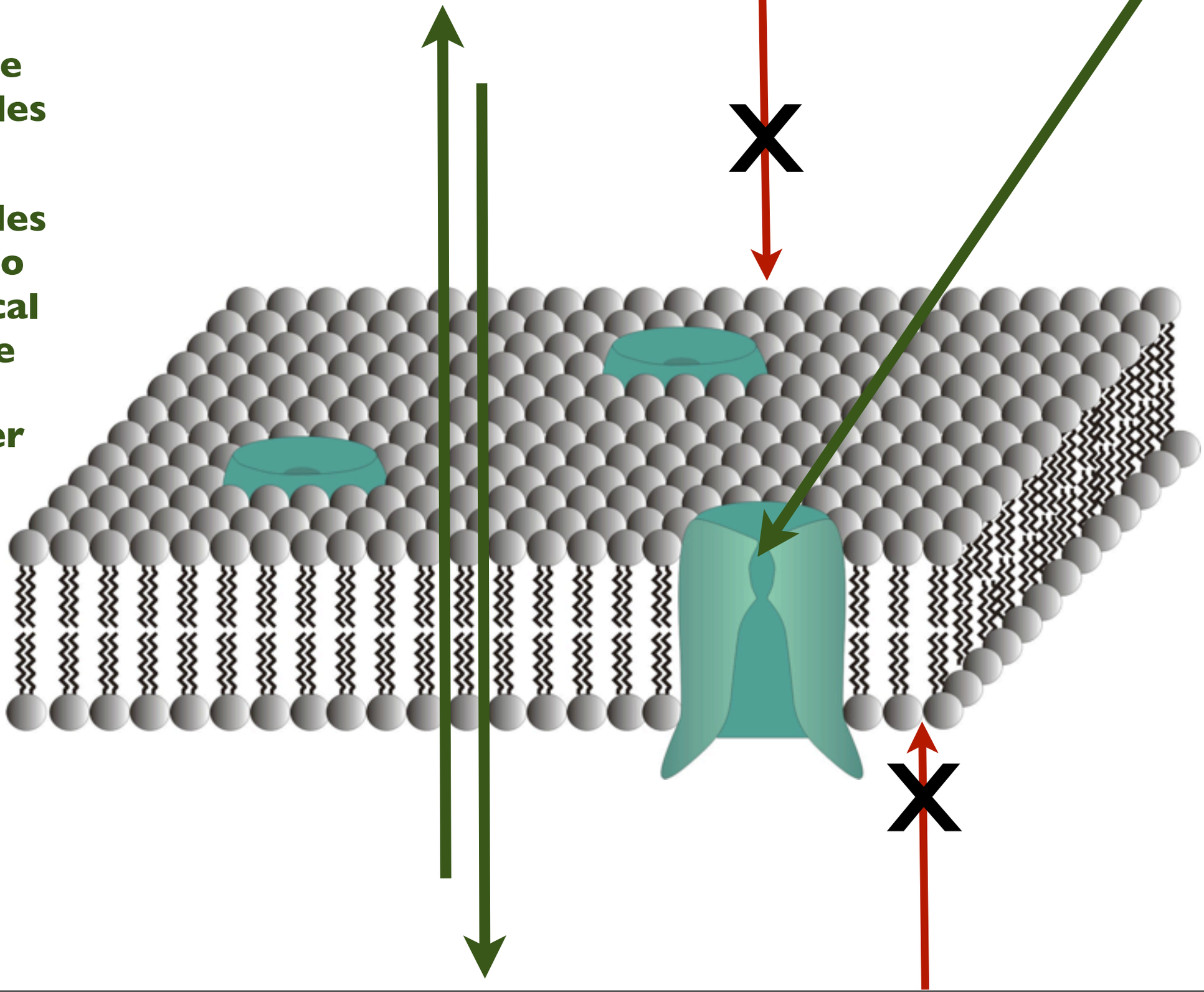
***Water**

However
If cell permits

Large Molecules

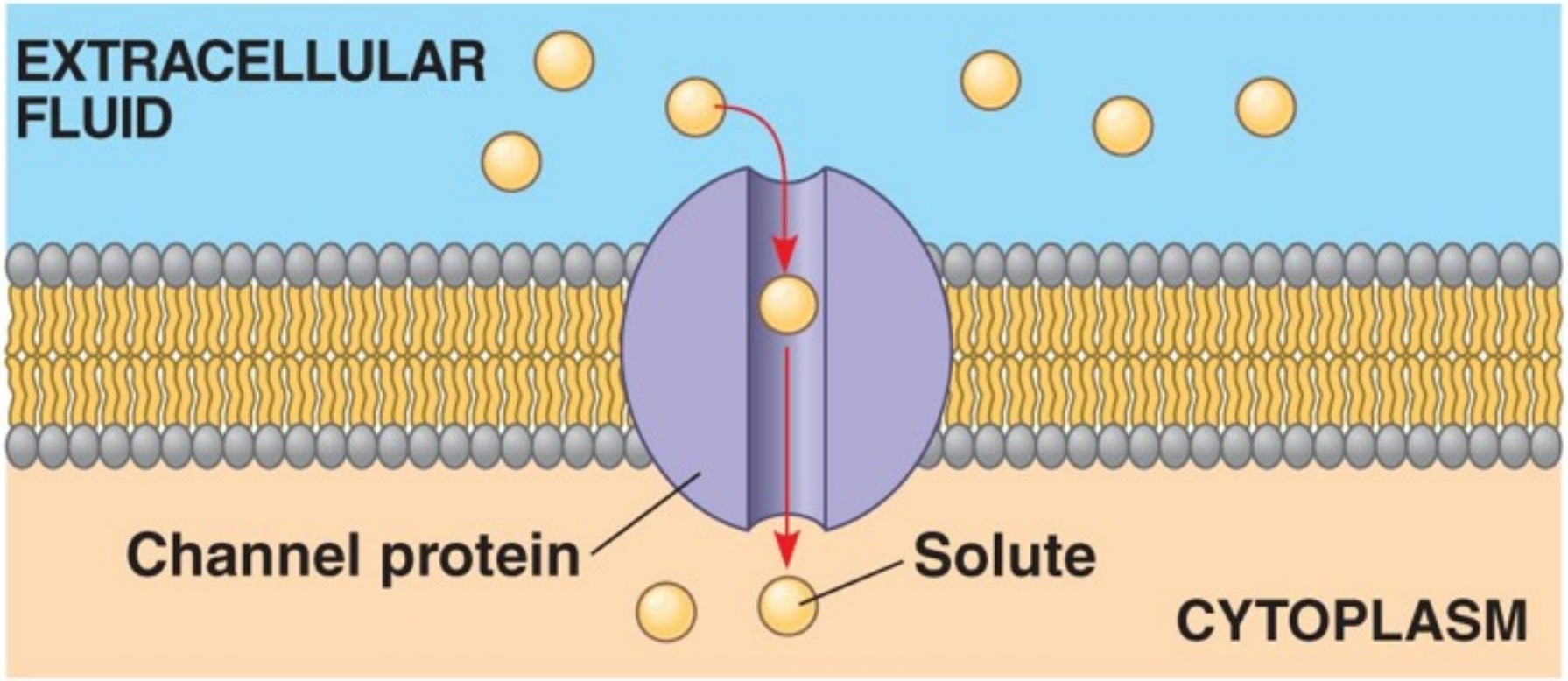
Water Soluble Molecules

Molecules with electrical charges

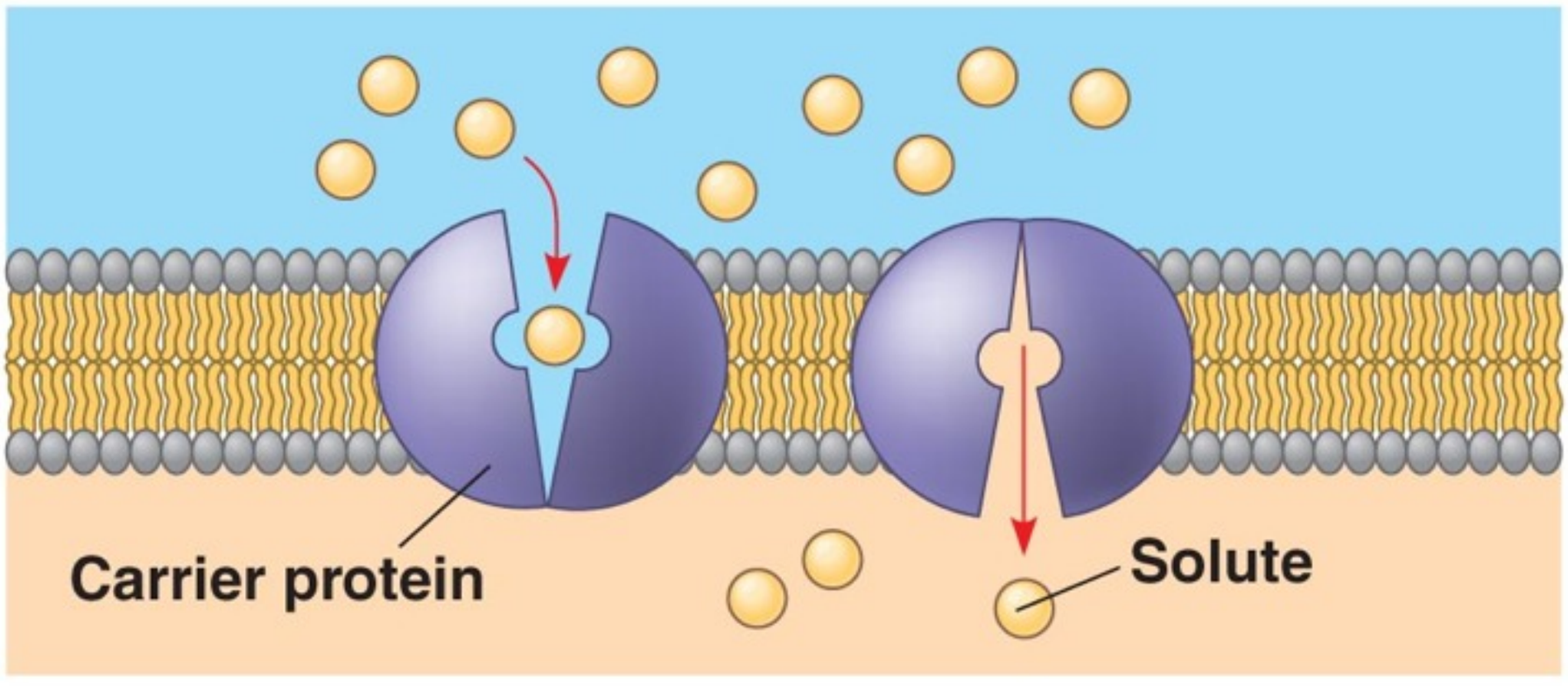


B. Transport Proteins

- Hydrophilic substances can pass through protein pores called ***transport proteins*** more specifically ***channel proteins*** whose channel is also hydrophilic.
    - **Aquaporins** for example greatly facilitates the rate of water transport.
- Other ***transport proteins*** hold on called ***carrier proteins*** hold onto their passengers, change shape and release to the other side



(a) A channel protein



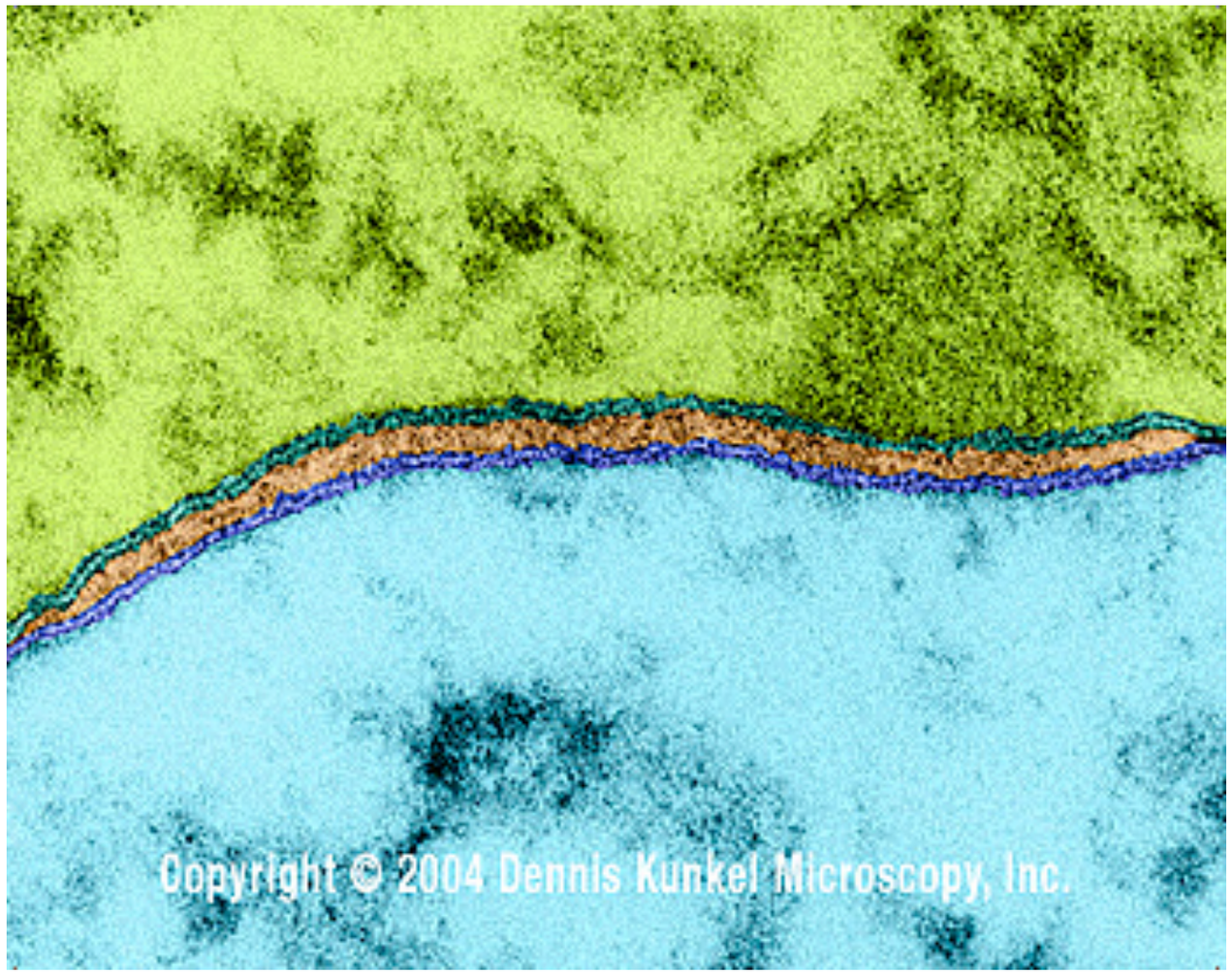
(b) A carrier protein

Selectively permeability depends on both the discriminating nature of the lipid bilayer and the specific proteins built into the membrane.

Cell Membrane

III.

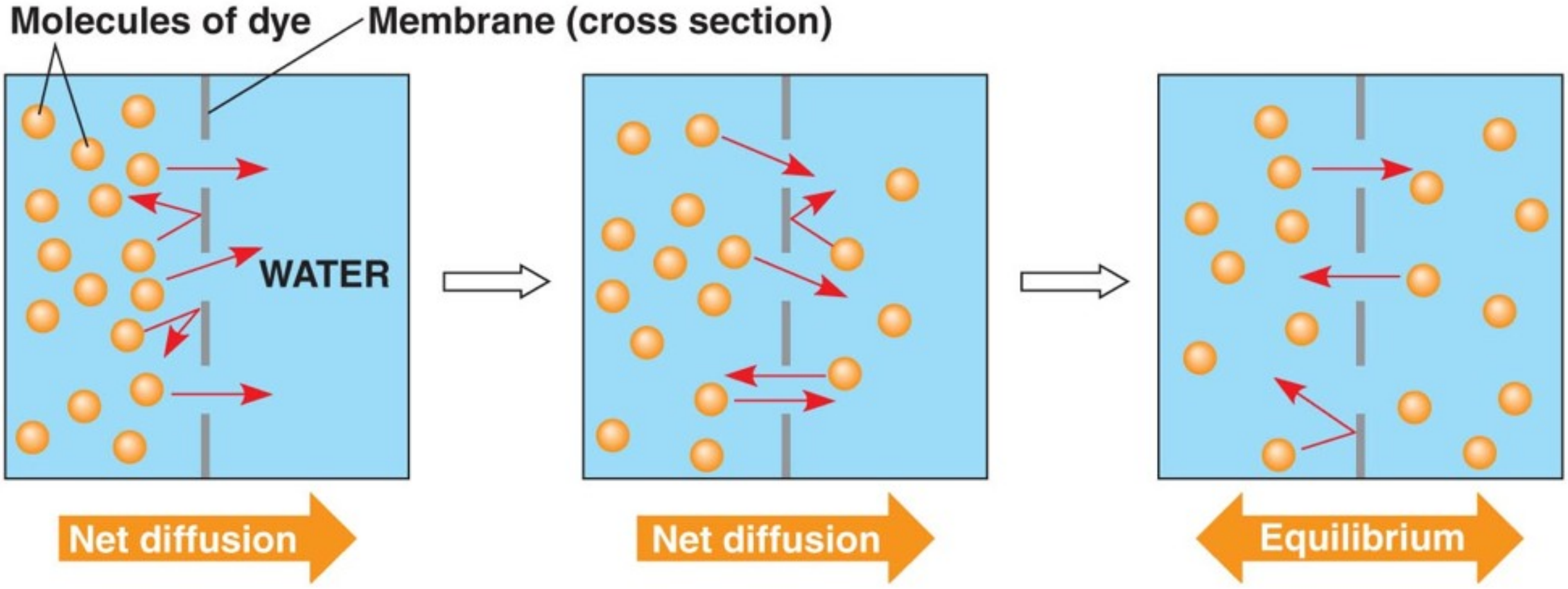
Main Idea: The direction of molecular movement across a membrane is determined by concentration gradients, while the mechanism is a result of the innate movement of molecules.



PASSIVE TRANSPORT IS DIFFUSION OF A SUBSTANCE ACROSS A MEMBRANE WITH NO ENERGY INVESTMENT

- **Passive transport** moves substances across membranes with no energy investment from the cell itself.
  - However energy is still required for any movement, where does it come from?
- The *Kinetic Molecular Theory* states that molecules are in constant random motion, these molecules therefore have their own energy.
- This motion results in **diffusion,** the movement of molecules from an area of high concentration to an area of low concentration. They “spread out”!

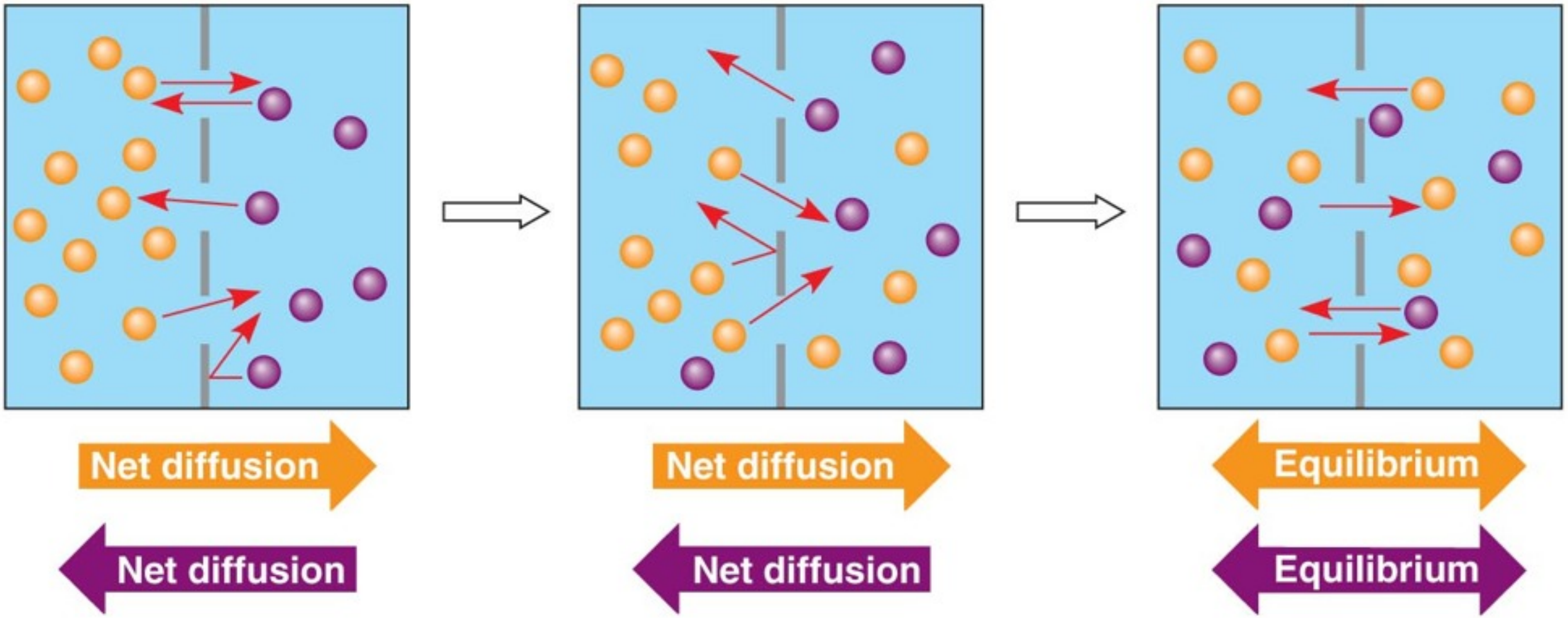
Diffusion



(a) Diffusion of one solute

THESE YELLOW CIRCLES REPRESENT EITHER SOLIDS OR GASES

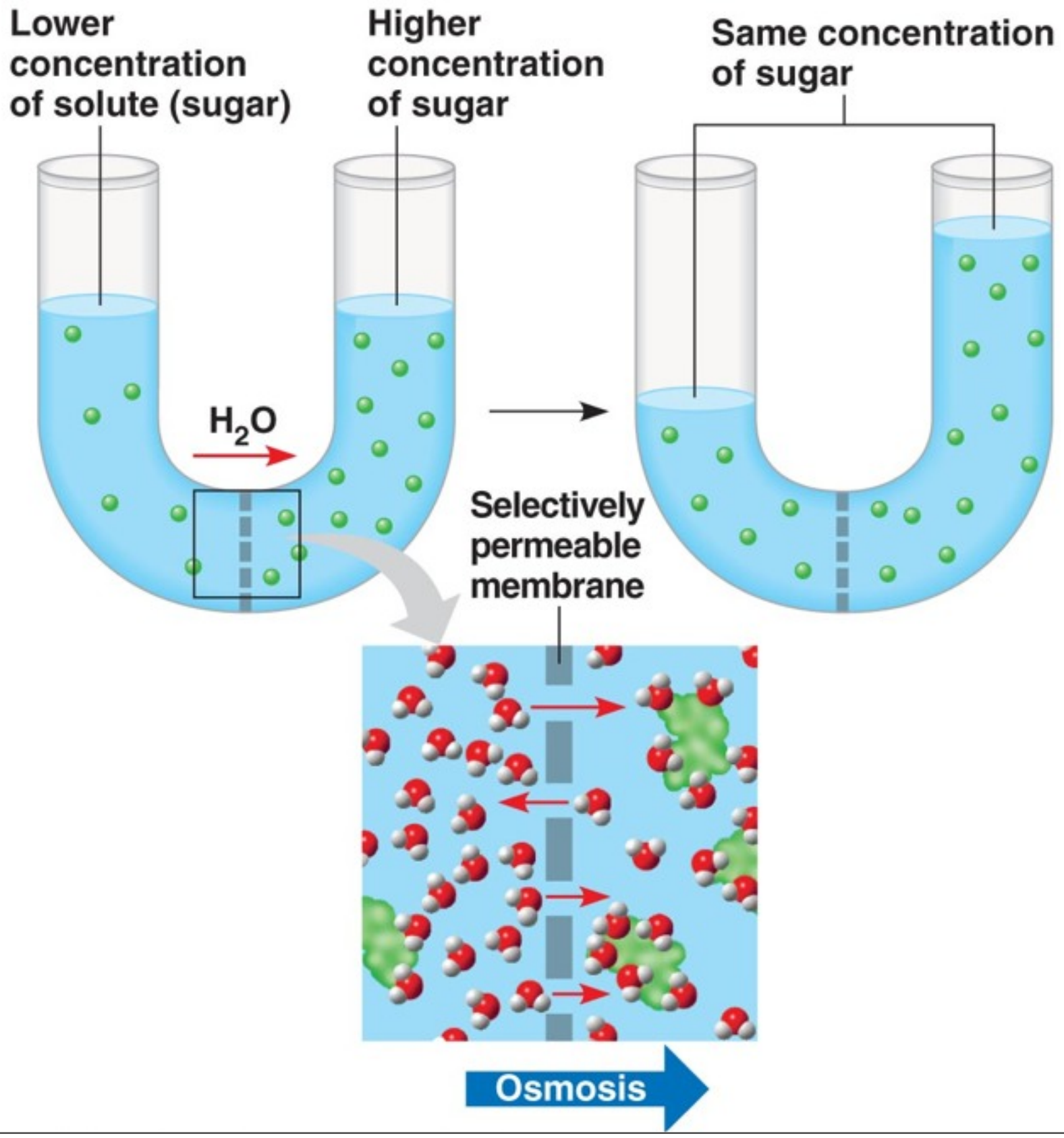
Diffusion



(b) Diffusion of two solutes

DIFFUSION OF SOLUTES IS INDEPENDENT OF OTHER SOLUTES

A. Effects of Osmosis on Water Balance



It has been said that water moves down its concentration gradient,

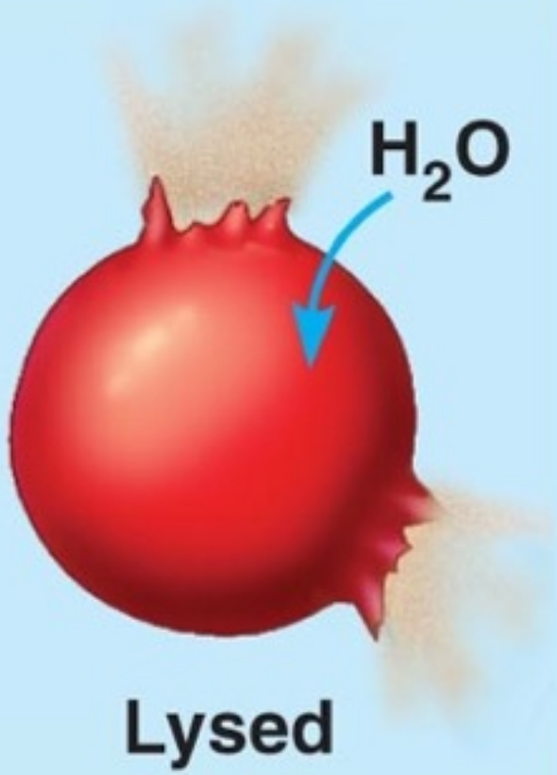
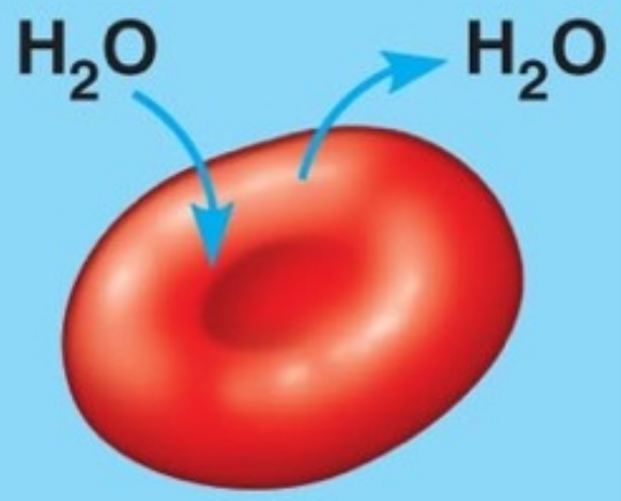
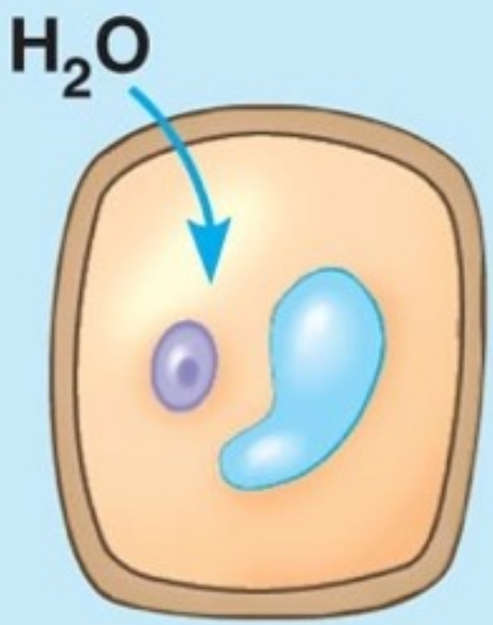
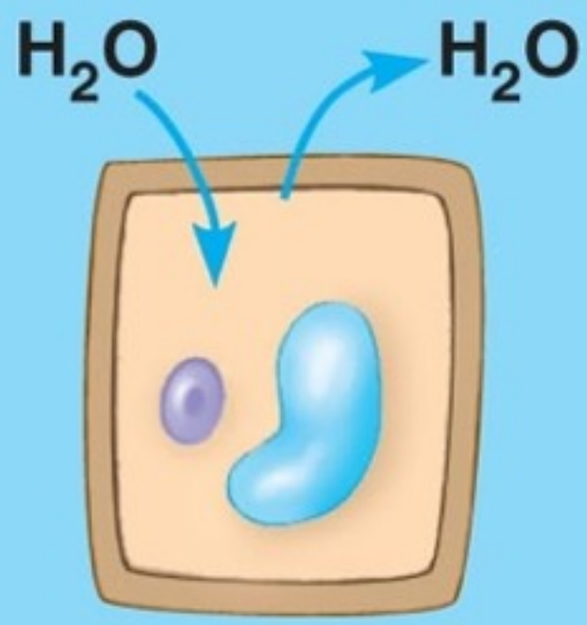
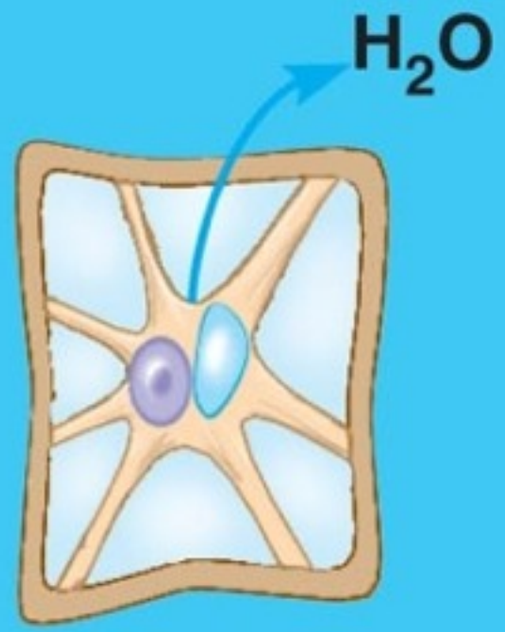
However it is more accurate and helpful if focus on solute concentration and remember that water moves from a less concentrated side to a more concentrated side. OR That water moves from a low solute concentration to a high solute concentration.

1. Water Balance of Cells Without Walls

- **Tonicity** is the ability of a surrounding solution to cause a cell to gain or lose water.
  - The key is the "non-penetrating solutes" relative to cell's interior
  - **Iso**tonic solutions are **same** as cell's solution thus no net movement of water.
  - **Hyper**tonic solutions have **more** than a cell's solution thus a net movement of water out of the cell.
  - **Hypo**tonic solutions have **less** than a cell's solution thus a net movement of water into the cell.

2. Water Balance of Cells With Walls

- Because these cells have rigid walls they can not burst.
- As water moves in the cell wall pushes back (*turgor pressure*) which opposes further water uptake
  - **Isotonic** solutions cause these cells to be *flaccid* (limp).
  - **Hypertonic** solutions cause a net loss of water, which results in *plasmolysis* (membrane pulls away from cell wall)
    - This causes a plant to wilt and die
  - **Hypotonic** solutions cause these cells to be *turgid* (stiff).
    - This is a healthy state for plants.

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


cellule d'épiderme d'oignon rouge
en présence d'eau salée.
page-svt.com
Jankowiak ced. (2009)

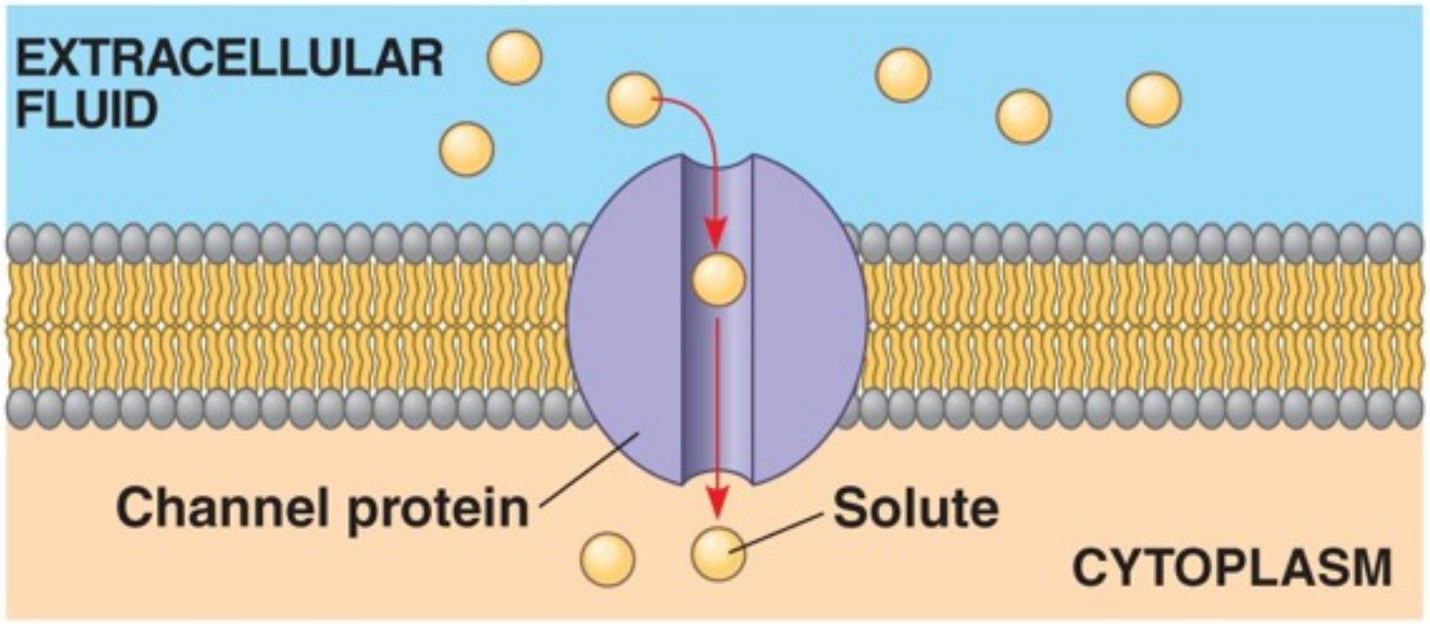
Water Balance of Cells Without Walls

- As a side note:
  - Seawater is isotonic to marine invertebrates so water regulation becomes a non-issue.
  - Terrestrial animals bathe their cells in an extracellular fluid that is constantly regulated to be isotonic.
  - However many organisms must regulate their internal solutes to maintain a water balance **(osmoregulation)**.
    - Recall the paramecium video from the last chapter. They use contractile vacuoles to excrete excess water.

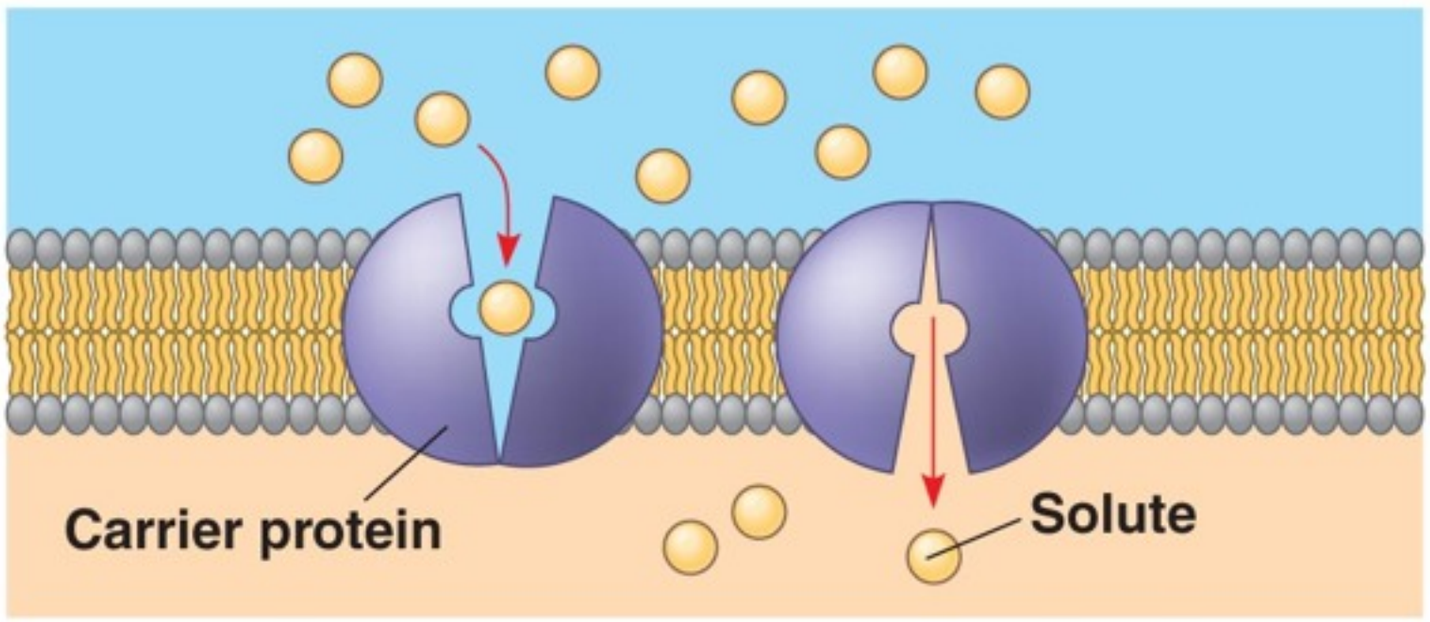
The water in which paramecium live is ____?

Hypotonic

B. Facilitated Diffusion



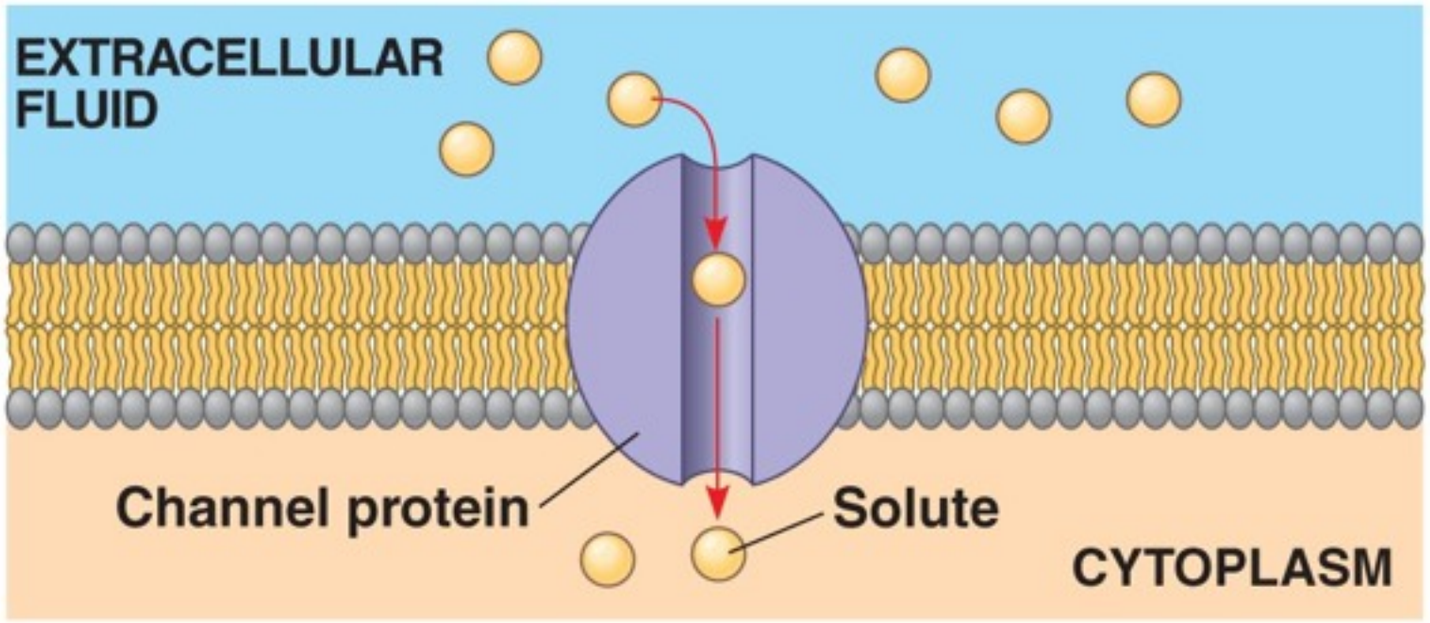
(a) A channel protein



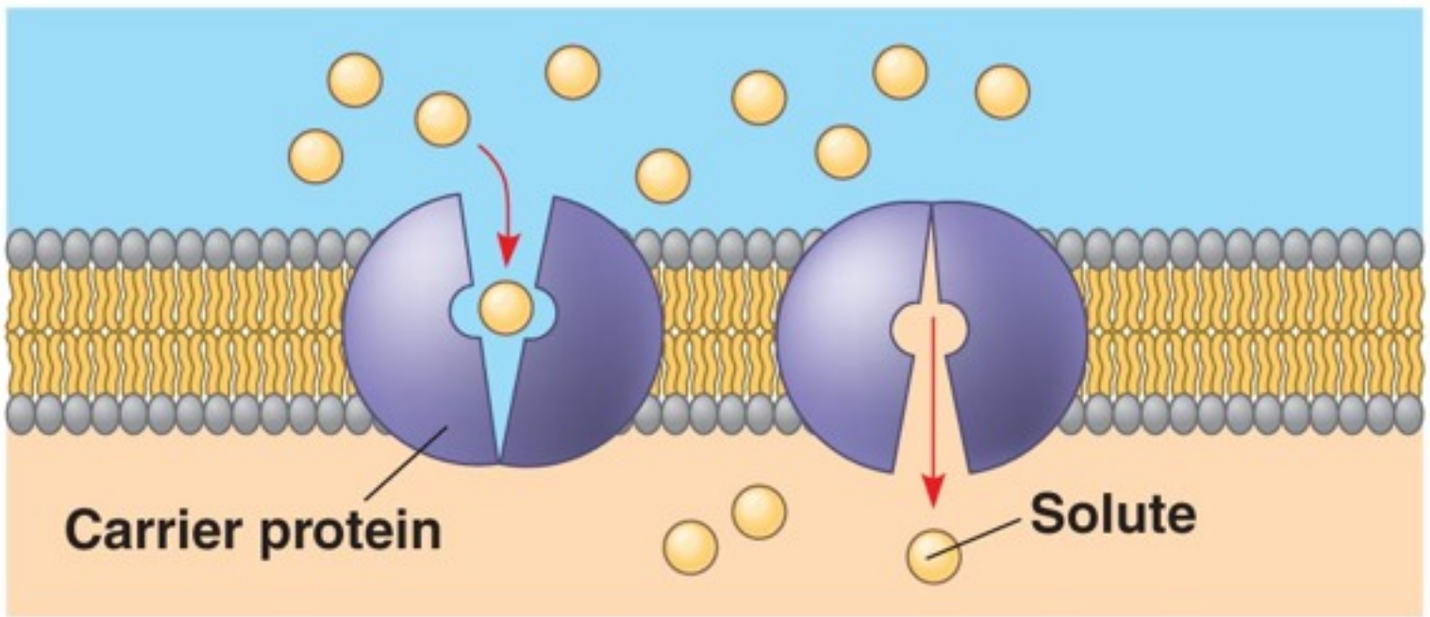
(b) A carrier protein

THE ONLY DIFFERENCE BETWEEN THIS AND REGULAR DIFFUSION IS THE ROUTE...IN SIMPLE DIFFUSION MOLECULES MOVE THROUGH THE LIPID BILAYER BUT HERE MOLECULES MOVE THROUGH A CHANNEL OR CARRIER PROTEIN INSTEAD. (STILL HIGH TO LOW, STILL NO ENERGY NEEDED BY CELL)

B. Facilitated Diffusion



(a) A channel protein



(b) A carrier protein

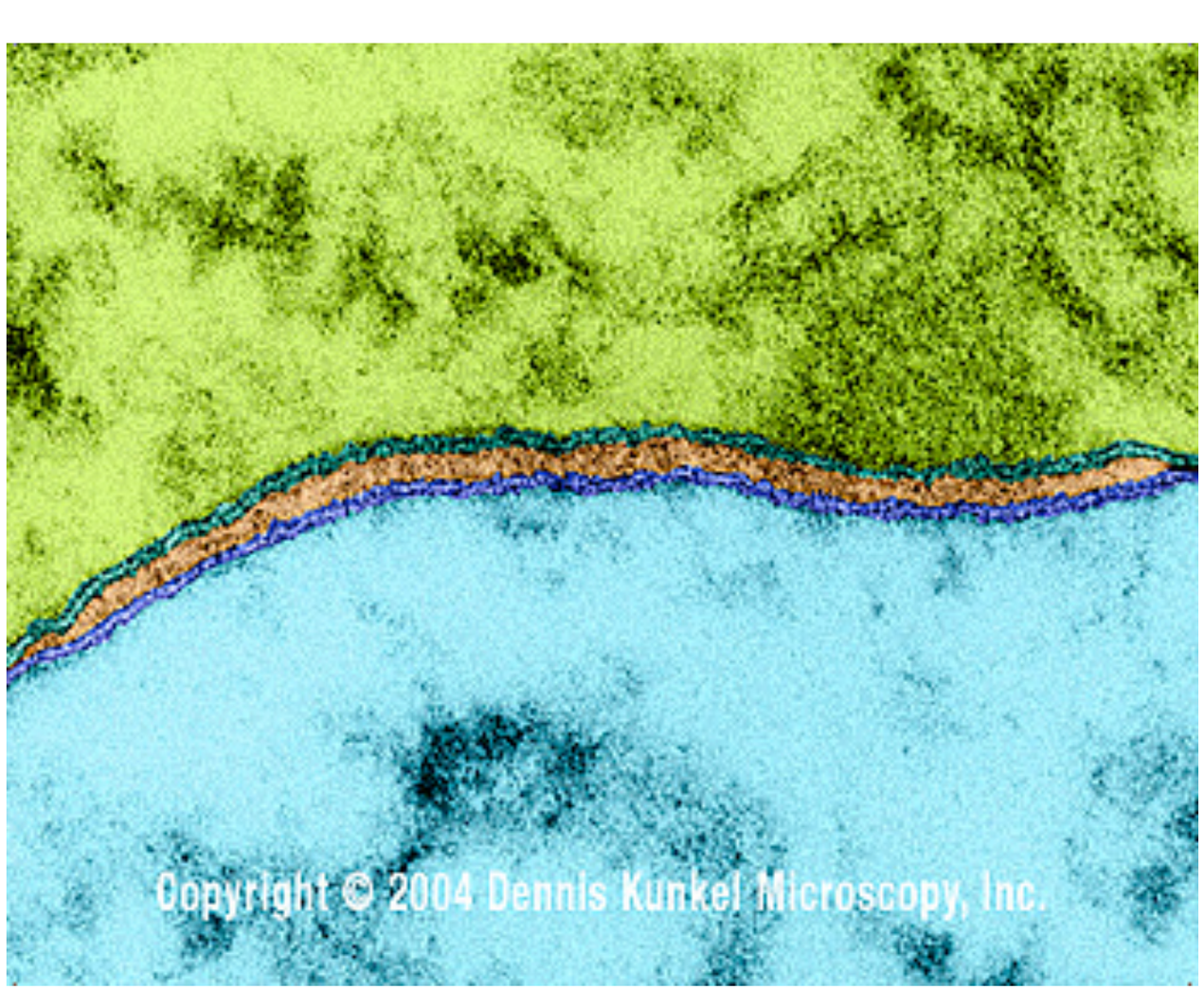
GATED CHANNELS:

BOTH OF THESE CAN ALSO ACT LIKE *GATED CHANNELS* WHERE THEY OPEN OR CLOSE IN RESPONSE TO SOME STIMULI, ELECTRICAL IMPULSES FOR EXAMPLE OR THE BINDING OF A SUBSTANCE

Cell Membrane

IV.

Main Idea: Molecules that do not pass freely through the lipid bilayer or protein channels can still move across the cell membrane however both an input of energy and a carrier protein is required.



ACTIVE TRANSPORT USES ENERGY TO MOVE SOLUTES AGAINST THEIR GRADIENTS

A. The Need for Energy in Active Transport

- **Active Transport** moves molecules against its concentration gradient and this requires the cell to invest energy.
  - It also demands a *carrier protein* to carry the molecule
- **Active Transport allows the cell to maintain an internal environment different from its surroundings!**

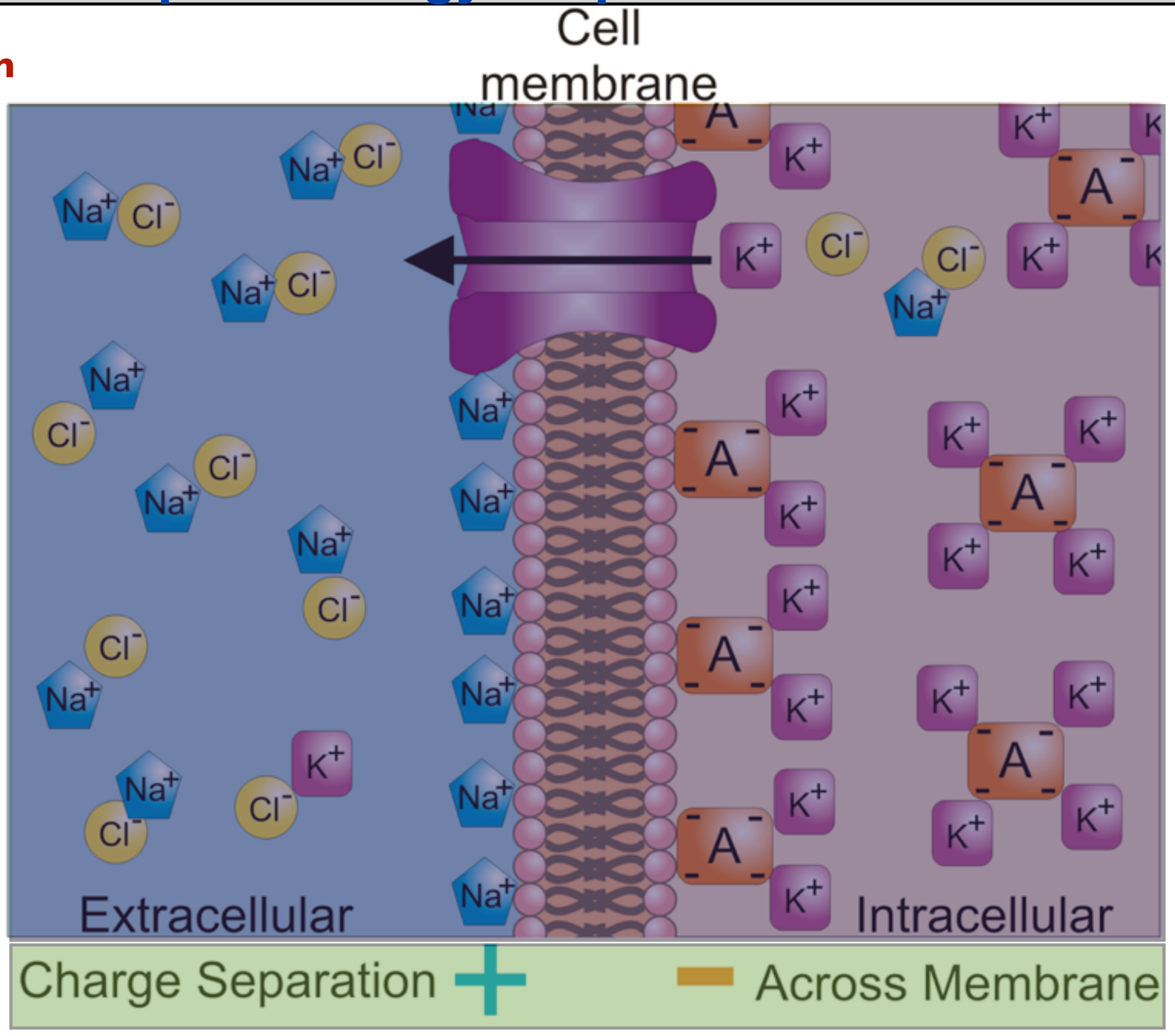
Internal environment that differs from the external environment

This internal environment does not happen by accident, the cell must expend energy to "produce it"

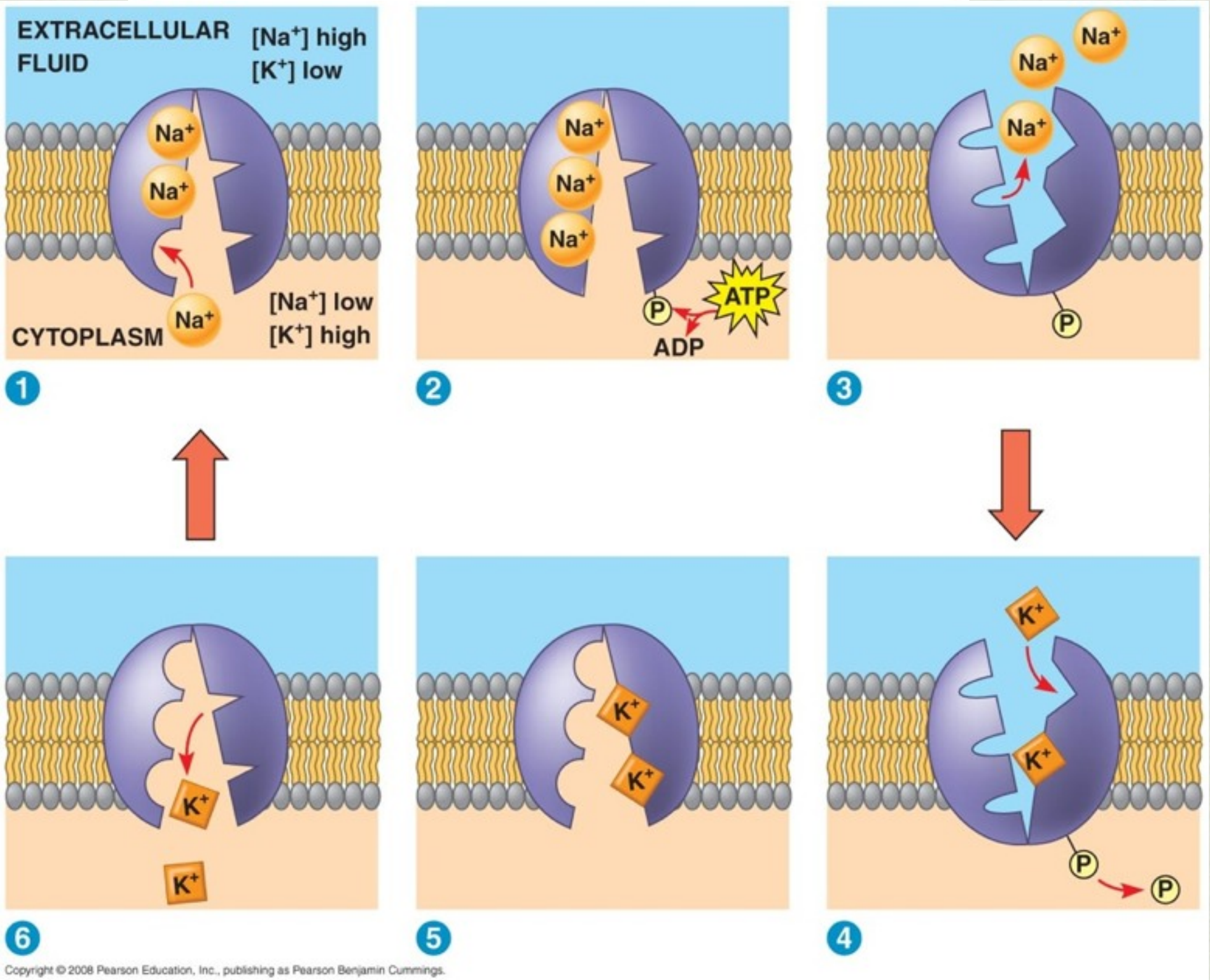
Concentration

Both Must Be Maintained

Charge



Sodium/Potassium Pump



KEEP TRACK OF THE NUMBER OF IONS GOING IN AND OUT!

B. How Ion Pumps Maintain Membrane Potential

- ALL cells have *voltag*e across their membrane, ***voltage*** is electrical potential energy
  - The voltage across a membrane is called ***membrane potential***
  - The cytoplasmic side is negative relative to the positive outside.
  - Caused by an unequal distribution of anions and cations.
  - Ranges from -50mV to -200mV (millivolts)
  - Acts like a battery!

How Ion Pumps Maintain Membrane Potential

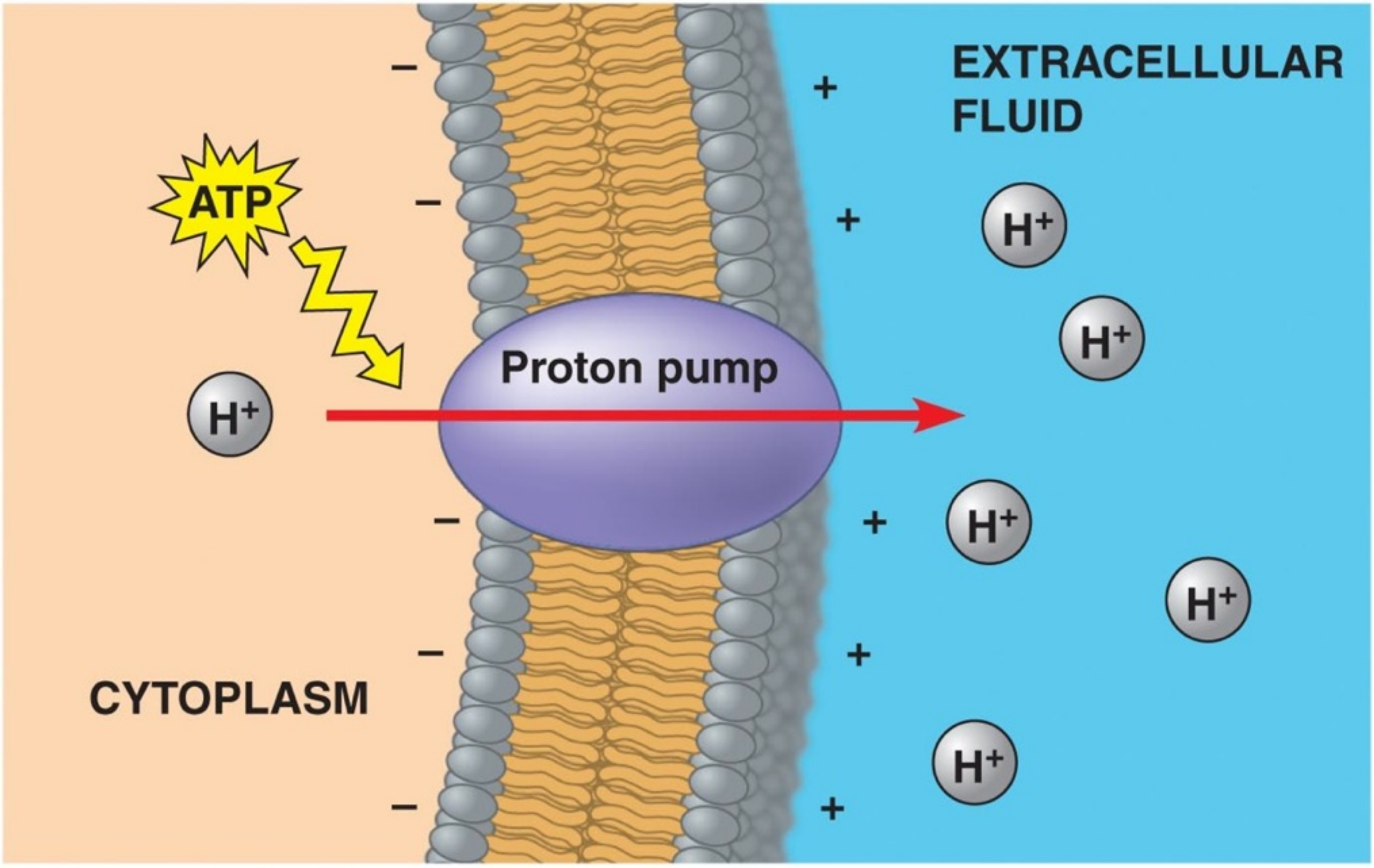
- ***THUS two forces drive diffusion of ions across a membrane***
  - *A Chemical Force (concentration gradient)* *AND*
  - *An Electrical Force (membrane potential)*
- *The combination of forces is called the* ***electrochemical gradient***
  - *As a result we must refine our definition of diffusion*
  - *Molecules (at least those with charges) diffuse down their electrochemical gradient.*

Do you think the an electrical gradient could be strong enough to oppose the chemical gradient?

YES

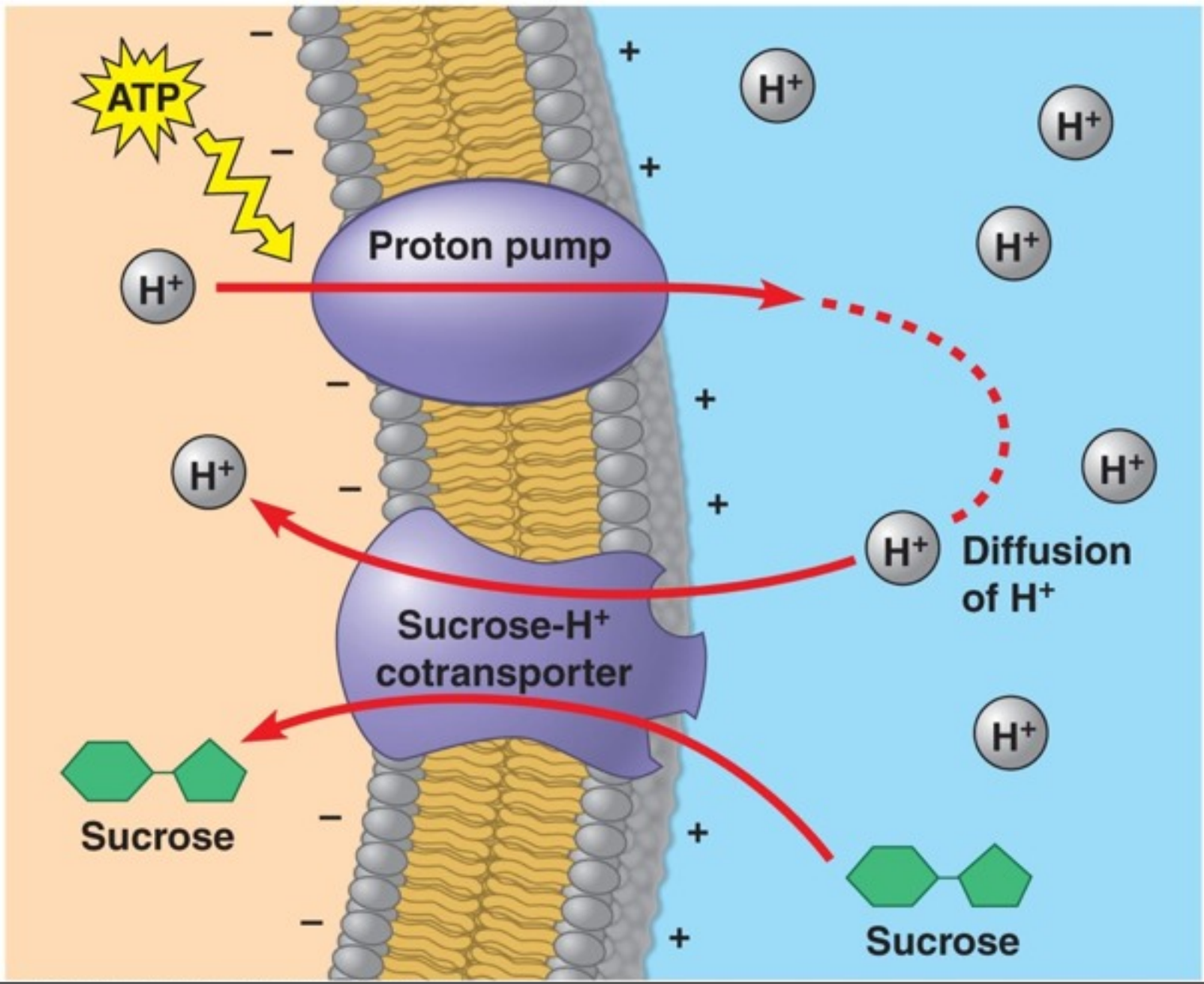
How Ion Pumps Maintain Membrane Potential

- Membrane proteins actively transport ions in a way that establishes a membrane potential
  - The **Na+/K+ pump** is the main pump used in animal cells
  - The **proton pump** is the main pump used by plants, fungi and bacteria.
- **ALL cells use about 20% of their energy budget for each of these pumps thus cells use nearly half of their total energy setting up membrane potentials!**



C. Cotransport: Coupled Transport by a Membrane Protein

- A single ATP powered pump that transports a specific solute can indirectly drive the active transport of several other solutes in a mechanism called **cotransport**.

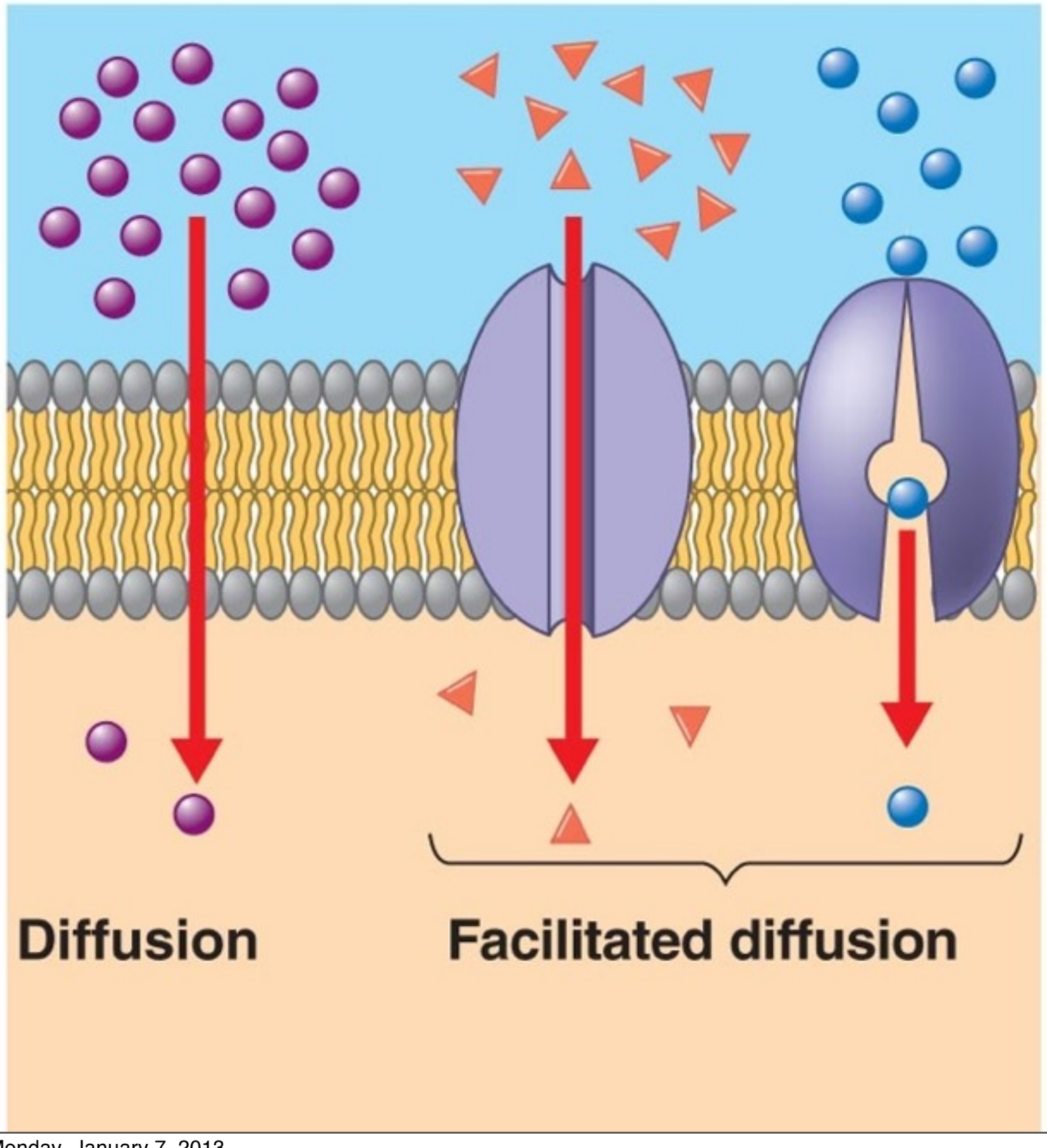


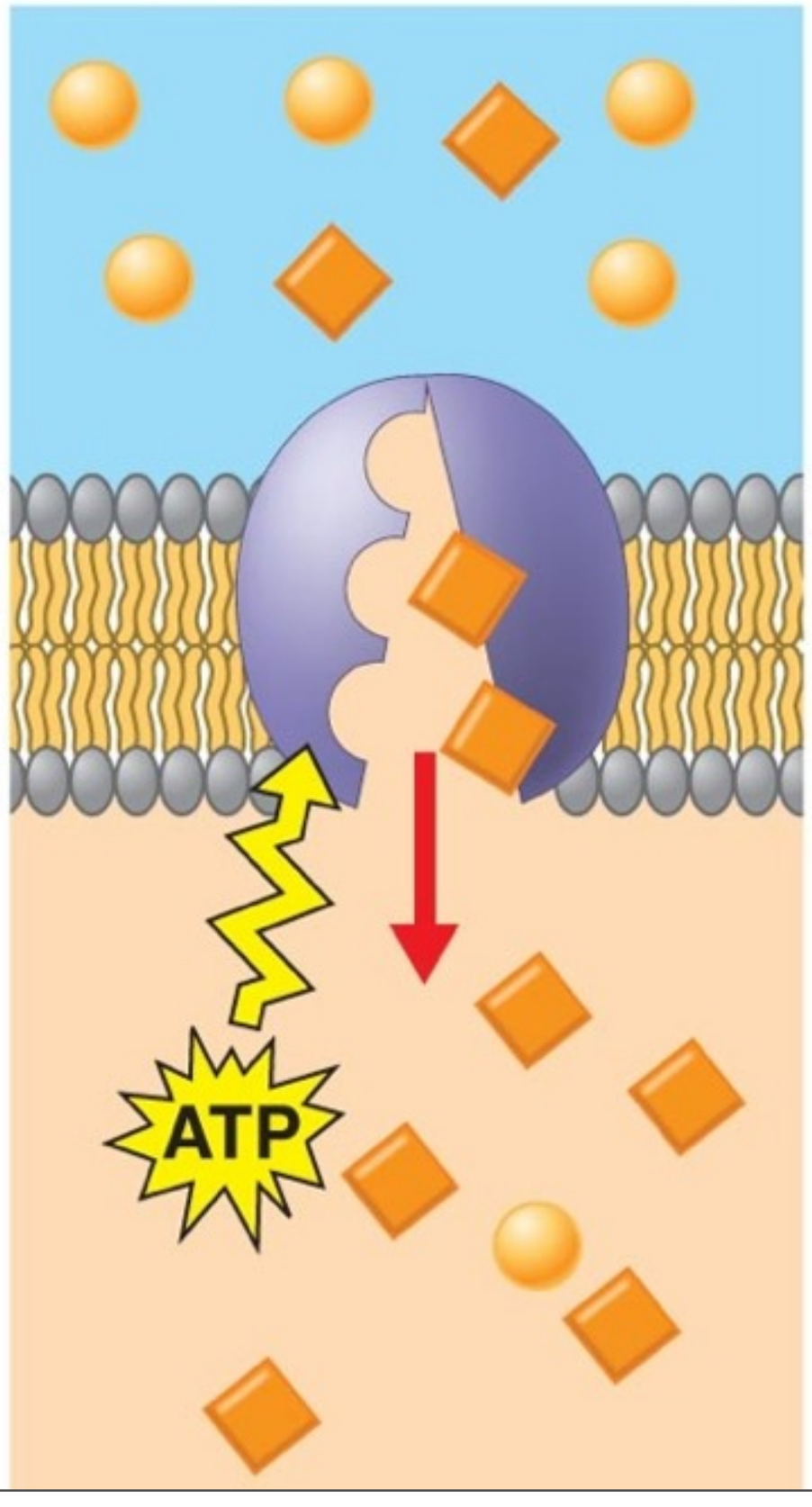
Passive transport

Review

Active transport

Review

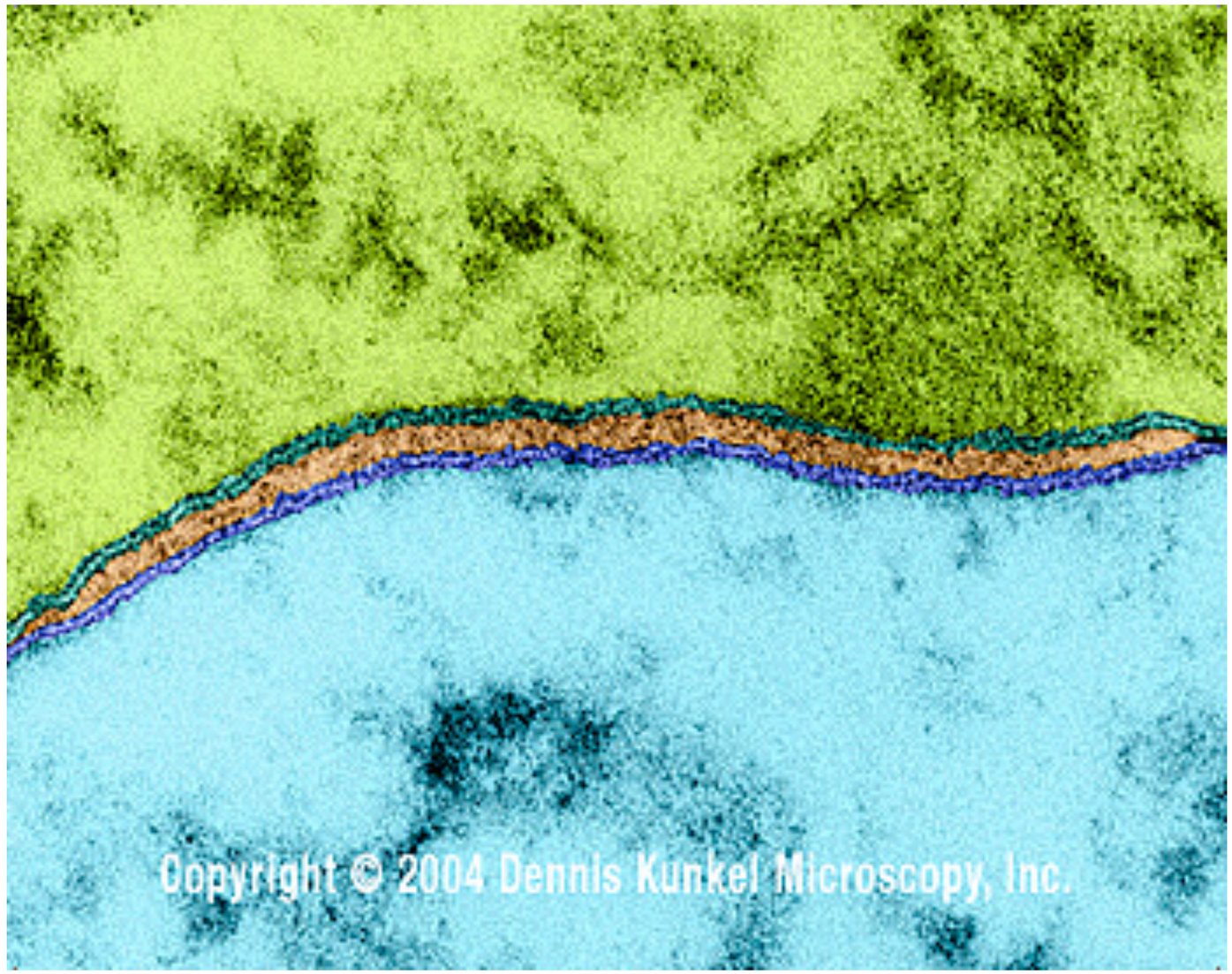




Cell Membrane

V.

Main Idea: Very large molecules can be moved across the membrane however it requires energy and a special mechanism.



BULK TRANSPORT ACROSS THE PLASMA MEMBRANE OCCURS BY EXOCYTOSIS AND ENDOCYTOSIS

A. Exocytosis

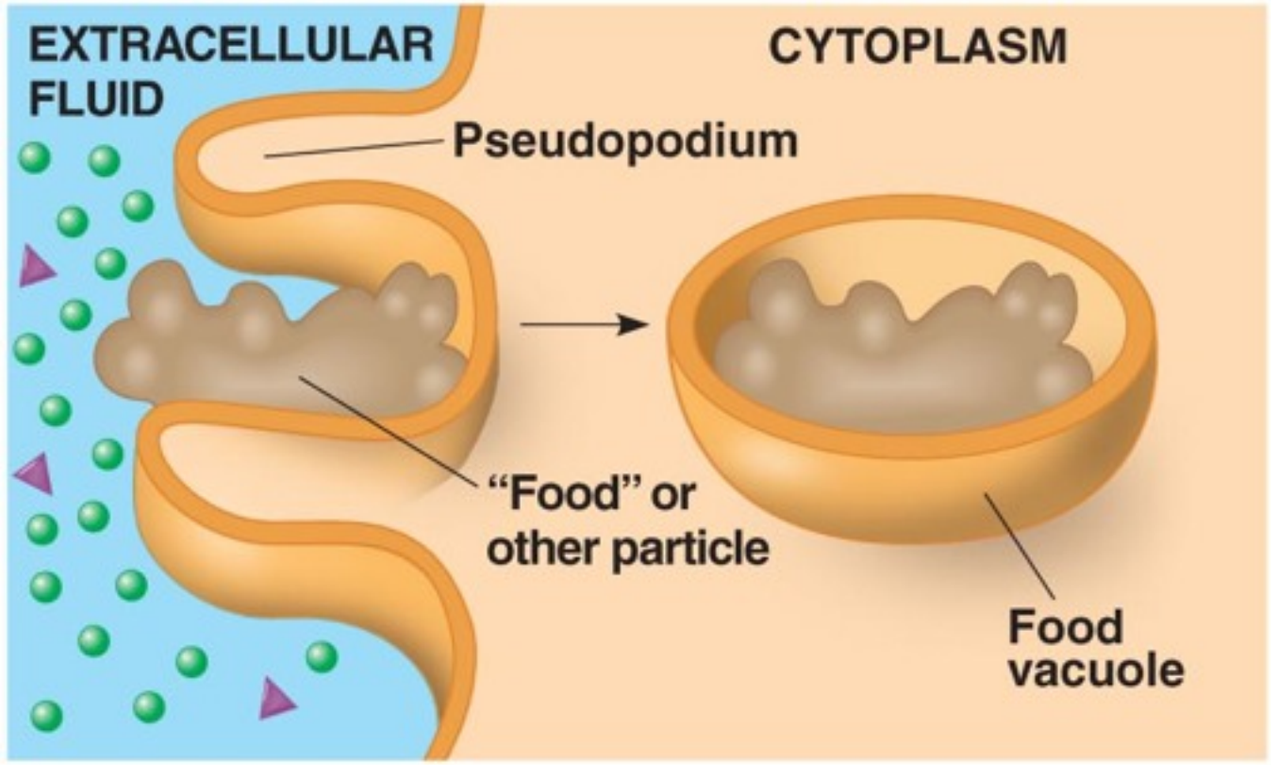
- **Exocytosis** involves the fusion of vesicles with the plasma membrane
- Pancreas secretes insulin in this way
- Neurons secrete acetycholine in this way

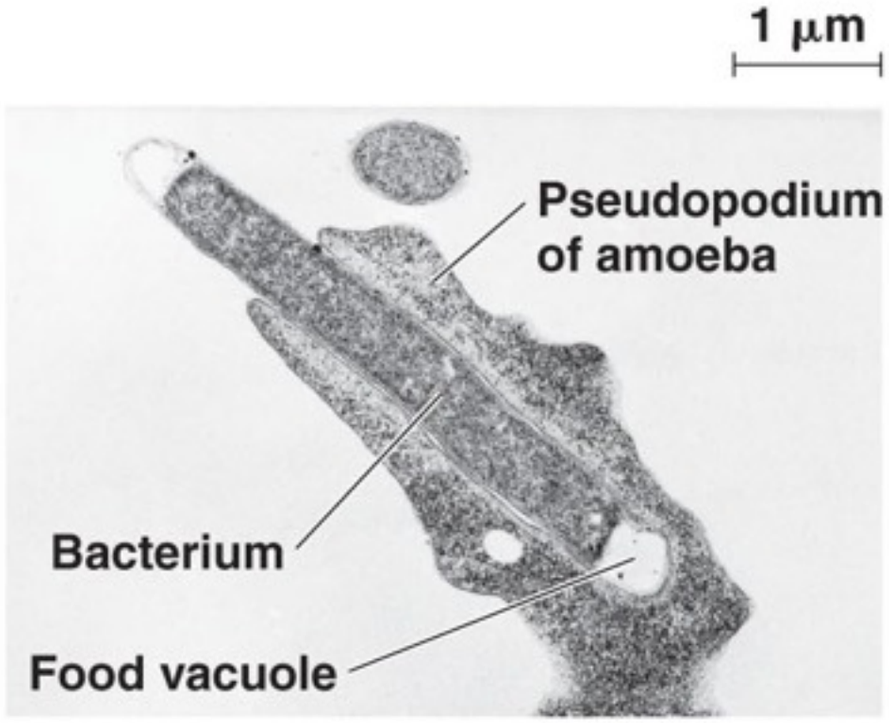
B. Endocytosis

- **Endocytosis** involves taking in substances by forming vesicles plasma membrane invaginates and pinches off
- There are three types of endocytosis:
  - *Phagocytosis* ("cell eating")
  - *Pinocytosis* ("cell drinking")
  - *Receptor Mediated Endocytosis* (like phagocytosis but a **ligand** must bind to a receptor in order for the process to continue)
    - Cholesterol is absorbed this way by cells
      - A **ligand** is describes any molecule that binds specifically to a receptor site on another molecule

Both endocytosis and exocytosis are important for membrane remodeling

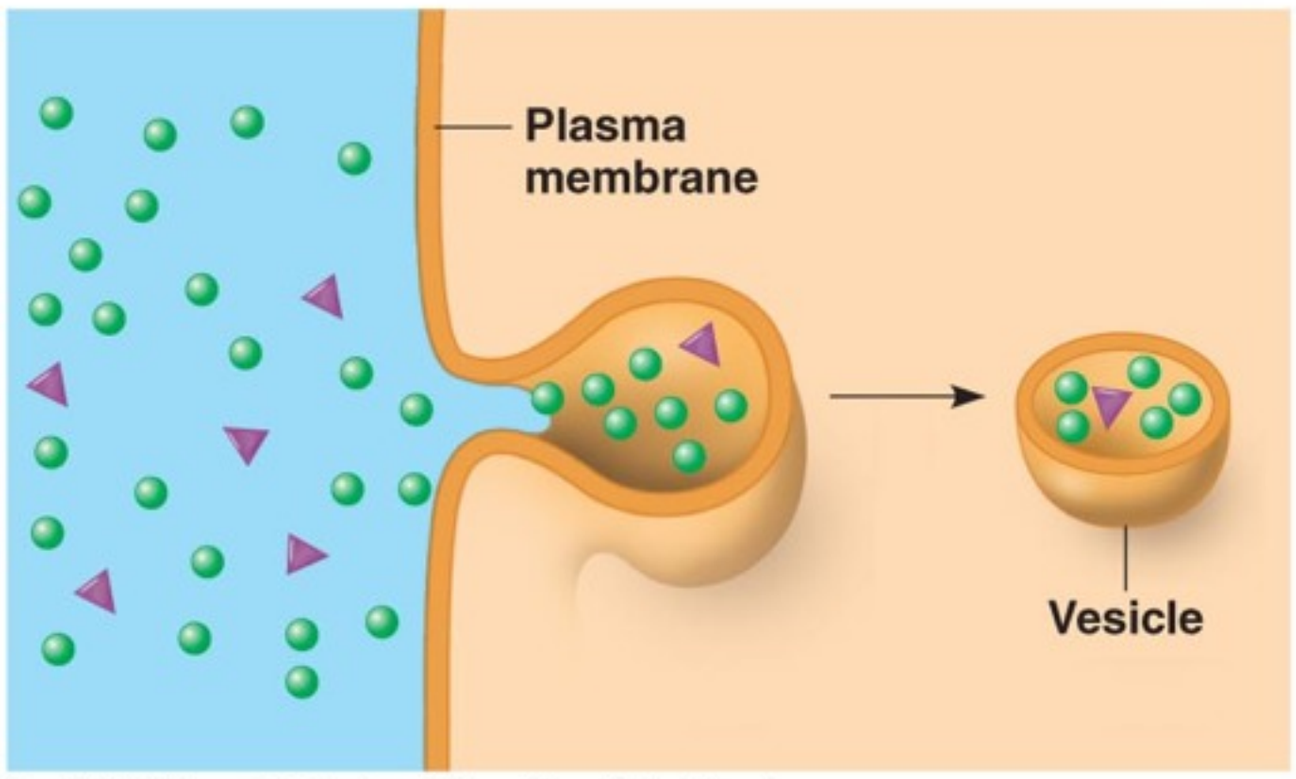
PHAGOCYTOSIS

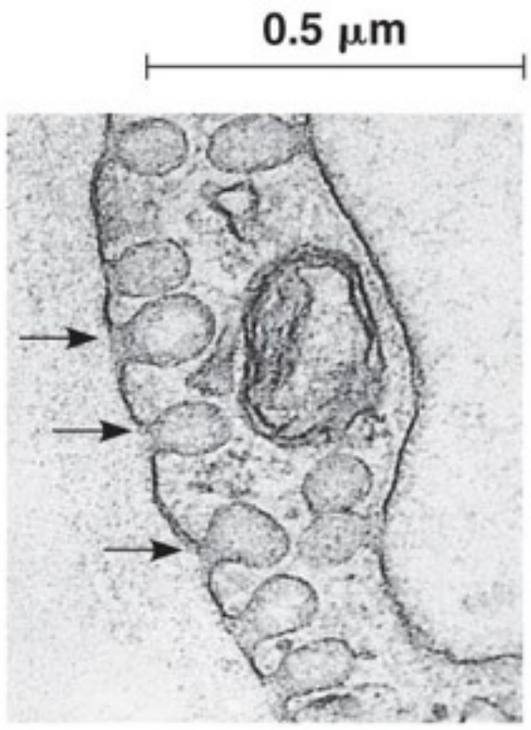




An amoeba engulfing a bacterium via phagocytosis (TEM)

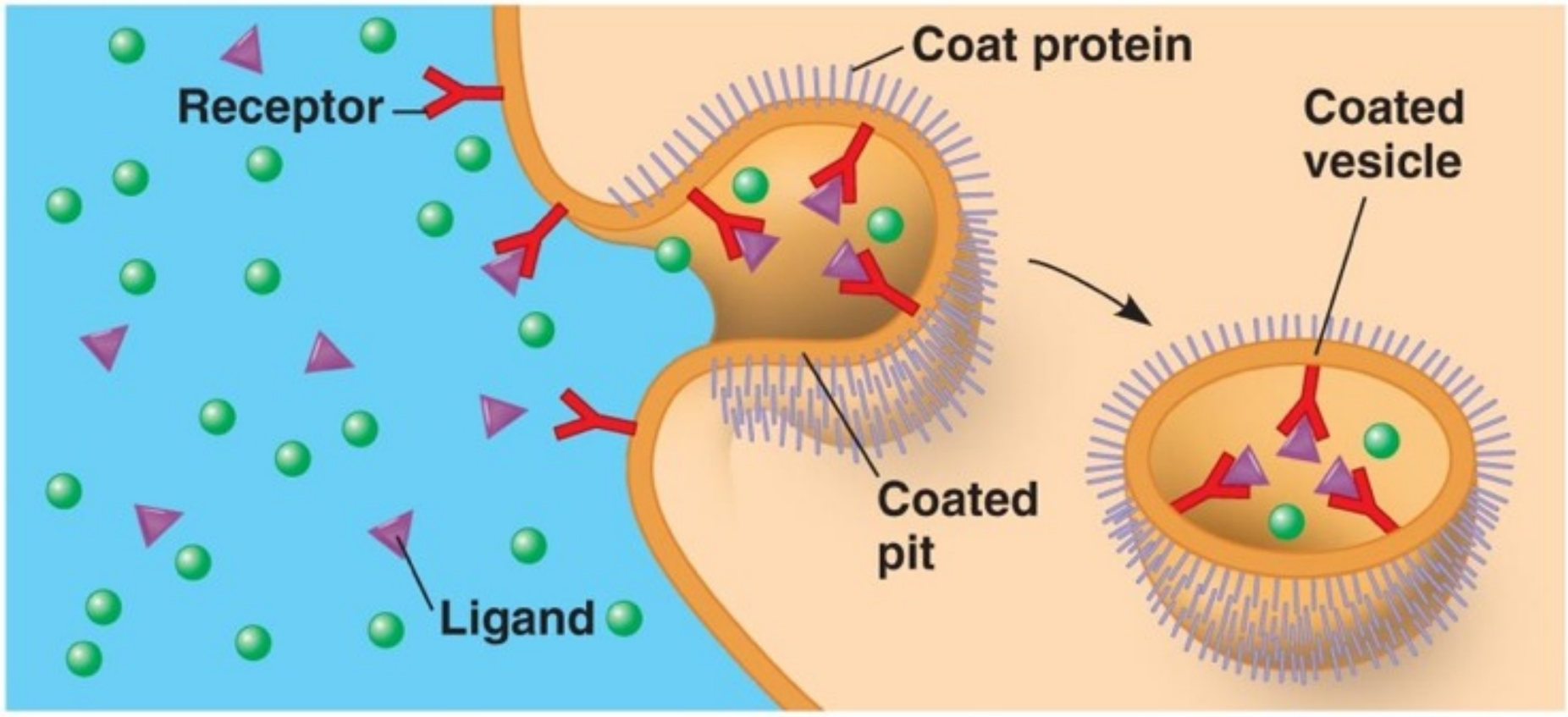
PINOCYTOSIS

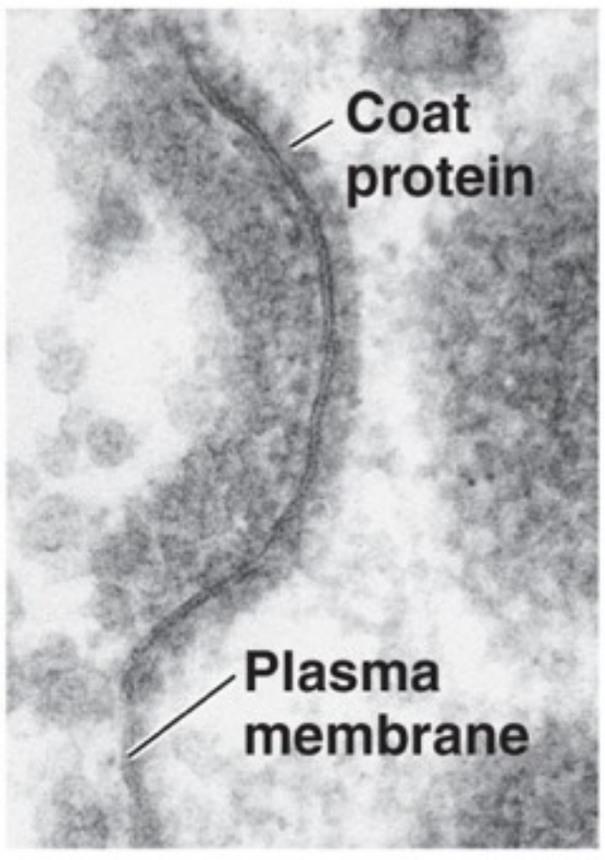


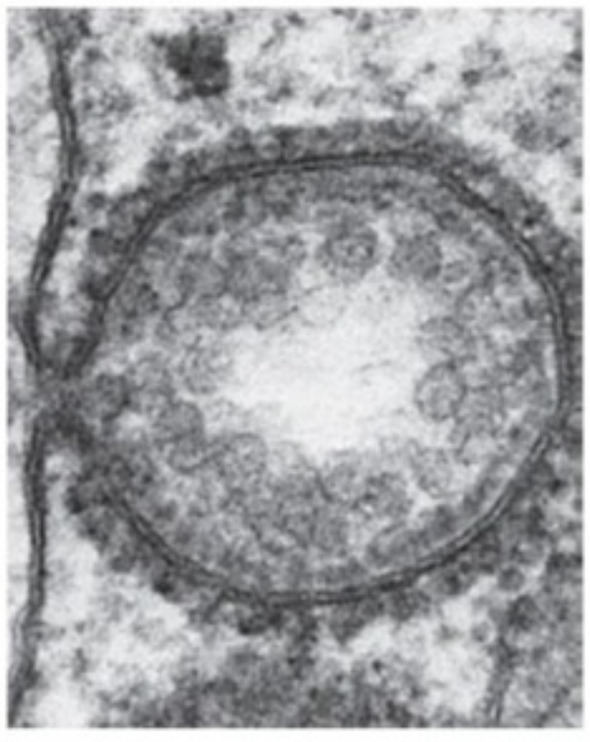


Pinocytosis vesicles forming (arrows) in a cell lining a small blood vessel (TEM)

RECEPTOR-MEDIATED ENDOCYTOSIS







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