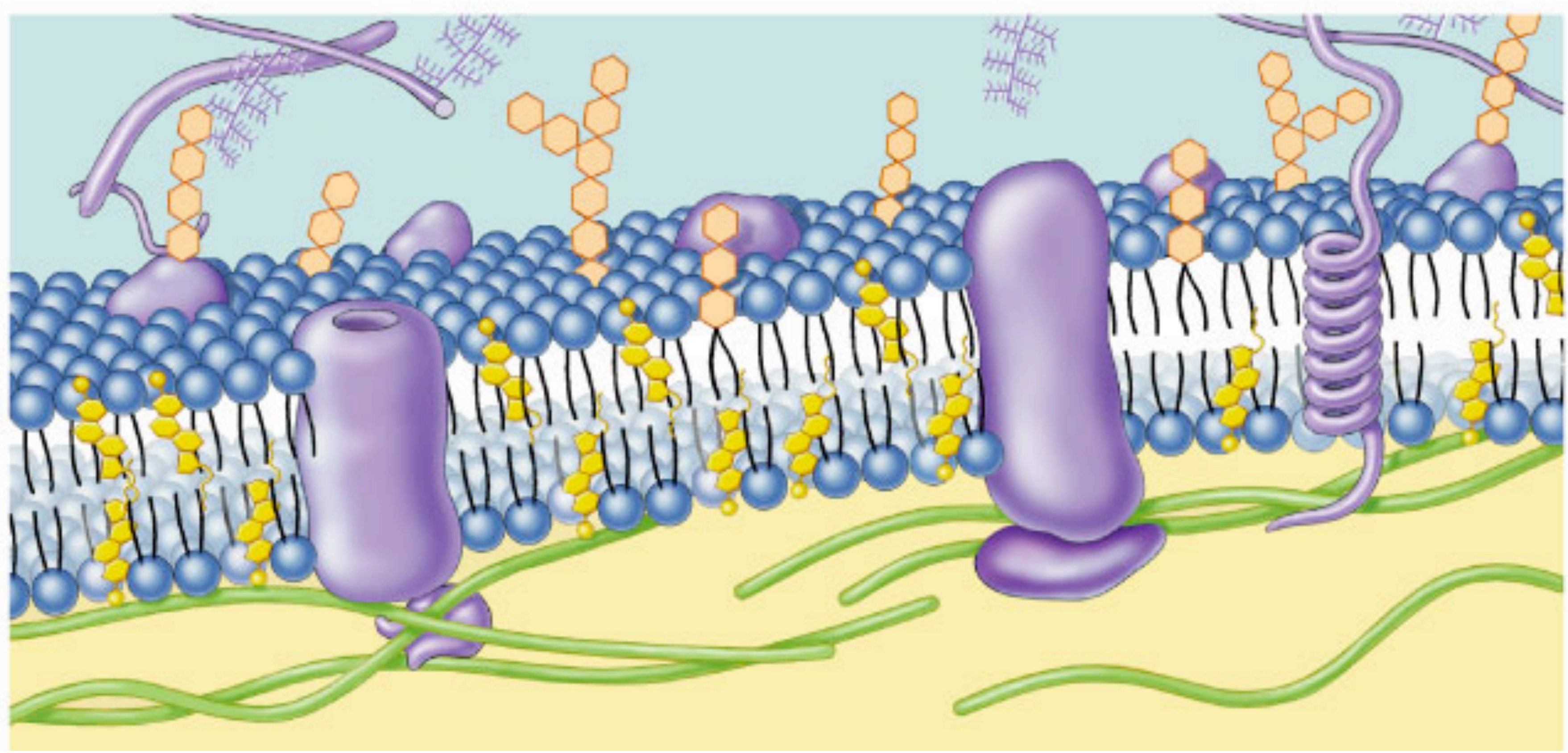
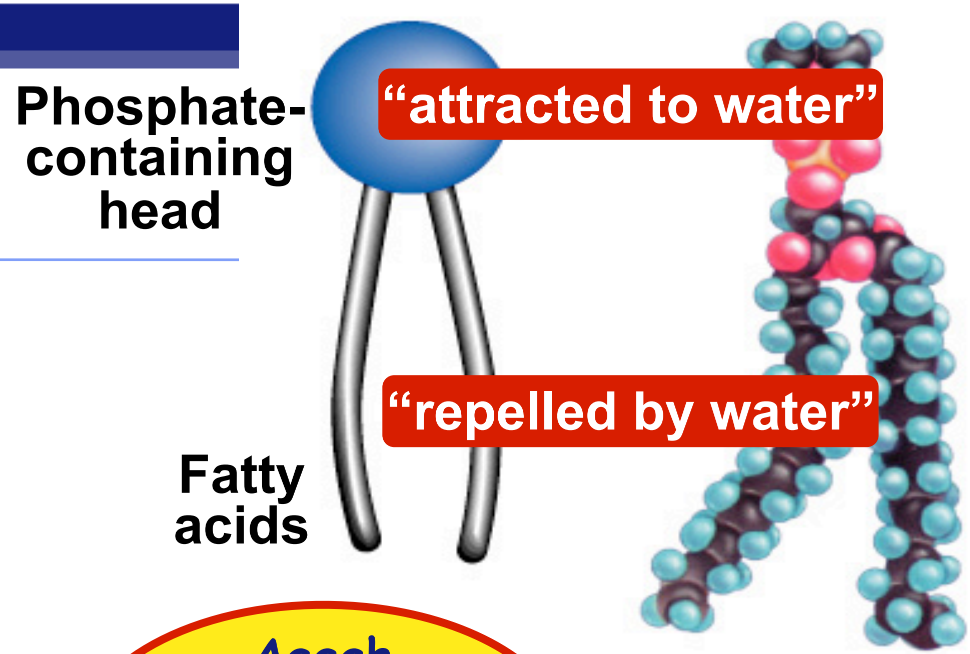
Chapter 7:

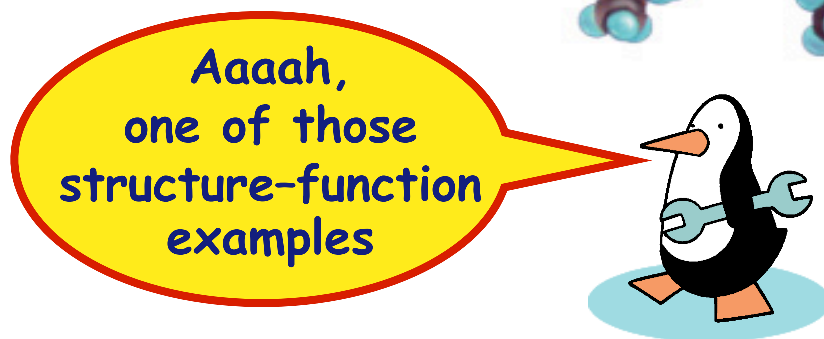
The Cell Membrane

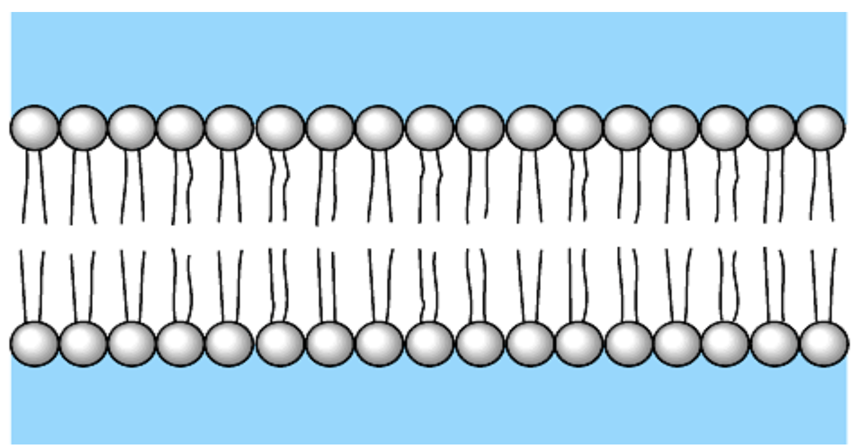


Phospholipids

- Are Amphipathic Molecules:
  - Phosphate-containing head
    - hydrophilic
  - 2 Fatty acid tails
    - Hydrophobic
- Arranged as a bilayer
  - Since tails (hydrocarbon portions of the fatty acids) are non-polar, they are ignored by the water in the aqueous environment
    - Hydrophobic exclusion occurs as tails are shoved together.
  - Charged heads are attracted to the polar water molecules

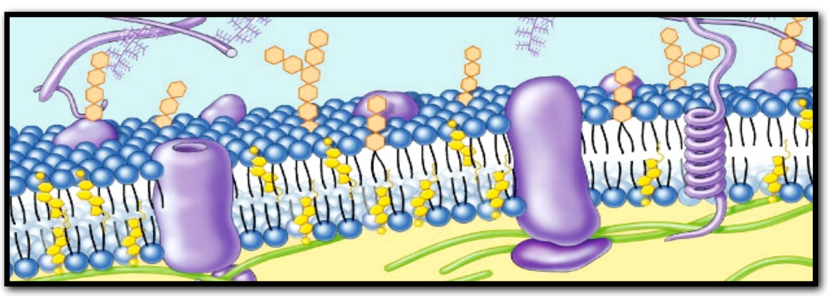


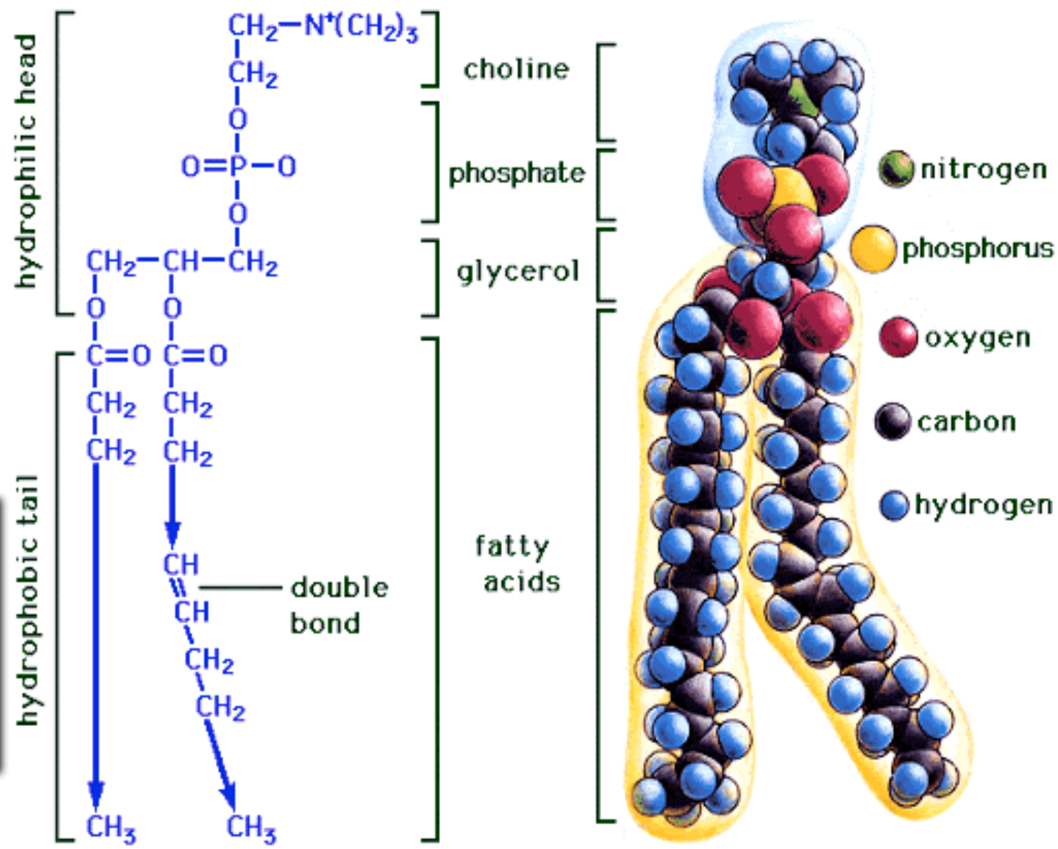




Membranes Serve as Selective Barriers

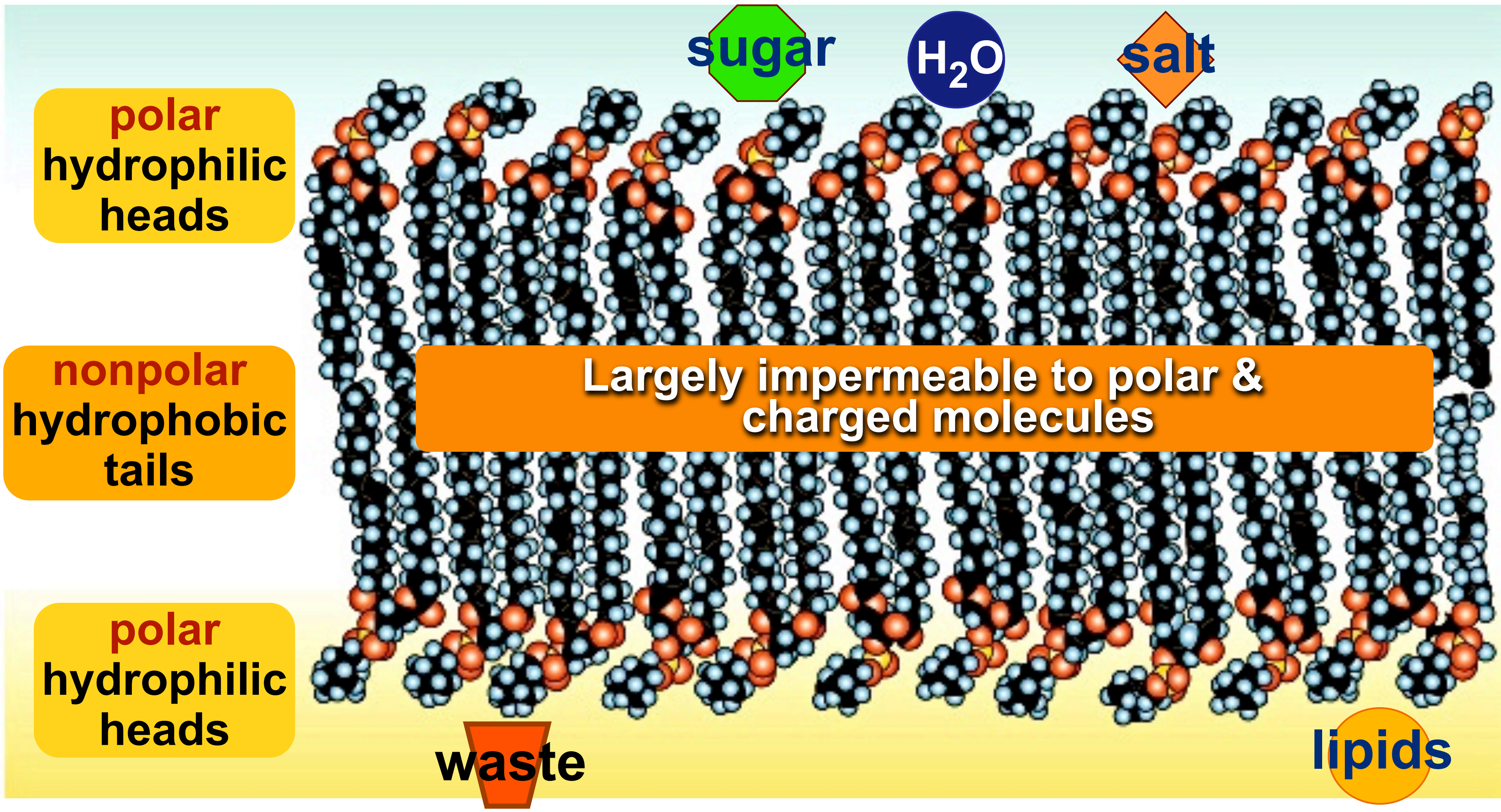
- Cell membranes <u>separate</u> the interiors of living cells from their external aqueous environments
- Cell membrane <u>separates</u> organelle contents from the cytosol in the rest of the cell
  - thin barrier = 8nm thick



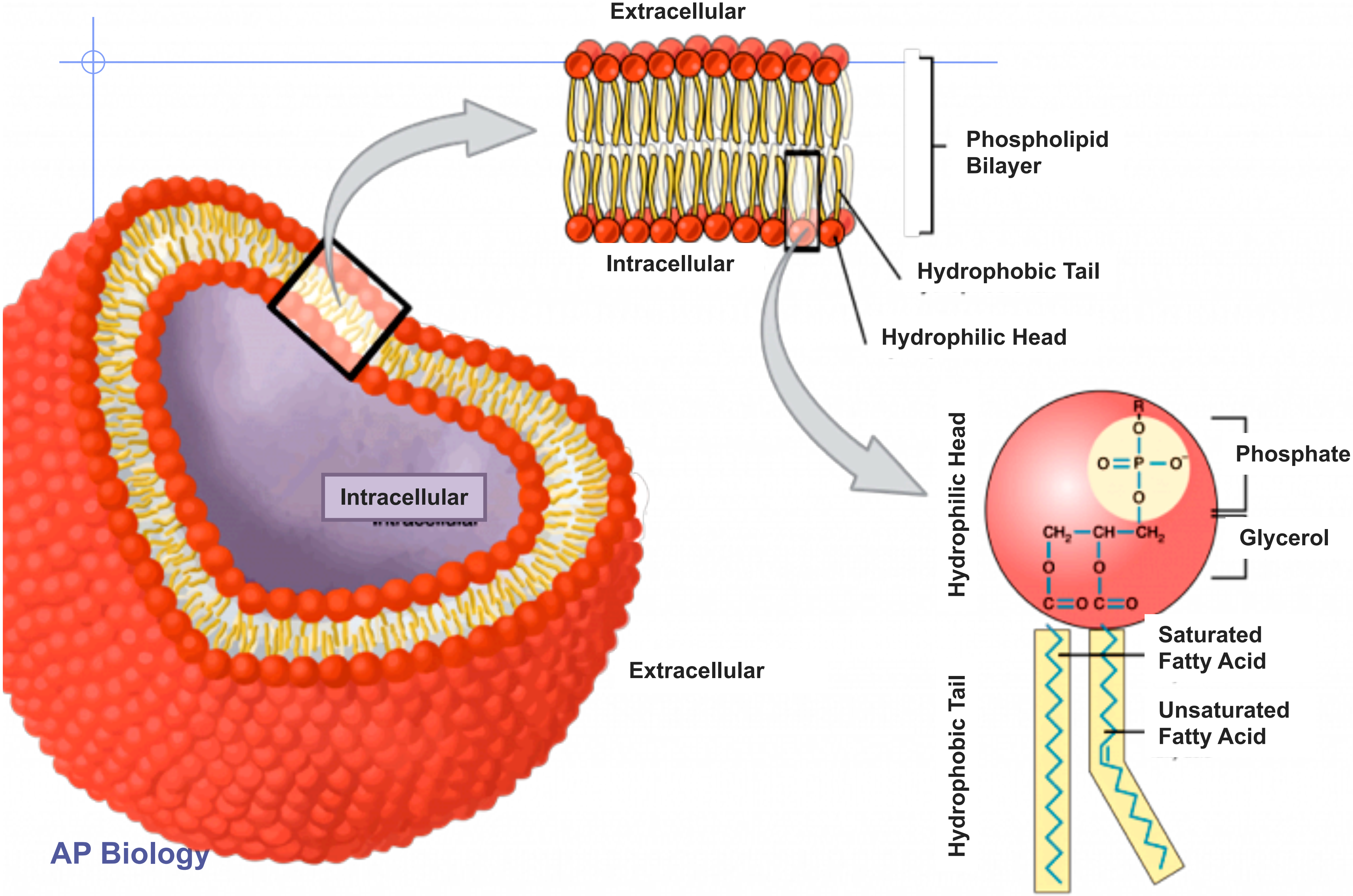


Membranes are Phospholipid Bilayers

- They are Selectively Permeable and serve as cellular barrier
  - Allows some substances to cross it more easily than others and substances to pass in a controlled manner.
    - This allows cells to maintain different concentrations and types of substances on the inside of the cell versus what is found on the outside

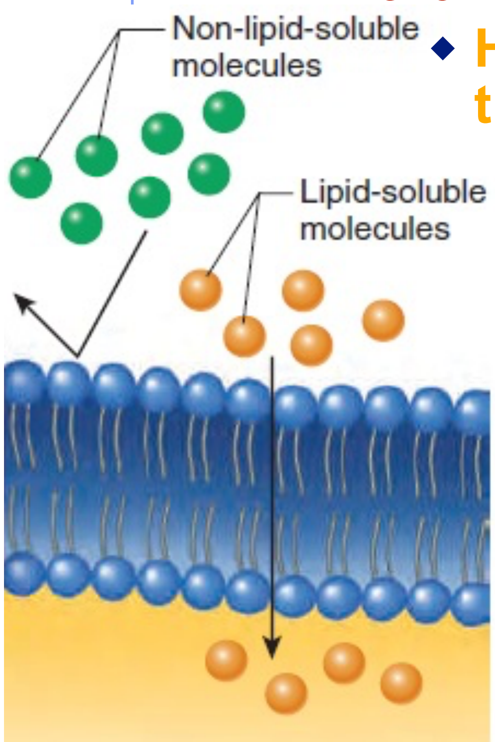


Membranes are Phospholipid Bilayers



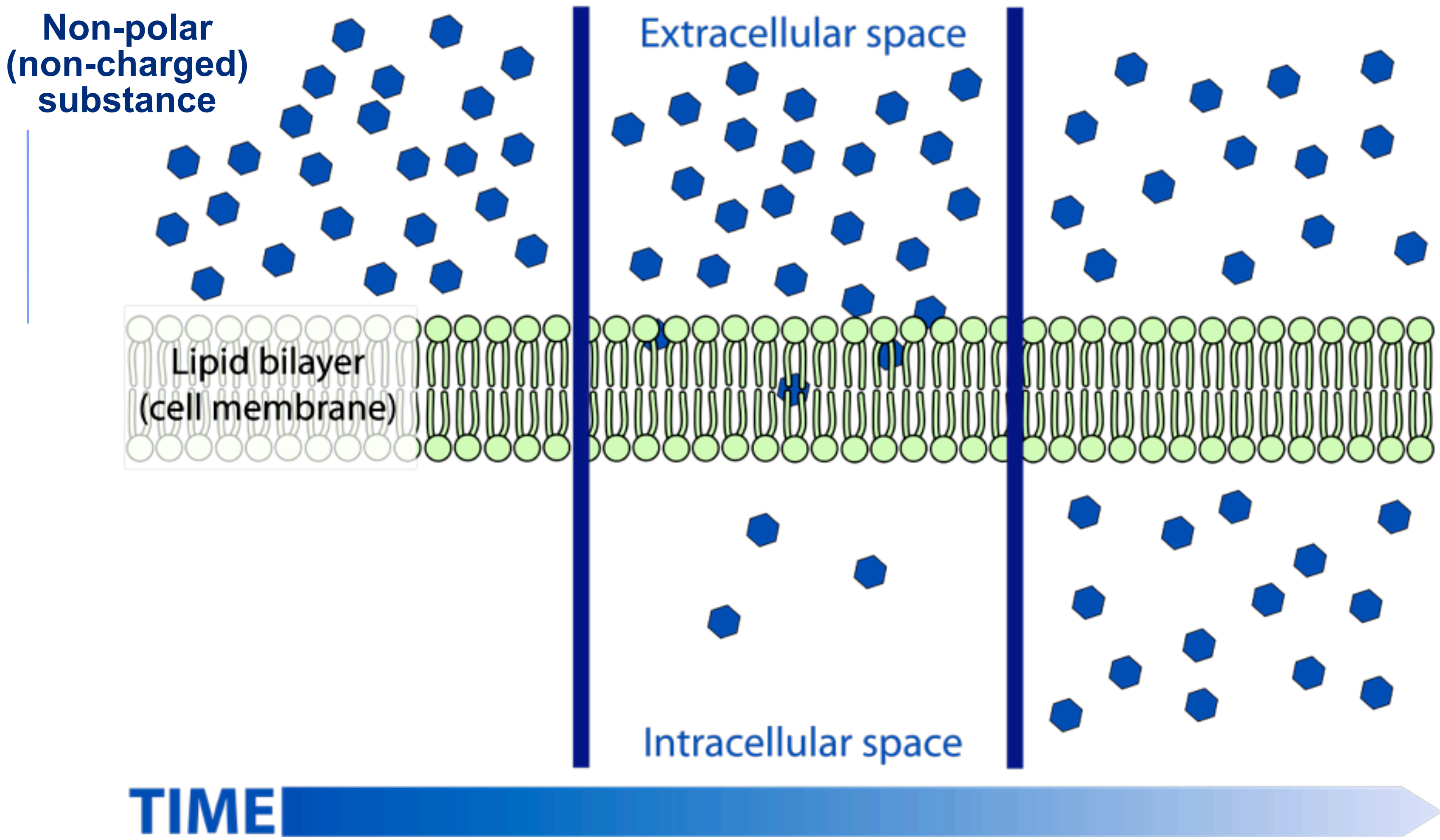
The Cell Membrane Are Selectively Permeable

- **Phospholipid bilayers allow some substances to cross more easily than others**
  - **Some substances can pass more easily, depending on their <u>size and characteristics</u>**
    - **Hydrophobic (non-polar) molecules pass much easier than hydrophilic (polar) substances**



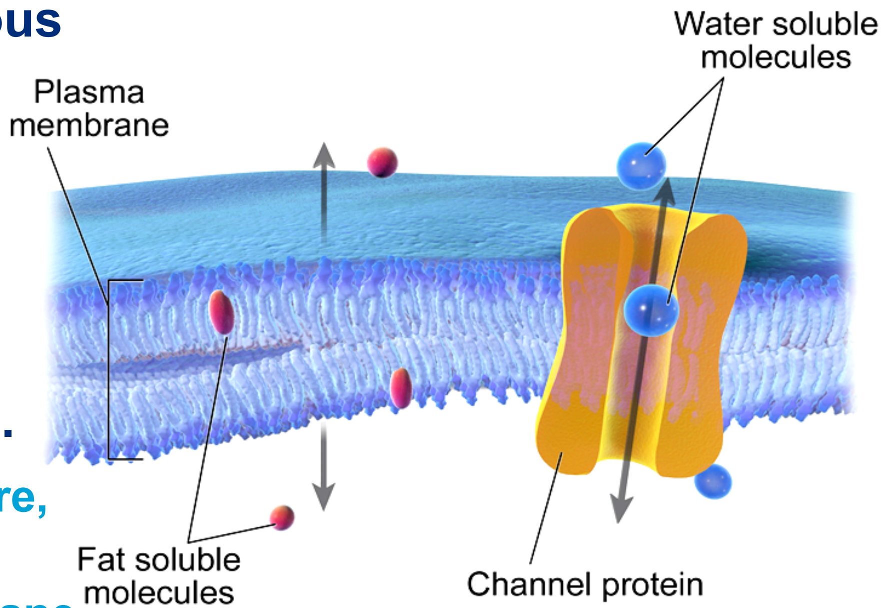
  - **Hydrophobic substances cross by traveling in between the phosopholipids**
    - **They move due to the random collisions substances in the aqueous solution experience due to <u>thermal energy</u>**
    - **Since they are hydrophobic (and have no partial or full permanent charges), these substances <u>do not</u> experience many intermolecular attractions with surrounding water molecules or the phospholipid heads on the side of the membrane where they are located on.**
      - **They, therefore, can slip through membranes easier <u>without</u> being prevented from doing so by attractions to water molecules & phospholipid heads**

Non-polar substances diffuse through phospholipid portions of membranes easily

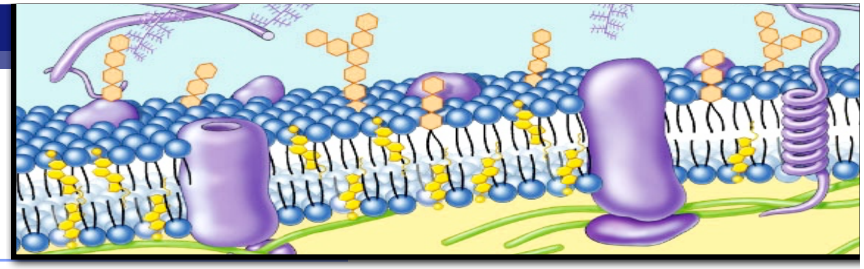


The Cell Membrane Are Selectively Permeable

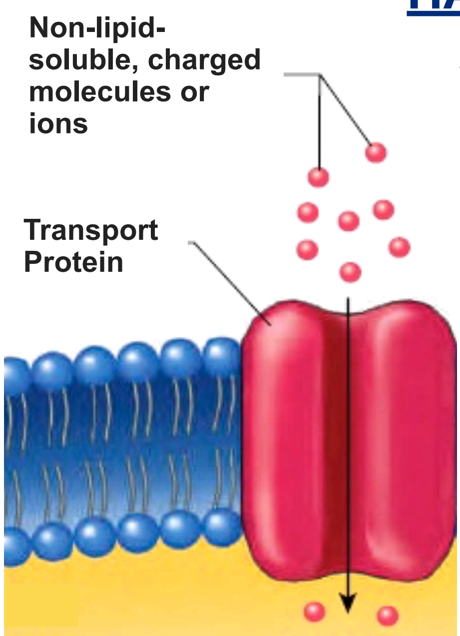
- **Passage of charged substances through membranes is strictly controlled**
- **Hydrophilic substances (polar molecules and charged ions) also exhibit kinetic motion due to thermal energy.**
  - **BUT when they get pushed towards the spaces in between phospholipids, they also experience intermolecular attractions to the water molecules in the aqueous solution on the side of the membrane they are located on**
  - **At the same time, hydrophilic substances are not attracted to the non-polar phospholipid tails at the core of the membrane.**
    - **Hydrophilic substances, therefore, do not easily travel in between phospholipids through a membrane.**



The Cell Membrane Are Selectively Permeable



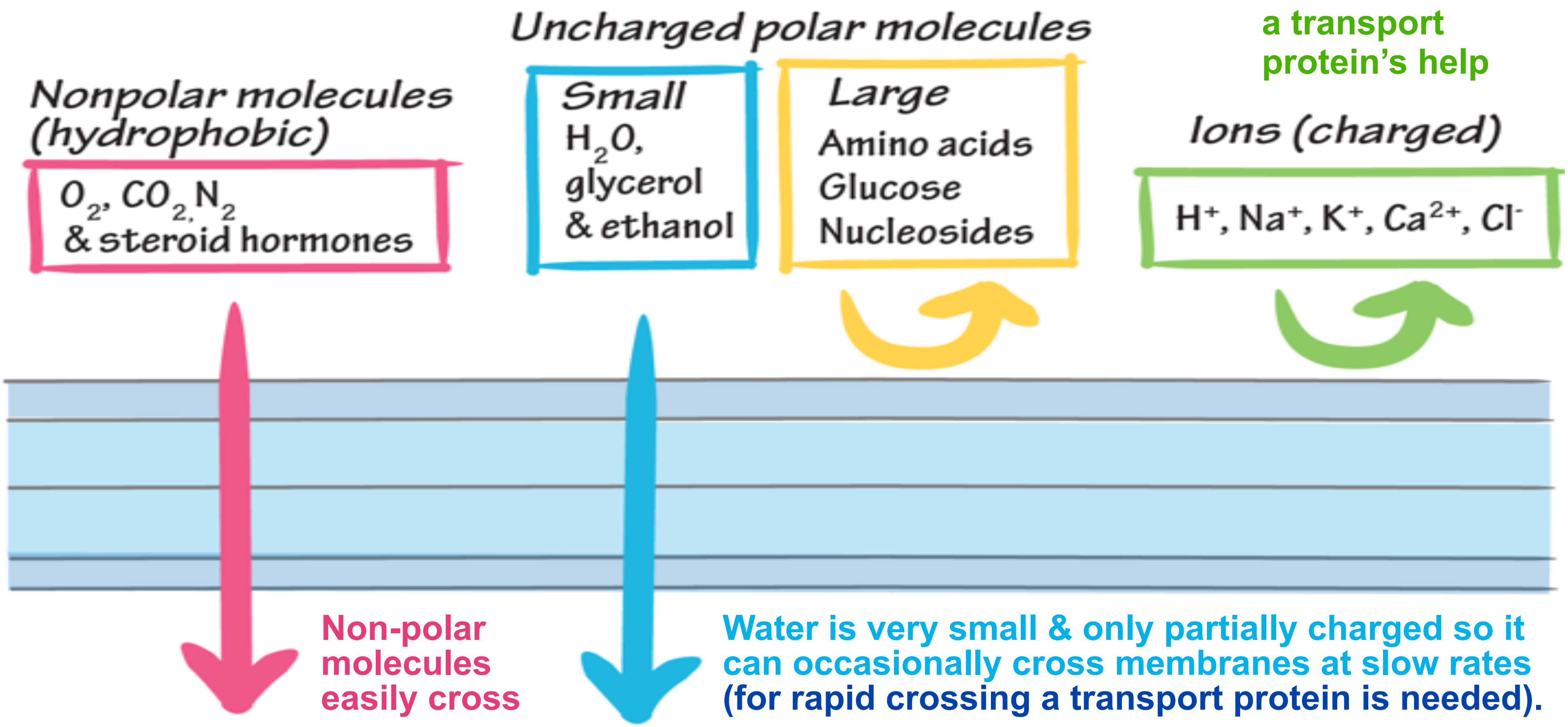
- Membranes control traffic in & out of cells, and in & out of organelles within eukaryotic cells
  - The phospholipid bilayer is largely <u>impermeable</u> to charged substances (polar molecules and ions)
    - Yet, charged substances (Ex: simple sugar monomers, amino acids, ions, proteins, ammonia - a waste product, etc...) still <u>HAVE</u> to pass into or out of a cell or into or out of organelles
      - <u>Transport proteins</u> embedded in the membrane will help smaller polar and charged substances (ions and monomers) pass through the membrane
        - Very large molecules (like macromolecules) either can't pass trough membranes or are transported in or out of the cell (or organelle) through <u>membrane pores</u> like nuclear envelope pores (or <u>gap junctions</u> between animal cells)
        - Very large molecules (like macromolecules) may pass into or out of the cell by <u>endocytosis and exocytosis</u> *(more on these processes later in this chapter)*



What can diffuse across a membrane without transport protein assistance?

Rate of diffusion
- ✓ Size – smaller diffuses faster
- ✓ Polarity – less polar diffuses faster
- ✓ Charged – does not diffuse

Large partially charged molecules & fully charged ions (even if small) **cannot** cross without a transport protein's help



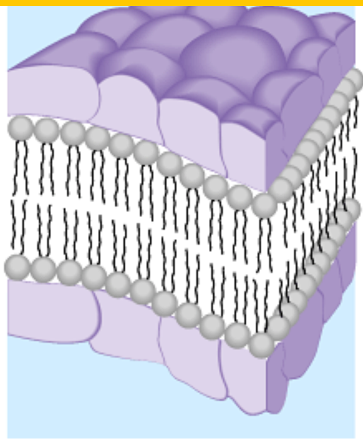
Cell membrane is more than lipids…

Today we know that there are peripheral and transmembrane proteins associated with and embedded in phospholipid bilayer

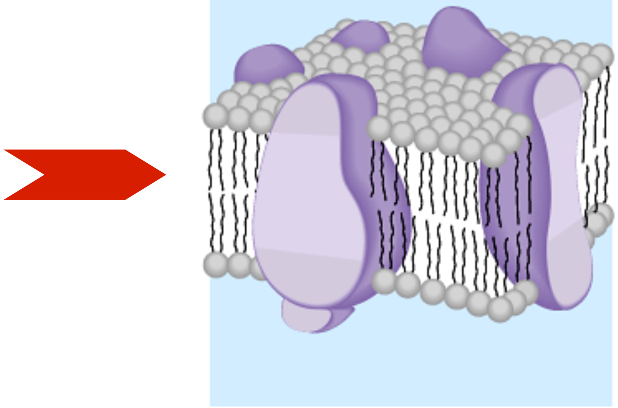
- But this wasn't always the case…
  - **Gorter & Grendel**: Structure must be made of phospholipid bilayer
  - **Davson and Danielli**: Proposed the Sandwich Model for how proteins and phospholipids are distributed in membranes
    - **Problems with the sandwich model?**

1. All cells are not identical. Differently functioning membrane must have different chemical structure and composition.
2. Membrane proteins are often amphipathic so not very soluble in only water.

SANDWICH MODEL: lipid bilayer with outer layer of proteins



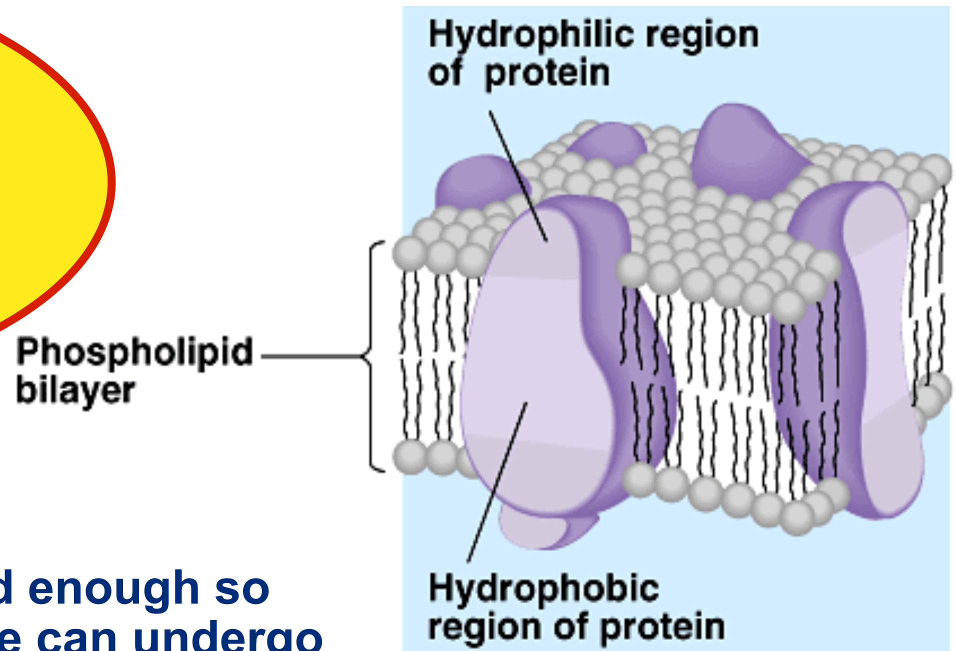
FLUID-MOSAIC MODEL: Proteins are in or attached to phospholipid bilayer membrane (Nicolson & Singer)



Cell membrane must be more than lipids…

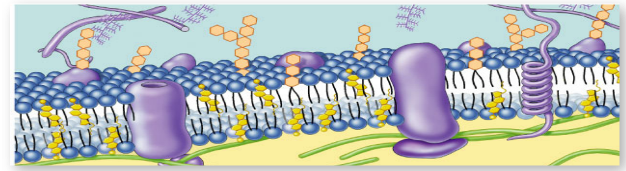
- In 1972, S.J. Singer & G. Nicolson proposed that membrane proteins are inserted into the phospholipid bilayer

It's like a fluid…
It's like a mosaic…
It's the
Fluid Mosaic Model!

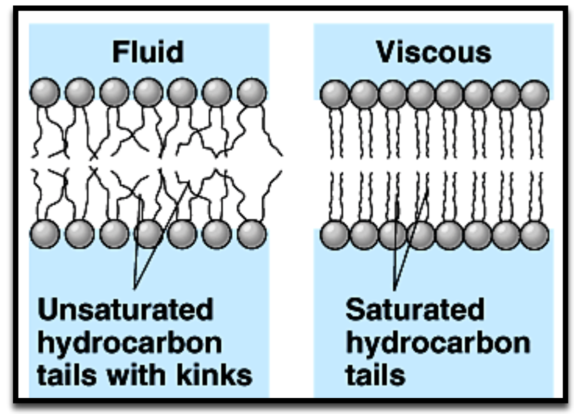


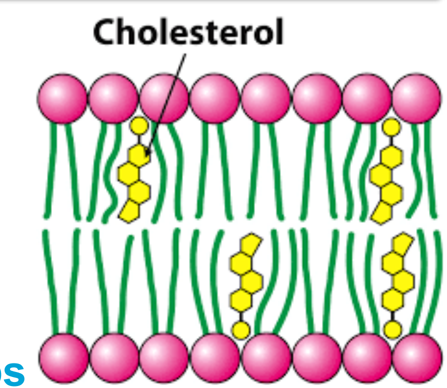
- Membranes must be fluid enough so proteins in the membrane can undergo conformational shape changes as they do their job and substances can cross the membrane effectively
  - Membranes **cannot** get too fluid though or the gaps between phospholipids become too big and the ability for the membrane to control which solutes pass in or out of the cell fails

Movement in & Fluidity of Membranes



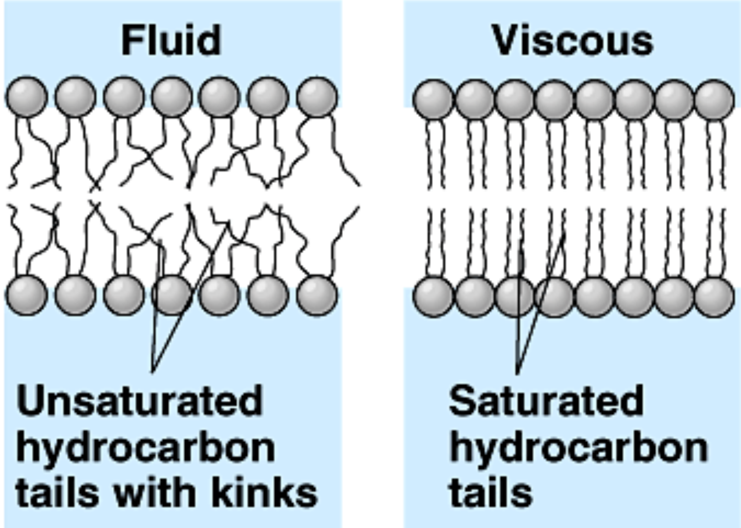
- **Hydrophobic interactions hold the phospholipids in the formation of a bilayer membrane**
  - **Phospholipids**
    - **Float around laterally - within one layer of phospholipids - rapidly**
    - **Can flip from one side of the bilayer to the other but this is rare**
  - **Proteins**
    - **Some float around in the membrane**
    - **Some move in specific directions along cytoskeletal fibers driven by motor proteins**
    - **Others are anchored by cytoskeletal fibers and hardly move at all**
  - **Fluidity**
    - **Saturated hydrocarbons**
      - **Higher % of phospholipids with unsaturated hydrocarbons keeps the membrane more fluid at lower temperatures than membranes with higher % of phospholipids with saturated hydrocarbons**
    - **Cholesterol**
      - **Helps membrane resist changes in fluidity**
      - **Restrains phospholipid movement in high temps**
      - **Hinders close packing of phospholipids in low temps**



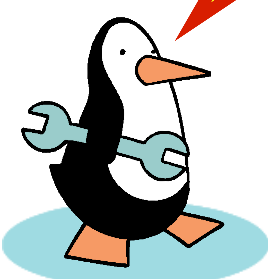


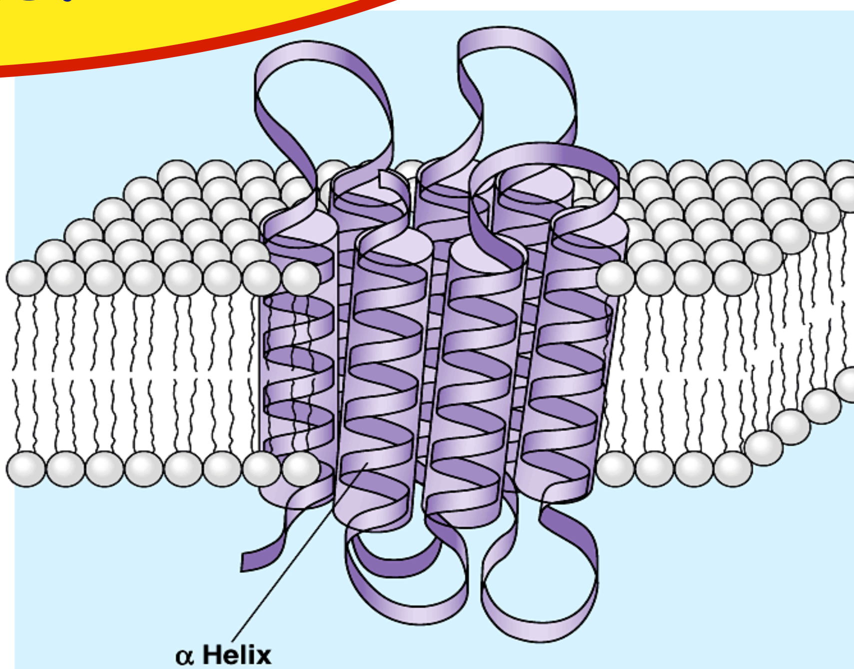
Membrane lipid composition varies by species and can be changed in some species

- Membranes must remain fluid & flexible
  - about as fluid as thick salad oil
- When temperatures drop, less thermal energy is in the system, less collisions occur and with less force, and phospholipids start packing more tightly together.
  - Phospholipids can be prevented from packing too tightly together (making the membrane too rigid) by altering the % of unsaturated vs saturated phospholipids
    - More unsaturated phospholipids prevents membrane from getting too viscous (thick)
      - Cold-adapted organisms, like winter wheat increase % of unsaturated-fatty-acid-containing phospholipids in autumn when temperatures start getting colder.

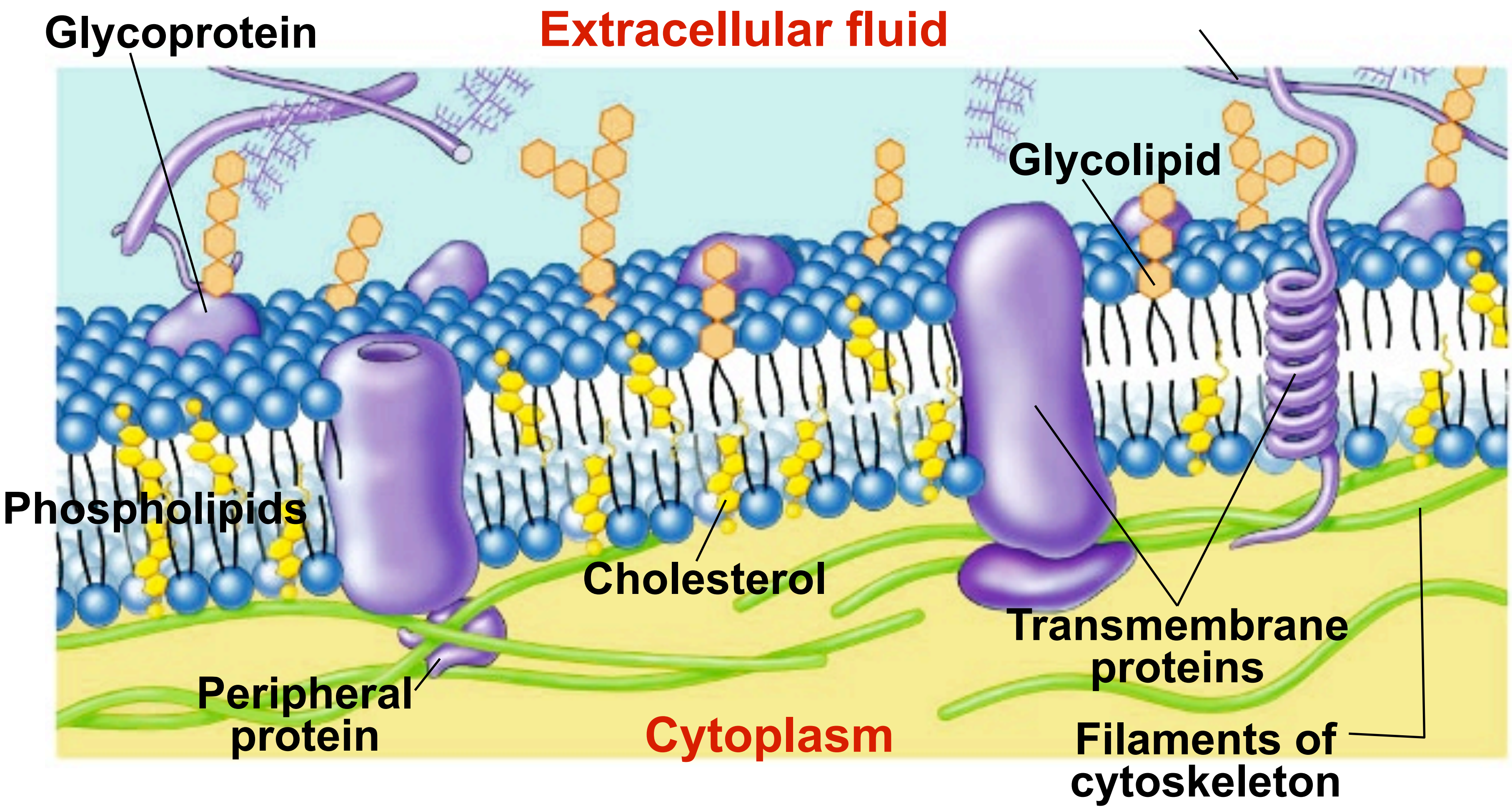


Why are **proteins** the perfect molecule to use to build structures in the cell membrane?



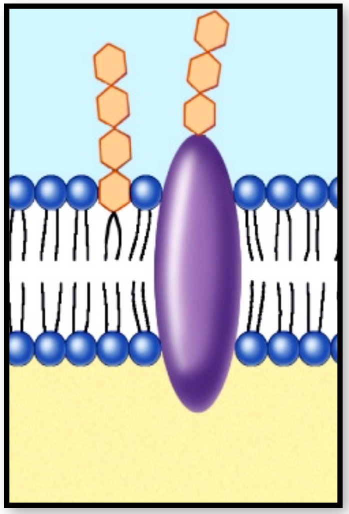


Membrane is a collage of proteins & other molecules embedded in the fluid matrix of the lipid bilayer



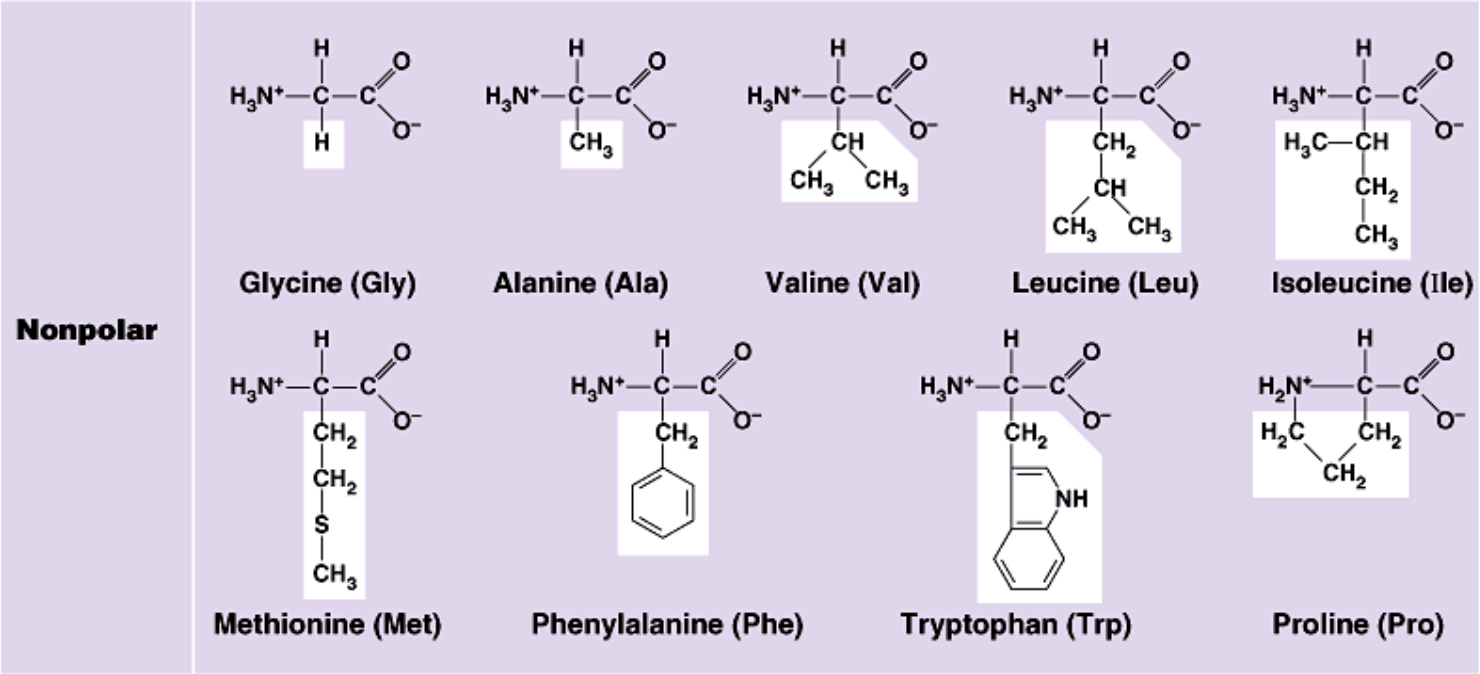
Membrane carbohydrates are seen as part of Glycolipids & Glycoproteins

- The carbohydrate portions include short branched polymers of around 15 sugar monomers covalently bonded together and attached to a phospholipid head or a membrane protein
  - These short carbohydrate polymers are often added to phospholipids and membrane proteins in the rough ER.
- Some play a key role in cell-cell recognition:
  - ability of a cell to distinguish one cell from another
  - important in organ & tissue development
  - basis for rejection of foreign cells by immune system
    - Ex: Glycoproteins make up some of antigens, molecules found on the surface of foreign or abnormal cells and viruses that vertebrate immune system cells can react to



Amino Acids Differ in R Group Properties

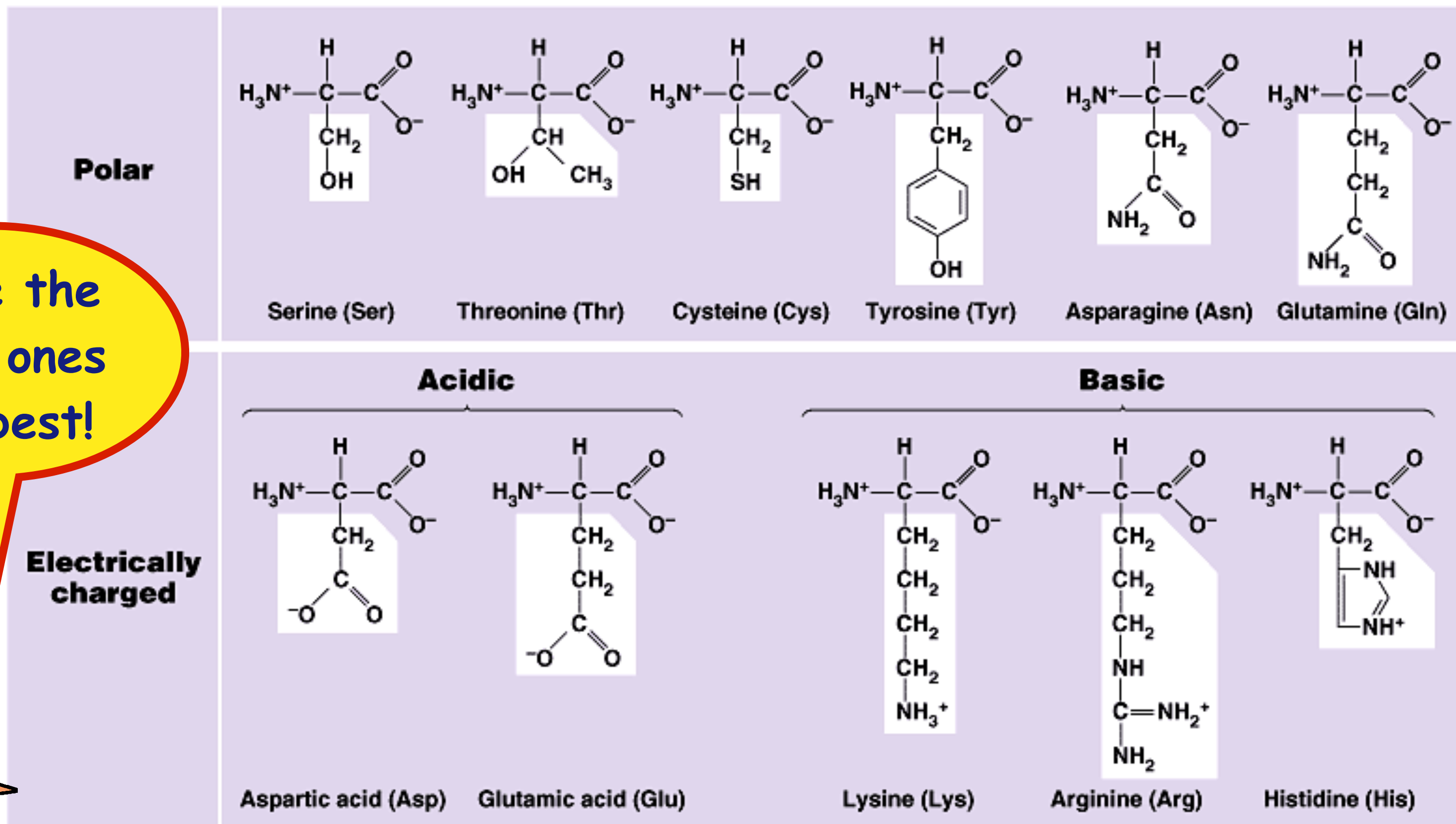
What do these amino acids have in common?

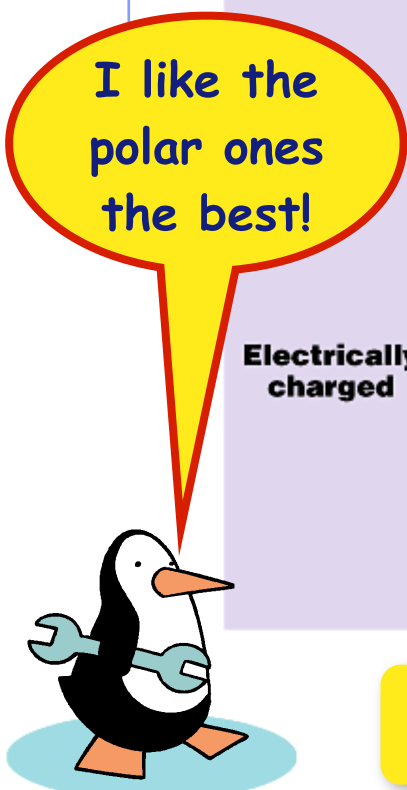


nonpolar & hydrophobic

Amino Acids Differ in R Group Properties

What do these amino acids have in common?

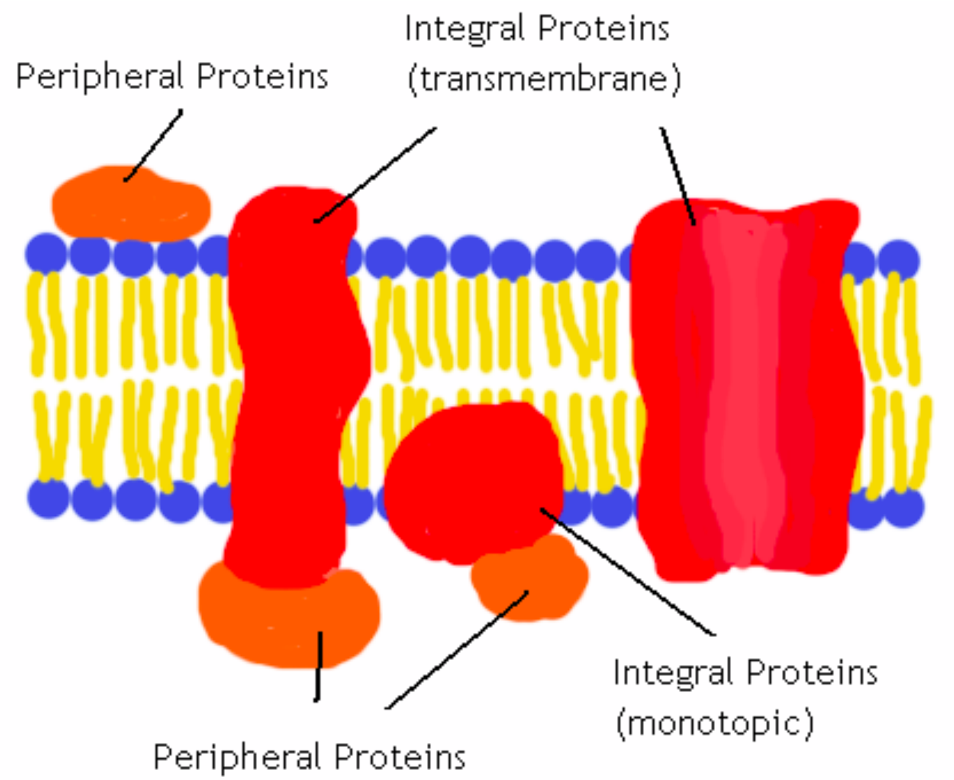




polar or charged & hydrophilic

Membrane Protein Types

- **Integral proteins** penetrate the hydrophobic core of the lipid bilayer.

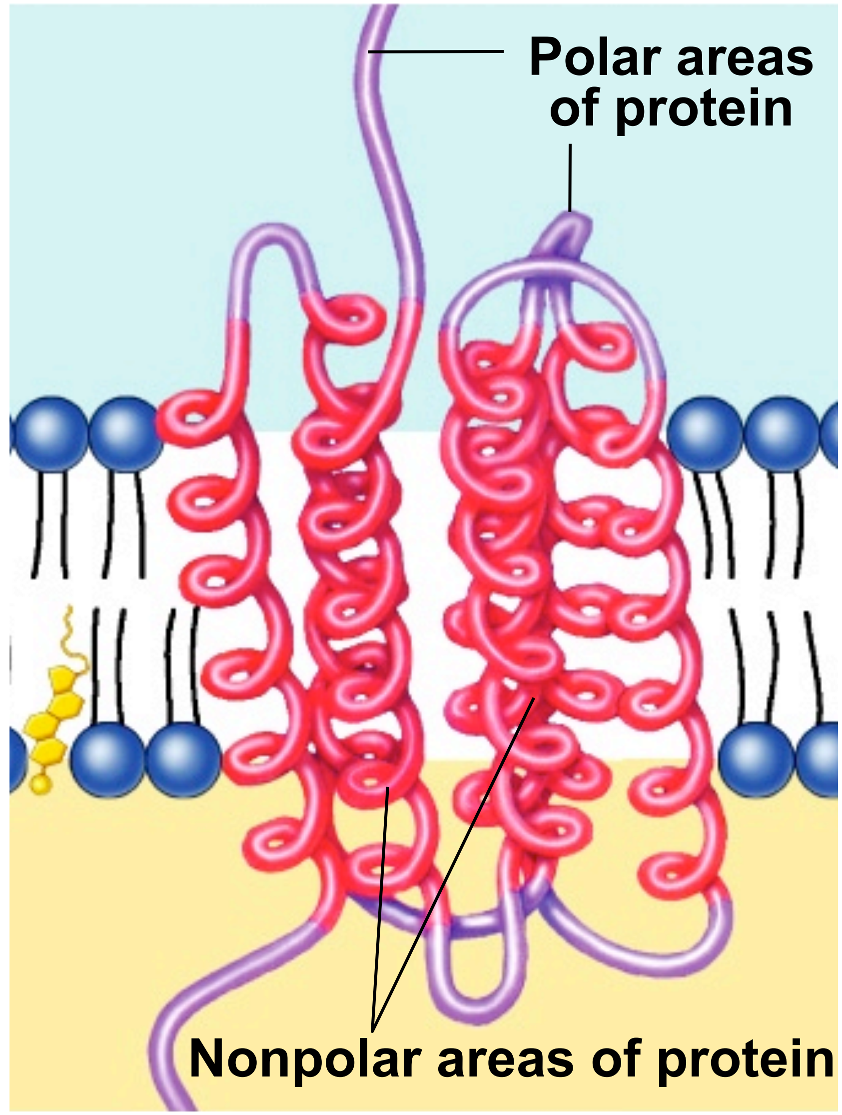


  - **Transmembrane** proteins span both phospholipid layers of the membrane
  - **Other integral proteins extend only partly into the lipid core, being found in one of the two phospholipid layers**

- **Peripheral proteins are not embedded in the lipid bilayer at all and are loosely bound to the surface of the membrane**

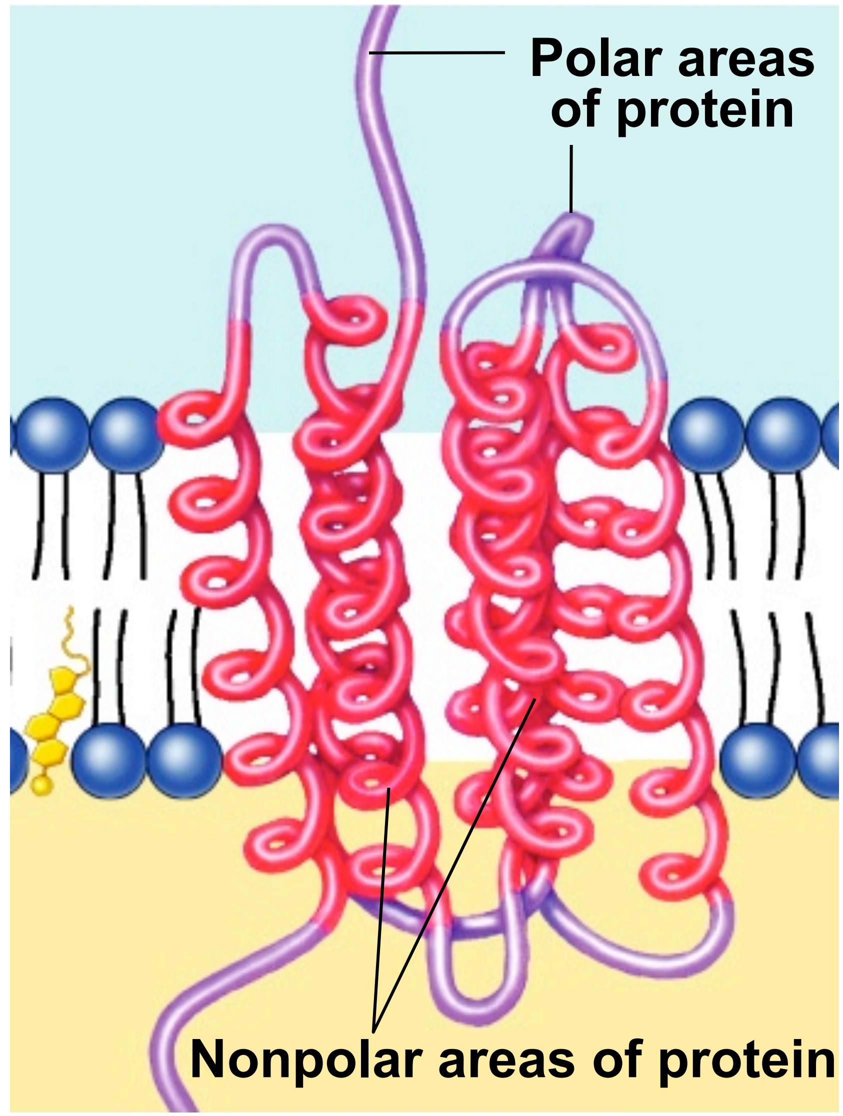
Proteins domains (key functional regions) anchor the molecule in a membrane

- The outer surfaces of membrane proteins facing the core of the phospholipid bilayer:
  - Protein polypeptides here are made up of non-polar amino acids facing the hydrophobic fatty acid tails of membrane phospholipids
    - span hydrophobic region of membrane
      - These non-polar amino acids of membrane proteins help anchor protein in the membrane because water on either side of the membrane does not attract/hydrogen bond with these amino acids' non-polar R groups



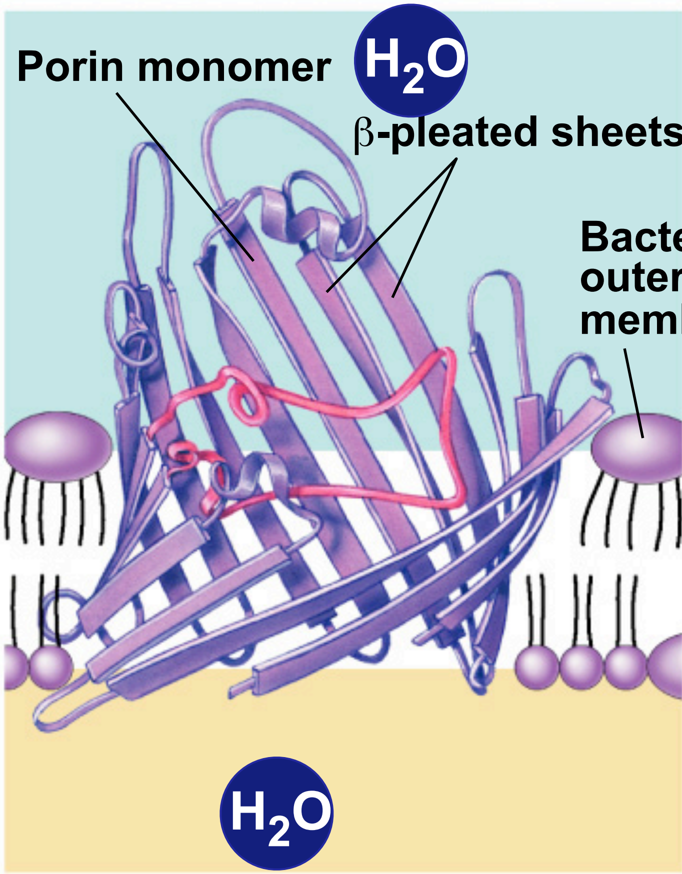
Proteins domains (key functional regions) anchor the molecule in a membrane

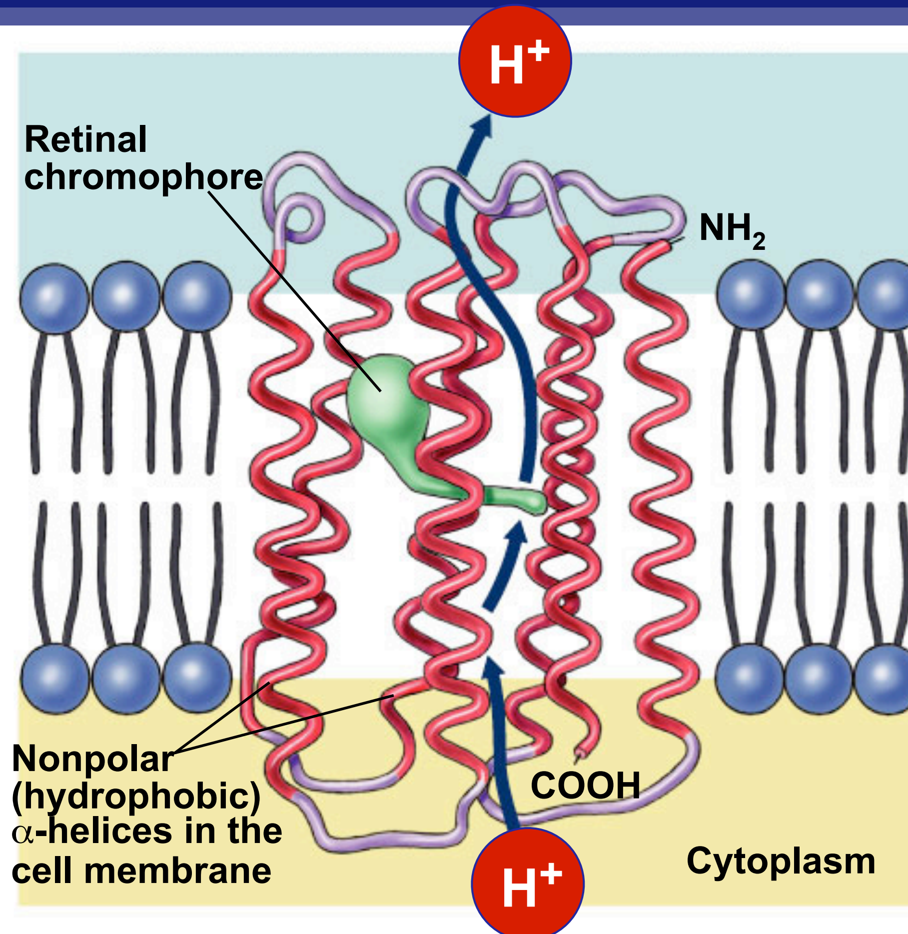
- On outer surfaces of membrane proteins facing aqueous fluids:
  - Protein polypeptides in these regions are made up of polar amino acids
    - The hydrophilic properties of the amino acids means they hydrogen bond with the water molecules outside the membrane
      - Membrane proteins that are transport proteins may have hydrophilic amino acids facing the interior passage way of the transport protein, where the hydrophilic substance is attracted to or must pass through



Examples of membrane transport proteins

aquaporin = water **channel** in bacteria

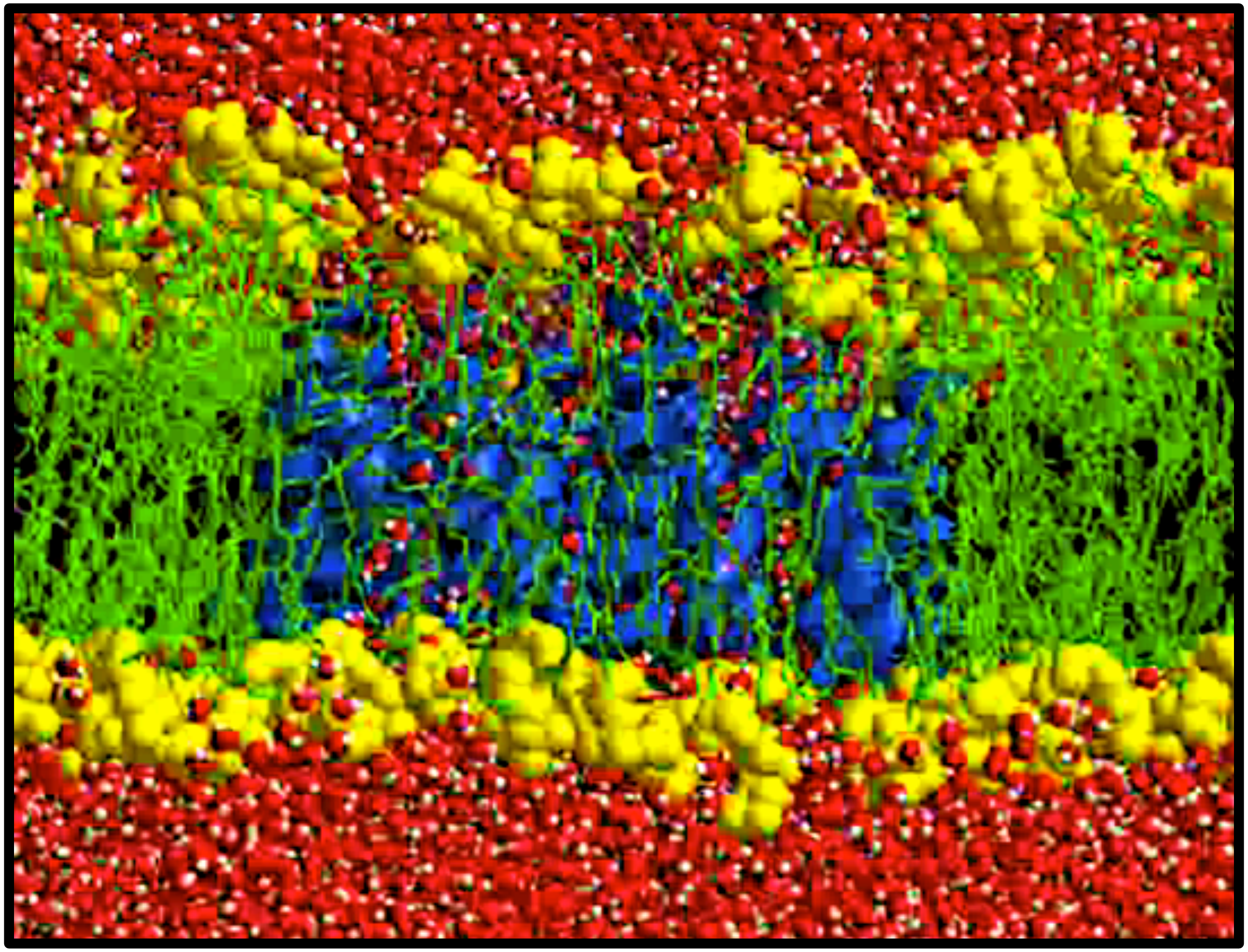




proton pump in photosynthetic bacteria

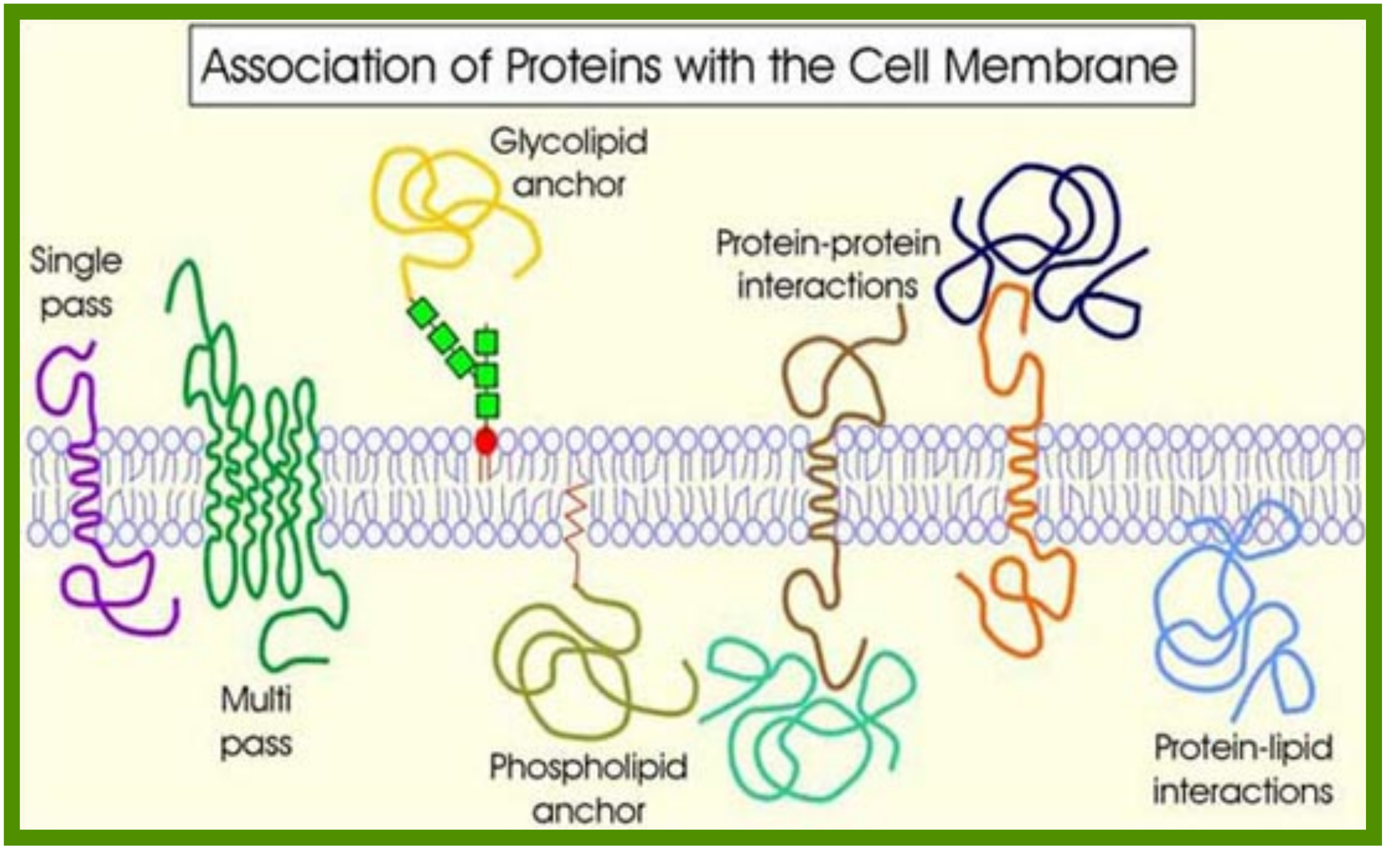
This pump functions by experiencing a **conformational shape change** = protein changes shape as it pumps hydrogen ions across the membrane

Aquaporin-1 in Action



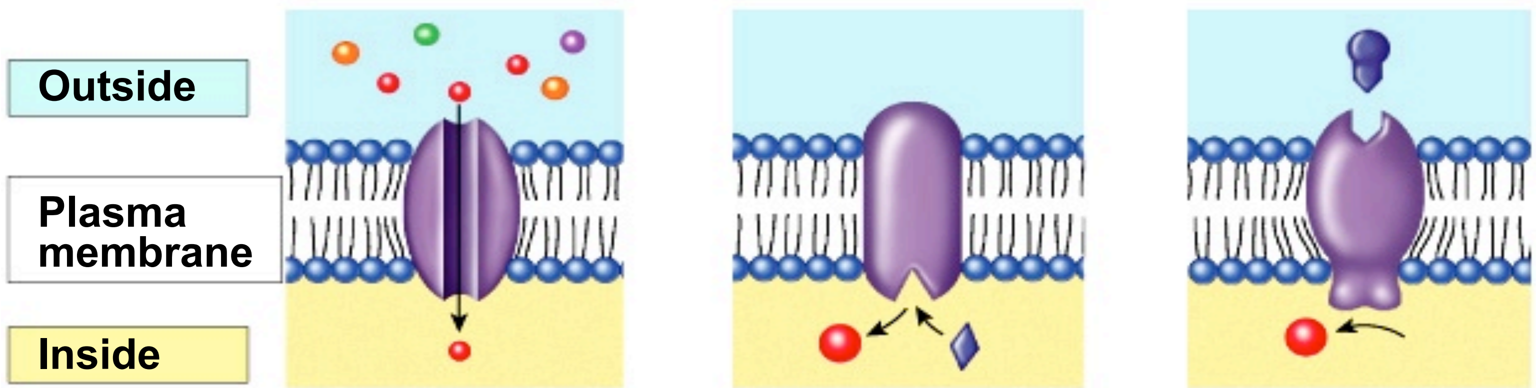
Water Molecules (Red) Crossing **Aquaporin Channel Protein** embedded in a phospholipid bilayer (head groups yellow; tails green)

Types of membrane associated proteins



http://www.erin.utoronto.ca/~w3bio315/picts/lectures/lecture2/MembraneProteinAssoc1.jpg

Many Functions of Membrane Proteins



Transport

- Span the membrane
- May provide selective hydrophilic channel
- May shuttles substances through changing shape
- May hydrolyze ATP for energy to actively pump substances

Enzymatic activity

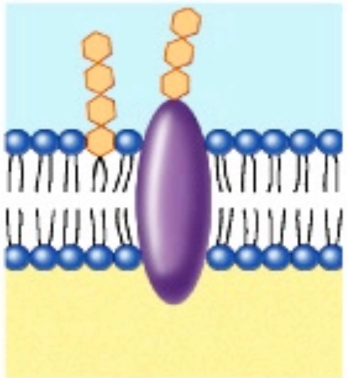
- Active site faces aqueous solution
- May be found alone
- Many enzymes may be organized into teams:

"multi-enzyme complexes"

Signal Transduction

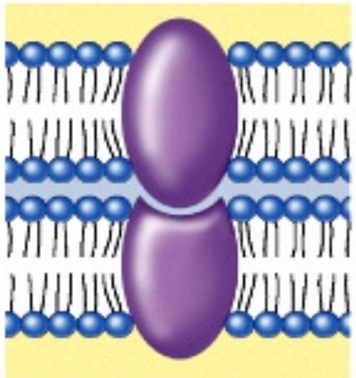
- Membrane Protein is the "receptor"
- Has binding site for a chemical messenger
- Binding of the signal molecule may cause shape change in the protein which passes the message to the inside of the cell

Many Functions of Membrane Proteins



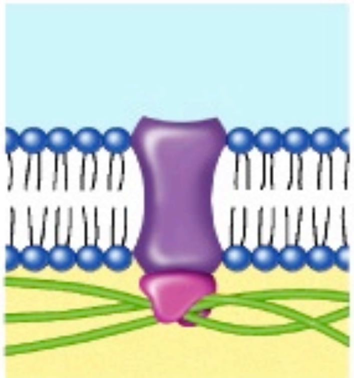
Cell-Cell Recognition

- Glycoproteins serve as I.D. tags
- These glyco-proteins are recognized by membrane proteins of other cells



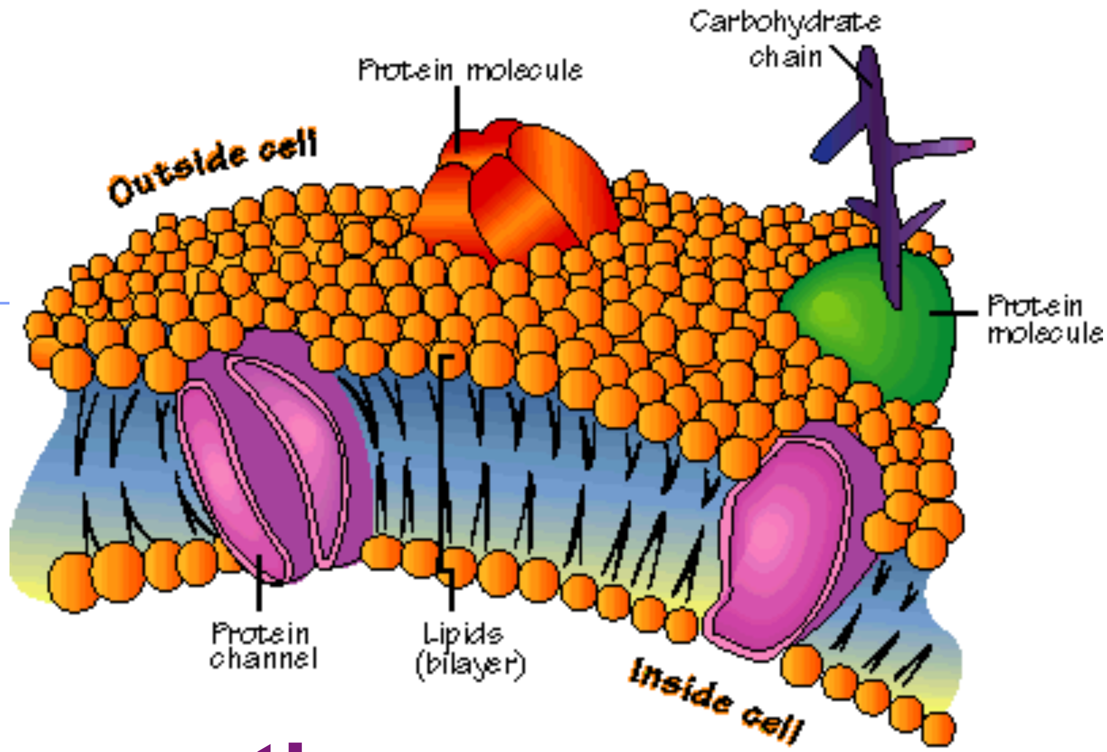
Intercellular Joining

- Membrane proteins of neighboring cells hook together in types of junctions.
- Examples include Gap Junctions and Tight Junctions



Cytoskeleton & ECM attachment

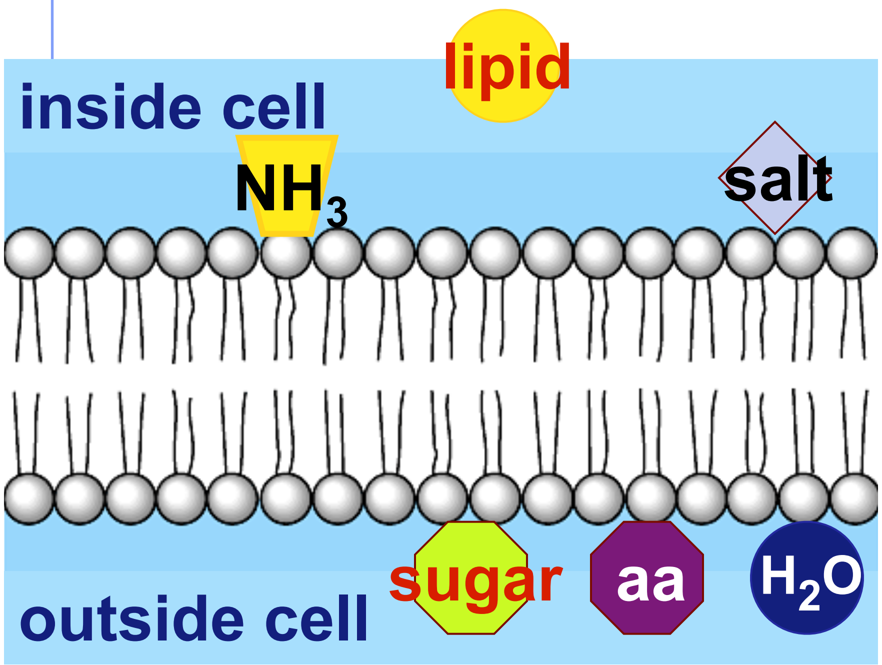
- Microfilaments non-covalently bind to membrane proteins
- Maintains cell shape
- Stabilizes location of some membrane proteins
- Through ECM, the cell can cooridinate extracellular and intracellular changes



Movement across the Cell Membrane

Diffusion through phospholipid bilayer

- What molecules can get through directly?
  - fats & other lipids
  - nonpolar molecules



- What molecules can NOT get through directly easily or at all?
  - polar molecules
    - H_2O, glucose
  - ions (charged)
    - salts, ammonium ion
  - large molecules
    - starches, proteins

Lipid Bilayer permeability

- **Hydrophic Substances:** dissolve in the lipid bilayer of the membrane and cross it without the help of proteins
  - O_2, lipids, CO_2
- **Hydrophilic Substances:** cannot pass through the hydrophobic core of the bilayer
  - Ions and polar molecules like glucose

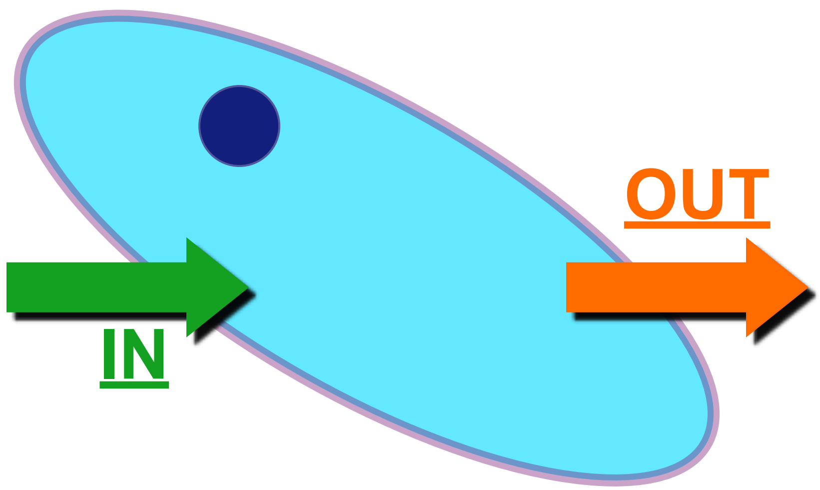
PROTEINS ARE THE KEY TO MAKING CELL MEMBRANES PERMEABLE TO HYDROPHILIC and CHARGED SUBSTANCE!

Diffusion across cell membrane

- **Cell membrane is the boundary between inside & outside…**
  - separates cell from its environment

Can it be an impenetrable boundary? <u>NO!</u>

<u>IN:</u>
<u>nutrients</u>
carbohydrates
sugars, proteins
amino acids
lipids
salts, O_2, H_2O

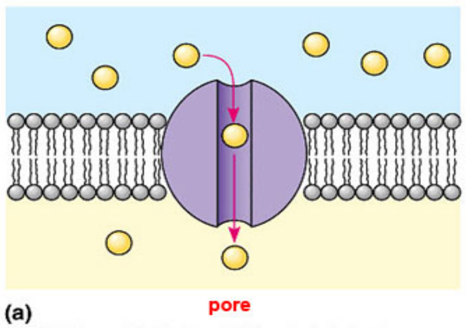


<u>OUT:</u>
<u>waste</u>
ammonia
salts
CO_2
H_2O
products

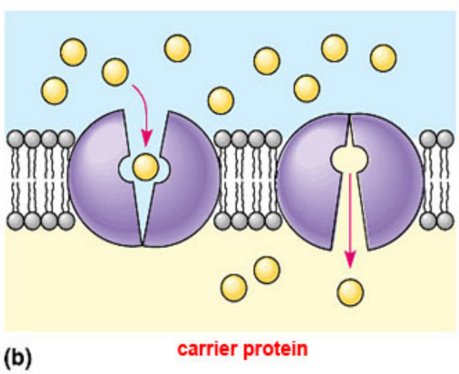
cell needs to move materials <u>in</u> & products or waste <u>out</u>

Lipid Bilayer Permeability

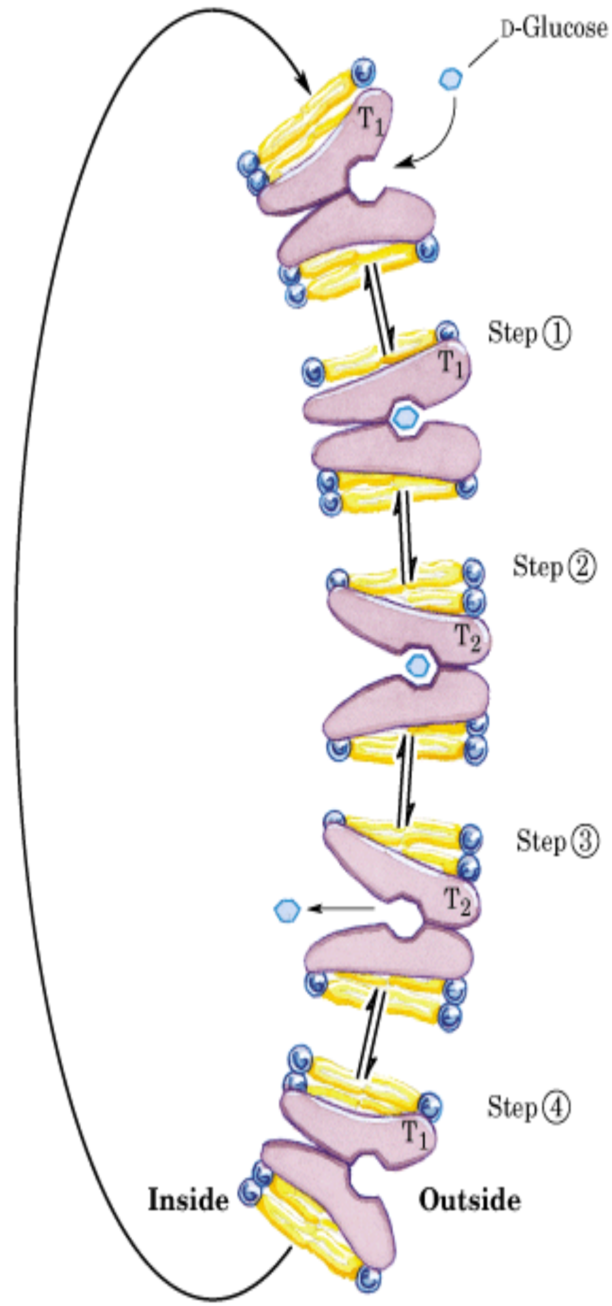
- **TRANSPORT PROTEINS SPAN CELL MEMBRANES:**



- **CHANNEL PROTEINS: PROVIDE HYDROPHILIC CHANNELS (PASSAGEWAYS)**
  - **EX: Aquaporins**



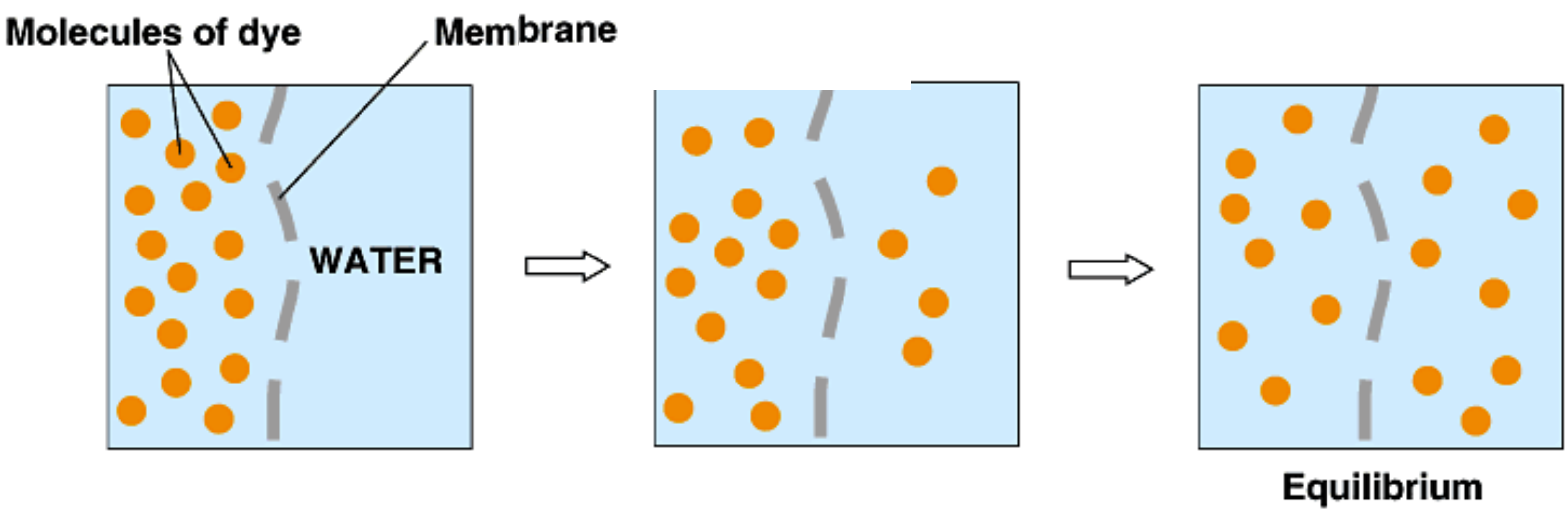
- **CARREIR PROTEINS: HOLD ONTO SUBSTANCES, CHANGE SHAPE THEMSELVES, AS THEY SHUTTLE SUBSTANCES ACROSS.**
  - **EX: Glucose Transporter**



- **TRANSPORT PROTEINS ARE HIGHLY SPECIFIC IN WHAT SUBSTANCE THEY HELP CROSS A MEMBRANE!!!**

Diffusion: the movement of a substance from an area of high concentration to an area of low concentration.

- **2nd Law of Thermodynamics** governs biological systems
  - universe tends towards disorder (↑ entropy)

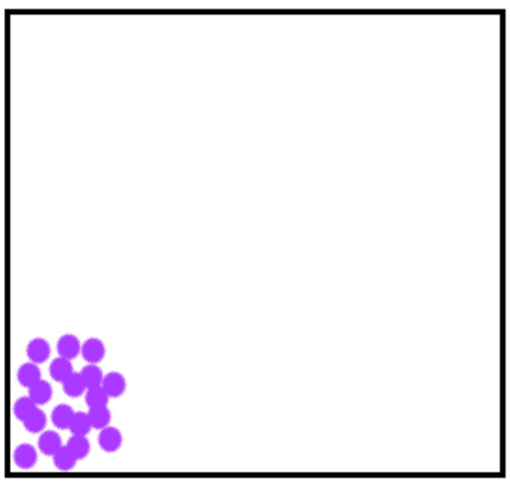


- **Diffusion**
  - Each substance moves down **ITS OWN** concentration gradient.
  - Though individual particles may move in any direction (due to random collisions caused by thermal energy), the substance's **net (overall) movement** is from an area of HIGH to LOW concentration

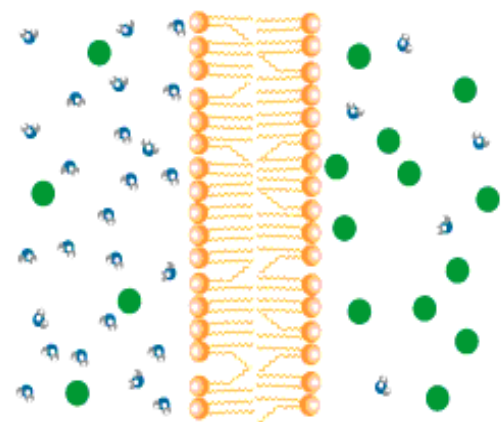
Diffusion

- **Move from HIGH to LOW concentration**
  - Diffusion is a form of "passive transport"
    - no energy needed
  - In Simple Diffusion:
    - <u>no proteins</u> is required to get a substance across the cell membrane

<u>Type of Simple Diffusion</u>:
Movement of water

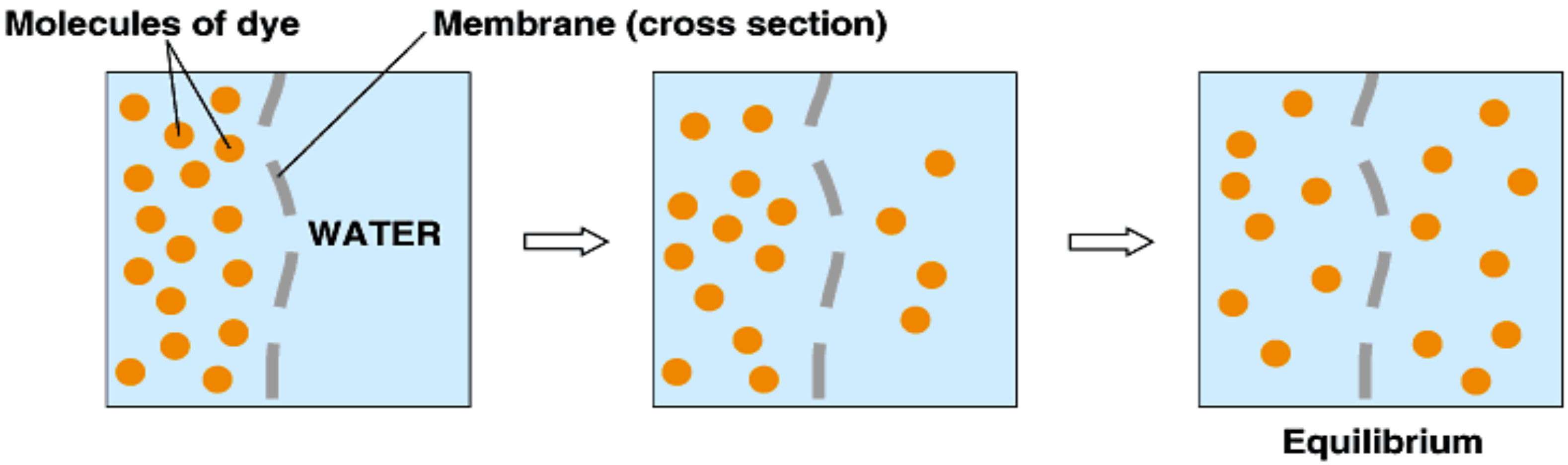


diffusion



osmosis

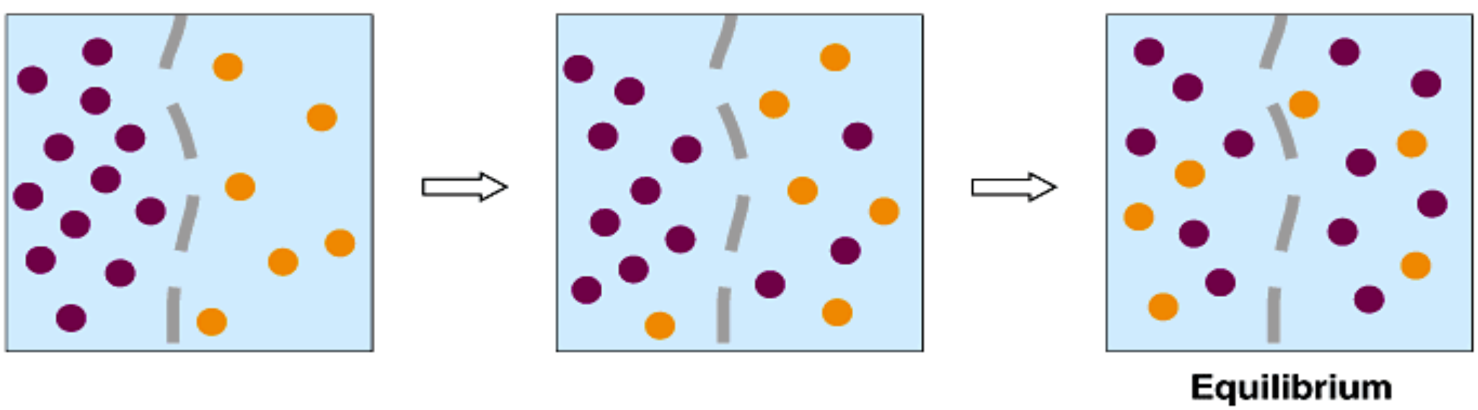
Simple Diffusion



(a) Diffusion of one solute

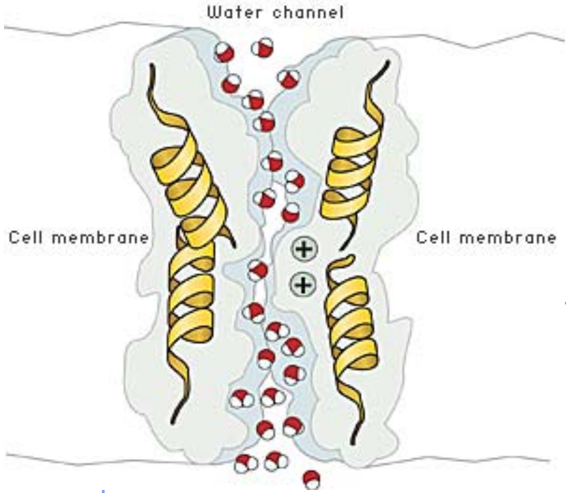
Movement continues until a state of dynamic equilibrium is reached:

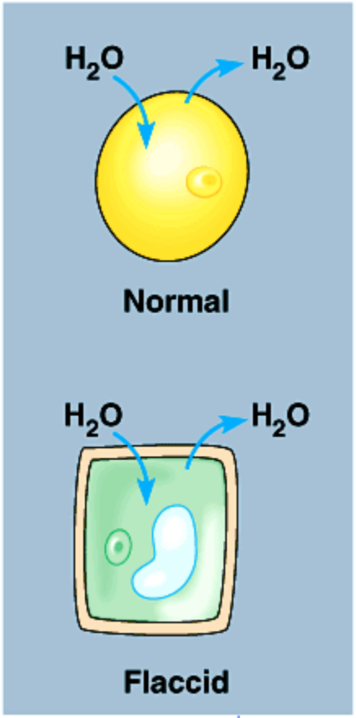
Solutes continue to cross the membrane but at equal rates back and forth (no more change in concentration)



AP

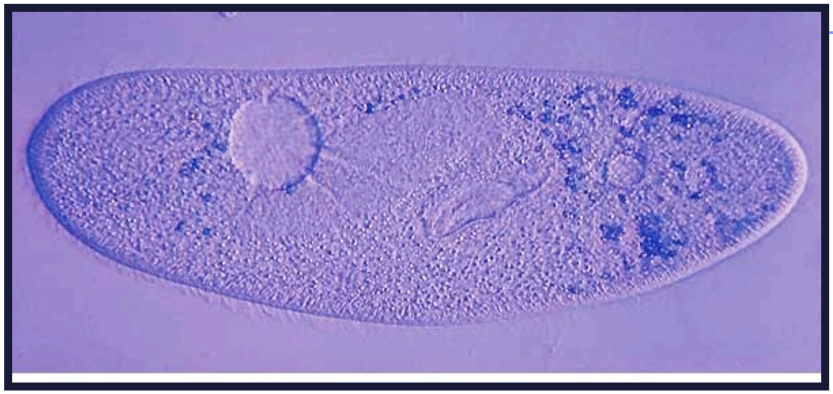
(b) Diffusion of two solutes





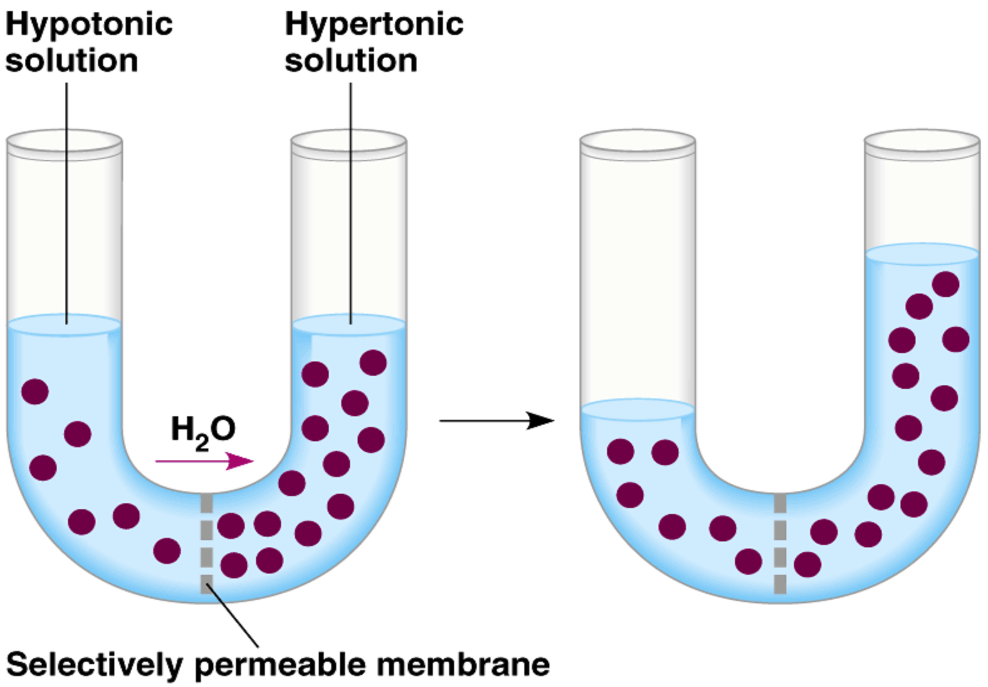
The Special Case of Water

Movement of water across the cell membrane



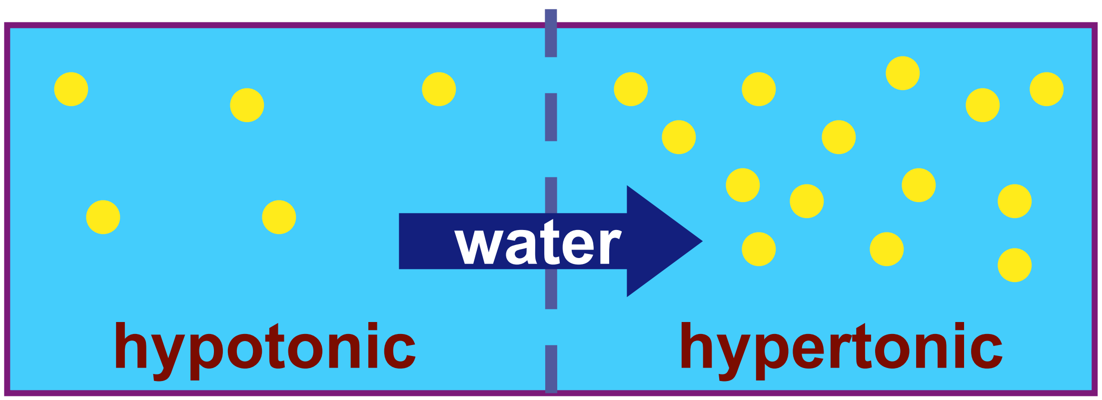
Osmosis is just diffusion of water

- Some water molecules (those in hydration spheres) are bound by intermolecular attractions to other hydrophilic substances and are not as free to diffuse within a solution
- Diffusion of water occurs from:
  - A region with a *HIGH concentration* of free water to one with a *LOW concentration* of free water
    - Water will thus move across a semi-permeable membrane from a *region of low solute concentration to that of higher solute concentration*



Concentrations of free water in different solutions affect the diffusion of free water (osmosis)

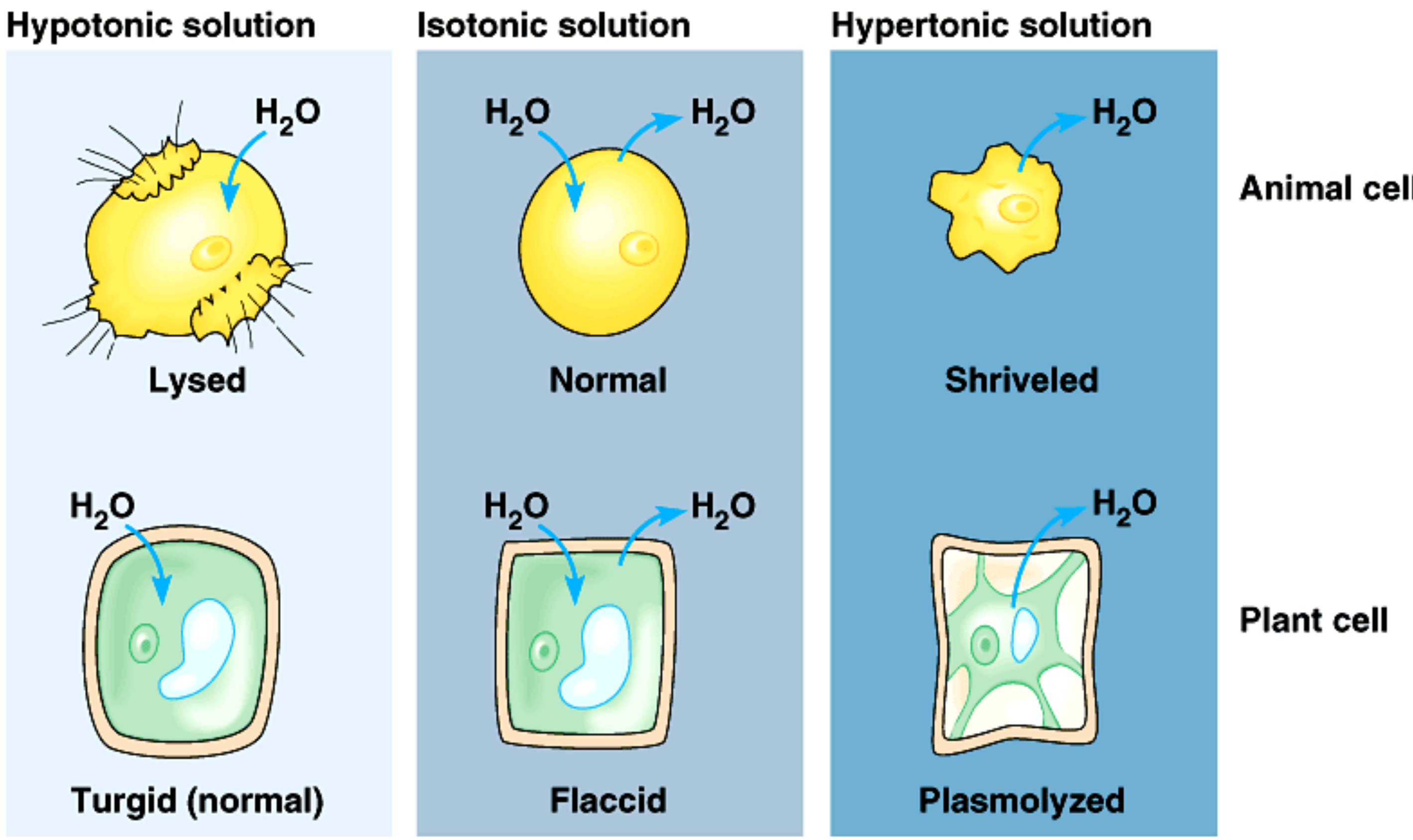
- Direction of osmosis is determined by comparing ***TOTAL*** **solute** concentrations
  - **Tonicity**: The ability of a solution to cause a cell to gain or lose water
  - **Hypertonic** - more solute, less free water
  - **Hypotonic** - less solute, more free water
  - **Isotonic** - equal solute, equal free water



net movement of water

Managing water balance

- Cell survival depends on balancing water uptake & loss



freshwater | balanced | saltwater

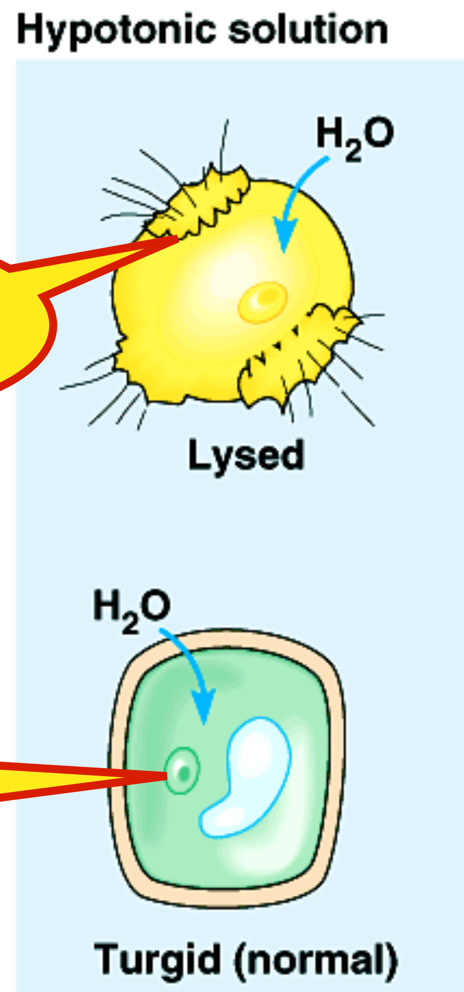
1

Managing water balance

- **Hypotonic Environments**
  (hypo = low solute concentration)
  - a cell in fresh water
  - high concentration of water around cell
    - Cell gains water by osmosis, swells & can burst
    - Ex: Paramecium
      - Problem: Water continually enters Paramecium cell in its freshwater habitat
      - Solution: Contractile vacuole
        - collect & pump excess water out of cell
          - requires ATP energy

ATP

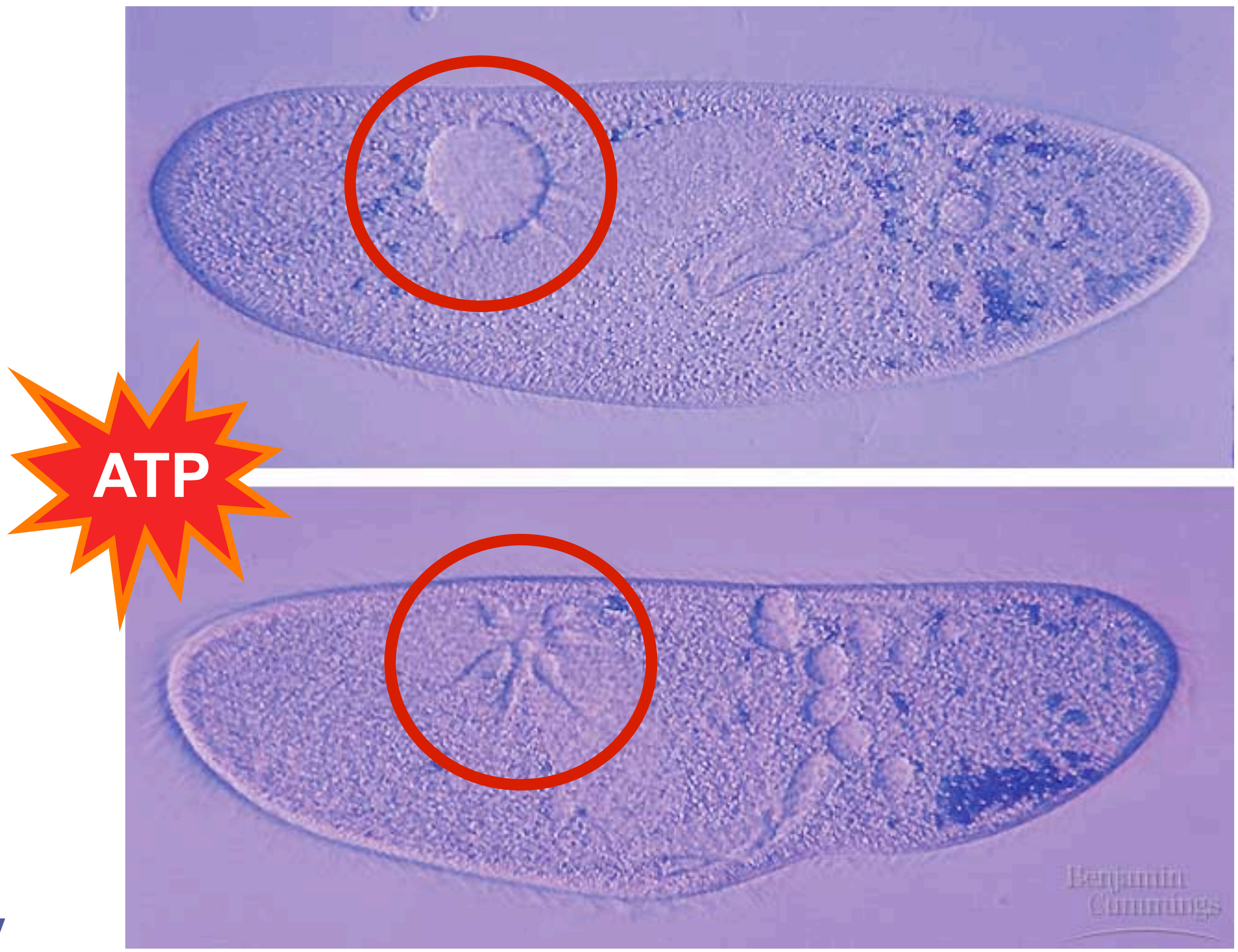
  - plant cells
    - become turgid = firm
      - cell wall protects these cells from bursting
    - Ideal situation for cells with cell walls



freshwater

Pumping water out - adaptation for osmoregulation

- **Contractile vacuole in *Paramecium***



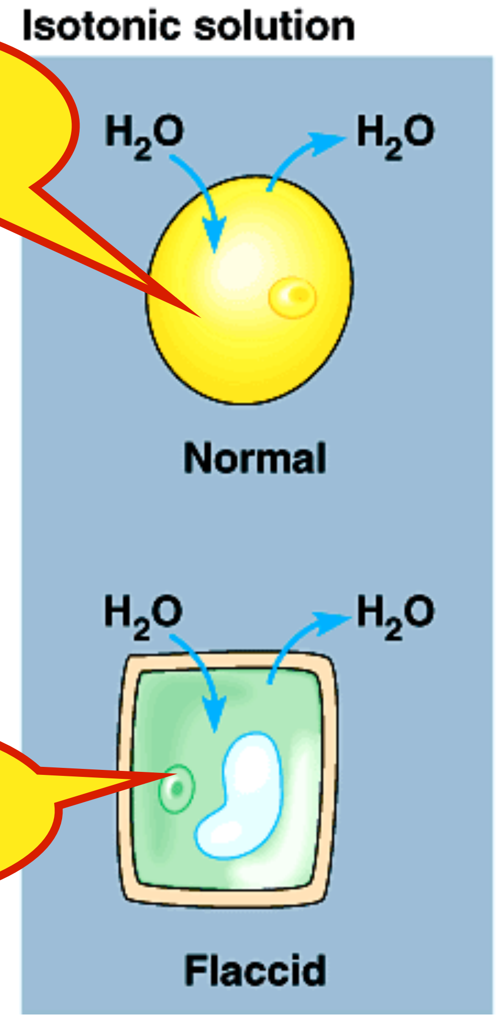
Managing water balance

- Hypertonic Environments
  (*hyper* = higher solute concentrations)
  - a cell in <u>salt water</u>
  - low concentration of water around cell
    - <u>Cell loses water & can die</u>
      - <u>Ex</u>: Shellfish
      - <u>Solution</u>: take up water or pump out salt
  - Plant cells
    - <u>plasmolysis</u> = wilting
      - can sometimes recover if placed back in more ideal conditions

Managing water balance

3

- **Isotonic Environment**
  (*iso* = same solute concentrations)
  - animal cell immersed in <u>mild salt</u> solution
  - no difference in concentration of water between cell & environment
    - Ideal situation for animal cells!
    - Not ideal situation for plant cells that remain soft and can't stack up against gravity as well
      - no <u>net</u> movement of water occurs
        - free water moves across membrane in <u>both</u> directions at equal rates
      - cell in <u>equilibrium</u>
      - volume of cell is <u>stable</u>
    - <u>Ex</u>: blood cells in blood plasma must remain stable [not implode or explode]
      - IV solutions in hospital are slightly salty to match solute concentration of blood cells

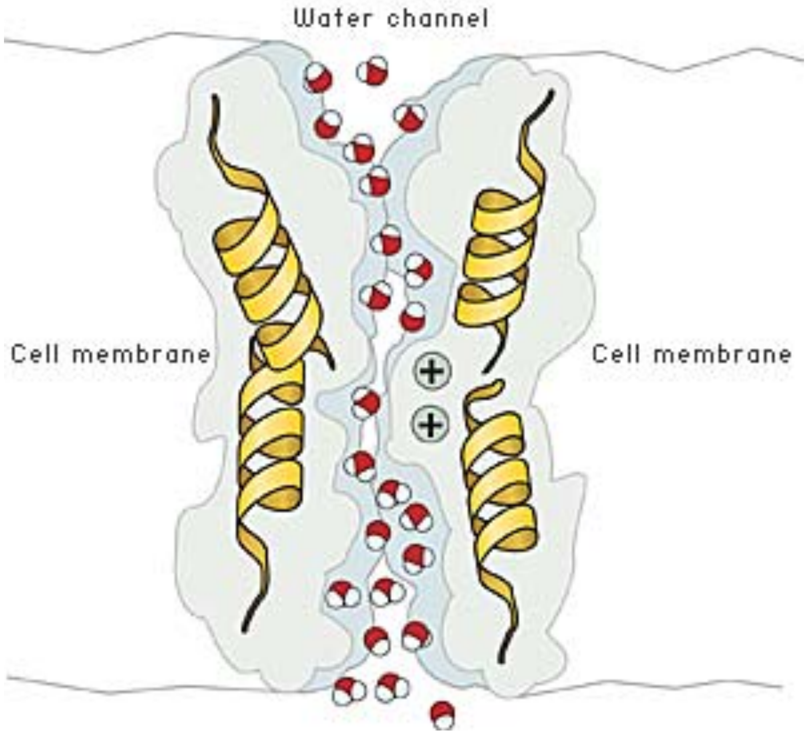


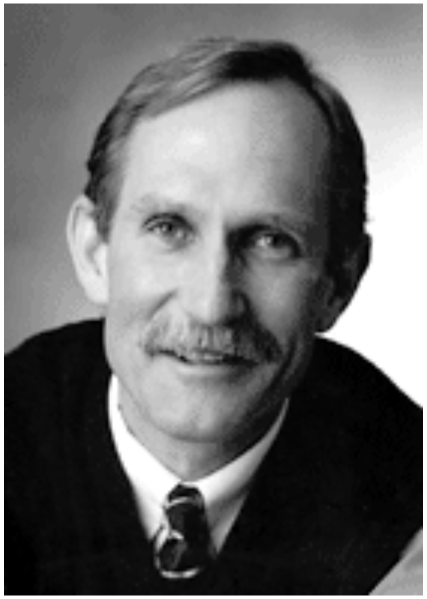
balanced

Aquaporins

1991 | 2003

- Channel proteins that allow water molecules to diffuse rapidly into & out of cells (across a membrane)
  - evidence that there were water channels
    - protein channels allowing steady flow of water across cell membrane

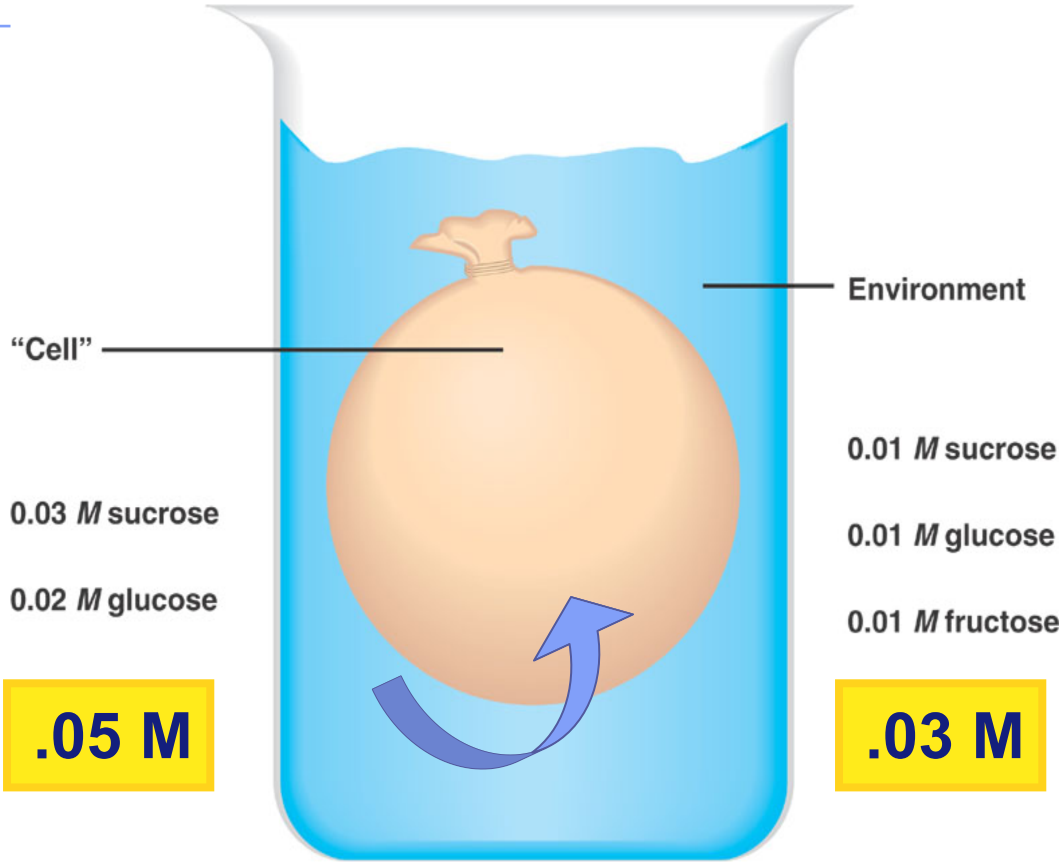




Peter Agre
John Hopkins

Roderick MacKinnon
Rockefeller

Do you understand Osmosis…?



.05 M

.03 M

Cell (compared to beaker) → hypertonic or hypotonic

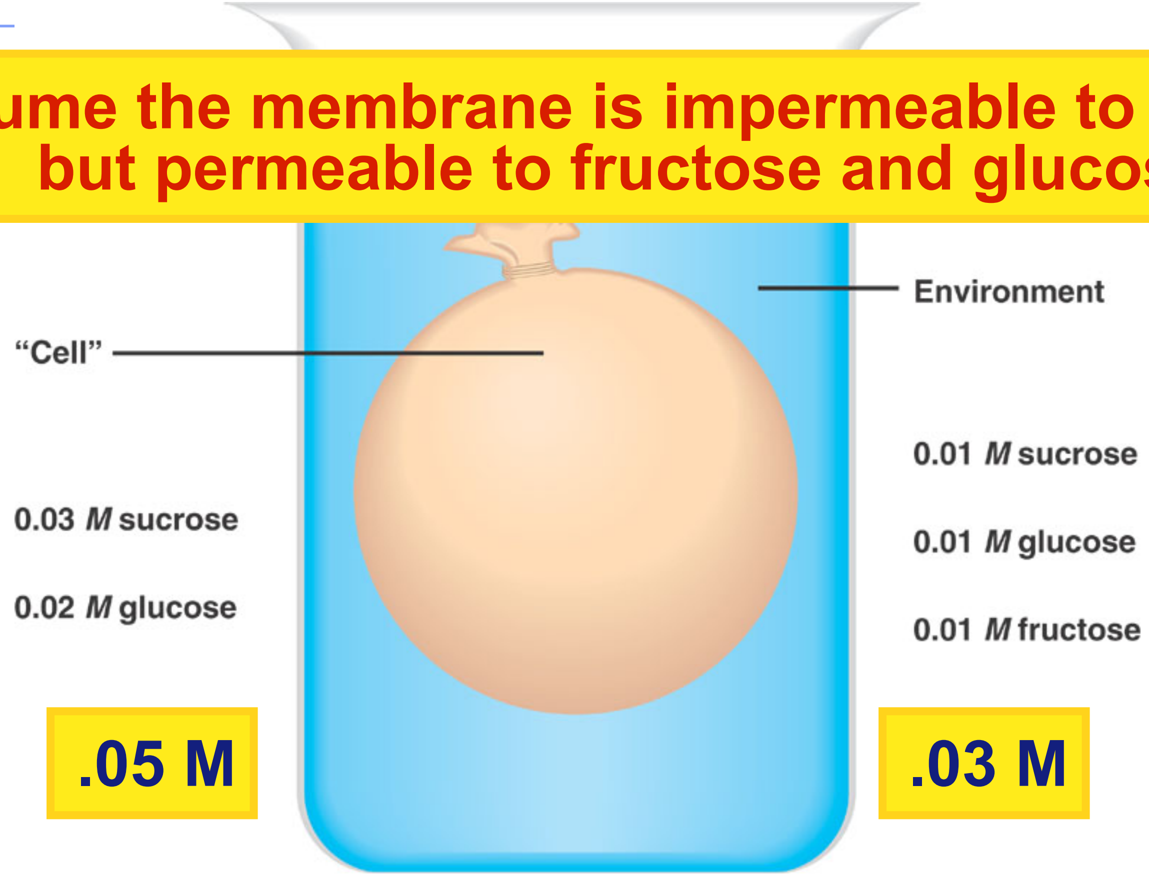
Beaker (compared to cell) → hypertonic or hypotonic

Which way does the water flow? → in or out of cell

AP

Do you understand Osmosis…?

Assume the membrane is impermeable to sucrose but permeable to fructose and glucose.

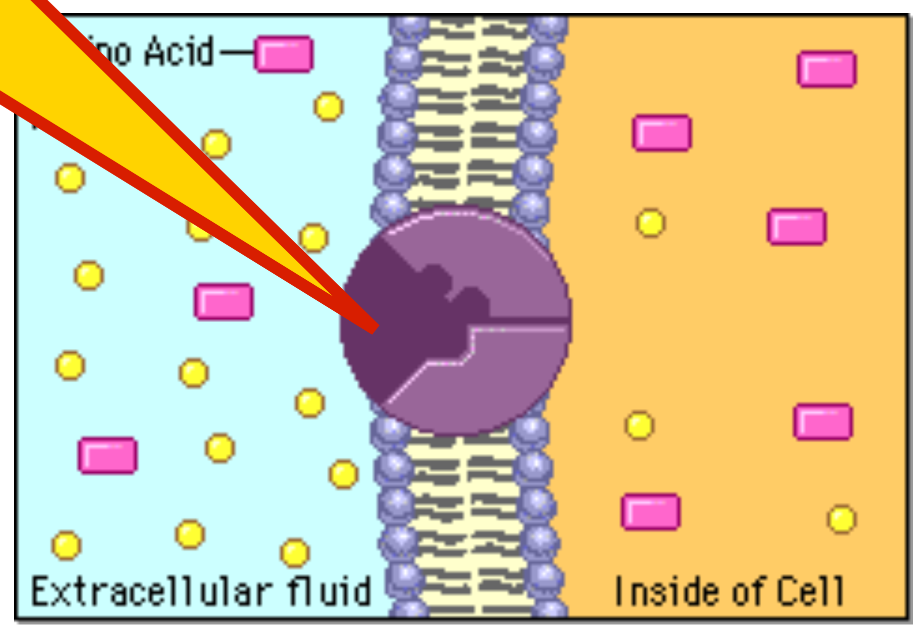


What way does glucose move? → into or **out of** cell

What way does sucrose move? → int **Neither** of cell

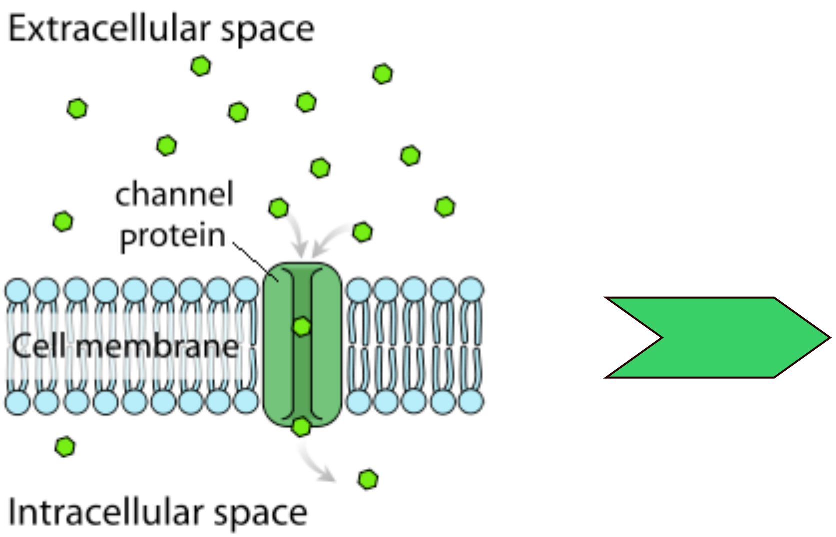
What way does fructose move? → **into** or out of cell

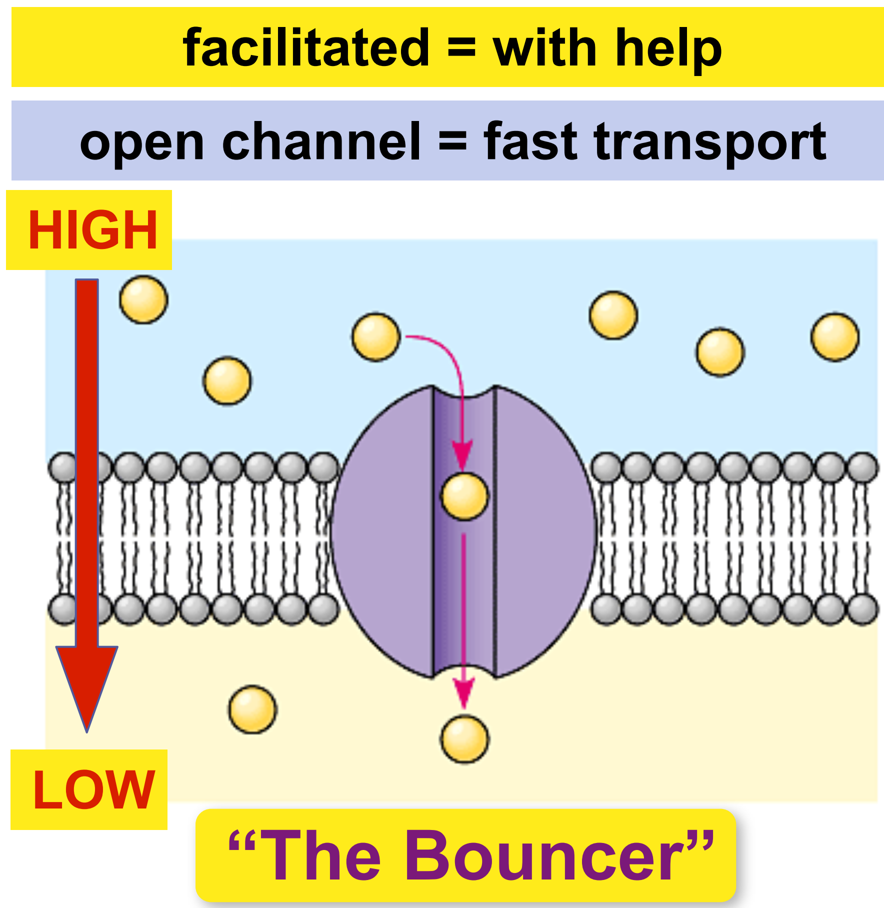
Any Questions??



Facilitated Diffusion (passive transport)

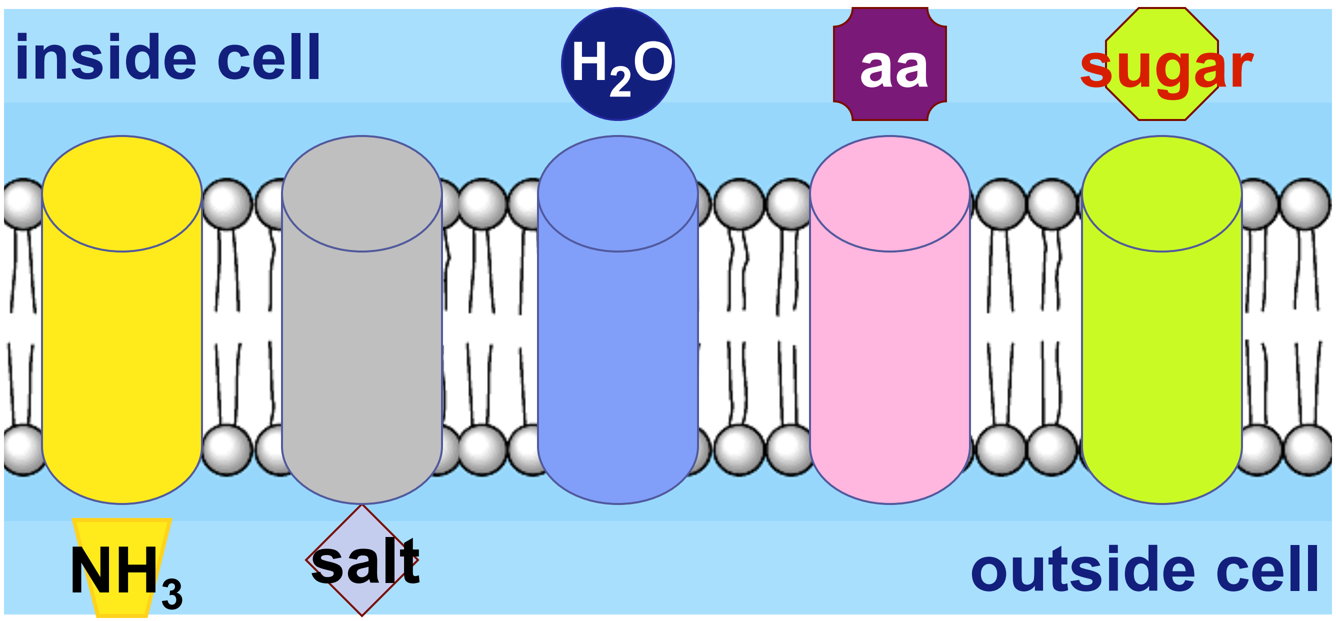
- Diffusion through protein channel and carrier proteins
  - These proteins move specific molecules across cell membrane
  - NO energy needed!!!
    - The diffusion that wants to occur normally is "HELPED" along since the particle is charged and cannot otherwise pass through the membrane by itself.

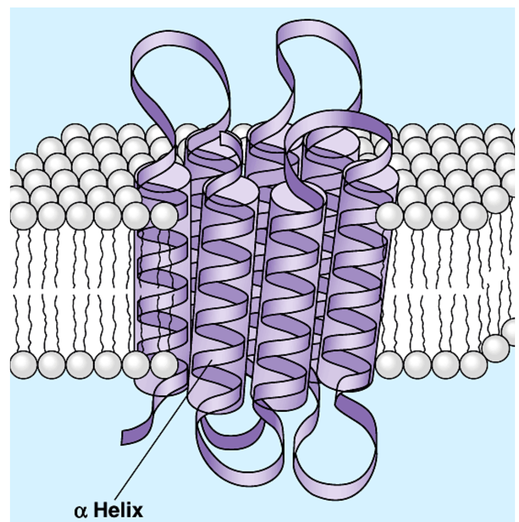




Membrane becomes semi-permeable to polar molecules via protein channels and carriers:

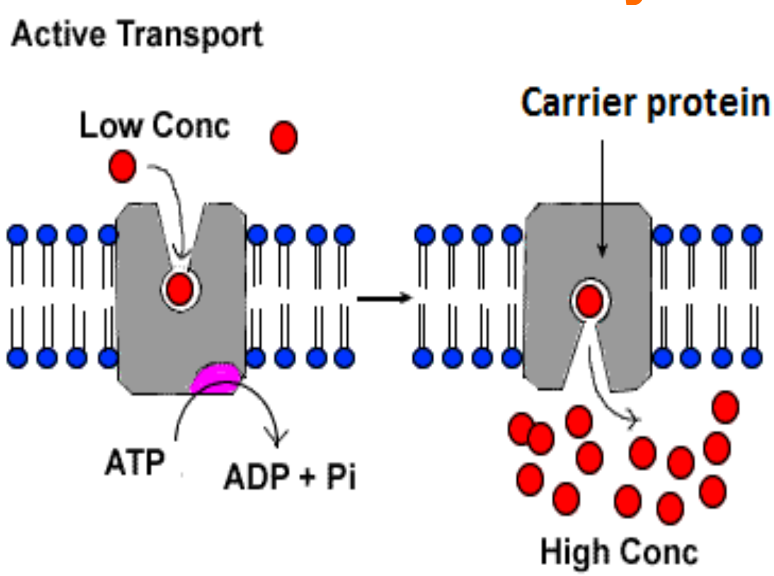
- Channel proteins can be ***Ion Channels***
  - Tunnels for specific ions to pass through
- Some are ***Gated-Ion Channels***
  - Tunnels that open and close in response to a stimulus
    - Stimuli can be signal molecules that bind to the transmembrane protein on the extracellular side of the membrane
    - Stimuli can be electrical signals like in the nervous system

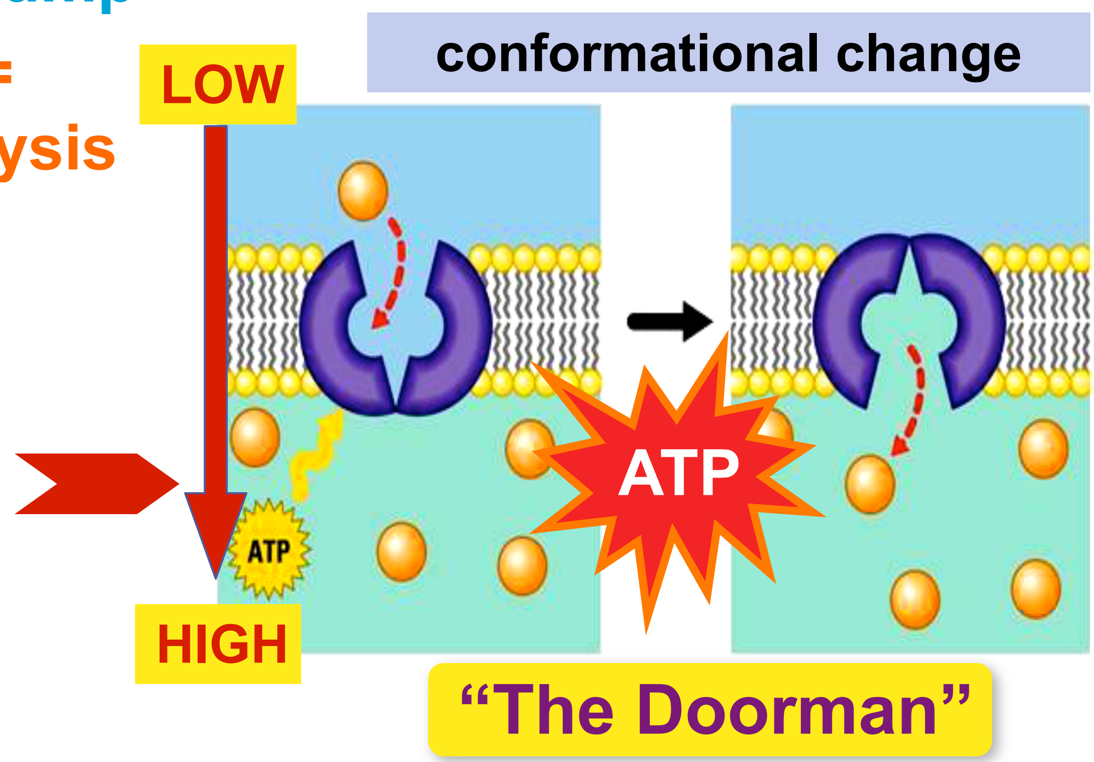




Active Transport

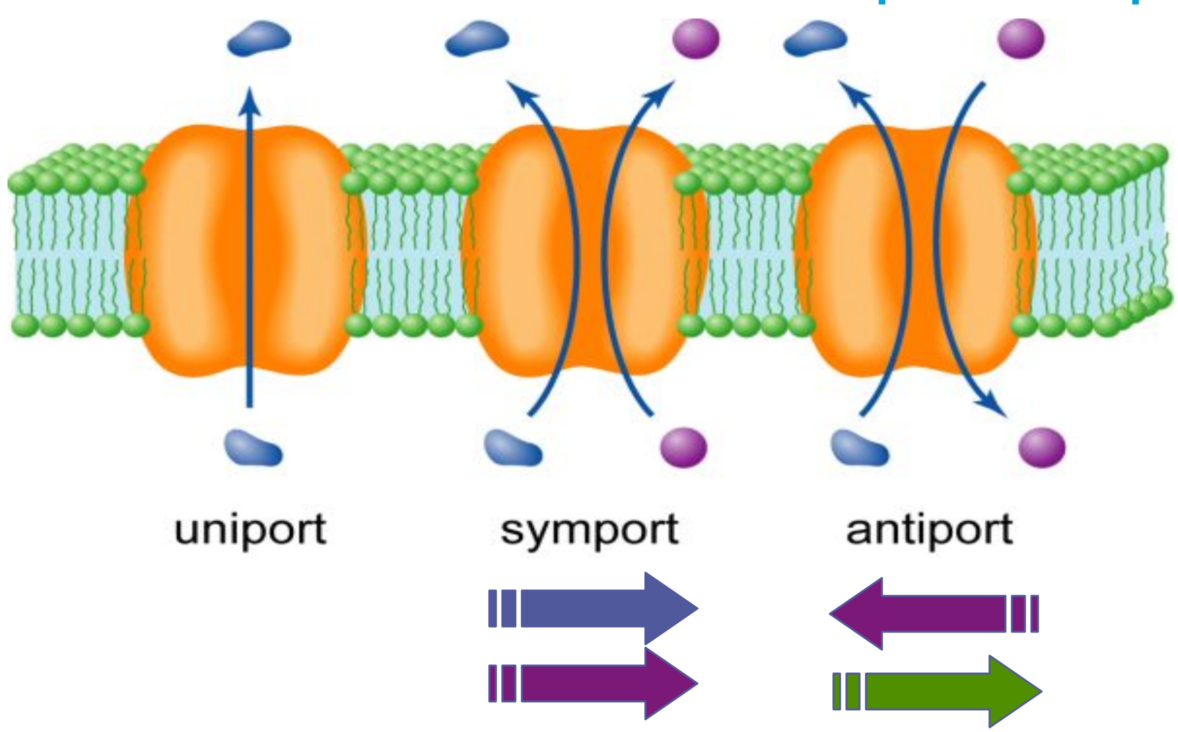
- **Cells may move molecules *against* the solute's concentration gradient**
  - **conformational shape changes in carrier proteins transport solutes from one side of membrane to another like a "pump"**
  - **"costs" energy = from ATP hydrolysis**



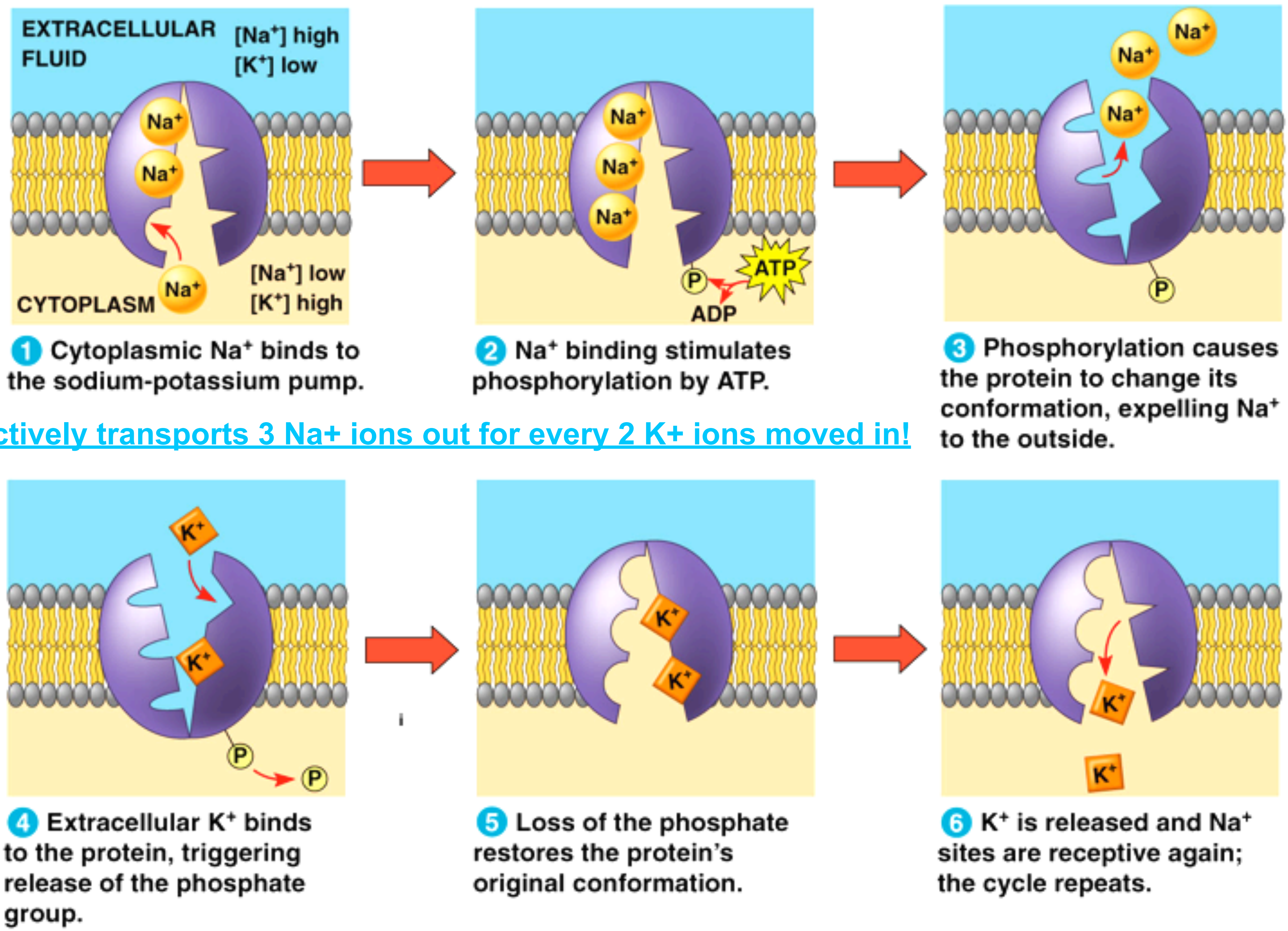


Active transport is directional

- Uniports: Move a single substance in one direction. Ex: Ca^{2+} carriers
- Symports: Move two substances in the same direction. Ex: Taking up a.a. from intestine requires simultaneous binding of Na+ by same transport protein.
- Antiports: Move two substances in opposite directions, on in and one out of the cell. Ex: Sodium-potassium pump.



Sodium-Potassium Pump



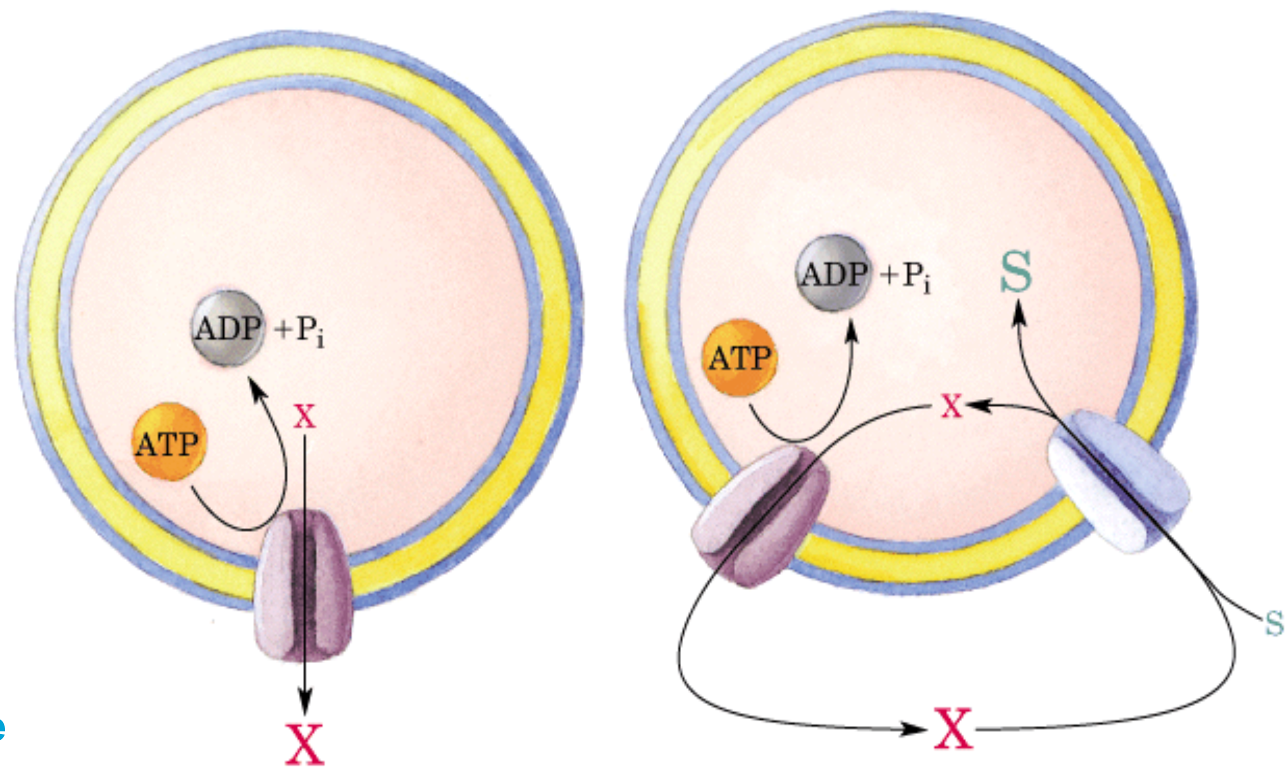
Actively transports 3 Na+ ions out for every 2 K+ ions moved in!

Primary & Secondary Active Transport

- **Primary Transport:** Requires the direct participation of the energy-rich molecule ATP
- **Secondary Transport:** Does NOT use ATP DIRECTLY. Rather, its energy is supplied by a solute concentration gradient established by a primary active transport that DOES use ATP DIRECTLY.

1. X is 1st actively pumped against concentration gradient using energy from ATP

2. Potential energy is now stored in the high concentration of solute X on one side of the membrane



Primary active transport

Secondary active transport

3. Finally, X diffuses down its own concentration gradient back into the cell, releasing the stored energy that is used to now actively pump S against its concentration gradient into the cell

Secondary Active Transport

In this scenario, prior to these pictures, ATP was used to actively pump Na+ out of the cell creating a concentration gradient for Na+

The high concentration of Na+ outside stores potential energy

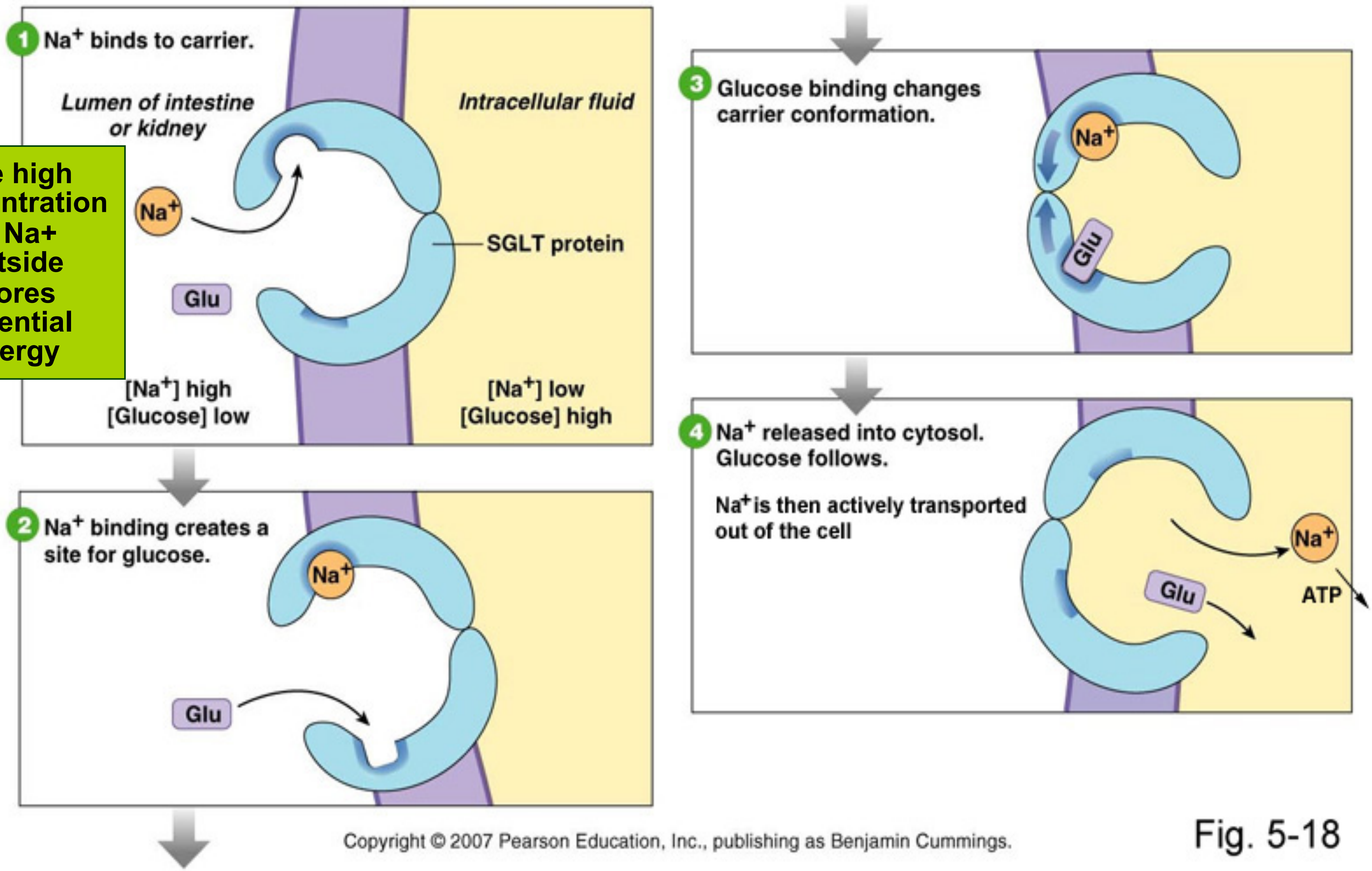


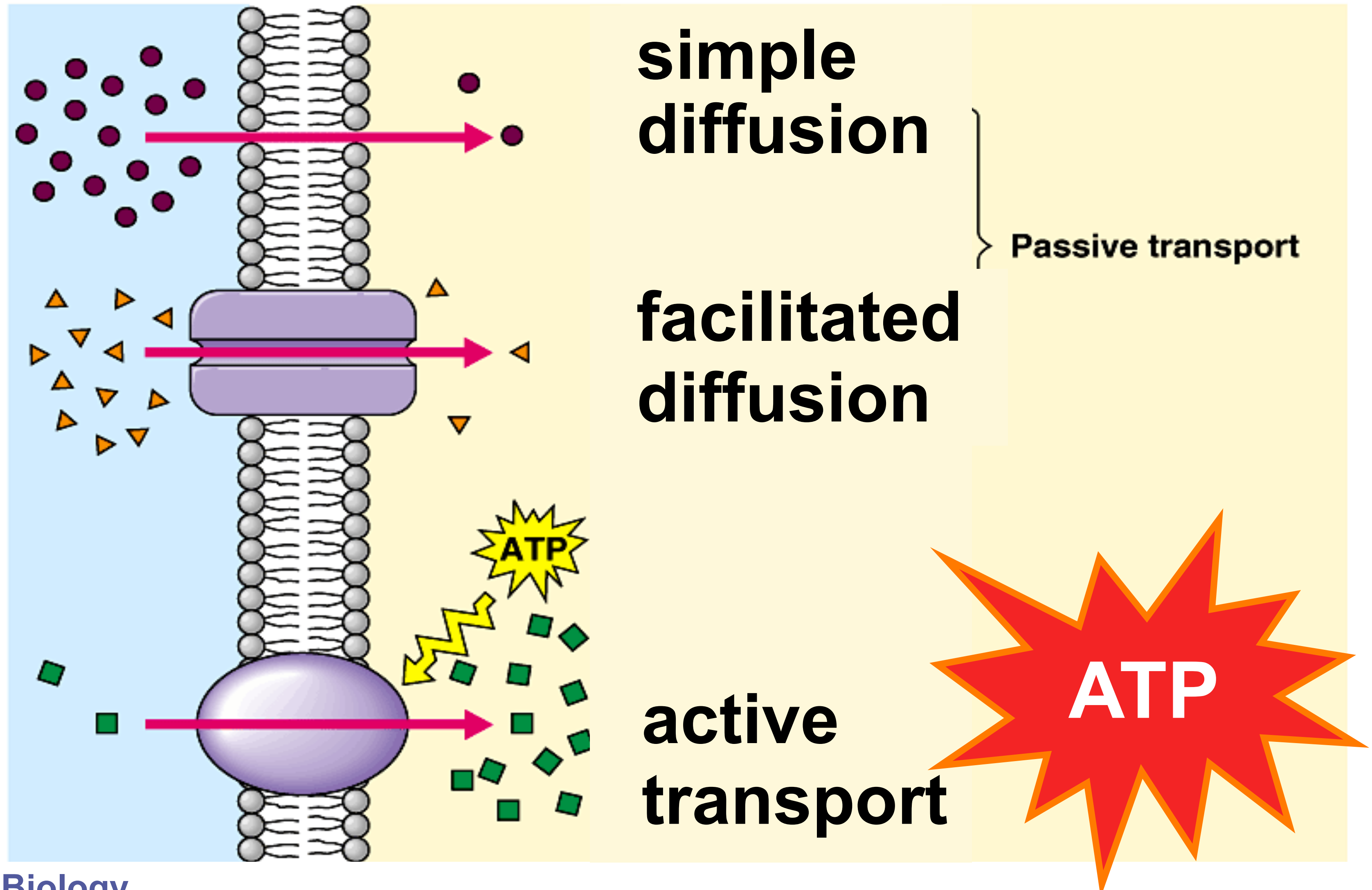
Fig. 5-18

Getting through cell membrane

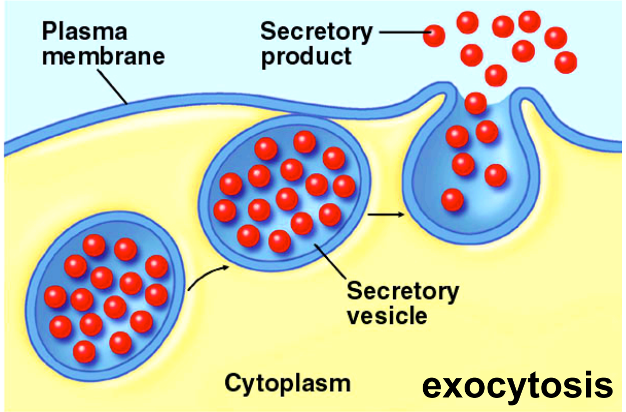
- **Passive Transport**
  - **Simple diffusion**
    - diffusion of non-polar, hydrophobic molecules
      - lipids & non-polar molecules (like oxygen & carbon dioxide gas)
    - **no** protein used
      - HIGH → LOW concentration gradient
  - **Facilitated transport**
    - diffusion of polar, hydrophilic molecules
    - through a **protein channel or carrier**
      - HIGH → LOW concentration gradient

- **Active transport**
  - diffusion *against* concentration gradient
    - LOW → HIGH concentration gradient
  - uses a **protein pump** (a carrier)
  - requires ATP

Transport summary



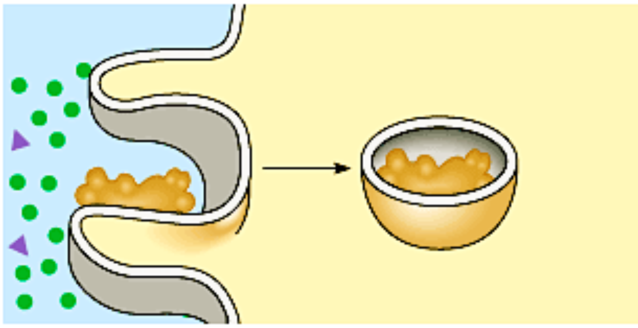
How about large molecules?



- Moving large molecules into & out of cell (uses ATP & is an example of Active Transport)
  - Through vesicles use
  - Exocytosis - secretion of molecules through the fusion of vesicles with the plasma membrane
  - Endocytosis - cell takes in biological molecules and particles by forming vesicles from the plasma membrane
    - Phagocytosis = "cellular eating"
    - Pinocytosis = "cellular drinking"
    - Receptor-mediated endocytosis = enables the cell to acquire bulk quantities of specific substances.
      - Receptor proteins are clustered in regions of the membrane called coated pits
      - Specific substances to be transported inward bind to these receptors
      - Plasma membrane with receptors and bound ligands then form a vesicle, moving into the cytoplasm

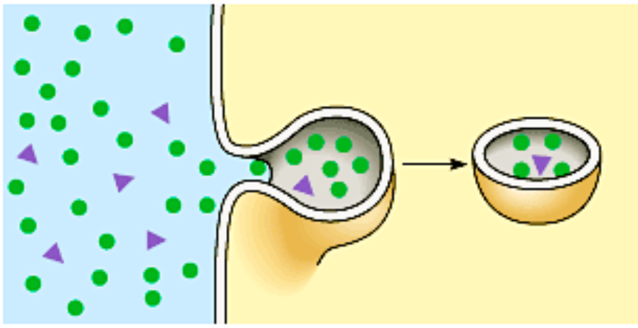
Types of Endocytosis

phagocytosis



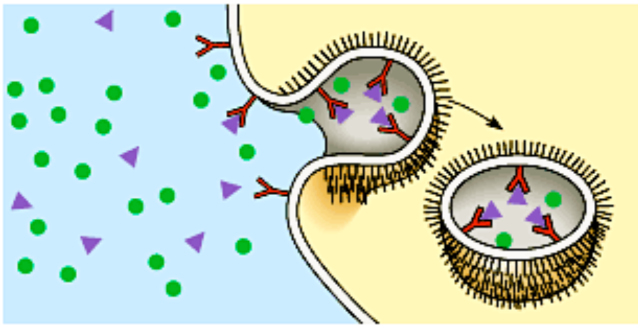
Fuse vacuole carrying larger extracellular structure with lysosome for digestion of vacuole contents

pinocytosis



non-specific process of taking in solution with any solutes in it

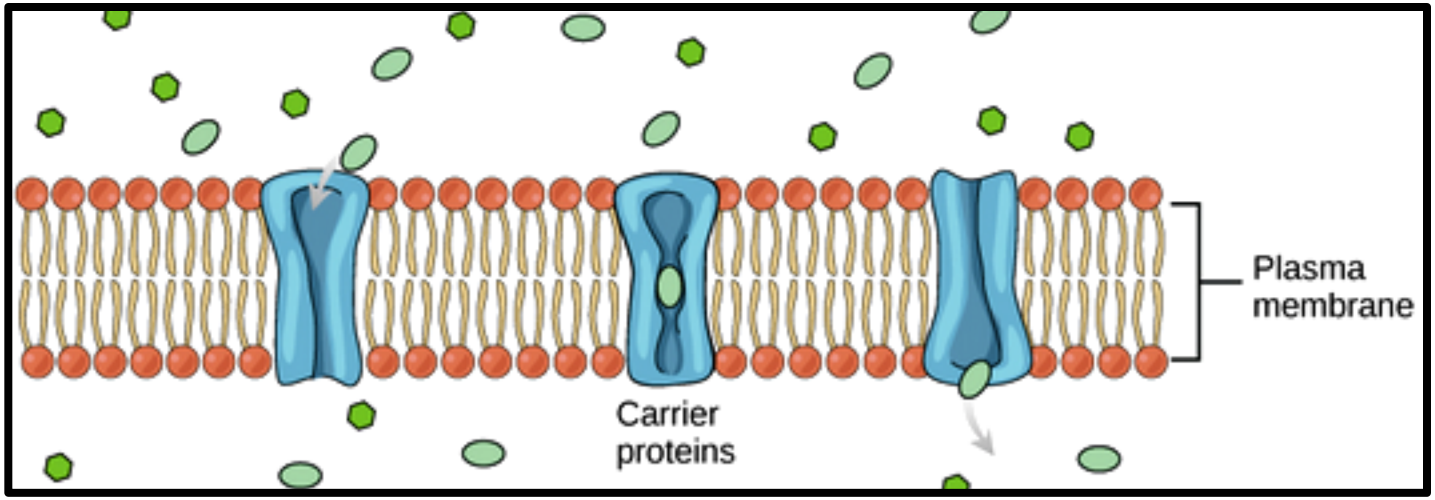
receptor-mediated endocytosis



Specific: ligands bind to membrane receptors to ensure that specific solutes are also carried into the cell

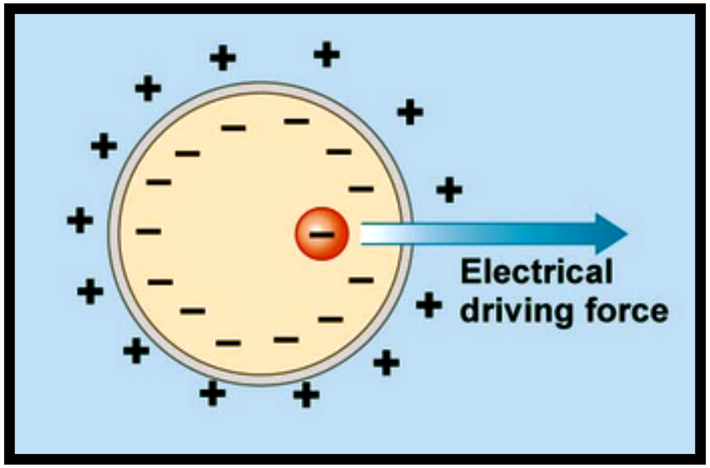
(Chemical) Concentration Gradients in Cells

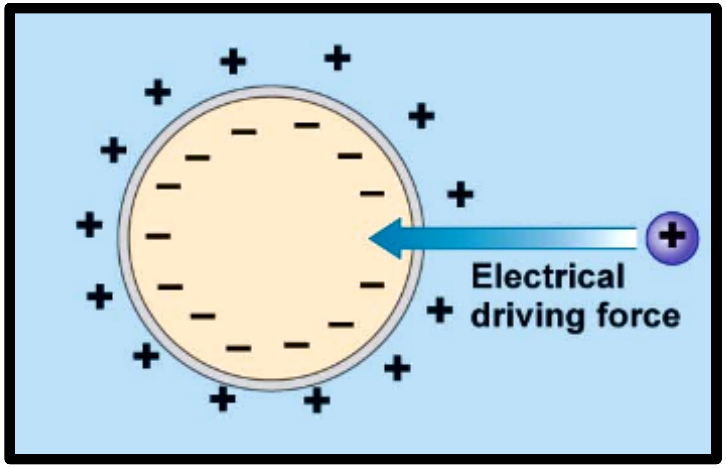
- **Chemical concentration gradients are differential concentrations of a chemical across a space or a membrane.**
  - **If there is a high concentration of glucose on one side of the membrane and a low concentration of glucose on the other, then a <u>chemical concentration gradient</u> exists across the membrane for glucose.**



Chemical & Electrical Gradients in Cells

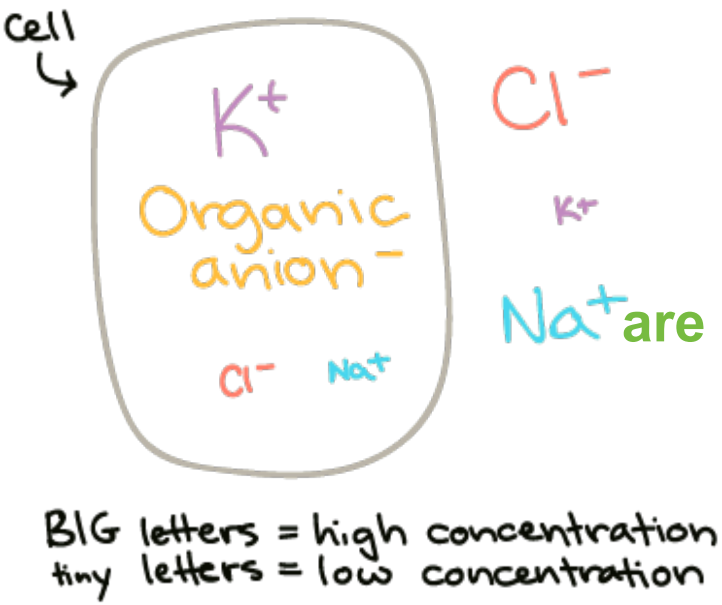
- Because certain ions move into and out of cells but not others and because cells contain proteins and other organic molecules that do not move across the membrane and are often negatively charged, there exists also an electrical gradient across the plasma membrane of cells.
  - An electrical gradient (or what we call a cell's membrane potential) is a difference of net (overall) charge, across the plasma membrane.
- The interior of living cells is electrically negative with respect to the extracellular fluid in which they are bathed.





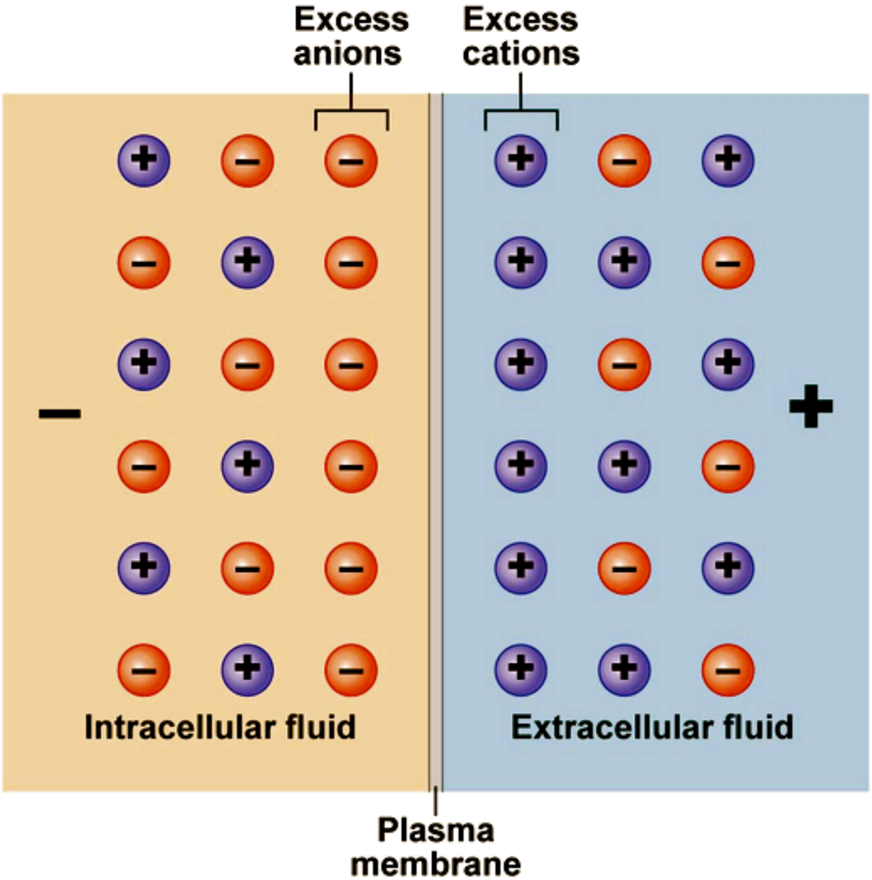
Chemical & Electrical Gradients in Cells

- The resting membrane potential of cells is caused by:
  - The **uneven distribution** of ions (charged particles) between the inside and the outside of the cell, and
  - The **differential permeability of the membrane** to different types of ions.
- Types of ions found in and around neurons for example:
  - Sodium (Na+) & Chloride (Cl-) are usually present at higher concentrations outside the cell.
  - Potassium (K+) & organic anions are usually present at higher concentrations inside the cell.



Membrane Potential = The Voltage Across a Plasma Membrane

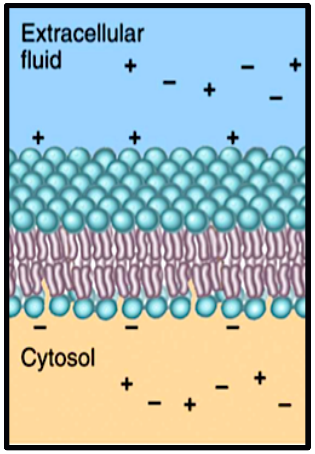
- The cell's membrane potential is a reflection of the separation of charges by the membrane.
  - The size of the membrane potential is measured in mV (one thousandth of a volt) and is proportional to the concentration of opposite charges separated by the membrane.
    - In the resting cell, there are more anions within the cell compared to outside the cell. Hence the potential is negative.



For most cells the membrane potential is around -70mV.

Chemical & Electrical Gradients in Cells

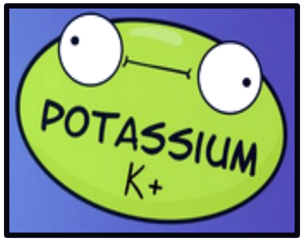
- Ions, atoms or molecules that have an overall charge can be affected by an electrical driving force (an electrical gradient) <u>in addition</u> to a chemical concentration gradient.
  - Remember, the electrical driving force across a cell membrane = <u>membrane potential</u>.
- If the concentration of positive charged particles (like cations) balance the concentration of negative charged particles (like anions) across the membrane, the membrane potential would be <u>zero</u> (0mV), for example.
  - This is <u>not</u> the case in the living cell: There is <u>usually more anions on the intracellular side of the membrane</u> than on the extracellular side.
    - The excess charges on either side of the membrane are attracted to the region on the opposite side of the separating membrane because the anions are attracted to the cations and vice versa.
      - Like a concentration gradient, <u>Potential Energy</u> (that can be used to do work) is stored in this electrical gradient too!



Chemical & Electrical Gradients in Cells

- **On the inside of the plasma membrane, cells have higher concentrations of potassium (K+) and lower concentrations of sodium (Na+) than does the extracellular-fluid-side of the membrane.**

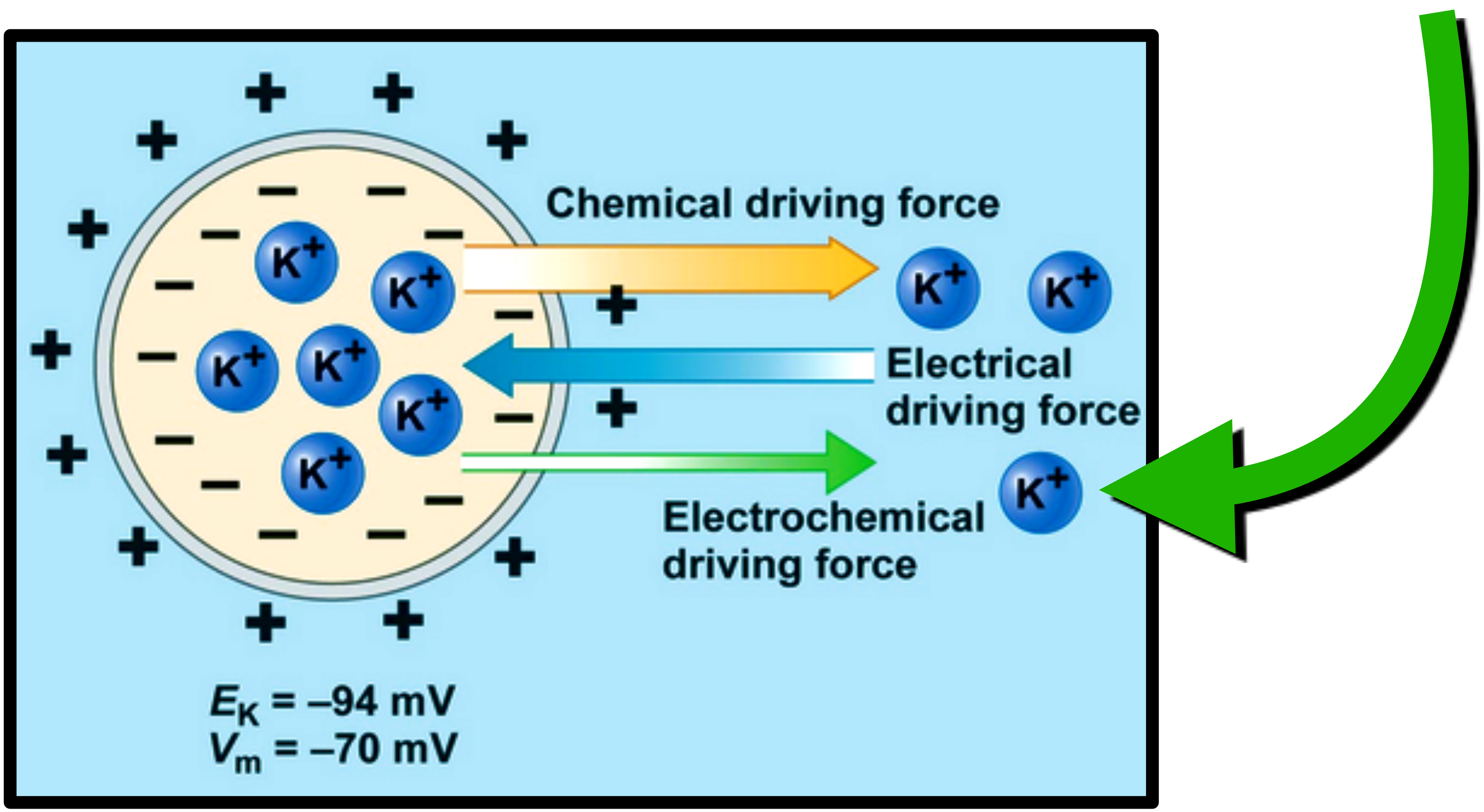
  - **In a living cell, the concentration gradient of Na+ tends to drive it <u>into</u> the cell**
  - **The electrical gradient of Na+ (a positive ion) also tends to drive it <u>inward</u> to the negatively-charged interior.**
- **The situation is more complex, however, for other elements such as potassium.**



  - **The electrical gradient of K+, a positive ion, tends to drive it <u>into</u> the cell, but…**
  - **The concentration gradient of K+ tends to drive K+ <u>out</u> of the cell.**
    - **The combined gradient of concentration and electrical charge that affects an ion is called its <u>electrochemical gradient.</u>**

Chemical & Electrical Gradients in Cells

- Particles with net positive or net negative charges diffuse in the direction determined by their electrochemical gradient (the combined effects of BOTH their concentration gradient and the electrical gradient)



Neurons Change Membrane Potential To Communicate with Other Neurons, Endocrine Cells, and Muscle Cells

- **Because there is an electrical potential difference across the cell membrane, the membrane is said to be <u>polarized</u>.**
  - **Neurons generate or prevent electrical signals through brief, controlled changes in the permeability of their cell membrane to particular ions (Na+ & K+) that changes their <u>starting membrane potential</u> (resting membrane potential), making their interiors more <u>positive</u> (depolarizing the cell) or <u>more negative</u> (hyperpolarizing the cell)**