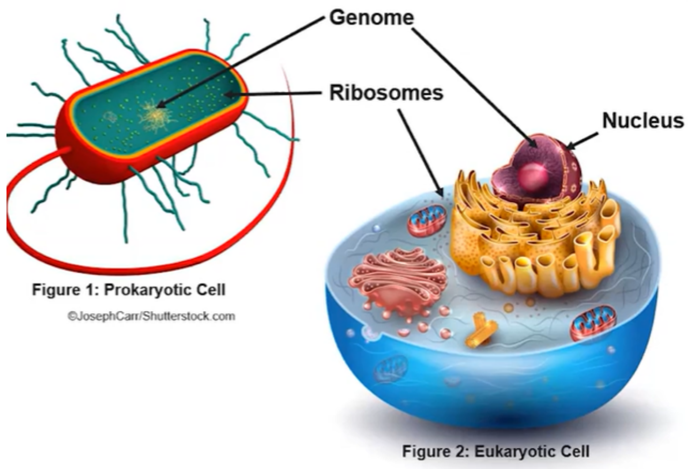
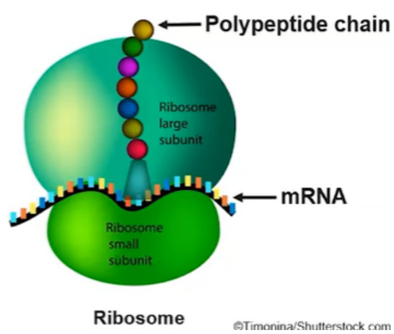
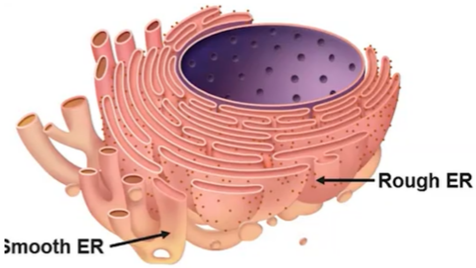
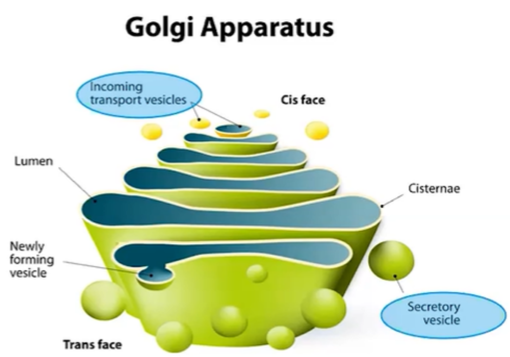
Cell Structure: Cellular Components

- Subcellular components universal to all cells
    - All living cells contain a genome and ribosomes, reflecting the common ancestry of all known life
    - Genomes are membrane-bound
    - Ribosomes synthesize protein according to mRNA sequence and the instructions that are encoded in that mRNA sequences originate from the genome of the cell
    - 

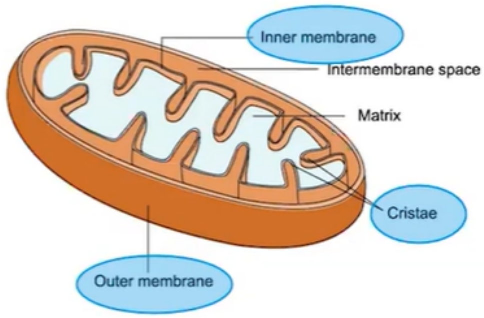
- Ribosomes
    - ribosomes consist of two subunits that are not membrane-bound
    - Ribosomes are made of ribosomal RNA (rRNA) and proteins
    - Ribosomes synthesize/make protein according to mRNA sequences
    - 

- Endoplasmic Reticulum
    - ER is a network of membrane tubes within the cytoplasm of eukaryotic cells
    - Two Forms: Rough ER and Smooth ER
    - Rough ER: has ribosomes attached to its membrane, compartmentalizes the cell, is associated with the packaging of newly synthesized proteins made by attached ribosomes for possible export from the cell

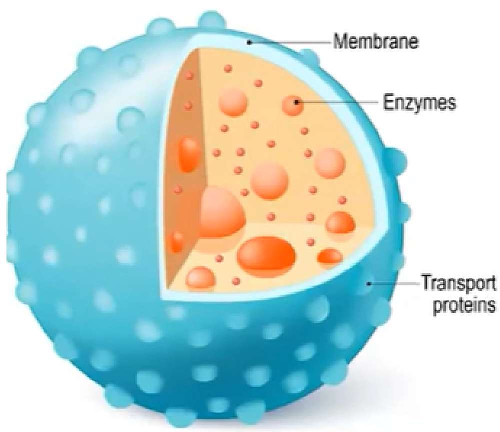
- Smooth ER: does not have ribosomes attached, functions include detoxification and lipid synthesis
- Structural differences between rough ER and smooth ER leads to functional differences
- 

- Golgi Apparatus
  - Series of flattened membrane-bound sacs found in eukaryotic cells
  - Involved in the correct folding and chemical modification of newly synthesized proteins and packaging for protein trafficking
  - Proteins to be used for secretion or use in the cell
  - Shipped in vesicle
  - 

- Mitochondria
  - Has a double membrane
  - Outer membrane is smooth and inner membrane is highly convoluted, forming folds called cristae
  - Functions in production of ATP energy that eukaryotic cells can use for cell work

- 

Mitochondria Inner Structure

- Lysosomes
    - membrane-enclosed sacs found in some eukaryotic cells that contain hydrolytic enzymes
    - hydrolytic enzymes can be used to digest a variety of materials such as damaged cell parts or macromolecules
    - 

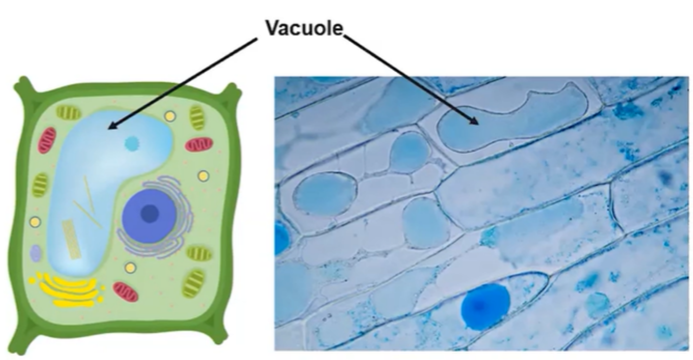
- Vacuoles
    - membrane-bound sacs found in eukaryotic cells
    - play variety of roles ranging from storage of water and other macromolecules to the release of waste from a cell
    - 

Figure 1: Plant Cell Model
Figure 2: Microscopic Image of Plant Cells
- Chloroplasts
    - Found in eukaryotic cells such as photosynthetic algae and plants

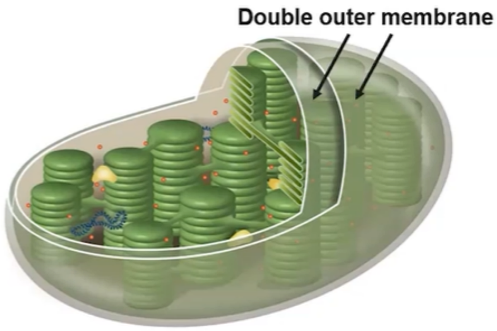
- Double outer membrane
- Specialized for capturing energy from the sun and producing sugar for the organism
- 

Figure 1: Chloroplast

Cell Structure and Function:

- Chloroplast
  - Specialized for photosynthesis and capturing energy from the sun to produce sugar
  - Compartments: thylakoid and stroma
  - Thylakoid: highly folded membrane compartments that are organized in stacks called grana
  - Thylakoid: membranes contain chlorophyll pigments that comprise the photosystems and electron transport chains can be found be found between the photosystems, embedded in the thylakoid membrane
  - Thylakoid: light-dependent reactions occur here
  - Thylakoid: folding of these internal membranes increases the efficiency of these reactions
  - Stroma: fluid between the inner chloroplast membrane and outside thylakoids
  - Stroma: the carbon fixation (Calvin-Benson cycle) reactions occur here
- Mitochondria
  - Double membrane provides compartments for different metabolic reactions
  - Mitochondria capture energy from macromolecules
  - The Krebs cycle reactions occur in the matrix of the mitochondria
  - Electron transport and ATP synthesis occur in the inner mitochondrial membrane

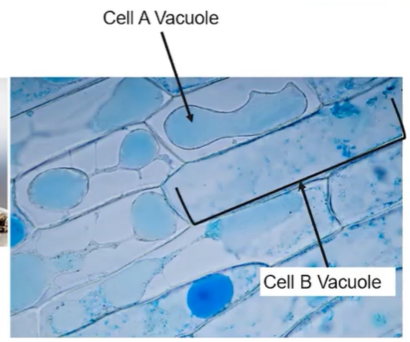
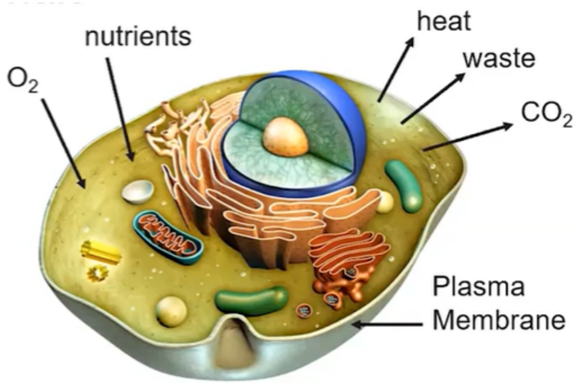
    - Folding of the inner membrane increases the surface area, which allows for more ATP to be made
- Vacuoles
    - Play a variety of roles, including storage and release of water, macromolecules, and cellular waste products
    - In plants, vacuoles aid in retention of water for turgor pressure
    - Turgor pressure is an internal cellular force, usually caused by water pushing up against the plasma membrane and cell wall
    - 
      Figure 1: Wilted Plant
      ©OhEngine/Shutterstock.com
      

      Figure 2: Microscopic Image of Plant Cells
- Lysosomes
    - Contain hydrolytic enzymes and can contribute to cell function in the following ways: intracellular digestion, recycling of organic materials, programmed cell death (apoptosis)
    - Macromolecule can enter through a vesicle, then hydrolytic enzymes can digest it, breaking it down into monomers, that can be used in the mitochondria as energy for cell
- Endoplasmic Reticulum
    - Provides mechanical support
    - Plays a role in intracellular transport
    - Rough ER carries out protein synthesis on ribosomes that are bound to its membrane
    - Rough ER, golgi apparatus, vesicles all transport proteins, golgi modifies

Cell Size:

- Cells are typically small
- Moving materials (such as nutrients and waste) in and out of cells gets more difficult the larger a cell is
- Cells need a sufficient amount of surface for exchanging materials with its surrounding environment
- Surface area of a cell: amount of surface covering the outer part of the cell

- The larger the surface area: volume ratio, the more efficient the cell is (12:1)
- As cell gets larger, the smaller the ratio gets
- Smaller cells typically have a higher surface area-to-volume ratio and more efficient exchange of materials with the environment
- As cells increase in volume, the relative surface area decreases making it difficult for larger cells to meet the demand for internal resources and remove waste sufficiently
- These limitations can restrict cell size and shape



-
- Surface area-to-volume ratio affects the ability of a biological system to obtain necessary resources, eliminate waste products, acquire and dissipate thermal energy, and otherwise exchange chemicals and energy with the environment
- Surface area of the plasma membrane must be large enough to adequately exchange materials
- As cells increase in volume, demand for internal resources increases, relative surface area decreases
- More complex structures are necessary to adequately exchange materials with the environment
- Use of specialized structures and strategies
    - Membrane folding increase surface area
    - The outer lining of the small intestine is highly folding containing finger-like projections called villi
    - The surface of each villi has additional microscopic projections called microvilli which further increase the surface area available for absorption of nutrients
    - If conditions arise that lead to the loss of this folding, these cells would not be as efficient in absorbing nutrients for the organism
    - Root hairs on the surface of plant roots increase the surface area of the root allowing for increased absorption of water and nutrients
    - As organisms increase in size, their surface area-to-volume ratio decreases, affecting properties like rate of heat exchange with the

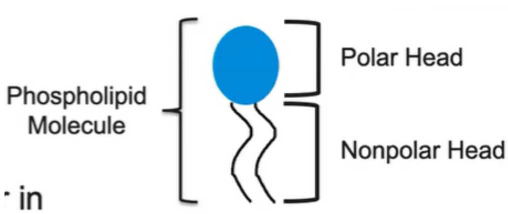
environment (ex. Flattened shape of ear allows elephant to dissipate more thermal energy as blood flows closer to the surface)
  - Organisms have evolved highly efficient strategies to obtain nutrients and eliminate wastes
  - Cells and organisms use specialized exchange surfaces, such as stomatal openings of leaves, to obtain molecules from and release molecules into the surrounding environment
  - When stomata are open, CO_2 can enter the leaf and O_2 and H_2O can be released into the atmosphere

Plasma Membranes:

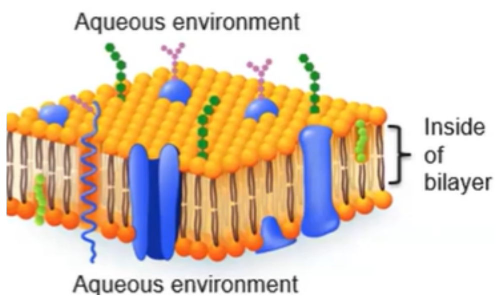
- Cells have membranes that allow them to establish an internal environment
- Cell membranes provide a boundary between the interior of the cell and the outside environment
- Cell membranes control the transport of materials in and out of the cell
- Cell membranes are made up of phospholipids
- Phospholipids are amphipathic
  - Hydrophilic phosphate head is polar
  - Hydrophobic phosphate tail is nonpolar
- Phospholipids simultaneously form a bi-layer in an aqueous environment
  - Tails are located inside the bilayer
  - Heads are exposed to the aqueous outside and aqueous inside environments
  - Hydrophilic phosphate regions oriented toward the aqueous external or internal environment
  - Hydrophobic fatty acid regions face each other within the interior of the membrane
- In the cell membrane, there are embedded proteins
- Embedded proteins can be hydrophobic or hydrophilic
- Peripheral proteins
  - Loosely bound to the surface of the membrane
  - Hydrophilic with charged and polar side groups
- Integral proteins
  - Span the membrane
  - Hydrophilic with charged and polar side groups
  - Hydrophobic with nonpolar side groups penetrate hydrophobic interior of bilayer
  - Ex. transmembrane proteins

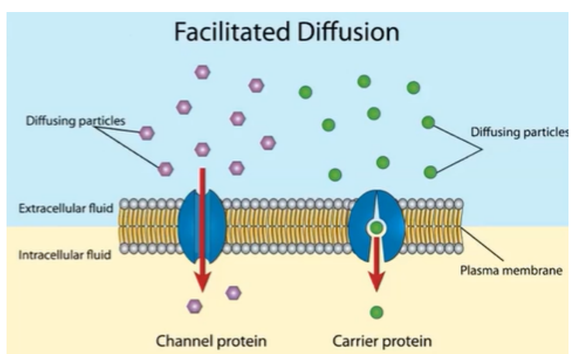
- Embedded proteins play various roles in maintaining the internal environment of the cell
- Membrane protein functions
  - transport
  - cell-cell recognition
  - Enzymatic activity
  - Signal transduction
  - Intercellular joining
  - Attachment for extracellular matrix or cytoskeleton
- The framework of the cell membranes is described as the Fluid Mosaic Model
  - Structured as a mosaic of protein molecules in a fluid bilayer of phospholipids
  - The structure is not static and is held together primarily by hydrophobic interactions which are weaker than covalent bonds
  - Most lipids and some proteins can shift and flow along the surface of the membrane or across the bilayer
  - Fluid mosaic model components include steroids
  - Cholesterol, a type of steroid, is randomly distributed and wedged between phospholipids in the cell membrane of eukaryotic cells
  - Cholesterol regulates bilayer fluidity under different environmental conditions
  - Fluid mosaic model components include carbohydrates
  - Diversity and location of the (molecules) carbohydrates and lipids enable them to function as markers
  - Glycoproteins- one or more carbohydrate attached to a membrane protein
  - Glycolipids- lipids with one or more carbohydrate attached
- Cytosol of a cell is aqueous

Membrane Permeability:

- 

· in
- Polar = hydrophilic, nonpolar = hydrophobic
- Fluid mosaic model is a moving phospholipid bilayer composed of varying types of molecules (proteins, steroids, carbohydrates)

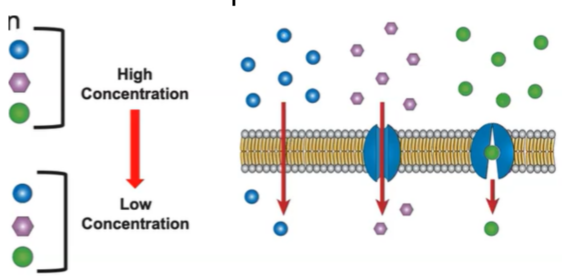
- 

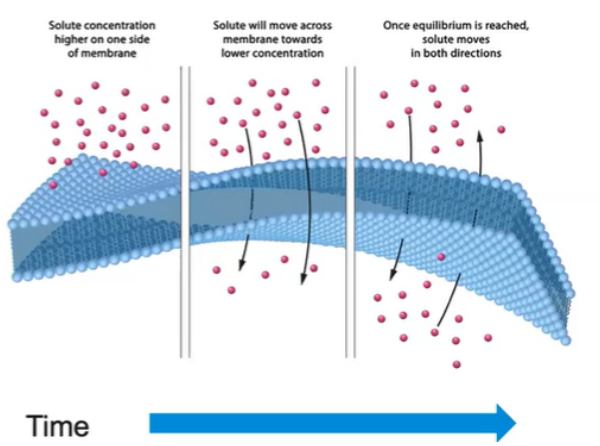
- Selective permeability is a direct consequence of membrane structure
- Cell membrane is selectively permeable
- Small nonpolar molecules pass freely: nitrogen (N_2), oxygen (O_2), carbon dioxide (CO_2)
- Hydrophilic substances such as large polar molecules and ions cannot move freely across the membrane
- Hydrophilic substances move across the membrane through embedded channel and transport proteins
    - Channel proteins- a hydrophilic tunnel spanning the membrane that allow specific target molecules to pass through
    - Carrier proteins- spans the membrane and change shape to move a target molecule from one side of the membrane to the other
- Small polar molecules, like H_2O, can pass directly through the membrane in minimal amounts
- 

- Cell wall is a structural boundary and permeable barrier
- As a structural boundary:
    - Protects and maintains the shape of the cell
    - Prevents against cellular rupture when internal water pressure is high
    - Helps plants stand up against the force of gravity
- As a permeable barrier:
    - Plasmodesmata: small holes between plant cells that allows the transfer of nutrients, waste, and ions
- Plant cells have cell walls, but animal cells do not
- Cell walls are composed of complex carbohydrates

- In plants, found as cellulose (polysaccharide)
- In fungi, found as chitin (polysaccharide)
- In prokaryotes, found as peptidoglycan (polymer consisting of sugar and amino acids)

Membrane Transport:

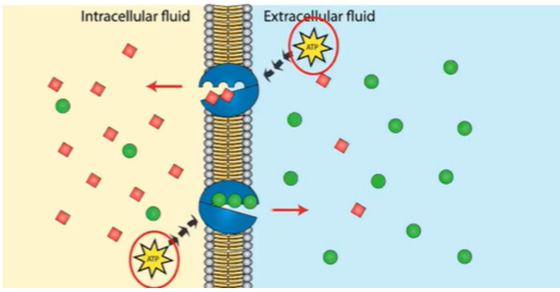
- Selectively permeable membranes allow for the formation of concentration gradients
- Concentration gradient is when a solute is more concentrated in one area than another
- A membrane separates two different concentrations of molecules
- 

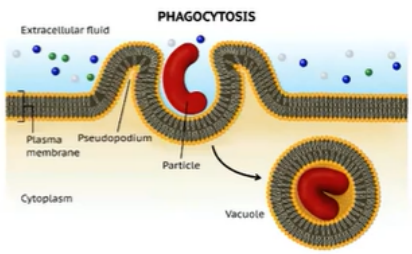
- Passive transport is the net movement of molecules from high to low concentration
- Net movement of molecules from high concentration to low without metabolic energy, such as ATP, needed
- Plays a primary role in the import of materials and the export of wastes
- 

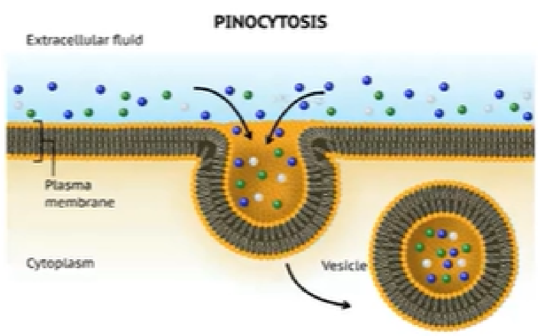
- Passive transport has two kinds: diffusion and facilitated diffusion
- Diffusion- movement of molecules from high concentration to low concentration
  - Small nonpolar molecules pass freely (Nitrogen, oxygen, carbon dioxide)
- Facilitated Diffusion- movement of molecules from high concentration to low concentration through transport proteins
  - Allows for hydrophilic molecules and ions to pass through membranes

- Active transport requires the direct input of energy (such as ATP) to move molecules from regions of low concentration to regions of high concentration
- Active transport moves against the concentration gradient

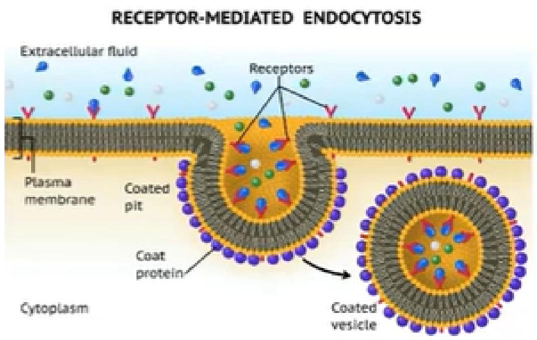
Active transport

- 

- Endocytosis requires energy to move large molecules into the cell (bringing large molecules in)
- The cell uses energy to take in macromolecules and particulate matter by **forming new vesicles** derived from the plasma membrane
    - Phagocytosis- cell takes in large particles
    - 

    - Pinocytosis- cell takes in extracellular fluid containing dissolved substances
    - 

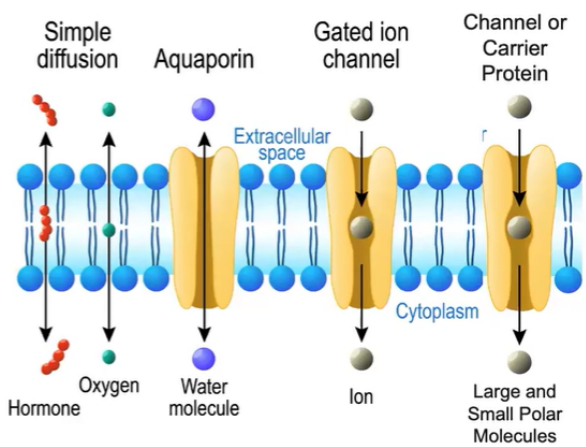
    - Receptor-mediated endocytosis- receptor proteins on the cell membrane are used to capture specific target molecules



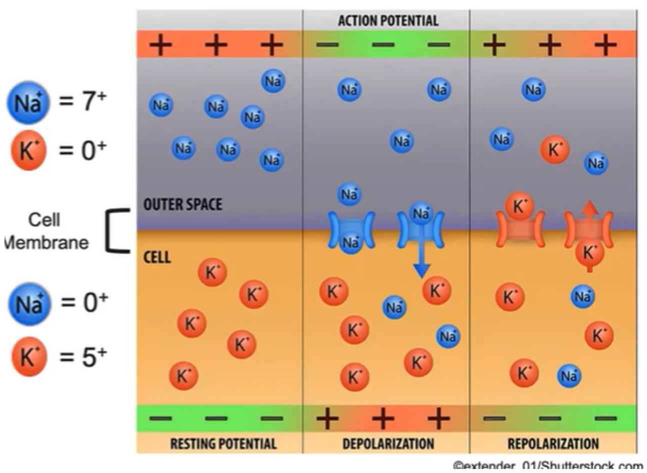
- Exocytosis requires energy to move large molecules out of the cell
- In exocytosis, internal vesicles use energy to fuse with the plasma membrane and secrete large macromolecules out of the cell
  - Proteins such as signaling proteins
  - Hormones
  - Waste

Facilitated Diffusion:

- Membrane proteins are necessary for facilitated diffusion
- Facilitated Diffusion- movement of molecules from high concentration to low concentration through transport proteins
  - Large and small polar molecules
  - Large quantities of water can pass through aquaporins
  - Charged ions, including sodium and potassium, require channel proteins



- Active transport establishes and maintains concentration gradients
- Active transport moves molecules and/or ions against their concentration gradient from low concentration to high concentration
  - Carrier proteins called pumps

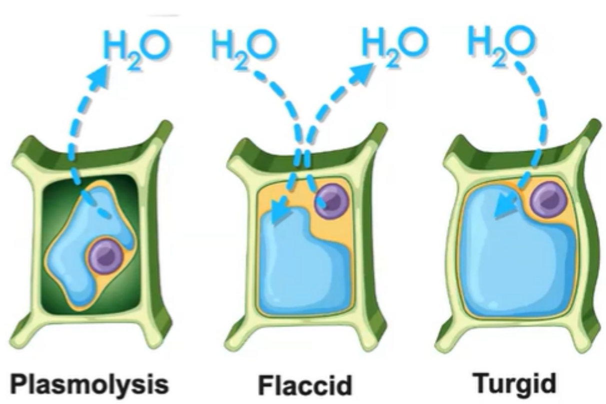
- Requires metabolic energy, like ATP
  - Establishes and maintains concentration gradients
- Membrane proteins are necessary for active transport
- Cotransport- secondary active transport that uses the energy from an electrochemical gradient to transport two different ions across the membrane through a protein
  - Symport- two different ions are transported in the same direction
  - Antiport- two different ions are transported in opposite directions
- Membranes may become polarized by movement of ions
- The cell membrane allows for the formation of gradients
- Electrochemical gradient
  - Type of concentration gradient
  - Membrane potential- electrical potential difference (voltage) across a membrane
- Membranes may become polarized by movement of ions across a membrane
- 

- The sodium/potassium pump contributes to the maintenance of membrane potential
  - 3 sodiums pumped
  - 2 potassium pumped in opposite direction, creating membrane potential

Tonicity and Osmoregulation:

- Water moves by osmosis
- Osmosis is the diffusion of free water across a selectively permeable membrane
- Large quantities of water move via aquaporins
- Osmolarity is the total solute concentration in a solution
  - Water has high solvency abilities
  - Solute is the substance being dissolved

- Solvent is the substance that dissolves a solute
- Solution is a uniformed mixture of one or more solutes dissolved in a solvent
- solvent + solute = solution

- Osmosis is the diffusion of free water across a selectively permeable membrane
- Tonicity affects a cell's physiology
- Tonicity- the measurement of the relative concentrations of a solute between two solutions (inside and outside of the cell)
- Internal cellular environments can be hypotonic, hypertonic, or isotonic to external environments
    - Hypertonic: more solute and less solvent
    - Isotonic: equal concentrations of solute and solvent
    - Hypotonic: less solute and more solvent
- Water moves by osmosis into the area with a higher solute concentration
- Water concentrations and solute concentrations are inversely related
- Water would diffuse out of a hypotonic environment to a hypertonic environment
- Solutes diffuse along their own concentration gradients, from the hypertonic environment to the hypotonic environment
- When a cell is in an isotonic environment, a dynamic equilibrium exists with equal amounts of water moving in and out of the cell at equal rates
    - No net movement of water takes place
- Osmoregulatory mechanisms contribute to survival
- In plant cells, osmoregulation maintains water balance and allows control of internal solute composition/water potential
    - Environmental hypertonicity: less cellular solute and more cellular water, plasmolysis
    - Isotonic solution: equal solute and water, flaccid
    - Environment hypotonicity: more cellular solute and less cellular water, turgid
    - 

- The cell wall helps maintain homeostasis for the plant in environmental hypotonicity

    - Osmotic pressure is high outside of the plant cell due to environmental hypotonicity
    - Water flows into the plant vacuoles via osmosis causing the vacuoles to expand and press against the cell wall
    - The cell wall expands until it begins to exert pressure back on the cell, called turgor pressure
    - Turgidity is the optimum state for plant cells
- In animal cells, osmoregulation maintains water balance and allows control of internal solute composition/water potential
    - Environmental hypotonicity: less cellular solute and more cellular water, shriveled
    - Isotonic solution: equal solute and water, normal
    - Environmental hypertonicity: more cellular solute and less cellular water, lysed/burst
- Components of an effective graph
    - Title: experiment details and what is being measured
    - Labeled axis with units: independent variable on x-axis, dependent on y-axis (DRY MIX)
    - Scaling- uniform intervals
    - Identifiable lines or bars: legend or label each line or bar
    - Trend line: line of best fit that shows the general pattern or overall direction of the data
- Types of graphs
- Line graph
    - Reveals trends or progress over time for multiple groups or treatments
    - Track changes over time, concentrations, etc
- X Y graph
    - Scatterplot
    - To determine relationships between 2 different things
    - Compare two variables that may or may not have a linear relationship
- histogram
    - Show how values in a data set are distributed across evenly spaced or equal intervals
    - Explore the relationship between 2 or more variables
- Bar graph: compare multiple groups or treatments to each other
- Box and Whisker plot: show the variability in a sample, ideal for comparing distributions in relation to the mean
- Dual Y: illustrate the relationship between 2 dependent variables
- Water potential measures the tendency of water to move by osmosis
- Water potential is calculated from pressure potential and solute potential

- Water potential = pressure potential + solute potential
- Water moves from an area of high water potential to an area of low water potential
- The values of water potential can be positive, zero, or negative
- The more negative the water potential, the more likely water will move into the area
- Water potential of pure water has a value of 0 in an open container, because there is no solutes or pressure
- Osmoregulation allows organisms to control their internal solute composition and water potential, water balance
- Increasing the amount of solute in water will cause
    - An increase in solute potential
    - A decrease in water potential
- Increasing water potential will cause
    - An increase in pressure potential
- Decreasing pressure potential will cause
    - A decrease in water potential
- Solute potential of a solution: in an open system, the pressure potential is zero, so water potential is equal to the solute potential
- Solute potential = -i * C * R * T
    - i = ionization constant
    - C = molar concentration (molarity = moles of solute/volume of a solution)
    - R = pressure constant (0.0831 L bars/mol K)
    - T = temperature in Kelvin (temp in Celsius + 273 = Kelvin)
- The addition of solutes is equal to a more negative solute potential
- Water moves by osmosis from areas of low solute potential to areas of high solute potential (or high water to lower water)

Mechanisms of Transport:

- Passive transport is the net movement of molecules down their concentration gradient
- Diffusion- movement of molecules from high concentration to low concentration
- Facilitated diffusion- movement of molecules from high concentration to low concentration through transport proteins
- Differences in relative solute concentrations can facilitate osmosis (diffusion of water across a selectively permeable membrane)
- Active transport is movement of molecules against concentration gradient
    - Protein pumps are carrier proteins used in active transport

    - Require metabolic energy, like ATP
    - Establishes and maintains concentration gradients
- Water is transported in small amounts across the membrane through simple diffusion

Compartmentalization:

- Cells have a plasma membrane that allows them to establish and maintain internal environments that are different from their external environments
- Eukaryotic cells have additional internal membranes and membrane-bound organelles that compartmentalize the cell
- Cellular components allow for various metabolic processes and specific enzymatic reactions to occur simultaneously, increasing the efficiency of the cell
- Cellular compartments: lysosomes
    - Membrane minimizes competing interactions
    - The hydrolytic enzymes of the lysosome function at an acidic environment
    - By having this compartmentalization, the inside of the lysosome can maintain a more acidic pH and allow for efficient hydrolysis to occur, while the rest of the cytoplasm can remain a more neutral environment
- Cellular compartments: mitochondria
    - Membrane folding maximizes surface area for metabolic reactions to occur
    - Electron transport and ATP synthesis occur in the inner mitochondrial membrane
    - Folding of the inner membrane increases the surface area, which allows for more ATP to be made
- Cellular compartments: chloroplasts
    - Membrane folding maximizes surface area for metabolic reactions to occur
    - The thylakoids are highly folded membrane compartments that increase the efficiency of the light dependent reactions

Origins of Cell Compartmentalization:

- Both eukaryotic and prokaryotic cells have a plasma membrane that separates their internal environment from their surrounding environment
- Prokaryotic cells have an internal region, nucleoid region, that contains its genetic material

- Eukaryotic cells have additional internal membranes and membrane-bound organelles that compartmentalize the cell (genetic material is contained within a membrane-bound nucleus)
- The nucleus and other internal membranes (ex. ER) are theorized to have formed from the infoldings of the plasma membrane
- Mitochondria evolved from previously free-living prokaryotic cells via endosymbiosis
    - A free-living aerobic prokaryote was engulfed by an anaerobic cell through endocytosis
    - The engulfed prokaryotic cell did not get digested by the engulfing cell; this arrangement became mutually beneficial
    - Over time, the engulfed cell lost some of its independent functionality and became the mitochondria of the eukaryotic cell
- Chloroplast evolved from previously free-living prokaryotic cells via endosymbiosis
    - A free-living photosynthetic prokaryote was engulfed by another cell through endocytosis
    - The engulfed prokaryotic cell did not get digested by the engulfing cell; this arrangement became mutually beneficial
    - Over time, the engulfed cell lost some of its independent functionality and became the chloroplast of the eukaryotic cell
- Theory of endosymbiosis: a previously free-living prokaryote (bacteria) was engulfed by another cell through endocytosis. After living together symbiotically for some time, the once free-living prokaryote lost its independent functionality and gave rise to either the mitochondria or the chloroplasts
- relationship/evidence between the functions of endosymbiotic organelles and their ancestors
    - Both mitochondria and chloroplasts have double membranes, which function to regulate the passage of materials into and out of the cell and to maintain a stable internal environment
    - Like prokaryotic cells; mitochondria and chloroplasts both have their own circular DNA encoding genetic information and can reproduce by a similar process used by prokaryotes
    - They both contain their own ribosomes that synthesize proteins
- Evidence supporting the evolution of mitochondria and chloroplasts through endosymbiosis includes the presence of double membranes, circular DNA, and ribosomes in both these organelles