Russelldw DAT Notes
Based off Cliffs & Barron's AP Biology

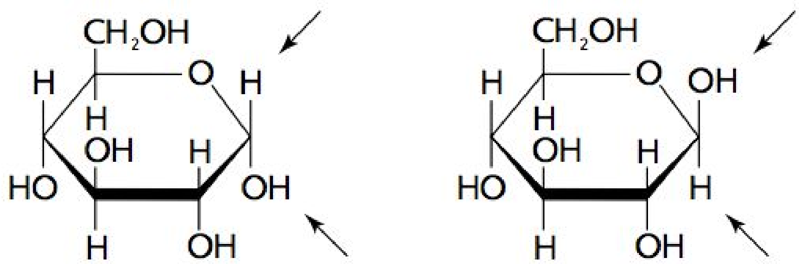
Chemistry

- Atomic Structure
    - Atoms in elemental state are neutral because #protons = #electrons
    - Ground State = Electrons in lowest available energy levels
    - Excited State = Electrons absorb energy and move to higher energy levels
    - <u>Isotopes</u> are the same atoms that have **different # of neutrons**
        - **Chemically isotopes are identical** because they have same number of electrons in the same configuration
- Atoms, Molecules, Bonds
    - Atoms form bonds due to interactions with the electrons
    - Bond Types:
        - Ionic
            - Electron Transfer from one atom to another
            - Electronegativity of atoms are very different
            - An atom that gains the electron is an anion
            - An atom that loses an electron is a cation
        - Covalent
            - Sharing of electrons between two atoms
            - Electronegativity of two atoms usually similar
            - Nonpolar
                - Electrons are shared equally, such as in O_2
                - Diatomic Molecules (O_2, H_2, etc)

            - CO_2 is nonpolar
        - Polar
            - Electrons shared unequally, such as in H_2O
        - Single, double, and triple covalent bonds form depending on if two, four, or six electrons are being shared between the two atoms
    - Hydrogen
        - Weak bonds
        - The partial positive charge of a hydrogen (such as in water) is attracted to the partial negative charge of another atom (such as the oxygen in a different water molecule)
- Properties of Water
    - The hydrogen bonds in water give it five unique properties:
        - 1. <u>Excellent Solvent</u>
            - **Ionic substances (NaCl) dissolve in water** because of the poles or charges allowing a good interaction with the poles on water. The partial charges on water can interact with the charges on Na+ and Cl- pulling them apart into the individual ions
            - **Polar molecules (such as HCl) and charged molecules (such as H3O+) also dissolve in water**
            - *Hydrophilic* = Dissolve in water
            - *Hydrophobic* = Do not dissolve in water (lacking the charged poles)
        - 2. <u>High heat capacity</u>
            - Requires much energy to change the temperature of water
            - Ocean remains constant temperature despite changes in surrounding air
            - Evaporated sweat takes with it a large amount of heat due to the high heat of vaporization. For the water to evaporate it has to absorb a large amount of your body heat
        - 3. <u>Ice floats</u>
            - Because hydrogen bonds are weak, they constantly break and reform. During freezing, the bonds form a crystal allowing separation. This makes it less dense, causing the ice to expand upon freezing
        - 4. <u>Water has strong cohesion and high surface tension</u>
            - Cohesion due to the poles attracted to each other (aka hydrogen bonding)
            - **High surface tension** due to the strong cohesion, allowing bugs to walk on water
        - 5. <u>Water has strong adhesion</u>
            - **Capillary action** (water being drawn up a paper towel or paint brush) is due to the combination of *cohesion and adhesion*
- pH

- Measures acidity or alkalinity of a solution
    - pH 1 = $1x10^{-1}$ = 0.1 molar hydrogen concentration
    - pH 2 = $1x10^{-2}$ = 0.01 molar hydrogen concentration
    - pH 3 = $1x10^{-3}$ = 0.001 molar hydrogen concentration
    - pH 7 = 0.0000001 molar hydrogen concentration
- pH 7 is 10,000 times more basic than pH 3 (10^4)
- **Buffers resist change in pH by absorbing excess hydrogen or donating hydrogen**

- Organic Molecules
    - Organic molecules contain carbon atoms
        - Macromolecules - Usually polymers
    - Functional groups
        - Functional groups give molecules specific properties such as acidity, polarity, etc.
            - Hydroxyl (Alcohol)
                - Sugars
            - Carboxyl (carboxylic acids)
                - Amino acids, fatty acids, sugars
            - Amino (amines)
                - Amino Acids
            - Phosphate (organic phosphates)
                - DNA, ATP, phospholipids
            - Carbonyl (ketones)
                - Acetone, sugars
            - Carbonyl (aldehydes)
                - Formaldehyde, sugars
            - Methyl
                - Fatty acids, oils, waxes
    - Four classes of organic molecules:
        - **1) Carbohydrates** (sugar = saccharide)
            - <u>Monosaccharide</u>
                - Single sugar molecule
                - **Fructose, Glucose, and Galactose** (isomers)
                - Note that sugars have the formula $C_xH_{2x}O_x$ so glucose and fructose is $C_6H_{12}O_6$ (they differ by placement of carbons)
                - **α-glucose vs β-glucose** differ by reversal of H and OH on the first carbon



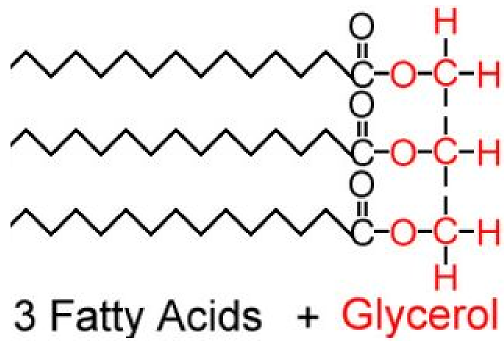
Alpha Glucose Beta Glucose

- Disaccharide
  - Two sugar molecules joined by a glycosidic linkage
  - During the process of joining, a water molecule is lost (condensation/dehydration reaction)
  - Glucose + Fructose = Sucrose (table sugar)
  - Glucose + Galactose = Lactose (milk sugar)
  - Glucose + Glucose = Maltose
- Polysaccharide
  - A series of connected monosaccharides (polymer)
  - Starch
    - α-glucose polymer
    - Energy storage in plant cells
    - Amylose and amylopectin
  - Glycogen
    - α-glucose polymer
    - Energy storage in animal cells (“animal starch”)
  - Cellulose
    - β-glucose polymer
    - Structural for walls of plant cells
    - Major component in wood
  - Chitin
    - β-glucose polymer (with a nitrogen attached to each glucose molecule)
    - Structural in walls of fungus and in exoskeletons of arthropods

■ **2) Lipids**

- Triglycerides
  - Fats and oils
  - Three fatty acids attached to a glycerol
    - Fatty acids = hydrocarbon chains with a COOH
  - Saturated
    - All single bonds between carbon atoms
    - Each carbon has two hydrogens (think saturated with hydrogens)

- Monounsaturated
  - One double bond between two carbons
  - Those two carbons have one hydrogen each
- Polyunsaturated
  - Two or more double bonds



- <u>Phospholipids</u>
  - Looks similar to triglyceride, but one of the fatty acid chains replaced by a phosphate group (and the phosphate has an "R" group attached to it)
  - Two fatty acid tails = nonpolar hydrophobic
  - Phosphate head = polar hydrophilic
  - Form Cell membranes
- <u>Steroids</u>
  - Contain a backbone of four carbon rings linked together
  - Cholesterol (within cell membranes)
  - Testosterone and Estrogen hormones

- **3) Proteins**
  - Polymers of amino acids covalently bonded (peptide bonds)
    - There are 20 different amino acids
    - Amino acids all have a central carbon bonded to an amino (NH_2), a Carboxyl (COOH) and a hydrogen (H). The fourth bond (R) makes it different
  - Types:
    - <u>Structural Proteins</u>
      - Keratin in hair/horns of animals
      - Collagen in the connective tissues
      - Silk in spider webs
    - <u>Storage Proteins</u>
      - Casein in milk
      - Ovalbumin in egg whites
      - Zein in corn seeds
    - <u>Transport Proteins</u>
      - Vesicles that transport materials in and out of cells
      - Oxygen carrying hemoglobin in RBCs

                - Defensive Proteins
                    - Antibodies
                - Enzymes
                    - Regulate rate of chemical reactions
            - Protein Structure
                - Primary
                    - Amino acid sequence
                    - Cys-Tyr-Phe-Gln etc.
                - Secondary
                    - 3D shape from **hydrogen bonding** of amino acids
                    - Fibrous proteins
                    - Alpha Helix (spiral)
                    - Beta Pleated Sheet (folded plane)
                - Tertiary
                    - Additional 3D shape
                    - Globular proteins
                    - Hydrophobic effect causing R groups to move towards the center of the protein to get away from the water
                    - **Disulfide bonds**
                - Quaternary
                    - Two or more peptide chains coming together by hydrogen bonding
        - **4) Nucleic Acids**
            - Stores genetic information
            - DNA is a polymer of nucleotides. Nucleotides include a nitrogen base, a five-carbon sugar (deoxyribose), and a phosphate group
            - The Four Nitrogen Bases:
                - Adenine (purine) double-ring
                - Thymine (pyrimidine) single ring
                - Cytosine (pyrimidine) single ring
                - Guanine (purine) double-ring
            - Differences of RNA:
                - It has ribose instead of deoxyribose
                - It has uracil instead of thymine
                - Single stranded, no double-helix
- Chemical Reactions in Metabolic Processes
    - Reactions require energy, because forming bonds requires activation energy. Many reactions occur spontaneously, but a catalyst lowers the activation energy which accelerates the reaction. The catalyst does not change in the process and can be reused over and over

- Metabolism is chemical reactions in biological systems (breaking down substances, synthesizing new products, etc.) Metabolic processes have the following in common:
  - 1. The direction of the reaction depends on the concentration of the reactants and products
    - Equilibrium means no net production of either
  - 2. Enzymes act as catalysts for metabolic reactions
    - Enzymes act on the substrate, and are specific to certain substrates only
    - Enzymes are unchanged during the reaction
    - Enzymes work to accelerate the reaction in both directions
    - Enzyme efficiency is affected by temperature and pH
    - Enzymes usually have the suffix “ase”
    - Enzymes have an active site where the reactants interact with causing the enzyme to change shape, which puts the substrate into a more favorable position so it can accelerate the reaction
  - 3. Cofactors assist enzymes (cofactors are <u>not</u> proteins)
    - Organic Cofactors (coenzymes) donate or accept part of the reaction (usually electrons)
    - Inorganic cofactors are often metal ions like Fe^{2+} and Mg^{2+}
  - 4. ATP is a source of activation energy of metabolic reactions
- How do living systems regulate chemical reactions? How do they know when to start or stop it? They do so by regulating the enzyme in the following ways:
  - 1. Allosteric enzymes
    - Enzyme has an “allosteric” site in addition to the active site. Activators and inhibitors can bind here to start or stop the enzyme
    - Feedback inhibition is where the end product acts as an inhibitor to disable the enzyme
  - 2. Competitive Inhibition
    - A substance can mimic the substrate and compete for the spot of the active site in the enzyme
  - 3. Non-competitive Inhibition
    - A substance binds to a location on the enzyme changing its conformational form, disabling the enzyme
  - 4. Cooperativity
    - When one substrate attaches, the enzyme becomes more receptive to additional substrates

- Isomers
  - Organic compounds with the same molecular formula, but different structures
  - Three Isomers:
    - 1. Structural Isomers
    - 2. Cis-Trans Isomers
    - 3. Enantiomers

- Mirror images (L and D) (or R and S)

The Cell

- Theory of Endosymbiosis
  - Mitochondria and chloroplasts were once independent prokaryotes who eventually joined larger cells. This was the first eukaryotic cell
- Prokaryotes
  - No internal membranes or organelles (no ER, mitochondria, vacuoles, etc)
  - Circular DNA
  - Small ribosomes
  - Both Anaerobic or aerobic metabolism
  - No cytoskeleton
  - Unicellular
  - Small cells
- Eukaryotes
  - Membrane bound organelles
  - Condensed DNA (wrapped with histones)
  - Larger ribosomes
  - Only aerobic metabolism
  - Cytoskeleton present
  - Multicellular
  - Large cells
- Organelles
  - Nucleolus
    - Assembly of ribosomes takes place here (large and small subunits)
    - rRNA synthesis
  - Ribosomes
    - Help create proteins (protein factories)
    - Found on rough ER
      - Proteins made here leave the cell
    - Found free floating in cytoplasm
      - Proteins made here are used within the cell
  - Peroxisomes
    - Both plant and animal cells
    - Convert hydrogen peroxide (H_2O_2) into water using catalase
    - Peroxisomes in liver cells detox alcohol
  - Endomembrane System
    - Regulates the movement of proteins
    - Includes nuclear envelope, ER, golgi, lysosomes, vesicles, vacuoles, and the plasma membrane
  - Nucleus

        - Contains chromosomes wrapped into histones
        - Surrounded by selectively permeable nuclear envelope that has pores for letting out bigger molecules (mRNA)
    - Endoplasmic Reticulum
        - Accounts for more than half the total membranes in the cell
        - Rough ER
            - Contains ribosomes for synthesis of proteins
        - Smooth ER
            - Synthesis of steroid hormones and lipids
            - Store Calcium in muscle cells for muscle contraction
            - Detox of drugs and poisons
    - Golgi Apparatus
        - Packages things from the rough ER and sends them to the cell or outside of the cell
    - Lysosomes
        - Sacs with digestive enzymes that take part in intracellular digestion
        - Helps break down/renew parts of the cell (autophagy)
        - Apoptosis - programmed cell death
        - Not usually found in plants
    - Mitochondria
        - Cellular Respiration takes place here (converting nutrients into ATP)
        - Outer double membrane and inner series of membranes called cristae
        - Have their own DNA separate from the DNA in the nucleus
            - Strong evidence for endosymbiotic theory
    - Vacuoles
        - Storage
        - Derived from ER and Golgi
        - Plants have a single large vacuole
        - *Contractile Vacuoles* found in freshwater protists
            - Used to pump out excess water
    - Chloroplast
        - Contain chlorophyll which is involved in photosynthesis (absorbing light, converting to sugar)
        - Plants and algae
        - Double outer membrane, and inner membrane system (thylakoids)
        - Contain their own DNA that is unique in resembling bacterial DNA
            - Strong evidence for endosymbiosis theory
    - Cytoskeleton
        - Microtubules
            - Protein tubulin
            - Support and movement for things in the cell
            - Found in the spindle fibers during cell division
            - Found in cilia and flagella (which provide motility for things)

            - Intermediate Filaments
                - Maintain and support the cell
            - Microfilaments
                - Protein actin
                - Cell movement
                - Muscle cell contraction
        - Centrioles, Centrosomes, and the Microtubule Organizing Center
            - Nonmembranous structures just outside the nucleus
            - Organize the spindle fibers
            - Centrioles are on either end of the cell where the spindle fibers attach. Centrosomes are two centrioles organized together
            - Plant cells have no centrosomes, but they have “MTOCs” or “Microtubule organizing centers”
        - Cell Wall
            - Plant cells and Algae
                - Made of cellulose
            - Fungi
                - Made of chitin
            - Primary Cell Wall is just outside the plasma membrane
            - Secondary Cell Wall (in some cells only) is underneath the primary
        - Plasma Membrane
            - Plasma membranes encloses the nucleus and cytoplasm, separating the inside from the outside
            - Selectively permeable, regulates things that enter and leave the cell
            - Fluid Mosaic Model
                - Double phospholipid bilayer with proteins dispersed throughout
                    - Polar hydrophilic heads
                    - Nonpolar hydrophobic tails
            - The plasma membrane contains cholesterol for stability
            - Proteins within the plasma membrane:
                - Transport
                - Enzymatic Activity
                - Signal Transduction
                - Cell-to-cell recognition
                - Cell-to-cell attachment
                - Attachment to the cytoskeleton and extracellular matrix
- Transport (in and out of the cell)
    - Active Transport
        - Involves pumping solutes against a gradient and requires energy (ATP)
        - Pumps or carriers
            - Na+/K+ pump in nerves to return the nerve to resting state
            - Electron transport chain pumps protons across the membrane
        - Contractile vacuoles in freshwater protists pumping out excess water

        - <u>Exocytosis</u>
            - Such as nerve cells releasing neurotransmitters
        - <u>Endocytosis</u>
            - *Pinocytosis* (uptake of dissolved particles - cell drinking)
            - *Receptor Mediated Endocytosis* (a form of pinocytosis when specific molecules in the fluid around the cell bind to receptors)
            - *Phagocytosis* (engulfing of participles - white blood cells)
    - Passive Transport
        - No energy required
        - Molecules move down the concentration gradient (from high → low)
        - <u>Diffusion</u>
            - Simple Diffusion
                - No protein channels involved
                - *Countercurrent exchange* is the bulk flow of fluids in opposite directions. An example of this is water flowing through fish gills in the opposite direction to blood, allowing maximal simple diffusion
            - Facilitated Diffusion
                - Movement of either solutes or water through hydrophilic protein channel
                - Water doesn't need to be facilitated, but with the assistance of aquaporin proteins in can move through faster
        - <u>Osmosis</u>
            - Specific type of simple diffusion involving water across a membrane
            - *Plasmolysis* is the movement of water out of a cell resulting in the collapse of the cell
        - <u>Dialysis</u>
            - Diffusion of solutes across a selective membrane
- Bulk Flow
    - Movement of a fluid in one direction in an organism
    - Example in humans is blood moving around the body
    - Example in plants is sap moving in trees from the leaves to the roots due to active transport in the phloem
    - Always from source → sink
- Cell Junctions
    - Anchor cells to each other or provide passageway for exchange of things between the cells
    - <u>Types</u>:
        - **Anchoring Junctions**
            - Desmosomes
            - Provides stability and holds things together

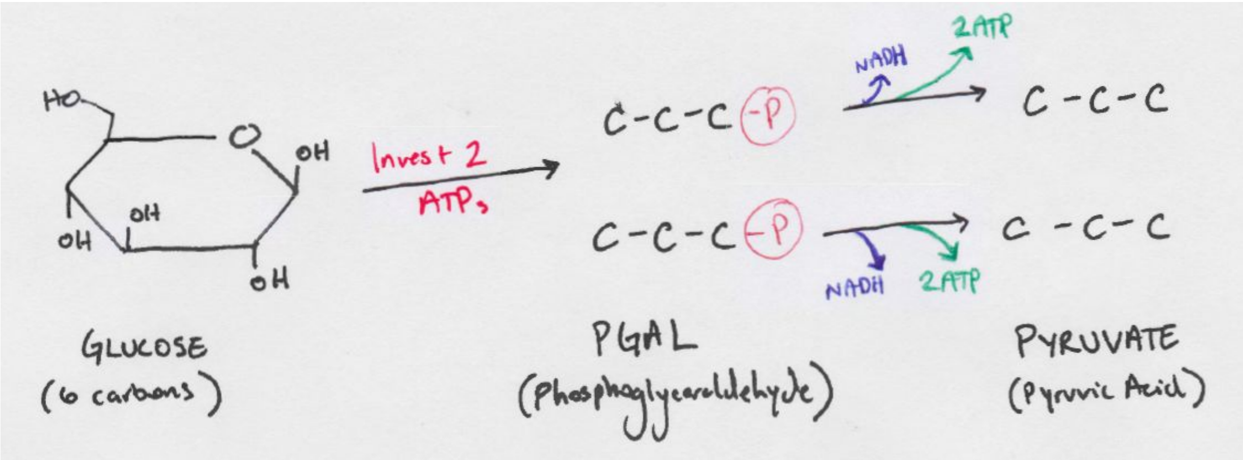
            - **Tight Junctions**
                - Seal, preventing things from passing from cell to cell
                - Found in digestive tract to get things into the bloodstream
            - **Gap Junctions**
                - Made up of connexin proteins
                - Allow ions and small molecules to pass from cell to cell
                - This is how the heart cells coordinate together to contract in unison
            - **Plasmodesmata**
                - The gap junctions of plant cells
- Cell Communication (Three Stages: Reception, Transduction, Response)
    - Types:
        - Quorum Sensing
            - Bacteria secrete molecules allowing them to communicate
        - Gap Junctions/Plasmodesmata
            - Allow communication due to direct transfer of materials from cell to cell
        - Paracrine Signaling
            - Local messages/signals are released (growth factors)
            - Includes synaptic signaling (release of neurotransmitters in a neuron)
        - Long Distance Signaling
            - Endocrine system
    - Cell Surface Receptors
        - Hydrophilic messengers (first messenger or ligand) cannot diffuse through a membrane, so they must bind to a receptor instead. The message is then carried on inside the cell by a second messenger (such as cAMP)
        - G-Protein Receptor
            - Spans the entire membrane
            - Ligand binds to it, changes the shape causing it to release an alpha subunit which binds to adenylyl cyclase, creating cAMP, etc.
    - Cytoplasmic Receptors
        - Smaller, nonpolar, hydrophobic ligands can diffuse through the plasma membrane to a receptor inside the cell
        - Steroids, Thyroid Hormone, Nitric Oxide

Cellular Respiration

- Cellular respiration is taking glucose that you ingest, and extracting ATP out of it to be used as energy in your body.
- Cellular respiration is either aerobic (with oxygen) or anaerobic (without oxygen).

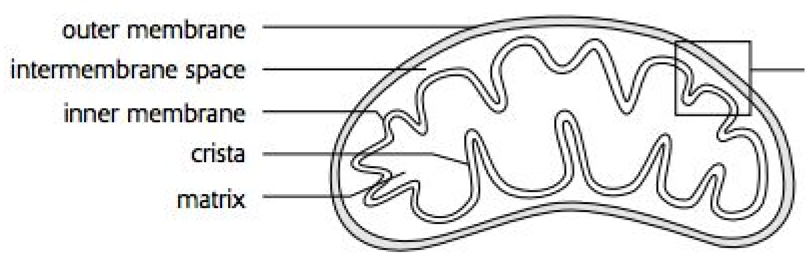
- If there is no oxygen present, then following glycolysis will be either lactic acid fermentation OR alcoholic fermentation.
- If oxygen is present, then following glycolysis will be the Krebs Cycle and the Electron Transport Chain.

- Things to know:
  - NAD^+ (nicotinamide adenine dinucleotide) and FAD (flavin adenine dinucleotide) are *coenzymes* that carry protons or electrons from glycolysis and the citric acid cycle to the electron transport chain
- 3 Parts:
  - **1. Glycolysis**
    - Glucose, a 6 carbon molecule, is split into two 3 carbon molecules (PGAL) which is then made into pyruvate. NADH and ATP is also made along the way.



    - 2 ATP input are used as an investment
    - 2 NADH molecules are produced from 2 NAD^+
      - NADH is energy rich
    - 4 ATP are produced from ADP and Phosphate
      - **2 NET ATP** produced
    - 2 Pyruvate molecules formed
  - **2. The Krebs Cycle (Citric Acid Cycle)**
    - Leading up to the cycle, a pyruvate molecule that was made in glycolysis combines with *coenzyme A (coA)* to produce acetyl CoA, which also produces 1 NADH and 1 CO_2
    - Acetyl CoA enters the cycle and combines with oxaloacetate (OAA) to make citrate. As the cycle continues, 3 NADH are produced, 1 $FADH_2$ is produced, and one CO_2 is released.
      - $FADH_2$ is also an energy rich molecule that can be made into ATP
    - Total for both pyruvates:
      - 8 NADH produced
      - 2 $FADH_2$ produced
      - 2 ATP produced

- **3. Electron Transport Chain (Oxidative Phosphorylation)**
    - ATP is then made from the NADH and $FADH_2$ that have been previously produced.
    - There is a series of proteins (mostly **cytochromes**) & atoms (iron) that is embedded in the inner membrane of the mitochondria. Electrons are taken from NADH and $FADH_2$ to be passed along the electron transport chain. As the electrons move down the steps in the chain, they give off energy as they move to lower and lower energy levels. **Oxygen is the final electron acceptor**. The energy is harvested and used to pump H^+ ions from the matrix, across the inner membrane, and into the intermembrane space (between the inner and outer membranes). The H^+ gradient causes H^+ ions to want to flow back into the matrix, which they do through an ATP Synthase Protein. As they move through this, it acts as a turbine and begins to spin, causing ADP and Phosphate Groups to be linked together to form ATP.
        - *Substrate Level Phosphorylation* is when a phosphate group uses its own energy to be transferred to an ADP molecule to form ATP. This occurs during glycolysis.
        - *Oxidative Phosphorylation* occurs when a phosphate group is added to ADP to form ATP, but the energy to form that bond is not from the phosphate group. Instead the energy is from the electron transport chains electrons which generated the H^+ gradient. This is what occurs during the electron transport chain.
    - Oxygen is the final electron acceptor in the electron transport chain. This ½ O_2 accepts two electrons, and then forms water with $2H^+$.
    - One NADH produces 3 ATP, and one $FADH_2$ produces 2 ATP
        - 38 ATP Produced Total from cellular respiration
        - 2 of these are used to transport NADH across the mitochondrial membrane, so technically you get 36 max produced.
- Mitochondria



- Outer Membrane
    - Double phospholipid membrane layer
- Intermembrane space
    - The place where H^+ accumulates
- Inner Membrane
    - Has convolutions called cristae

        - Electron Transport Chain is here
        - ATP synthase is here, which phosphorylates ADP to form ATP
    - Matrix
        - Fluid material
        - The Krebs Cycle (Citric Acid Cycle) occurs here
        - Pyruvate is converted to acetyl CoA here

- Anaerobic Respiration
    - If oxygen is not present in the cell, then there is no final electron acceptor at the end of the electron transport chain. If this happens, **a large amount of NADH accumulates** (it has nowhere to donate its electrons). After a while, because there is no new ATP being produced, the cell can die.
    - Anaerobic respiration is a way that cells avoid dying even when they lack oxygen. There are two common pathways that can be taken, but *both have the same purpose which is to replenish* NAD^+ so that glycolysis can continue on once more:
        - Alcohol Fermentation
            - The two molecules of pyruvate lose there carboxyl group (a carbon and 2 oxygens) which causes a release of CO_2. Left over is **acetaldehyde**. This can be reduced (gains a hydride anion) by NADH to be turned into ethanol.
            - So for every pyruvate, 1 CO_2 and 1 acetaldehyde are produced
            - Energy from NADH is used to reduce the acetaldehyde, producing 1 ethanol and 1 NAD^+.
            - This is how bread is made from yeast, as well as how beer and wine are produced. The CO_2 is the carbonation in the drinks, and the ethanol is the alcohol.
            - Objective
                - The goal is to produce more NAD^+ to allow glycolysis to continue. When there is no oxygen, there is low amounts of NAD^+ because it is all made into NADH during glycolysis.
                - This pathway creates more NAD^+ by recycling the NADH made in glycolysis, which the cell can do over and over. Remember that 2 ATP is made from glycolysis, which is better than nothing.
            - **Sample Question**: *Why does yeast undergo anaerobic respiration in the absence of oxygen?*
                - Answer: **To oxidize NADH to NAD+**
                - Normally, NADH will donate its electrons to oxygen in aerobic conditions, producing NAD^+ for use again in respiration.

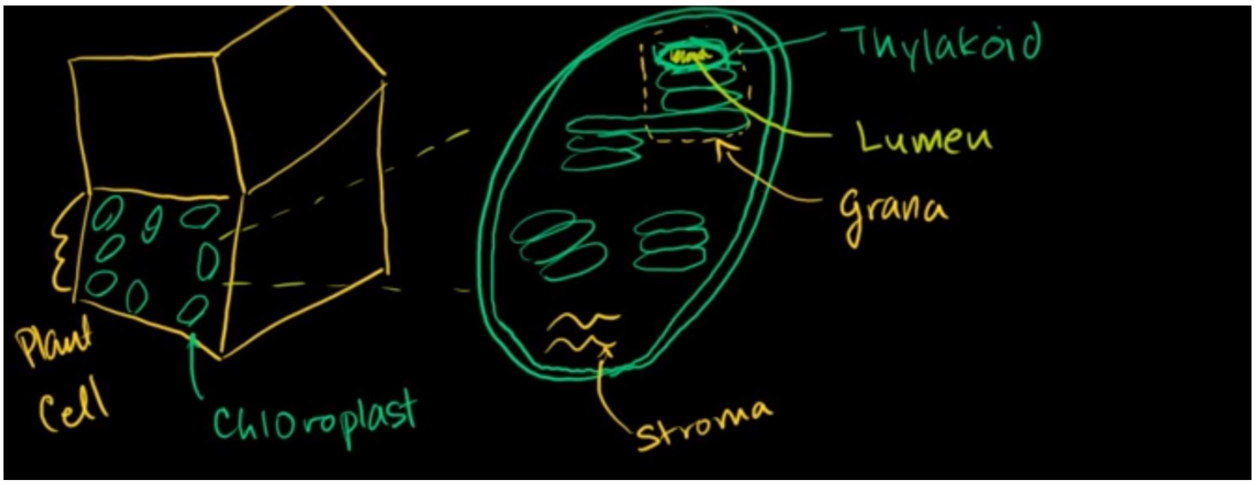
- In the absence of oxygen as a final electron acceptor, NADH builds up inside of the cell (because it has nowhere to give its electrons). So the yeast will activate anaerobic respiration, which converts pyruvate into acetaldehyde, which releases CO_2. Acetaldehyde will then convert into ethanol, and this is where the magic happens. The energy in NADH is used to drive this reaction, which releases NAD+. Now the free NAD+ can undergo glycolysis and the cell can produce at least 2 more ATP through anaerobic respiration, rather than dying.

- Lactic Acid Fermentation
  - The pyruvate produced in glycolysis is used to oxidize the NADH so it becomes NAD^+ in order that we have more NAD^+ for glycolysis to continue occurring.
  - Pyruvate gets reduced (gains electrons) and turns into lactic acid (or lactate).
  - In many animals, the lactate is transported to the liver where it is converted back to glucose if there is enough ATP.

Process	**Location**	**Reactants**	**Products**
Glycolysis	Cytosol	Glucose ATP NAD^+ ADP	Pyruvate ATP NADH
Krebs Cycle	Mitochondrial Matrix	Acetyl CoA NAD^+ FAD ADP	CO_2 NADH $FADH_2$ ATP
Electron Transport Chain	Mitochondrial Cristae	O_2 NADH $FADH_2$ ADP	ATP H_2O NAD^+ FAD
Alcoholic Fermentation	Cytoplasm	Pyruvate NADH	CO_2 NAD^+ Ethanol
Lactic Acid Fermentation	Muscle Cells	Pyruvate NADH	Lactate NAD^+

Photosynthesis

- $6CO_2 + 6H_2O + \text{light} \rightarrow C_6H_{12}O_6 + 6O_2$
- Plant Cells contain chloroplast organelles which contain thylakoids (a stack of thylakoids is called a grana). The light reaction of photosynthesis takes place in the membrane of the thylakoid.
  - Stroma = Fluid in the chloroplast
  - Lumen = Space inside the thylakoid
  - H^+ are pumped from the stroma into the lumen as electrons travel down the chain.
  - Khan Academy Video

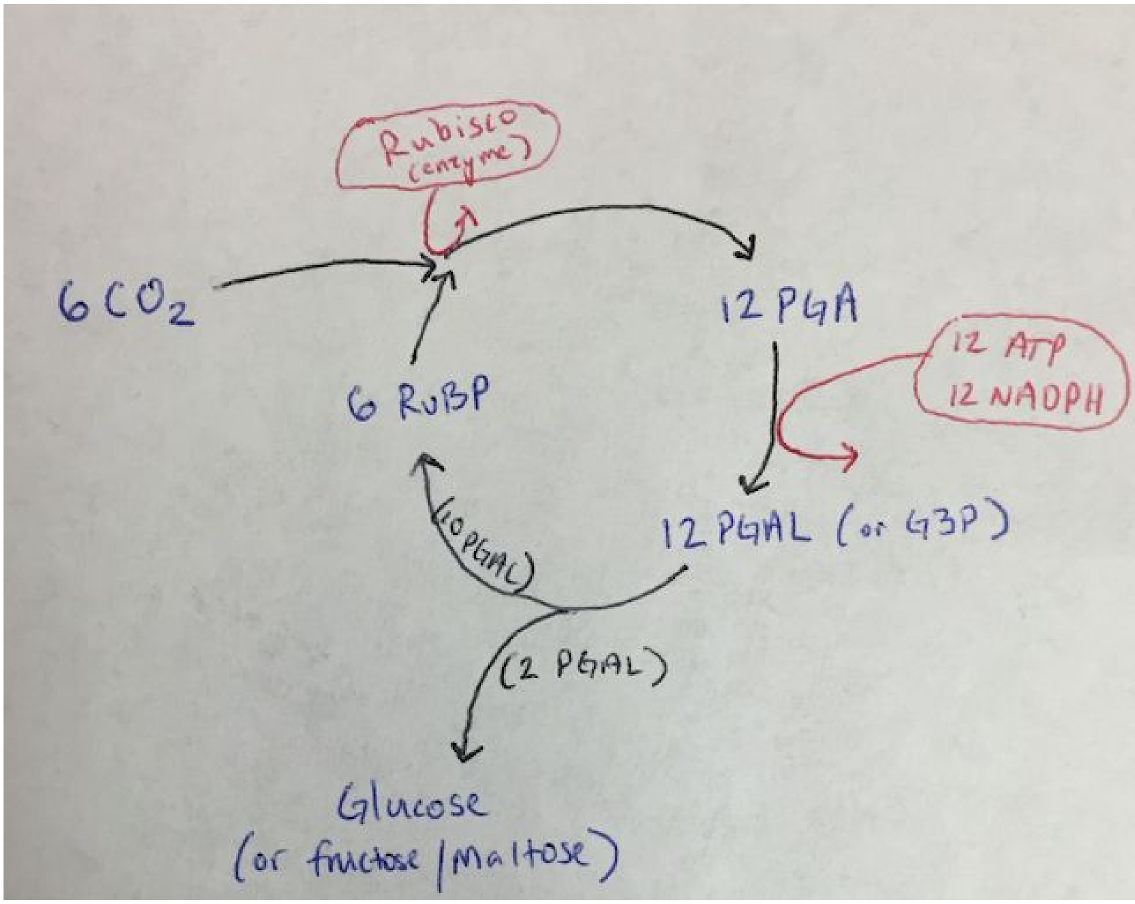


- **Light Reaction** (Takes in water, produces ATP, NADPH)
  - Pigment molecules are located in plant cells which can absorb certain wavelengths of light to harvest the energy. There are different pigments within the cell so that different wavelengths of light can be absorbed. The light is absorbed by a pigment, and energy is absorbed into the electrons within the pigment molecule (the electrons are now in an excited state). From here, the electrons re-emit the absorbed energy which is absorbed by electrons of a different pigment molecule that are close by. This process of absorption, energy re-emission, absorption continues as energy bounces around the pigments. When the energy reaches a ***Chlorophyll A*** molecule (either P_{700} or P_{680}) this process is stopped. Chlorophyll P_{700} forms a pigment cluster called photosystem I, whereas Chlorophyll P_{680} forms photosystem II
    - Chlorophyll a and Chlorophyll b (green)
    - Carotenoids (red, orange, or yellow)
  - *Non-cyclic Photophosphorylation* is the process of making ATP using the energy from light:
    - PSII - Electrons in P_{680} within photosystem II are energized by light and increase in energy level

        - Two electrons are passed down to the first molecule in the ETC...called the "**primary electron acceptor**"
        - The electrons continue down the electron transport chain (which includes proteins like **ferredoxin** and **cytochrome**)
        - The excited electrons move along the electron transport chain releasing energy as they go to lower levels. This energy is used to pump protons from the stroma (the fluid in the chloroplast organelle) to the middle of the thylakoid lumen. The protons then exit the thylakoid and return back to the stroma through ATP synthase. This causes the phosphorylation of ATP molecules from ADP and P_i.
        - The electron transport chain ends at photosystem I (with P_{700}). The electrons are once more energized by sunlight, and then they get passed to the primary electron acceptor $NADP^+$. Along with H^+ it forms **NADPH**, a coenzyme that can have energy harvested from it in the calvin cycle.
        - Water is split to replace the two electrons that originated in PSII and were removed to travel down the electron transport chain. As a result, O_2 gas is released by the plant and one of the H^+ provides the hydrogen needed for NADPH.
    - *Cyclic Photophosphorylation*
        - Instead of the electrons in PSI being added to form NADPH at the end, the e^- are recycled back to photosystem II where they can run along the electron transport chain again to create additional ATP.

- **Calvin Cycle - Dark Reaction** (Light Independent Reaction) (Takes in CO_2, ATP and NADPH, produces PGAL/G3P)
    - **The calvin cycle fixes CO_2** meaning CO_2 comes in as an unreactive inorganic molecule, and is incorporated into an organic molecule that can be used in biological systems (glucose). To make glucose the calvin cycle must repeat **six** times, **using six CO_2** molecules.
    - The process:
        - *Carboxylation*: **6 CO_2** (from the atmosphere) react with **6 RuBP** to form **12 PGA** molecules. This is catalyzed by the enzyme **rubisco**. The PGA formed is a three carbon molecule
        - *Reduction*: **12 ATP and 12 NADPH** are used to convert the 12 PGA into **12 PGAL** (PGAL is also called G3P). Because of all the ATP and NADPH going into this step, the PGAL is very high in energy. The ADP and P_i released from this go back to non-cyclic photophosphorylation.
        - *Regeneration*: **10 out of the 12 PGAL molecules are converted into 6 RuBP** which was the original molecule that combined with CO_2 at the beginning. This allows the cycle to continue.
        - *Carbohydrate Synthesis*: The **2 remaining PGAL molecules are used to form glucose**, the common energy storage molecule. Fructose and maltose can also be formed (they are also monosaccharides). Glucose

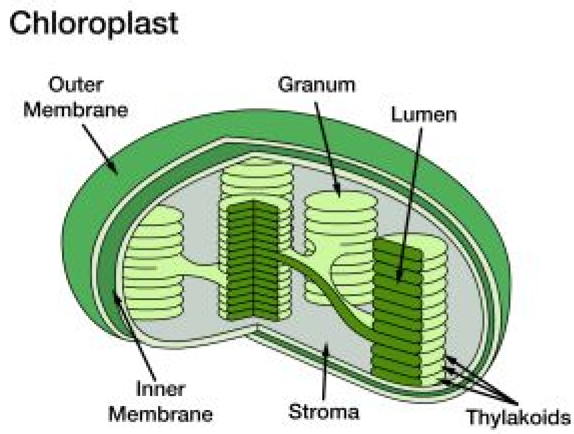
molecules can then be combined to form polysaccharides like starch and cellulose.



- No light is used in the calvin cycle (it is the *dark* reaction) but <u>the process cannot occur in the absence of light</u> because it depends upon the energy from ATP and NADPH in the light dependent reactions photophosphorylation!

- Chloroplasts
  - These are the organelles where **both the light-dependent and light-independent reactions take place**.
  - The chloroplast organelle has a double lipid membrane. Inside is a fluid called **stroma**. Floating in the stroma are little discs called **thylakoids** which have a membrane of their own. A stack of thylakoids is called **grana**.
    - Outer Membrane: Double layer of phospholipids just like the plasma membrane of the cell
    - Intermembrane space: The small area between the inner and outer membranes
    - Inner membrane: The second membrane, also a double phospholipid bilayer
    - <u>Stroma</u>: The fluid material in the organelle. This is **where the Calvin Cycle (dark reaction) occurs**.

        - Thylakoids: Pancake-like discs. The membranes of the thylakoids is where the protein complexes (PSI and PSII) of the electron transport chain are. **This is where the light-dependent reactions take place**.
        - Thylakoid Lumen: The inside of the thylakoid where H^+ ions build up.

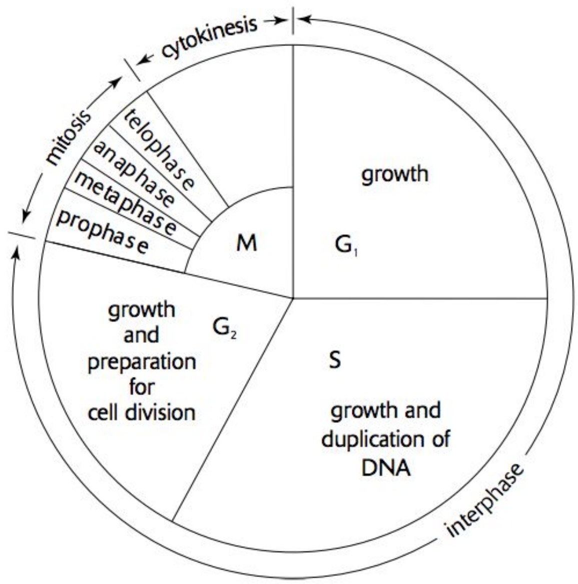


- Chemiosmosis in Chloroplasts
    - This is the **mechanism of ATP generation**, related to the proton concentration building up in the thylakoid lumen to active ATP Synthase
        - 1. H^+ ions accumulate inside the thylakoids. This occurs via the energy from the electron transport chain, transporting the H^+ from the stroma into the lumen of the thylakoid by a cytochrome protein.
        - 2. This creates a lower pH inside the thylakoid, as well as an electrical gradient.
        - 3. ATP Synthase generates ATP as protons flow through down the concentration gradient.
        - 4. The ATP is used to generate PGAL (G3P).
- Photorespiration (inefficiency of photosynthesis)
    - The process of "fixing" oxygen by the rubisco protein (the same one that fixes CO_2)
    - This happens because rubisco is not super efficient. Fixing oxygen does not create any useful molecules, and it decreases the amount of CO_2 that is fixed.
    - RuBP combines with O_2, and creates Phosphoglycerate (PGA) but it also creates a useless product called Phosphoglycolate which has to be digested by peroxisomes in the cell. **This can reduce photosynthesis efficiency by 25%**.
- C4 Photosynthesis
    - A method to improve photosynthesis by avoiding photorespiration (by operating in an environment with no oxygen)
        - On the surface of the leaf are pores called **stomata** (singular: stoma) where air enters or leaves the cell
        - Inside are **mesophyll cells** which is where photosynthesis takes place. These cells are close together, but still have some spacing so that the air (consisting of O_2, CO_2, etc) can enter.

        - Deeper in the leaf (not exposed to the air coming through the stomata) are **bundle sheath cells**.
    - CO_2 enters mesophyll cells, and instead of reacting with rubisco, it reacts with PEP (a 3 carbon molecule) to get OAA (4 carbons, hence C4). This reaction is facilitated by the **PEP carboxylase enzyme**, which fixes CO_2 but cannot fix O_2, unlike RuBP. This enzyme is the reason C4 photosynthesis can avoid photorespiration.
    - OAA is made into **malate**, and the malate is taken into the bundle sheath cells through tubes connecting them called **plasmodesmata**.
    - In the bundle sheath cells, the malate is converted into CO_2 and pyruvate. The pyruvate can leave and go back to the mesophyll cell to make more PEP allowing the cycle to continue. The CO_2 builds up in the bundle sheath cell (there is no oxygen in here, only CO_2!).
    - Now that there is an environment with only CO_2, the Calvin Cycle can efficiently take place within the bundle sheath cells without oxygen interfering. Glucose is produced as normal, but much more efficiently!
    - Another benefit of this is **the C4 plant can close the stomata more often** preventing the escape of H_2O
        - C4 plants are in hot, dry climates (they can preserve their water. If the stomata were left open, water would flow out in exchange for the incoming CO_2)
    - So overall it minimizes photorespiration and reduces loss of water
- CAM Photosynthesis
    - Intended for Desert Plants
    - At night when they are not afraid of losing water, CAM plants keep their stomata open to let CO_2 in. It fixes the CO_2 in the same way the C4 plants do (the CO_2 reacts with PEP, and is converted to OAA and then to Malate) and the malate is stored in storage areas during night time (in vacuoles or other organelles).
    - When the sun is out, the plant closes the stomata to prevent water loss (no CO_2 or O_2 can enter). The malate is pumped into the stroma of the chloroplast so that plenty of CO_2 is available even with the stomata being closed. Photosynthesis can then continue like normal!

Cell Division

- Consists of both Nuclear Division as well as Cytokinesis
    - Nuclear Division can be either mitosis or meiosis



- Mitosis Cell Cycle:
    - Interphase (not technically part of mitosis, but occurs just before)
        - G_1 Phase
            - Growth
        - S Phase
            - Growth
            - Synthesis of second DNA molecule
        - G_2 Phase
            - Growth and preparation for division
        - General
            - Cell is not dividing
            - DNA contained within the nuclear envelope. The nucleoli (nucleolus) are visible from inside the nucleus
            - Outside of the nucleus, two microtubule organizing centers/centrosomes (MTOC) are next to each other
    - Prophase
        - Chromatin starts to condense into chromosomes
        - Nucleoli disappear (the organelle that makes ribosomes)
        - The nuclear envelope breaks down
        - Formation of the mitotic spindle
            - Centrosomes move to opposite poles
            - Microtubules develop and increase in length. These connect at the kinetochore of a centromere
    - Metaphase
        - Chromosomes align on the metaphase plate in center of cell

        - The microtubules (which are attached to the chromosomes at the kinetochore) pull the chromosomes apart into two chromatids. Once separated, each chromatid is considered a full chromosome (each has a centromere of its own)
    - Anaphase
        - The microtubules are still connected to the chromosomes (now split) and the microtubules shrink, causing them to pull the chromosomes to different ends of the cell
        - As anaphase comes to an end, each pole of the cell has a complete set of chromosomes (as many as the original cell started with) however each chromosome only has one copy of DNA rather than two)
    - Telophase
        - A nuclear envelope develops around each pole, forming the two separate nuclei
        - The chromosomes go back to chromatin (unpack)
        - The nucleoli appear again
    - Cytokinesis
        - In plants, vesicles come from the golgi apparatus and form together at the plane of the dividing cell. The vesicles fuse, forming a **cell plate**, which becomes the new plasma membranes for the two daughter cells. Cell walls then develop
        - In animals, microfilaments form a ring inside between the dividing cells. Shortening of these microfilaments causes a **cleavage furrow**, and the cell is then divided into two daughter cells
- Meiosis Cell Cycle:
    - Meiosis I
        - Prophase I
            - Chromatin condenses into chromosomes
            - Nucleolus disappears
            - Spindle apparatus develops
            - **Synapsis** Occurs
                - The pairing of homologous chromosomes
                - A pair is called a **tetrad** or **bivalents**
            - Crossing over takes place between non-sister chromatids (called **chiasma**)
            - **Synaptonemal Complex**
                - A tetrad with a chiasmata and crossing over
        - Metaphase I
            - The homologous chromosomes line up together at the metaphase plate
            - Microtubules from one pole connect to the kinetochore of one member of each pair of chromosomes, and the microtubules on

the other pole connect to the kinetochore of the other member of the pair

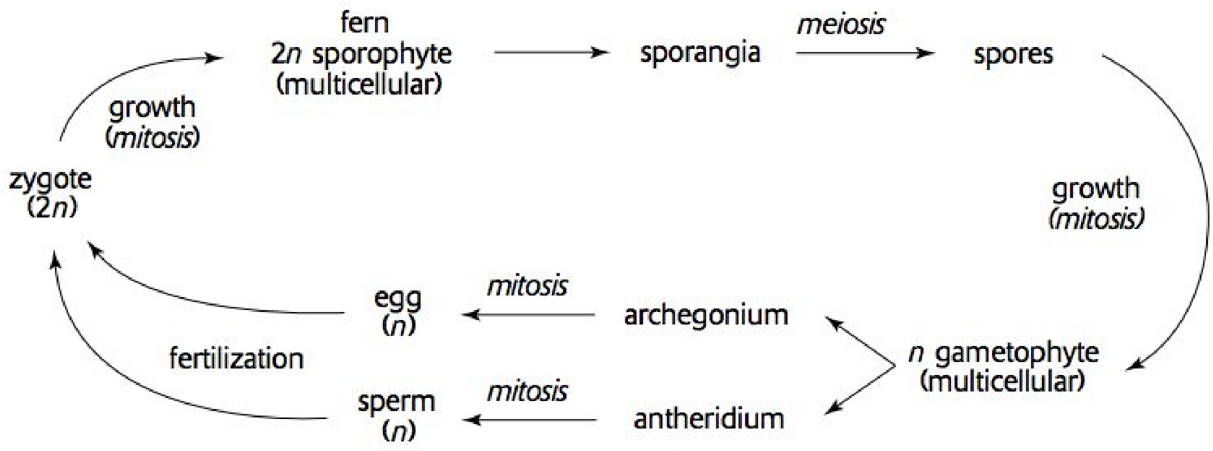
- Anaphase I
  - The tetrads uncouple as chromosomes are pulled to opposite poles
- Telophase I
  - The chromosomes are separated to separate poles, and a nuclear envelope is formed around them
    - The new nucleus contains half the original number of chromosomes, but each chromosome contains two chromatids
  - In some species, cells now go through cleavage furrows/cell plates and undergo cytokinesis. In other species, cytokinesis is delayed until after meiosis II

- Meiosis II (Meiosis II is the same as mitosis)
  - Prophase II
    - Nuclear envelope disappears
    - Spindle develops
    - No chiasmata or crossing over in this phase as there is in prophase I
  - Metaphase II
    - The chromosomes line up individually on the metaphase plate (no tetrads are formed)
    - This looks similar to metaphase in mitosis except there is half the number of chromosomes now
  - Anaphase II
    - Each chromosome is separated into two sister chromatids
    - Once again, same as in mitosis with half the chromosomes
  - Telophase II
    - The nuclear envelope reappears at each pole
    - Cytokinesis occurs, resulting in four haploid daughter cells. Each cell contains half the number of chromosomes, and each chromosome has only one sister chromatid. Later on during interphase, the DNA will be copied so that each chromosome will have two chromatids

- Comparing Meiosis and Mitosis:

Table 6-1			
Characteristics in a Human Cell	***Mitosis***	***Meiosis I***	***Meiosis II***
Chromosome number in a parent cell before division begins	46	46	
Chromatid number in a parent cell before division begins	92	92	
Crossing over at prophase	No	Yes	No
Chromosome arrangement on metaphase plate	Chromosomes line up	Homologues pair	Chromosomes line up
Number of chromosomes in each daughter nucleus	46	23	23
Number of chromatids in each daughter nucleus	46	46	23
Number of daughter cells at end of division	2	2	4
Chromosome notation for daughter cells	$2n$	n	n
Genome notation for daughter cells	diploid	haploid	haploid
Purpose of division	cell replacement, organism growth, asexual reproduction	sexual reproduction	
Genetics of daughter cells	genetically identical (clones)	genetically variable	
Type of cells where division occurs	somatic cells	reproductive cells (ovaries, testes, anthers)	
Type of cells produced	somatic cells	gametes: eggs, sperm, pollen	

- The Life Cycle
  - Humans
    - 2n=46
    - 46 chromosomes in somatic cells
    - 23 chromosomes in gametes (made by somatic cell going through meiosis - made in testes or ovaries)
  - Plants (fern)
    - Meiosis produces **spores**, which are haploid cells that divide by mitosis to become a multicellular haploid structure. This multicellular haploid structure is called a **gametophyte**.
      - Gametes are produced by the gametophyte because it is already haploid.
    - Two gametes fuse together to form a diploid **sporophyte**
    - Cells in the sporophyte divide by meiosis to make haploid spores



Fern Life Cycle

- Genetic Variation (meiosis only)
  - Crossing over
    - Prophase I
  - Independent Assortment
    - Metaphase I, when tetrads are pulled apart it is random which chromosome goes to which pole
  - Random joining of gametes
    - A random sperm fertilizing a random egg
- Regulation of the Cell Cycle
  - What tells a cell when and if to divide?
    - 1. Surface to volume ratio
      - [see here]
    - 2. Genome to volume ratio
      - As the cell grows, its volume increases, but its genome size remains constant. As the G/V decreases, the cell's size exceeds the ability of its genome to produce sufficient amounts of materials for regulating cellular activities.
    - 3. Checkpoints
      - G_1 Checkpoint
        - Are conditions appropriate to undergo cell division? Is the cell programmed to go through with it? If not, the cell enters the G_0 phase
      - G_2 Checkpoint
        - Was DNA replication sufficiently accurate to proceed?
      - M checkpoint
        - During metaphase
        - Did the microtubules connect to the kinetochores properly?
    - 4. CDKs (Cyclin-dependent kinases)

            - Enzymes that phosphorylate proteins, activating them. The proteins then regulate the cell cycle
            - CDKs activated when bound by a cyclin (they are cyclin-dependent)
        - 5. Growth Factors
            - When a cell is damaged, it releases one type of growth factor (a signaling molecule) that can bind to a membrane receptor of another cell, causing it to undergo division
        - 6. Density-dependent inhibition
            - When the cells around a cell become too much (it is too dense) then the cells stop dividing
        - 7. Anchorage dependence
            - In order for cells to divide they usually need to be anchored to a surface, such as another cell. If not they will not undergo division

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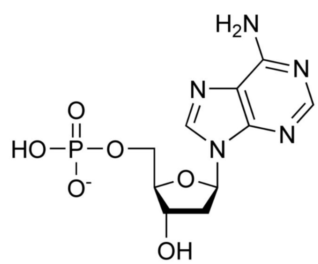
Heredity

- The Law of Segregation
    - When forming gametes, homologous chromosomes are separated so that each gamete only gets one
    - This separates the **alleles**
- The Law of Independent Assortment
    - Related to segregation, when homologous chromosomes go to separate gametes, it **does not influence any other chromosome pairs** (they are independent)
- Complete Dominance, Monohybrid Cross
- Complete Dominance, Dihybrid Cross
- Test Crosses
- Incomplete Dominance
    - When the phenotypes from a dominant and recessive allele are blended together and are **both partially expressed**
    - R = red, r = white, Rr = Pink
- Codominance
    - Both phenotypes are **completely expressed**, not blended
    - With the flower example above, you would have a flower with both red and white patches
- Multiple Alleles
    - Blood Type (I_A, I_B, or I)
    - Subscripts (or superscripts) are used because A and B are codominant
- Epistasis
    - One gene affects the expression of a different gene
    - Common for pigmentation

        - One gene codes for whether or not there is color in animal fur (Cc)
        - Another gene codes for what color, such as Black or brown (Bb)
        - Anything with cc would have no color
        - If you have CC or Cc, you are either black (BB or Bb) or brown (bb)
- **Pleiotropy**
    - When one gene has multiple phenotypes
- Polygenic Inheritance
    - Many genes acting together to produce a single phenotype
    - Continuous variation - related to a range of heights from short to tall
- Linked Genes
    - Genes on the same chromosome, usually inherited together.
- Sex-Linked Inheritance
    - Genes found on the X Chromosome
    - Y chromosome as well, but these are rare
- X-Inactivation
    - Barr body in females
- Nondisjunction
    - Chromosomes fail to separate in either meiosis (anaphase I) or mitosis (anaphase). This causes daughter cells to have either extra or missing chromosomes
    - Can produce polyploidy (such as down syndrome)
- Human Genetic Defects
    - Point Mutations
        - A single nucleotide is incorrect in the DNA. Caused by:
            - Substitutions
            - Deletions
            - Insertions
    - Aneuploidy
        - A genome that has either **extra OR missing chromosomes**
        - Down Syndrome (Trisomy 21)
        - Turner Syndrome (Nondisjunction of sex chromosomes)
    - Chromosomal Aberrations
        - Duplications
            - A segment of the chromosome is repeated on the same chromosome
        - Inversions
            - A segment of a chromosome is taken out, flipped, and inserted back in the same spot. It is now reversed
            - AABBCCDD → AACCBBDD
        - Translocations
            - One segment of a chromosome moves to another chromosome

Molecular Genetics

- Nucleotides
  - Monomers consist of three things:
    - Nitrogen Base (A,T,G,C,U)
    - Sugar
    - Phosphate



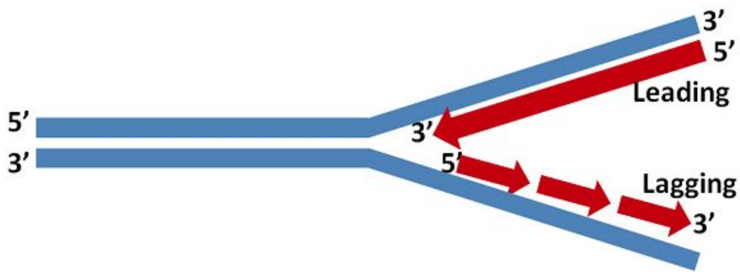
  - Note that both DNA and RNA are nucleotide polymers

- DNA
  - Sugar
    - Deoxyribose
  - Nitrogen Bases
    - Adenine
    - ***Thymine***
    - Guanine
    - Cytosine
  - Function
    - Contains the genes
  - Structure
    - Double Helix
- RNA
  - Sugar
    - Ribose
  - Nitrogen Bases
    - Adenine
    - ***Uracil***
    - Guanine
    - Cytosine
  - Function
    - **mRNA**
      - Provides instructions for the order of amino acids
      - The template used for creating the protein product
      - Three neighbor nucleotides in an mRNA are called a **codon**, as one codon codes for one specific amino acid

            - 64 possible codons, 20 amino acids
        - **tRNA**
            - Short molecule
            - Transports and delivers the amino acids to the ribosome
            - Contains an anticodon, which base pairs with the codon of the mRNA
                - The third nucleotide does not always need to match exactly for this pairing to occur (this is called a **wobble**)
        - **rRNA** - Part of a ribosome structure
            - The nucleolus is where rRNA is transcribed from DNA
            - rRNA combines with other proteins and are assembled into the large and small subunits of a ribosome. The ribosome is what takes in the tRNA and the mRNA to form the protein during translation
            - Ribosomes have three binding spots:
                - One for mRNA
                - One for the tRNA that carries the growing protein chain (P site)
                - One for a second tRNA that delivers the next amino acid to be added to the protein chain (A site)
    - Structure
        - Linear (mRNA), Cloverleaf (tRNA), globular (rRNA)

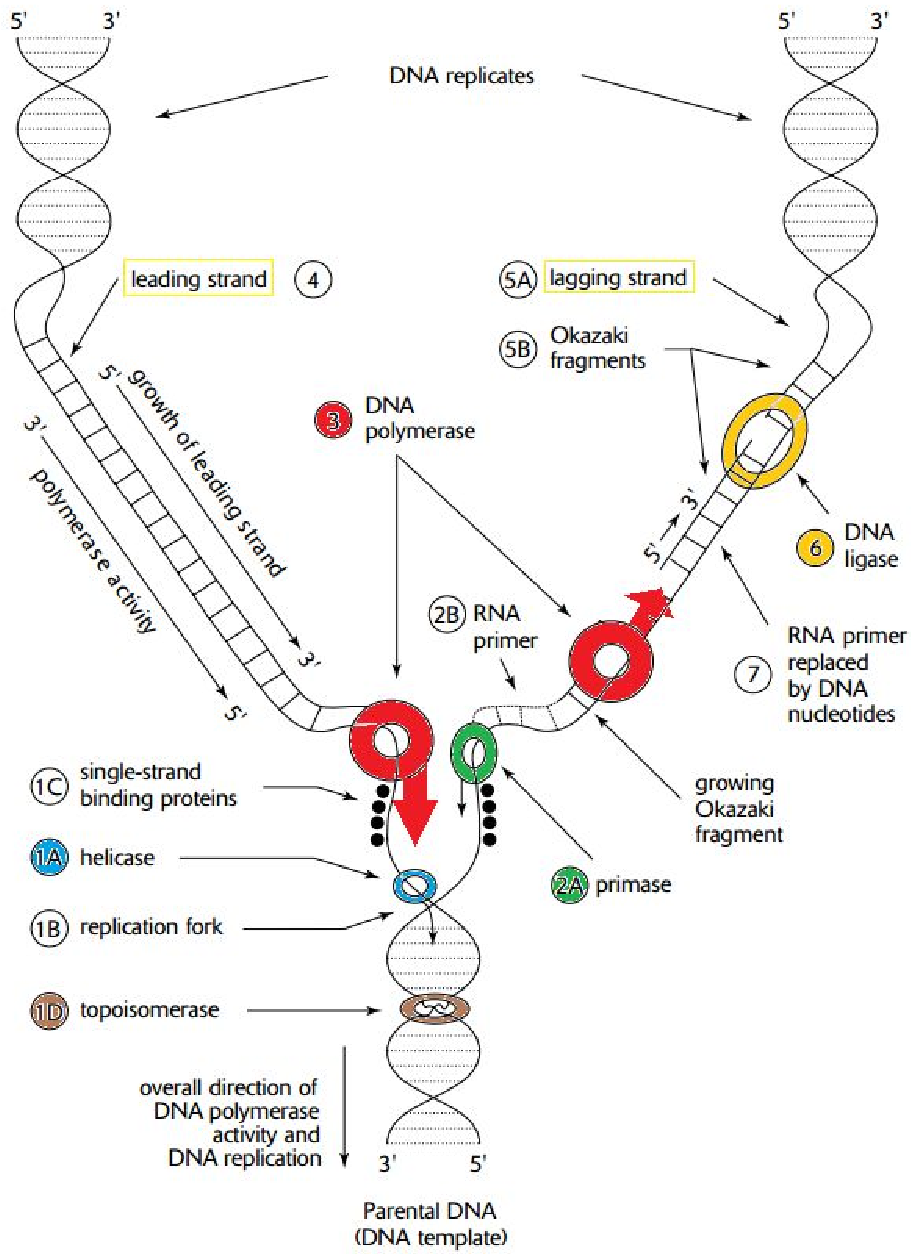
- **DNA Replication** [Video]
    - Semi-Conservative Replication
        - During interphase, the DNA is replicated by the synthesis of a new chromatid. In order to copy the DNA, the double helix needs to be unzipped or separated. Both strands will be a template for the newly copied strands, thus the new strands have one old strand (the template) and one new strand which was added to it by DNA Polymerase.
        - Single-strand binding proteins keep the two DNA strands separated
    - Replication Fork, Origin of Replication, Termination site.
        - **Helicase** enzyme unwinds the DNA helix, creating the replication fork (Y Shape)
            - Strands separated with Helicase, an RNA Primer is added which gives DNA polymerase a starting point, new strands are synthesized
            - **Topoisomerases** are enzymes that prevent knots from forming as the DNA is unzipped. It does this by breaking and rejoining the double helix
        - **The replication fork** is where the DNA strand is being both unwound, and a new strand is being synthesized.
        - The origin of replication is where the synthesis of the new strand begins

        - The termination site is where DNA synthesis ends
    - Directionality of DNA replication
        - It is **bidirectional**
        - There is a leading strand and a lagging strand, but DNA is synthesized in both directions
    - DNA Polymerase
        - **DNA Polymerase** is the enzyme that synthesizes a new strand
            - DNA Polymerase moves in the 3' → 5' direction
            - Because of this, **the new DNA strand is synthesized in the 5' → 3' direction.**
        - When DNA polymerase makes a mistake, it can backtrack and cut out the mistake (proofreading). Note that RNA polymerase cannot do this.
        - The polymerase needs an RNA primer to be laid down before it can attach to the DNA strand
            - **Primase** is an enzyme that begins replication with a tiny fragment of RNA nucleotides. This is called an RNA primer.
            - The leading strand, and every single okazaki fragment will have an RNA primer.
            - The RNA nucleotides are later replaced with DNA by polymerase.
    - Leading Strand and Lagging Strand Synthesis



        - Leading Strand (3' → 5' template)
            - Replication is continuous
            - The DNA polymerase simply follows the replication fork, assembling together a 5' → 3' DNA strand
        - Lagging Strand (5' → 3' template)
            - Replication is discontinuous
            - Because DNA polymerase can only move in the 3' → 5' direction, this causes problems for the strand that is going 5' → 3''.
            - This strand is called the lagging strand, and must be synthesized in pieces called **Okazaki fragments**, which is discontinuous
                - DNA Polymerase has to wait until helicase unzips part of the DNA, and then it can jump on to synthesize short segments at a time
                - DNA ligase connects the fragments together
    - Key Proteins for DNA Replication

        - Helicase (unzips the DNA strands)
        - DNA Polymerase 1 (degrades RNA primers after replication)
        - DNA Polymerase Holoenzyme (does the synthesis)
        - Ligase (seals the gaps from the Okazaki fragments)
    - Telomere Replication [Video]
        - Because of the way that the lagging strand works, there is one empty space on the end of the DNA. This happens because DNA polymerase needs an RNA primer to start replicating, and an RNA primer needs a DNA strand to connect. This causes chromosomes to slowly shorten after every replication cycle.
        - **Telomerase** is an enzyme that attaches to the end of the template strand, and adds a few repeat DNA nucleotides on the end to extend it. DNA polymerase can then come to finish replication. The left over repeating segment generated by telomerase is simply there to prevent the loss of important information

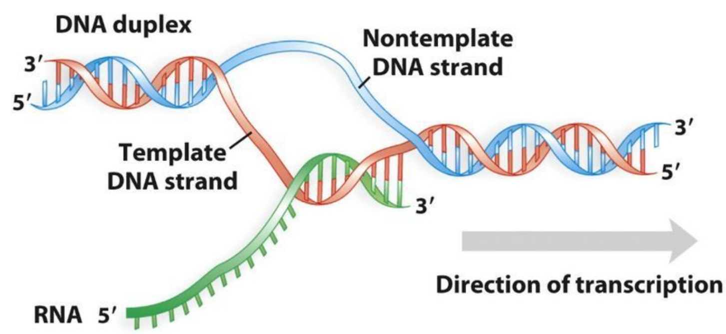


DNA Replication

[see full image here]

- **Transcription**
  - Initiation
    - DNA has a promoter region called a **TATA box** (contains the sequence T-A-T-A).
    - RNA Polymerase attaches to the promoter region and starts unzipping the DNA into its two strands.
  - Elongation

        - RNA polymerase continually unzips the DNA as it assembles RNA nucleotides from one of the DNA strands. This strand is made 5' → 3' (just as in DNA replication).
        - The new strand being formed is mRNA, and it is made from only one DNA strand.
    - Termination
        - RNA polymerase will eventually come to a termination point which is just a repeating sequence of nucleotides (often A-A-A-A-A-A…in eukaryotes)
    - The coding, template, noncoding, and nontemplate strands
        - On the DNA you have a **template** strand (the one that RNA is being made from) and you have the **nontemplate** strand. RNA Polymerase uses the template strand to make the mRNA (the mRNA will have the same sequence as the nontemplate strand, and the opposite sequence of the template that it was made from).
        - **Template Strand** (of DNA): Noncoding. It has the opposite sequence as the mRNA.
        - **Nontemplate Strand** (of DNA): Coding. It has the same sequence as the mRNA (except the Ts are replaced with U)

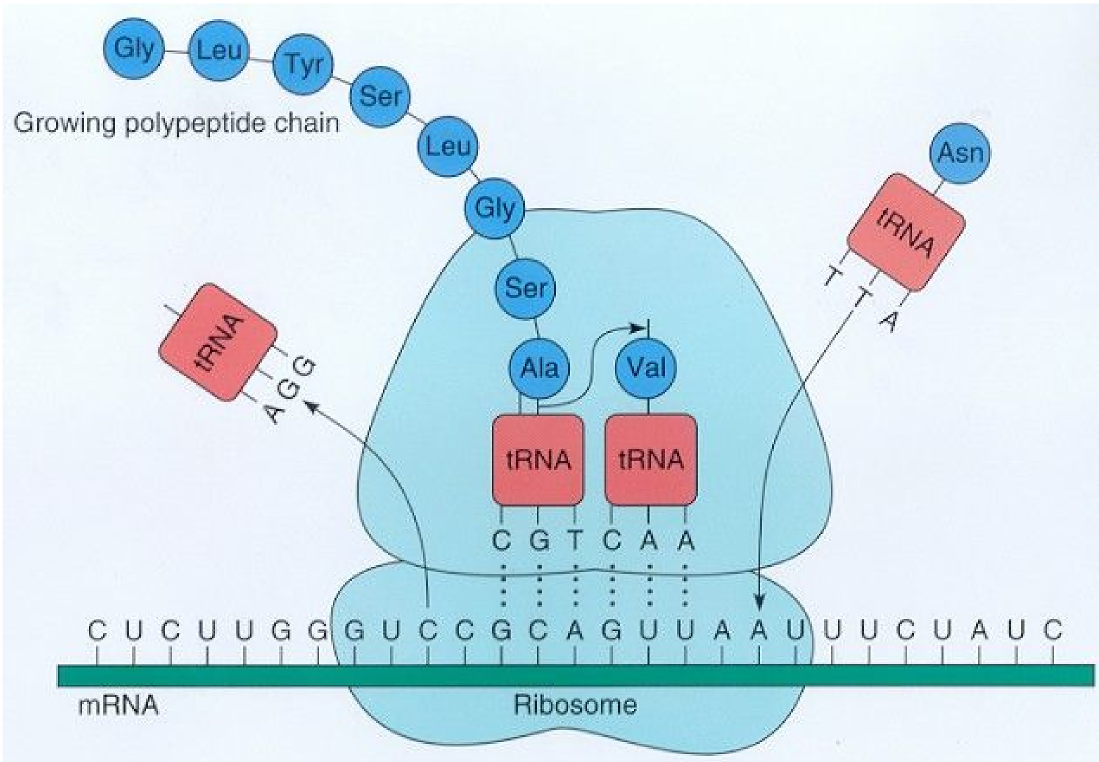


    - RNA Polymerase
        - **RNA polymerase does not need a primer** (does not need a free 3' hydroxyl group like DNA does).
            - RNA Polymerase is not good at initiating the process of making RNA. Once it gets going it is fine, but to start off it needs help.
        - Types of RNA Polymerase
            - Prokaryotic
                - Has one RNA polymerase which makes all 3 types of RNA.
            - Eukaryotic
                - Polymerase 1 = Ribosomal RNA
                - Polymerase 2 = Messenger RNA
                - Polymerase 3 = Transfer RNA
            - The RNA Polymerase are very specific and usually only make that one type.
- mRNA Processing

- An mRNA molecule needs to be altered before it leaves the nucleus to be made into a protein
    - <u>5’ Cap Added</u>
        - Guanine nucleotide with two phosphates (GTP)
        - Stabilizes the mRNA
        - Place of attachment for the small subunit of the ribosome
    - <u>3’ Poly-A Tail Added</u>
        - ~200 Adenine nucleotides
        - Stability
        - Controls the movement of the mRNA
    - <u>Splicing</u>
        - RNA Splicing
            - snRNP’s (small nuclear ribonucleoproteins) delete the introns and splice together the exons
        - Alternative Splicing
            - This creates multiple mRNA strands, all different from each other, which all code for a different protein
- Types of mRNA

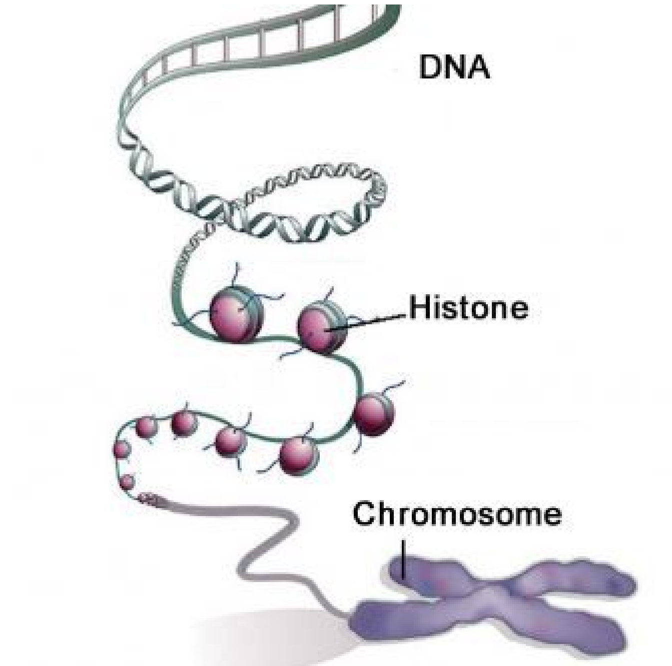
- <u>**Translation**</u>
    - The mRNA, tRNA, and ribosome units are all moved into the cytoplasm (across the nuclear envelope)
    - Amino acids attach to 3’ end of tRNA (forming **aminoacyl-tRNA**)
        - This requires one ATP
        - Enzyme specific reaction
        - High energy bond
    - Energy for translation to occur is provided by GTP (acts similar to ATP)
    - <u>Initiation</u>
        - The small ribosomal subunit attaches to the mRNA near the 5’ end
        - tRNA carrying the amino acid attaches to the mRNA. This always begins with the start codon AUG (the anticodon is UAC).
            - The codon is on the mRNA
            - The anticodon is on the tRNA
        - The large ribosomal subunit then attaches to the mRNA, which forms the complete ribosome
        - At this point we have a tRNA (occupying the P site of the ribosome) holding a methionine
    - <u>Elongation</u>
        - Another tRNA with an amino acid moves into the A site of the ribosome
        - The methionine from the first tRNA is removed, and linked to the amino acid on the other tRNA. The first tRNA that was holding the methionine is released
        - <u>**Translocation**</u> is the movement of tRNA from the A site to the P site.
    - <u>Termination</u>

- The ribosome will come in contact with a stop codon on the mRNA
- The polypeptide is released
- The two ribosomal subunits are released



- Mutations
  - A mutation is any DNA nucleotide sequence that does not exactly match the original DNA that it was copied from
    - They can occur from errors during DNA replication
    - They can occur from environmental effects
      - Caused by **mutagens**
        - Note that *carcinogens* are mutagens that cause cancer
  - Point Mutations (single nucleotide errors):
    - Substitution
    - Deletion
    - Insertion
    - *Frameshift
      - Due to a deletion or insertion, but not a substitution
      - Ruins the entire protein, as all codons are changed
  - Silent Mutation
    - The mutated codon still codes for the same amino acid
    - No effect, hence the name silent mutation.
  - Missense Mutation

        - Occurs due to a point mutation. It is when a single nucleotide change results in a codon that codes for a different amino acid.
        - Minor to severe effects (can ruin protein folding).
        - Cause of Sickle-Cell disease.
    - Nonsense Mutation
        - The mutated codon codes for a STOP codon.
- DNA Repair
    - Mechanisms to repair replication errors and prevent mutations:
        - Proofreading
            - This is done by DNA polymerase. As it adds nucleotides during replication, it double checks to make sure it is correctly pairing with the template strand. If not, it makes the correction
        - Mismatch repair
            - Enzymes repair errors that don't' get fixed during proofreading.
        - Excision repair
            - This if for nucleotides that are damaged from mutagens. Enzymes remove and replace them.
- DNA Organization
    - **Histones**
        - Proteins that DNA coils around.
    - Nucleosomes
        - The DNA-histone complexes
    - Chromosomes
        - Tightly compacted DNA
        - Only present during cell division
    - Chromatin
        - A matrix of DNA packaged with proteins. This is how DNA is arranged when the cell is not dividing. Two types of chromatin exist:
            - **Euchromatin** is when DNA is loosely bound to the histones
            - **Heterochromatin** is where the nucleosomes are tightly compacted, and DNA is transcriptionally inactive
    - **Transposons** (transposable elements)
        - Pieces of DNA that can move around and insert themselves into different locations of the DNA
        - These can have the effect of a mutation, as they can change how genes are expressed, or if they are expressed at all
        - Some transposons have no effect



- The Molecular Genetics of Bacteria (Prokaryotes)
  - No nucleus or organelles
  - Prokaryotic Chromosome
    - A single, circular piece of DNA
    - **Lacks histones** and proteins
  - Binary Fission
    - Cell division in prokaryotes
    - Both cells have one chromosome at the end
    - No spindles, microtubules, centrioles (there is no nucleus)
    - Binary fission is a form of asexual reproduction in prokaryotes and some organelles within eukaryotes (mitochondria and chloroplasts). The DNA is duplicated and then the two copies migrate to opposite sides of the cell, and the cell then splits into two. The consequence of this is that **all the bacteria and progeny are genetically identical** (no genetic variation).
  - Plasmid
    - Not a chromosome.
    - Short, circular DNA.
    - The genes can be helpful but are **not necessary for survival** of the bacteria.
    - Replication of plasmids occur independent of the chromosome.
    - **Episomes** are found in plasmids but can be incorporated into the chromosome.
  - Genetic Variation
    - Conjugation
      - DNA exchange between bacteria

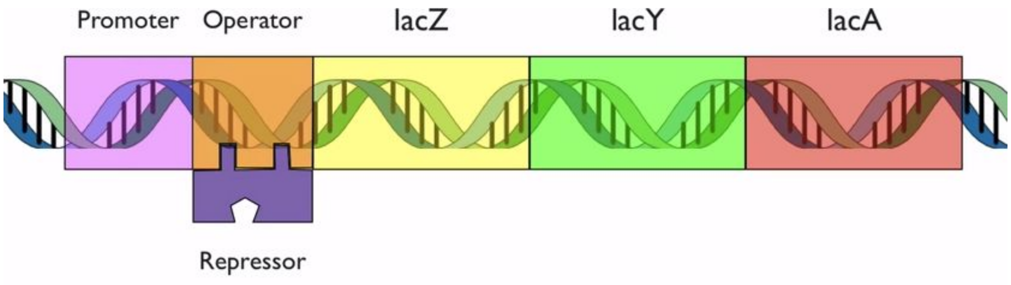
- **Pilus** (pili)
    - A tube made by a donor bacteria that connects to the receiving bacteria.
    - The donor sends DNA to the recipient through the pilus
    - If the recipient receives the **F plasmid**, it can become a donor cell because the F plasmid contains the genes to make the pilus.
    - **R plasmids** provide resistance against antibiotics.
- **Transduction**
    - A virus introduces new DNA into the genome of bacteria.
- Transformation
    - Bacteria absorb some DNA around them and put it into their genome

Regulators of Gene Expression

- The reason why different cells produce different products, despite the fact that all cells contain the same DNA
- **Transcriptional Regulation**
    - How efficiently a gene is transcribed. (how many copies of RNA are made from that gene in a given amount of time)
    - Energy Efficient, Time Inefficient
- **Translational Regulation**
    - Where you control if the mRNA is destroyed, or if it is translated into a protein
    - Energy Inefficient, Time efficient

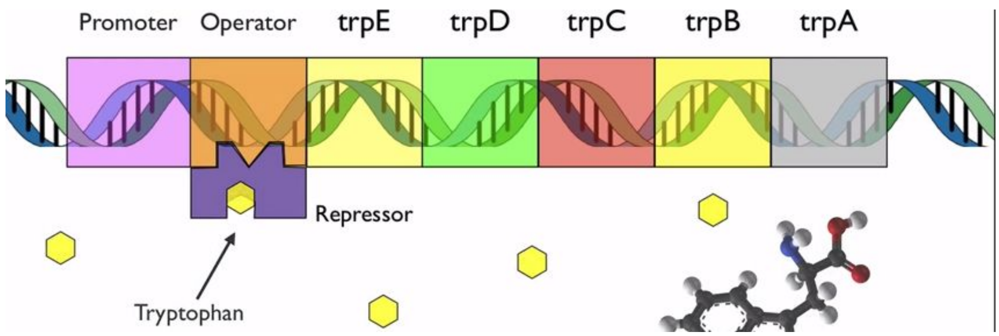
- **Operon** (control the transcription of a gene in *prokaryotes*) [Video]
    - Operons are made of: Promoter, Repressor or Activator, Operator, Genes
        - Promoter
            - DNA sequence where RNA polymerase attaches
        - Operator
            - Can bind a repressor to block RNA polymerase
        - Activator
            - Positive Regulation
            - An activator is a protein that turns up gene expression by assisting the attachment of RNA polymerase to the promoter
        - Repressor
            - Negative Regulation
            - A repressor is a protein that blocks the gene from being activated (blocks transcription) by occupying the operator region so that RNA polymerase cannot work
            - If you ever have a protein that shuts off transcription/gene expression then it is negative regulation.

- Genes
  - Structural genes code for enzymes that direct the process of the operon
  - Regulatory genes are outside of the operon and code for repressors and activators



- **Lac Operon**
  - Lactose Function
    - In the bacterial lac operon shown above, notice the Promoter, Operator, and Genes are all DNA sequences, but the repressor is a protein
    - When we ingest lactose, one of the lactose molecules binds inside the repressor which changes its shape. The repressor is then released which activates transcription.
    - The proteins which are made break down the lactose. Once the lactose is gone, the repressor turns back to its normal place and sits back inside the operator (turning transcription off).
    - The genes are **polycistronic** (one mRNA with all three genes - B-galactosidase, permease, Trans-acetylase all of which are needed)
  - Glucose Function (maybe not important for DAT)
    - The Lac operon also has an activator site. The activator site must bind cAMP to work
    - When glucose is present, cAMP levels are low and transcription is not activated
    - When glucose is not present, cAMP levels are high and transcription is activated
  - Two conditions need to be met for expression of Lac Operon genes: The **presence of lactose** (so that the repressor falls off), and **no glucose** (so that cAMP is present on the activator) [Video]
  - The Lac Operon is catabolic - it breaks down lactose.
  - The enzymes produced by this operon which breakdown lactose are called **inducible enzymes**, because lactose is required to induce (turn on) the operon.
- **Trp Operon**
  - Tryptophan Function
    - In the bacterial trp operon shown below, this operons job is to make enzymes that synthesize tryptophan (a necessary amino acid) when it is not present.

- In this case, when Tryptophan is present, it binds to the repressor which then binds to the operator and stops transcription. If there is no tryptophan, the repressor unbinds from the operator, and then mRNA is made which creates tryptophan
  - Tryptophan is acting as a **corepressor**.
- The Trp Operon is anabolic since it creates tryptophan.
- The enzymes produced by this operon which synthesize tryptophan are called **repressible enzymes**, because the genes stop producing enzymes only in the presence of a repressor.



- Control the Transcription of a gene in *Eukaryotic* Cells
  - Regulatory Proteins
    - Activators and Repressors determine the binding of RNA Polymerase
  - Nucleosome Packing
    - Acetylation and Methylation
  - RNA Interference
    - siRNA (short interfering) block transcription or translation
    - siRNA comes from dsRNA (RNA molecules that fold back on themselves and are then cut up by enzymes)
- Recombinant DNA
  - Any DNA segments from different sources, whether that be a different chromosome, a different organism, etc.
  - Transposons
  - Crossing Over
  - Bacterial Conjugation or Viral Transduction
  - Artificially
    - Using restriction enzymes to cut up the DNA
    - Unpaired “sticky end” inserted into a “vector” molecule
    - Plasmids are common vectors used for this
- Biological Tools and Experimental Techniques
  - **Restriction enzymes**
    - Enzymes from bacteria that we use to cut specific sequences of DNA
    - The remaining single stranded **sticky ends** are left.

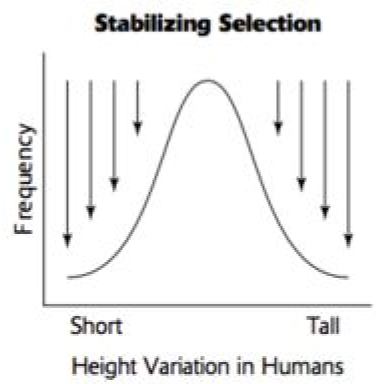
- **<u>Gel Electrophoresis</u>**
    - Separates DNA molecules based on their size
        - DNA is first cut using restriction enzymes
    - Also used to separate proteins and amino acids
    - Small molecules run faster through the gel
    - <u>Cathode → Anode</u>
- **<u>DNA Probe</u>**
    - A strand of a nucleic acid molecule **radioactively tagged**
    - Used to tag a specific DNA sequence in a sample, allowing us to detect inherited genetic defects.
- PCR
    - DNA is copied/amplified
    - Sample put in with Taq Polymerase (a heat-stable form of DNA polymerase) as well as nucleotides (A, C, T, G) and primers.
- **<u>RFLPs</u>** (Restriction Fragment Length Polymorphisms)
    - A restriction fragment is a segment of your DNA that has been treated with restriction enzymes. Everyone has different patterns when comparing non-coding regions of DNA. The differences are called "RFLPs"
    - RFLP analysis gives **DNA fingerprints**.
- **<u>cDNA</u>** (Complementary DNA)
    - A way to get DNA without any of the introns, so that scientists can clone a human gene using bacteria
    - Fully processed mRNA is extracted from cells, and placed with the enzyme **reverse transcriptase** which turns the mRNA into DNA.

Evolution

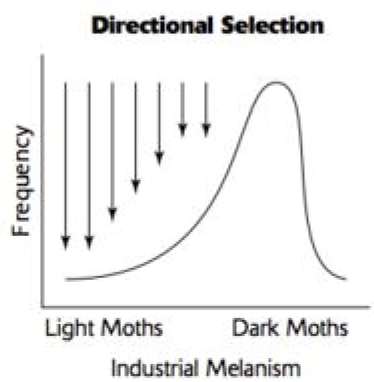
- Evolution is changes in allele frequencies in populations over time
- Two Types:
    - <u>Microevolution</u>
        - Study of how new species come about
        - Changes in organism populations from generation to generation
    - <u>Macroevolution</u>
        - Study of relationship between related species, and patterns of change between the species
        - Phylogeny
- Evidence for Evolution
    - Paleontology
        - Fossils revealing evidence of change
    - Biogeography
        - Unrelated species in similar environments may resemble each other
        - Strong evidence for natural selection

- Embryology
  - Studies and reveals similarities in relation to development among organisms
- Comparative Anatomy
  - **Homologous Structures** are closely related parts on different species, such as forelimbs of cats, humans, etc. They may look different, but they were put together and derived in the same way. Organisms with homologous structures had a common ancestor.
  - **Analogous Structures** may look alike, but they are not related (did not come from the same ancestor). Evolution occurred independently. Example is the fins and body shapes of sharks and dolphins.
- Molecular Biology
  - Related species have more common DNA sequences
  - All living things share the same genetic code (common ancestor)

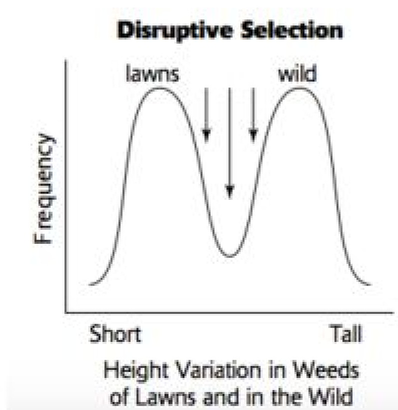
- Natural Selection
  - Some individuals in certain populations may obtain phenotypes that are more favorable for that particular environment. These superior adaptations gives the offspring a greater chance at survival, and a higher "**fitness**". An organism's fitness is related to their ability to have offspring (more surviving offspring = more fitness)
    - Favorable = **Adaptive**
    - Unfavorable = **Maladaptive**
  - Darwin's Arguments:
    - <u>Population sizes remain somewhat stable</u>, even though species have potential to produce millions of offspring over the course of 750+ years
    - <u>Resources are limited</u> and this causes problems as population size increases. Organisms will compete for survival...**survival of the fittest**
    - <u>Traits vary</u> among individuals in a population
    - Variation is heritable (Although Darwin did not know of genetics)
    - As <u>favorable traits accumulate</u> in a population over time, evolution occurs
  - Selection Types:
    - <u>Stabilizing Selection</u>
      - Eliminates unusual traits
      - The most common trait is the best adapted, the least common are bad



- Directional Selection
  - Favors a trait at one extreme
  - The extreme trait becomes more and more extreme over time

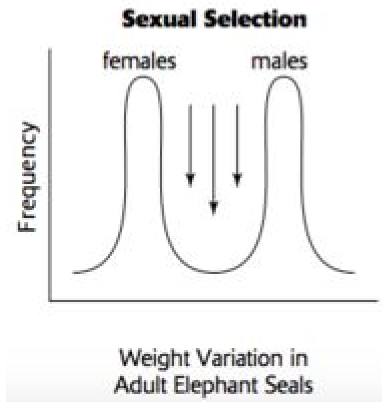


- Disruptive Selection
  - Eliminates common traits
  - The **least common trait is the best adapted**
  - Tall weeds in the wild are better as they compete for sunlight, but short weeds on lawns are better as they escape mowing



- Sexual Selection
  - Natural selection arising through preference by one sex for certain characteristics in individuals of the other sex.

            - Traits allowing males to mate more frequently are advantageous.
            - Male competition (evolution of antlers and horns)
            - Female Choice (evolution of male traits that attract females)



        - <u>Artificial Selection</u>
            - <u>Not</u> a type of Natural Selection
            - Things like dog breeding
            - Unnatural...brought about by humans
- How variation in populations arise:
    - **Mutations**
    - **Sexual Reproduction**
        - Independent Assortment
        - Crossing Over
        - Random sperm fertilizing a random egg
    - **Diploidy**
        - Recessive alleles provide a variety that is protected from natural selection, and can show up in future generations.
    - **Outbreeding**
        - Mating of unrelated individuals
    - <u>**Balanced Polymorphism**</u>
        - When <u>two or more alleles are maintained in a population</u>, meaning that heterozygous could be more advantageous than homozygous dominant, etc.
        - Heterozygote Advantage
            - Aa better than AA or aa
            - Aa, AA, and aa all maintained phenotypes
        - **Hybrid Vigor (Heterosis)**
            - When the hybrid child is more advantageous than either parent (of different species)
        - **Frequency-Dependent Selection (Minority Advantage)**
            - The least common phenotypes are the best
            - Rare phenotypes are best, but after selection occurs the rare will become common, and it is no longer advantageous.

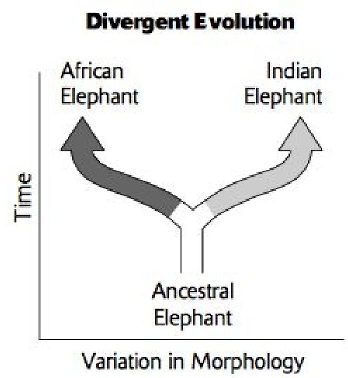
            - Multiple phenotypes are maintained because they alternate between low and high frequencies
- Causes of change in allele frequencies:
    - Genetics teaches us that natural selection is not the only cause of evolution
    - Advantageous Mutations
    - **Gene Flow**
        - Due to the flow of individuals into or out of a population
        - Individuals can leave or join a population, taking away or bringing in new alleles
    - **Genetic Drift**
        - *Random* change in alleles
        - ***Founder Effect***
            - A group migrates away from their population to somewhere new, and by chance, the migrating group contains alleles different from their population.
            - The "founder" of that population introduces the unique allele.
        - ***Bottleneck Effect***
            - A population suddenly has a dramatic decrease in size
            - Caused by natural disasters, etc.
    - **Non-random Mating**
        - Mates are selected based on the traits they have
        - Mates are selected based on their location (they are nearby)
        - Inbreeding
        - Sexual Selection

- <u>Genetic Equilibrium (Hardy-Weinberg equilibrium)</u>
    - Populations are in genetic equilibrium if their *allele frequencies do not change* from generation to generation
    - There is **NO EVOLUTION OCCURRING** at this equilibrium
        - No Natural Selection
        - No Mutation
        - No gene flow (the population is isolated from others)
        - No genetic drift (large population)
            - No founder effect or bottleneck effect!
        - Random Mating
    - Calculations:
        - p and q = allele frequencies
        - p^2 and q^2 = frequency of homozygotes
        - 2pq = frequency of heterozygotes
        - **p + q = 1**
        - **$p^2 + 2pq + q^2 = 1$**
    - [Example]

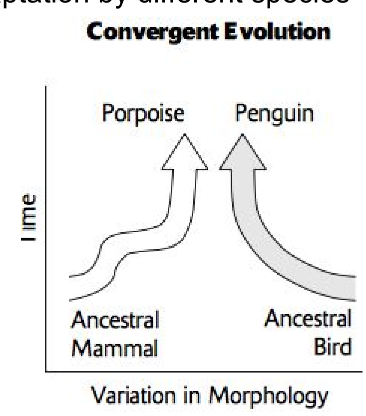
- <u>Speciation</u> (formation of new species) occurs by:
  - 1) **Allopatric Speciation**
    - A <u>barrier</u> is placed which divides a species into two. Both species evolve over time (mutations, natural selection, genetic drift).
    - If joined back together, the two populations will not breed, and therefore a new species was made
  - 2) **Sympatric Speciation**
    - Formation of new species without a barrier. This can occur by:
      - <u>Balanced Polymorphism</u> [bookmark]
        - “Suppose, for example, a population of insects possesses a polymorphism for color. Each color provides a camouflage to a different substrate, and if not camouflaged, the insect is eaten. Under these circumstances, only insects with the same color can associate and mate. Thus, similarly colored insects are reproductively isolated from other subpopulations, and their gene pools diverge as in allopatric speciation.”
      - <u>Polyploidy</u>
        - 3n, 4n, 5n, etc. (more than 2 sets of chromosomes)
        - If an individual has nondisjunction during meiosis and becomes 4n, they can no longer mate with normal diploids, and speciation occurs immediately
      - <u>Hybridization</u>
        - Hybrids diverge from parents
  - 3) **Adaptive Radiation**
    - When many species are formed quickly from one ancestor
    - The ancestor is introduced to diverse conditions, and different species may be more suited to certain conditions

- Maintaining Reproductive Isolation (if barriers do not exist, there are other things preventing gene flow)
  - **Prezygotic Isolation** (prevents fertilization)
    - Habitat Isolation (species never meet)
    - Temporal Isolation (species mate at different times/seasons)
    - Behavioral Isolation (necessary signs or rituals not performed)
    - Mechanical Isolation (incompatible genitalia)
    - Gametic Isolation (female and male gametes do not recognize each other)
  - **Postzygotic Isolation**
    - Hybrid Inviability (zygote does not properly develop)
    - Hybrid Sterility (example of a mule - hybrids have no fertility)
    - Hybrid Breakdown (hybrids have reduced fertility)

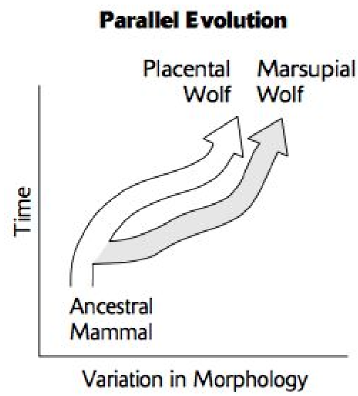
- Evolution Patterns
    - 1) <u>Divergent Evolution</u>
        - If two different species came from the same ancestor, but they become more and more different over time
        - A result of:
            - Allopatric Speciation
            - Sympatric Speciation
            - or Adaptive Radiation



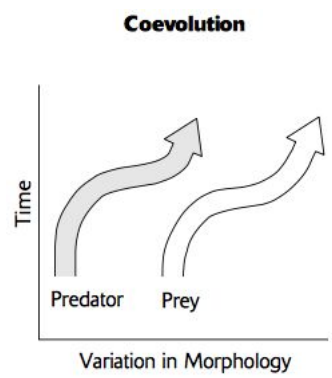
    - 2) <u>Convergent Evolution</u>
        - Two species share similar traits without having a common ancestor
        - Usually due to the animals living in similar circumstances, and so they adapt independently
        - **Analogous Traits**
            - Traits that are similar/resemble each other due to independent adaptation by different species



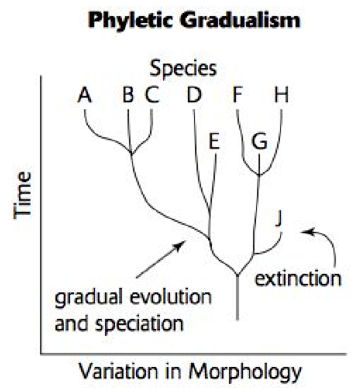
    - 3) <u>Parallel Evolution</u>
        - Two species diverge from a common ancestor, and then those two species evolve in a similar way parallel to each other afterwards



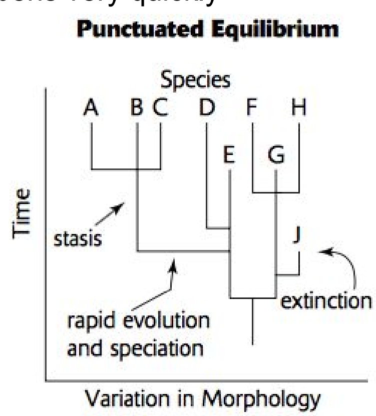
- 4) <u>Coevolution</u>
  - If a predator has a mutation that increases his ability to catch prey, and the prey also has a mutation that increases his ability to escape the predator



- Macroevolution
  - Evolution for **groups of species** over extended periods of geologic time, as opposed to evolution of *individual species* as we've been talking about
  - Two Macroevolution Theories:
    - 1) <u>Phyletic Gradualism</u>
      - By small and simple things are great things brought to pass
      - Many **gradual small changes over long periods of time** is how evolution happens
      - Fossils are evidence of this because they are snapshots at certain time periods of the evolutionary process, but there are not intermediate stages of evolution represented in fossils



- 2) <u>Punctuated Equilibrium</u>
  - The majority of time consists of periods without evolution occurring
  - There are **short periods in time where evolution occurs very rapidly**
  - Fossils could also be evidence of this theory because the absence of fossils revealing intermediate stages of evolution confirms that it happens very quickly



- The Origin of Life
  - Chemical Evolution is the study of how life began
    - Heterotroph Theory
      - A theory that states the first cells were **heterotrophs** (organisms incapable of making their own food)
  - 1) <u>The earth and the atmosphere formed</u>
    - Atmosphere formed from volcanic outgassing the molten interior of planet earth.
    - Atmosphere contained little O_2, but it contained CO, CO_2, H_2, N_2, H_2O, S, HCl, and HCN (a reducing atmosphere).
  - 2) <u>The seas formed</u>
    - The earth cooled down causing gases to condense, resulting in the water and minerals that make up the seas.
  - 3) <u>Complex Molecules Synthesized</u>
    - Amino acids, acetic acid, formaldehyde, etc.

            - Monomers...the building blocks for polymers.
        - **Inorganic Molecules made into Organic Molecules via energy from UV light, lightning, radioactivity, and heat** ("organic soup").
        - It is very likely that the formation of simple molecules was made possible only by the absence of oxygen from the atmosphere during that time (oxygen is very reactive).
    - 4) Polymers and self-replicating molecules synthesized
        - Monomers → Polymers via dehydration condensation (loss of H_2O)
        - **Proteinoids** formed
            - These are abiotic polypeptides formed by allowing amino acids to dehydrate on hot, dry substrates.
    - 5) Organic Molecules were Concentrated and Isolated into protobionts
        - **Protobionts**
            - A self-organized sphere of lipids that provided a border where chemical reactions could take place (like a cell does).
            - The ***precursors*** of cells.
            - Unable to reproduce.
        - **Microspheres and Coacervates**
            - Abiotically produced protobionts
    - 6) Primitive Heterotrophic Prokaryotes formed
        - **Heterotrophs**
            - Living organisms that cannot make their own food
            - Obtain energy by consuming other substances
            - Pathogenic bacteria is an example
        - The "organic soup" on the earth (made from the inorganic molecules) was the original source of organic materials for these heterotrophic organisms
        - Natural selection occurred over time for competing cells
    - 7) Primitive Autotrophic Prokaryotes formed
        - **Autotroph**
            - Heterotrophs mutated, gaining the ability to make their own food
            - Highly succesful cells
        - These cells harvested light energy or energy for inorganic substances in order to make their organic compounds
        - *Cyanobacteria* (photosynthetic bacteria) is an example
    - 8) Oxygen and Ozone Layer formed and Abiotic Chemical Evolution ended
        - **Autotrophs release oxygen as a byproduct, which accumulated over time in the atmosphere**.
        - O_2 reacting with UV light formed the ozone
            - The ozone absorbs UV light, preventing it from reaching the surface of the planet
            - This prevented the abiotic synthesis of organic molecules from occurring because the UV light was the major source of energy
    - 9) Eukaryotes formed (Endosymbiotic Theory)
        - **Endosymbiotic Theory**

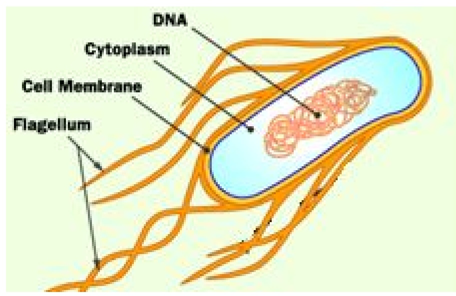
                - Eukaryotic cells originated from various prokaryotes who, when together, formed a mutually beneficial association
                - Mitochondria, chloroplasts, etc. moved inside a prokaryote to form the eukaryote
            - Evidence for this theory:
                - Mitochondria & Chloroplasts
                    - Both have their own <u>circular DNA</u> that contains <u>no proteins</u> (naked) just like bacteria and cyanobacteria does
                    - The <u>ribosomes also resemble bacteria</u> and cyanobacteria
                    - These organelles <u>reproduce independently</u> of the eukaryotic cell, <u>similar to binary fission</u> in bacteria
                    - <u>Double membranes</u> possibly originating from the prokaryote surrounding the organelle
                    - <u>Thylakoid membranes in chloroplasts are similar to the photosynthetic membranes</u> contained in cyanobacteria.
- Evolution of Fish
    - Jawless fish → Cartilaginous fish → Lobe-finned fish
    - For the purpose of the DAT, it is helpful to know other significant steps in the evolution of **chordates**. These steps <u>*in order of evolution*</u> include formation of the following structures:
        - Notochord (first seen in lancelets and tunicates) →
        - Head (first seen in hagfish) →
        - Vertebral column (first seen in jawless fish - also known as Class Agnatha, e.g. lampreys) →
        - Jaw and mineralized skeleton (first seen in chondrichthyes, e.g. sharks) →
        - Lungs/lung derivatives (first seen in ray-finned fish) →
        - Lobed fins →
        - Limbs with digits (amphibians) →
        - Amniotic eggs (reptiles) →
        - Production of milk (mammals).

Biological Diversity

- Taxonomy: Things to Know
    - Dumb King Phillip Came Over From German Soil
        - Domain
        - Kingdom
        - Phylum
        - Class
        - Order
        - Family

- **Genus**
- **Species**

- Genus and Species are used to name organisms, such as *Canis lupis* or *Homo sapien*
- Prokaryotic vs Eukaryotic Cells
  - Prokaryotic
    - A single chromosome
    - No nucleus or organelles (but there is a **nucleoid** region)
    - A plasmid (circular DNA) is sometimes present in addition to the single chromosome.
    - Flagella made of the protein "**flagellin**"



  - Eukaryotic
    - Chromosomes are long and tightly packaged with histone proteins
    - Nucleus and organelles present
    - Flagella and cilia made of the protein "**tubulin**" arranged 9+2
- Autotrophs and Heterotrophs
  - Autotrophs
    - Photoautotrophs
      - Use **photosynthesis** to make their own food from sunlight
    - Chemoautotrophs
      - Use **chemosynthesis** to make their own food from inorganic substances (H_2S, NH_3, etc.)
  - Heterotrophs
    - Obtain their energy by consuming autotrophs/things made by autotrophs.
    - Examples
      - Parasites
      - Decomposers (saprobes/saprophytes)
- Anaerobes vs Aerobes
  - Obligate Anaerobe
    - Need the absence of oxygen to survive
    - Obligated to have no O_2
  - Obligate Aerobes
    - Need oxygen to survive
    - Obligated to have O_2

        - Facultative Anaerobe
            - In the absence of oxygen, it can switch from aerobe → anaerobe

- Domains of Classification - ABE
    - **<u>Archaea</u>** (or archaebacteria)
        - These are <u>prokaryotes</u> that cannot be classified as bacteria for the following reasons:
            - Bacterial cell walls contain peptidoglycans whereas **archaeal cell walls contain <u>various polysaccharides</u>**.
                - Also note that for eukaryotes (plants), the cell walls contain cellulose and fungi cell walls contain chitin.
            - The phospholipids in their plasma membranes differ from bacteria and eukaryotes (branched hydrocarbon chains, whereas eukaryotes and bacteria are unbranched)
        - These have some similarities to eukaryotes, including:
            - Both have **histones** that package the DNA (bacteria have no histones)
            - Ribosome activity is **not inhibited by antibiotics** in either eukaryotes or archaea (but it is in bacteria).
        - Groups of Archaea:
            - 1) <u>Methanogens</u>
                - Obligate anaerobes (cannot live in the presence of oxygen)
                - Live in the mud, as well as guts of animals and produce methane (CH_4)
                - They fix carbon in CO_2 using energy from H_2 to produce the methane.
            - 2) <u>Extremophiles</u>
                - Halophiles
                    - Live in high concentrations of salt (Great Salt Lake, Dead Sea, or salty foods)
                    - Can be aerobic heterotrophs, or anaerobic autotrophs (photosynthetic)
                        - Use the pigment bacteriorhodopsin
                - Thermophiles
                    - Usually sulfur-based chemoautotrophs
                    - Live in high heat environments such as geysers
                - Some extremophiles also live in high or low pH environments or high pressures in thermal vents deep in the ocean.
    - **<u>Bacteria</u>** (or eubacteria)
        - Bacteria are the hardest to classify because of how old they are.
        - These are <u>prokaryotes</u> that differ from eukaryotes and archaea in the following ways:

- Bacterial cell walls are made with **peptidoglycan** (a sugar polymer with amino acids).
- **No histones**.
- Ribosome activity **inhibited by antibiotics**.

▪ Categorization of Bacteria by their features:
  - 1) How they metabolize resources for nutrition
  - 2) Some bacteria produce **endospores**
    - A non-reproductive structure containing the bacterium's DNA.
  - 3) How they move/their means of motility
    - Flagella, corkscrew motion, and gliding through slime that they produce.
  - 4) Their shape, which can be *cocci* (spherical), *bacilli* (rod shaped), and *spirilla* (spirals)

  - 5) The cell wall thickness
    - Cell walls can be stained with the "**Gram stain technique**"
    - If positive, they have a thick wall, if negative, a thin wall

▪ Common Groups of Bacteria:
  - Cyanobacteria
    - Photosynthetic just like plants, so they release O_2.
      - Use chlorophyll a as well as a pigment called **phycobilin**.
    - Some have cells called **heterocysts** which fix nitrogen, allowing it to make nitrogen containing amino acids or nucleotides.
    - So they are **autotrophs that can fix nitrogen**.
  - Chemosynthetic Bacteria (Nitrifying Bacteria)
    - **Autotrophs**
    - **Nitrifying** (convert nitrite into nitrate...$NO_2^- \rightarrow NO_3^-$)
  - Nitrogen-Fixing Bacteria
    - **Heterotrophs that fix nitrogen**
    - Many have mutualistic relationships with plants
      - They live in **nodules** (special structures within plant roots)
  - Spirochetes
    - Coiled
    - Move in a corkscrew type motion

- Their flagella is on the inside of the cell wall (internal flagella)

- **Eukarya** (or eukaryotes)
  - There are four kingdoms in eukarya (Protista, Fungi, Plantae, Animalia)
  - Kingdom Protista
    - The relationships in this kingdom are the most poorly understood, and it is sometimes used more for convenience than to accurately measure evolutionary relationships (some may represent convergent evolution)
    - Organisms in Kingdom Protista can be:
      - Algaelike (or plantlike)
      - Funguslike
      - Animallike
      - Unicellular
      - Multicellular
    - **Algaelike** (plantlike) - All are autotrophs and obtain food via photosynthesis (using chlorophyll a)
      - 1) Euglenoids
        - One to three flagella at their leading end (front)
        - Instead of a cell wall, they have **pellicles**, which is a thin protein layer that wraps around the membrane
        - Can become heterotrophic if no light is present
        - Have an **eyespot** which allows **phototaxis** (move in response to the light)
      - 2) Dinoflagellates
        - Two flagella (one posterior, one transverse that lays in a groove around it, like the ditch in the death star)
        - Can be bioluminescent (like fire flies)
        - Can also produce neurotoxins damaging to humans
      - 3) Diatoms
        - Unicellular
        - Have hard shells (tests) made of silica (SiO_2)
      - 4) Brown algae
        - Multicellular
        - Flagellated sperm cells
        - Giant seaweeds/kelp
      - 5) Rhodophyta (red algae)
        - Contain red pigments called **phycobilins**.
        - Multicellular
        - Gametes do not have flagella

- 6) Chlorophyta (green algae)
    - Have chlorophyll a and b
    - Cellulose in cell walls
    - Store their carbs as starch
    - Variety in sexuality
      - Isogamous (sperm and egg same size)
      - Anisogamous (sperm and egg different size)
      - Oogamous
    - **Charophytes** are a lineage of chlorophyta, and are believed to be the ancestor of plants
- **Animallike** (Protozoa) - Heterotrophs that consume either living cells or dead matter
  - Rhizopoda
    - **Amoebas**
    - Move by pseudopodia (extensions of their body).
    - Pseudopodia also surround food and do phagocytosis.
  - Foraminifera (forams)
    - Have shells (tests) made of calcium carbonate.
    - Good indicator of underlying oil deposit in ancient marine sediments
  - Apicomplexans
    - Parasites of animals
    - Characterized by their apical complex
      - A complex of organelles at the end of the cell
    - **No physical means of movement**
    - Form spores that complete its life cycle, sometimes in multiple hosts (such as malaria...it spends part of its life cycle in mosquitoes and part in humans)
  - Ciliates
    - Use cilia to move and for other things as well.
    - **Paramecium** is one example
    - Probably the most complex cell because of specialized structures such as mouths, anal pores, contractile vacuoles (for water balance), two kinds of nuclei (one large macronucleus and several small micronuclei), etc.
- **Funguslike** - These protists resemble fungi because they form either filaments or spore-bearing bodies.
  - Cellular slime molds
    - Spores germinate into amoebas which feed on bacteria

- When food is limited, the amoebas all aggregate together into a single unit and move as a “slug”
- The individual cells of the slug then mobilize to form a stalk with a capsule at the top similar to the spore-bearing bodies of many fungi.
- Spores are then released, which repeat the cycle when they germinate. The stimulus for aggregation is **cyclic AMP** (cAMP), which is secreted by the amoebas that experience food deprivation first.

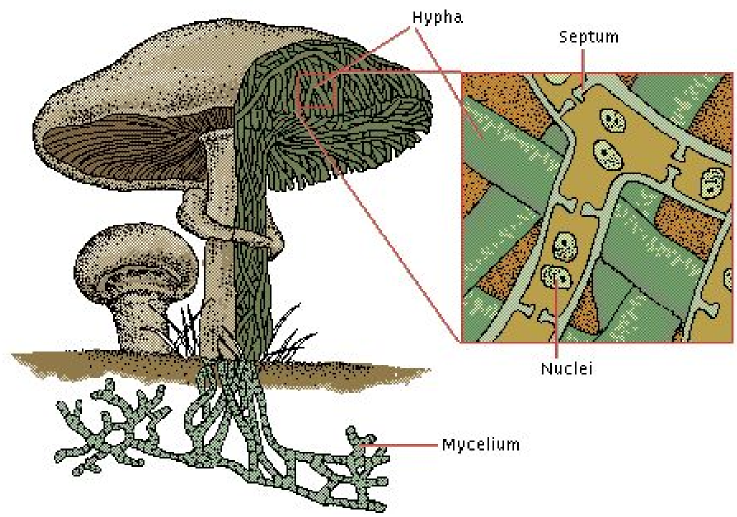
- Plasmodial slime molds
    - Grow as a single, spreading mass (or plasmodium) feeding on decaying vegetation.
    - When food becomes unavailable or when the environment dries up, stalks bearing spore capsules form.
    - Haploid spores released from the capsule germinate into haploid amoeboid or flagellated cells, which fuse to form a diploid cell. The diploid cell grows into the spreading plasmodium.

- Oomycota
    - Include the water molds, downy mildews, and white rusts.
    - They are either parasites or saprobes.
    - They are much like fungi in that they form filaments (hyphae) which secrete enzymes that digest the surrounding substances. The breakdown products of digestion are then absorbed.

- The filaments of the Oomycota **lack septa**, or cross walls, which in many of the true fungi partition the filaments into compartments. Because they lack septa, they are **coenocytic**, containing many nuclei within a single cell.
- Also, the cell walls of the Oomycota are made of **cellulose**, rather than the chitin found in the true fungi.

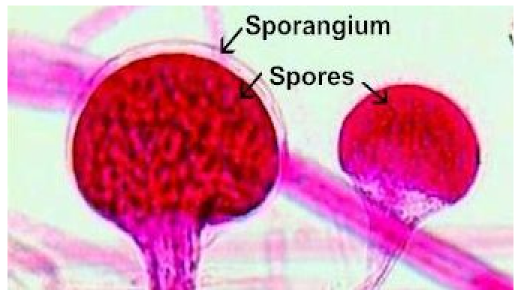
Kingdom Fungi

- Fungi grow via **hyphae** filaments (hypha) which form a mass called **mycelium**. Some fungi have **septa** (cross walls) that divide this filament into compartments that contain a single nucleus.
  - If they lack this septa they are **coenocytic** (multinucleated).



- The cell walls in fungi are made of **chitin** (a sugar).
- Fungi are either parasites or saprobes, absorbing the breakdown products from the action of digestive enzymes that they secrete.
  - Many parasitic fungi have hyphae called **haustoria** that penetrate their host.
- [Sexual Reproduction]
  - Normally fungi are haploid, but they become diploid to reproduce.
  - **Plasmogamy** is when two fungi fuse cells to produce a single cell with nuclei from both strains. **Dikaryon** is a pair of haploid nuclei from two fungi fusing cells.
  - **Karyogamy** is when the two haploid nuclei in a dikaryon fuse to form a diploid
  - Meiosis then occurs to produce the haploid condition
- Asexual Reproduction

- Fragmentation
    - Breaking up of hyphae
- Budding
    - The pinching off of an outgrowth of hyphae
- Asexual Spores
    - **Sporangiospores** are spores produced in saclike capsules called sporangia (sporangium) that are each borne on a stalk called a sporangiophore.



    - **Conidia** (singular, conidium) are formed at the tips of specialized hyphae, not enclosed inside sacs. Hyphae bearing conidia are called **conidiophores**.

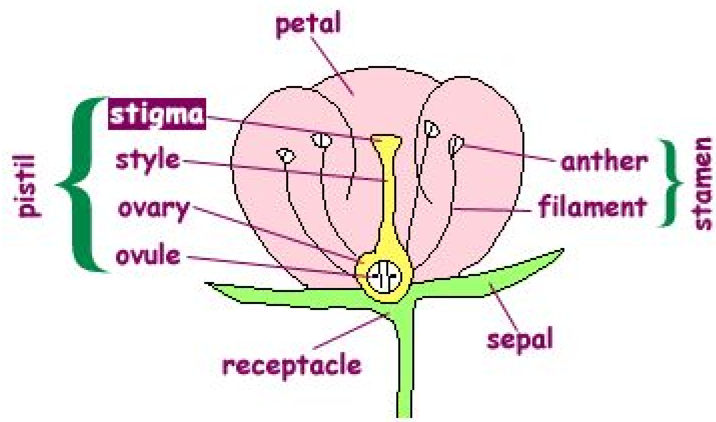
- Fungus Types [read about them here]
    - 1) Zygomycota
        - Bread mold
        - Lack septa
        - Reproduce Sexually (zygospores)
    - 2) Glomeromycota
        - Lack septa
        - No zygospores
        - Mutualistic relationship in plant roots called mycorrhizae
    - 3) Ascomycota
        - Contain Septa
        - Reproduce sexually (ascospores)
        - Yeasts
    - 4) Basidiomycota
        - Contain Septa
        - Also reproduce sexually (basidiospores)
    - 5) Deuteromycota
        - "Imperfect" Fungi
        - No sexual reproduction has been observed
        - Penicillin
    - 6) Lichens
        - Fungi + Algae relationships (algae is a protist)
        - Fungus provides water/protection

- Algae provides sugar/nitrogen

- Kingdom Plantae
  - Plants had to adapt to surviving on land without the constant protection of water.
    - The dominant type of most plants is the **diploid sporophyte**.
    - Plants contain a **cuticle**, which is a waxy covering that prevents dessication (drying out)

    - Plants developed a vascular system allowing water to be distributed throughout the plant, removing their total dependency on being surrounded by water. This vascular system allowed the plants to start evolving more now that they were not dependent on water.
      - True leaves developed as centers for photosynthesis, true stems developed to provide a framework to support leaves, and true roots developed to obtain water and anchor the plant.
      - Two groups of vascular tissues evolved, **xylem** and **phloem**.
        - Xylem is specialized for water transport
        - Phloem is specialized for sugar transport.
    - Sperm developed to be distributed by wind or animals (pollen) rather than by water.
    - **Anthophyta** are advanced plants that protect their gametophytes inside an ovary.
    - Other advanced plants change depending on the season or weather.
      - **Deciduous trees** (shed leaves during slow periods of growth to prevent water loss).
      - Plants that respond to rain by flowering.
  - Plant Divisions:
    - Bryophytes (Mosses, Liverworts, Hornworts)
      - Gametes produced in gametangia.
      - The **only non tracheophytes** meaning they lack Xylem and Phloem (they do not have true roots, stems, leaves).

        - Water must be readily available in the environment for absorption and transport of sperm because the lack of vasculature, so they often live in damp environments.
    - Lycophyta
        - Tracheophytes (they have xylem and phloem - true leaves, stem, roots etc.)
        - Club Mosses, Spike Mosses, Quillworts.
        - Produce strobili (spore bearing)
    - Pterophyta (Ferns) - all are tracheophytes
        - Ferns
            - Produce sori (clusters of sporangia)
            - Sporangia undergo meiosis to make spores
        - Horsetails
            - Hollow and ribbed stems joined at nodes
        - Whisk Ferns
            - Branching stems without roots
            - No roots or leaves (“**secondary loss**”)
    - Coniferophyta (gymnosperms)
        - Conifers include pines, firs, spruces, junipers, redwoods, cedars, and others.
    - Anthophyta (angiosperms)
        - Flowering plants
        - Only angiosperms produce fruits (which originate from the ovary).
        - **Pistil** (female reproductive structure)
            - Ovary (protects gametophytes)
            - Style
            - Stigma
        - **Stamen** (male reproductive structure)
            - Anther (pollen bearing)
            - Filament (stalk)
        - Petals attract pollinators



Fertilization Method

- Pollen lands on the stigma (sticky)
- A **pollen tube**, an elongating cell that contains the vegetative nucleus (or **tube nucleus**) grows down the style toward an ovule. There are two sperm cells inside the pollen tube
- Ovules within the ovary consist of a megaspore mother cell surrounded by the nucleus and integuments. The megaspore mother cell divides by meiosis to produce four haploid cells, the **megaspores**. One surviving megaspore divides (three times) by mitosis to produce eight nuclei. Six of the nuclei undergo cytokinesis and form plasma membranes.
- The result is an **embryo sac**. At the micropyle end of the embryo sac are three cells, an **egg cell** and two **synergids**. At the end opposite the micropyle are three **antipodal cells**. In the middle are two haploid nuclei, the **polar nuclei**.
- When the pollen tube enters the embryo sac through the micropyle, one sperm cell fertilizes the egg, forming a diploid zygote. The nucleus of the second sperm cell fuses with both polar nuclei, forming a triploid nucleus. The triploid nucleus divides by mitosis to produce the **endosperm**, which provides nourishment for subsequent development of the embryo and seedling. The fertilization of the egg and the polar nuclei each by a separate sperm nucleus is called **double fertilization**.

- Review Table

- <u>Kingdom Animalia</u>
    - Commonalities
        - Animals are all heterotrophs, multicellular, dominantly diploid, usually motile, undergo embryonic development.
    - Differences
        - Tissue Complexity
            - The <u>eumetazoa</u> group of animals all have tissue layers that develop into organs, etc.
            - The <u>parazoa</u> group of animals do not have tissue layers or organs.
        - Body Symmetry
            - **Radial Symmetry** (circular, only front and back or top and bottom)
                - Radially symmetric organisms resemble a pie where several cutting planes produce roughly identical pieces. Such an organism exhibits no left or right sides. They have a top and a bottom surface only.
                - Starfish are an example.
            - **Bilateral Symmetry** (dorsal, ventral, anterior, and posterior sides)
                - Only one plane, called the sagittal plane, divides an organism into roughly mirror image halves.
        - Cephalization
            - Those organisms with bilateral symmetry have greater innervation towards the head (anterior end)
            - Think of the brain
        - Gastrovascular cavity
            - One opening (sac like)
            - Two openings (digestive tract)
        - **<u>Coelom</u>**
            - A coelom is a cavity that develops during embryonic development from the mesoderm layer.
            - Acts as a **cushion** for internal organs
        - Segmentation
            - Segmented body parts or body parts that repeat.
        - <u>Protostomes</u> vs <u>Deuterostomes</u> (the two Developmental Patterns)
            - Protostomes early cleavage is at a slight angle, whereas deuterostomes is straight
            - There is an infolding in the blastula stage that forms a cavity called the archenteron which becomes the

mouth in the protostome and the anus in the deuterostome
        - The coelom (cushion) forms by the mesoderm splitting in protostomes, and from outpouching in the wall of the archenteron in deuterostomes.
        - See here for comparison
- Groups (Phyla):
    - Porifera
        - Sponges
        - Classified as parazoa (no true tissue)
        - **Choanocytes** cells use to draw in water. They then pass food to **amoebocytes** to distribute nutrients. Water then exits through the **osculum**
        - Sponge wall contains **spicules**
    - Cnidaria
        - Jellyfish, sea anemones, and corals.
        - Medusa or polyp body forms
    - Platyhelminthes
        - Flatworms
            - Free-living flatworms (carnivores)
            - Flukes (animal parasites)
            - Tapeworms (internal parasites - do not contain their own digestive tract so they need pre-digested food)
    - Nematoda
        - Roundworms
        - Have their own complete digestive tract
        - Soil-dwellers that recycle nutrients
    - Rotifera
        - Rotifers (microscopic)
        - Have organs contained in pseudocoelom, and a complete digestive tract
        - Filter feeders (see here)
    - Mollusca
        - Includes snails, bivalves, octopuses, and squids
        - Most have shells
    - Annelida
        - Segmented worms including leeches, earthworms, and polychaete worms
    - Arthropoda
        - Spiders, insects, crustaceans, scorpions, and various related organisms.
        - Jointed appendages

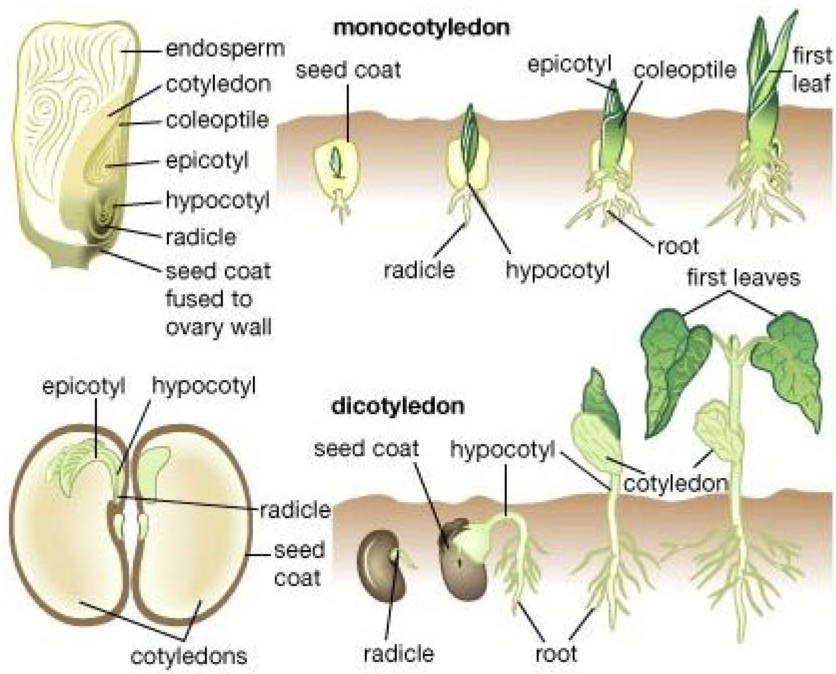
                - **Chitin exoskeleton**
                - Some are **nymphs**
                    - Born as smaller versions of the adult, and they grow up and change
                - Some are **larvae**
                    - Maggots specialized for eating
                    - Eventually go into a cocoon (**pupa**) to undergo metamorphosis
            - Echinodermata
                - Includes sea stars, sea urchins, and sand dollars
                - Most have a complete digestive tract
            - Chordata
                - All contain the following features during development:
                    - **Notochord**
                        - Functions as support in development, but usually replaced by bone.
                        - Becomes part of the vertebral column, as well as muscles of the axial skeleton.
                    - **Dorsal hollow nerve cord**
                        - Basis of nervous system
                        - Often becomes spinal cord.
                    - **Pharyngeal gill slits**
                        - Becomes gills or can disappear
                    - **Muscular tail**
                        - Often lost during embryonic development (such as in humans)
                - Invertebrate chordates
                    - Lancelets and tunicates
                - Vertebrate chordates
                    - Sharks, fish, amphibians, reptiles, birds, and mammals
                    - Characterized by a series of bones, the vertebrae, that enclose the spinal cord.
                - Review Table
- Domain Eukarya Review

Plants

- Review

- The seed plants include:
  - Gymnosperms (conifers)
  - Angiosperms (flowering plants)
    - Dicots
    - Monocots
- Plant Tissue
  - 1) Ground Tissue
    - Parenchyma
      - Site of photosynthesis
      - Most common ground tissue
      - Thin cell walls
    - Collenchyma
      - Thick cell walls, but flexible
      - Mechanical Support
    - Sclerenchyma
      - Thickest cell walls
      - Mechanical Support
  - 2) Dermal Tissue
    - Epidermal cells (secrete the waxy *cuticle*)
    - Guard Cells (around stomata)
    - Specialized cells (hair cells, stinging cells, glandular cells)
  - 3) Vascular Tissue (Xylem + Phloem = Vascular Bundle)
    - Xylem
      - Water and mineral transport
      - Mechanical Support
      - Xylem cells contain a **secondary cell wall** for added strength
        - "Pits" are where this secondary cell wall are absent
      - Dead cells at maturity (they consist of cell walls but lack the cellular components)
      - Types of Xylem Cells:
        - **Tracheids**
          - In tracheids, which are long and tapered, water passes from one tracheid to another through pits on the overlapping tapered ends of the cells.
        - **Vessel Elements** (or vessel members)
          - Vessel members are shorter and wider than tracheids, and have less or no taper at their ends. A column of vessel members is called a vessel.
          - Water passes from one vessel member to the next through areas devoid of both primary and secondary cell walls. These areas are called perforations and are literally holes between cells

            - Water moves through these better and more easily than the tracheids (they are more evolutionarily advanced)
        - Phloem
            - Transport of sugars
            - Made up of cells called **sieve-tube members** (or sieve-tube elements) that form fluid-conducting columns called sieve tubes
            - The sieve-tube members are living at maturity, unlike the xylem cells
            - Lack nuclei and ribosomes, but contain other cell components
            - Pores on the end of the cells form sieve plates (junctions that connect two cell cytoplasms)
            - Each sieve-tube member is connected with companion cells (which are parenchyma) by a tube called plasmodesmata.
- The Seed
    - Embryo + seed coat + storage material = a seed
        - Storage material can be endosperm or cotyledons (cotyledons are formed by digesting/using the storage material in an endosperm)
        - The embryo contains:
            - Epicotyl (the top part)
                - Becomes the shoot tip
            - Plumule
                - Young leaves attached to the epicotyl
            - Hypocotyl
                - Below the epicotyl
                - Attached to the cotyledons
                - Becomes the young shoot
            - Radicle
                - Develops into the root
                - Only forms in some plants
            - Coleoptile
                - A sheath that surrounds and protects the epicotyl

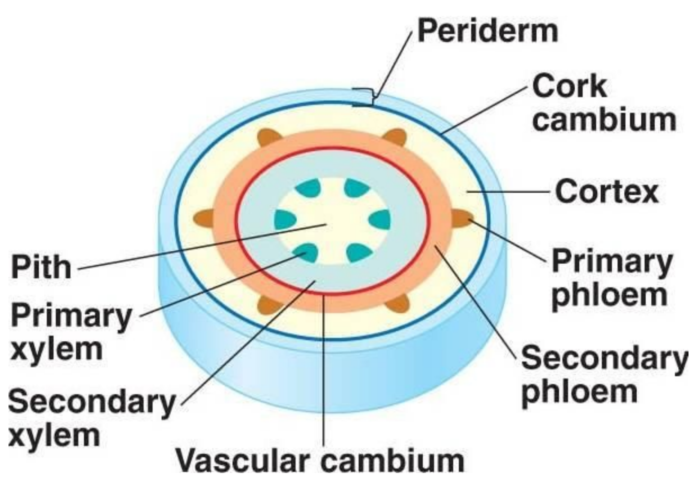


- Germination and Development
    - A seed reaches maturity, and then becomes dormant until certain cues are triggered for it to grow (water, temperatures, light, etc.)
    - The Process
        - Germination begins by the absorption of water
        - The seed swells, the seed coat cracks
        - The radicle produces roots to anchor the seed
            - The root cap protects the apical meristem behind it
        - The hypocotyl elongates, producing the shoot
        - In the young seedling, it grows at the **apical meristems** (the tips of the roots and shoots) - this is called primary growth.
            - These are areas of cells that are actively dividing, called **meristematic**
            - These dividing cells form an area called the **zone of cell division**
            - After division, the newly formed cells absorb water and begin to elongate, forming the **zone of elongation** (this is what we perceive as growth)
            - Behind the zone of elongation is the **zone of maturation/differentiation** where cells mature into xylem, phloem, parenchyma, or epidermal cells.
    - Primary vs Secondary Growth
        - **Primary Growth**
            - Most monocots
            - When actively dividing cells are only at the apical meristems
            - Increases the length of the root or the shoot

- Primary tissues develop from this type of growth (Primary xylem and primary phloem refer to vascular tissues originating from apical meristem growth)

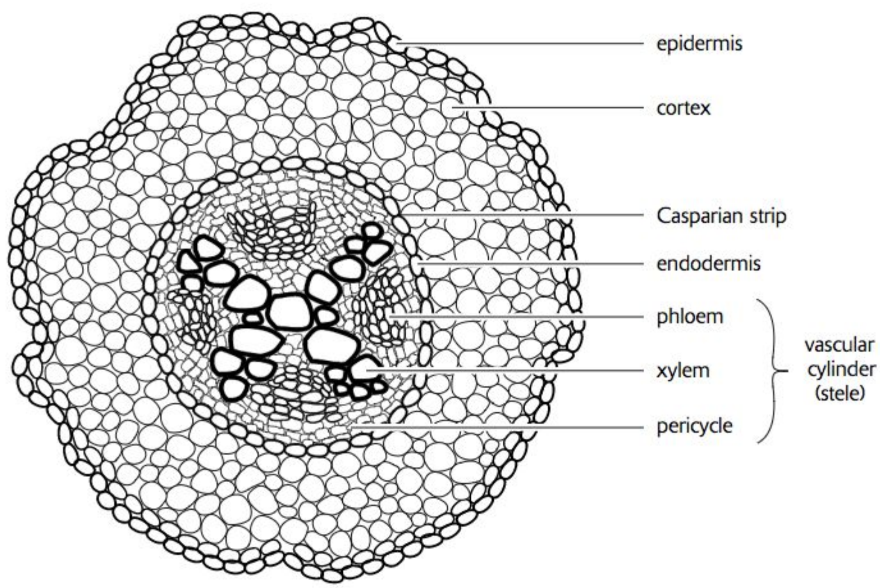
- **Secondary Growth**
  - Conifers and woody dicots
  - Occurs in addition to primary growth
  - Increases the lateral dimensions of the plants (the girth)
  - Occurs at two lateral meristems:
    - Vascular Cambium
      - Produces secondary xylem and phloem
    - Cork Cambium
      - Produces periderm (protective covering on the outside)

Secondary growth in stems

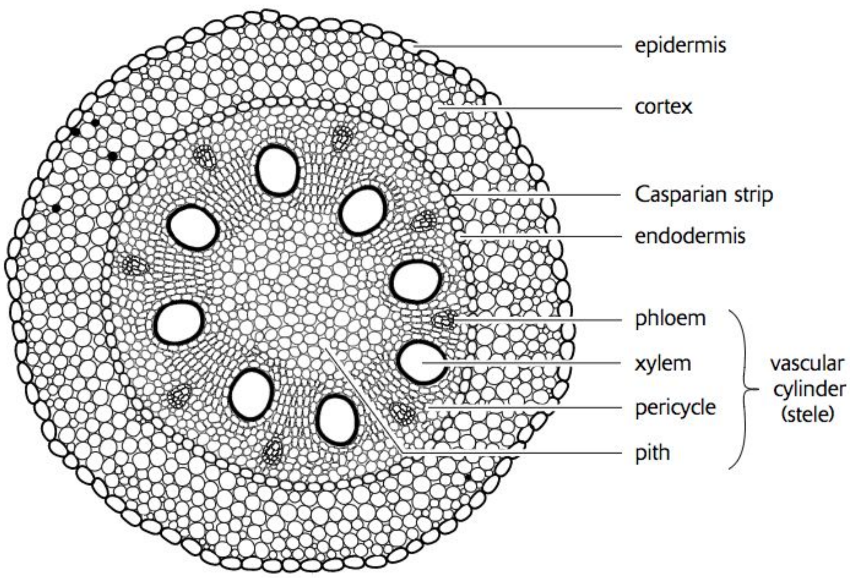


- Primary Structure of Roots
  - Epidermis
    - Lines outside surface of root
    - Produce root hairs in the zone of maturation to increase absorption
    - Root hairs die as the zone of maturation ages, requiring constant growth of the root to produce more
  - Cortex
    - Bulk of the root
    - Functions in storing starch
  - Endodermis
    - A ring at the inner cortex
    - **Casparian Strip** is a band of fatty material called suberin. This creates a water impermeable barrier inbetween cells

        - As a result of the casparian strips, all water passing through the endodermis must pass through the endodermal cells and not between the cells.
        - In this way, the endodermal cells control the movement of water into the center of the root (where the vascular tissue resides) and prevent water movement back out to the cortex
- Vascular Cylinder (Stele)
    - Tissues inside the endodermis
    - The outer part is the **pericycle** from which lateral roots arise
        - Inside this pericycle is the vascular tissue

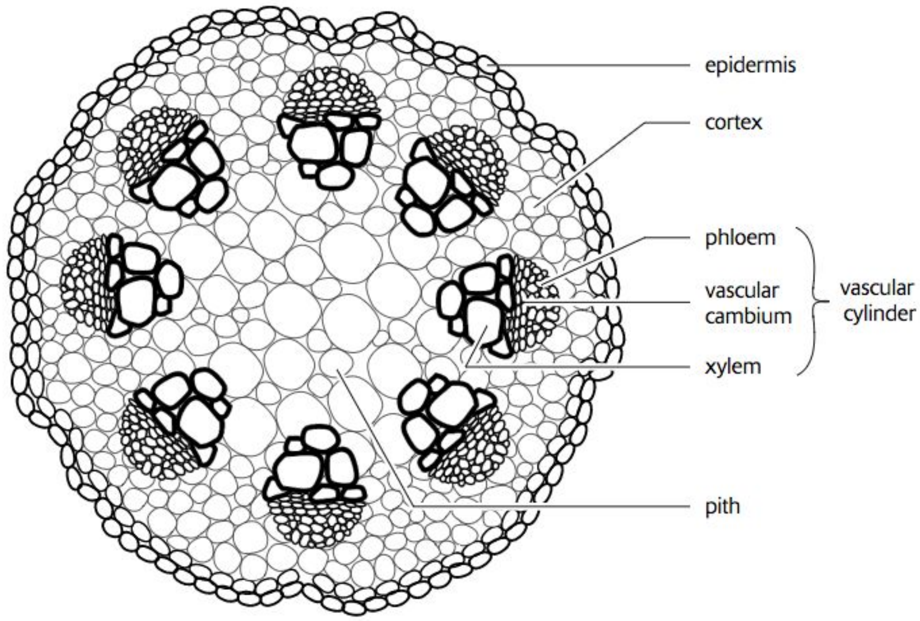


Dicot Root

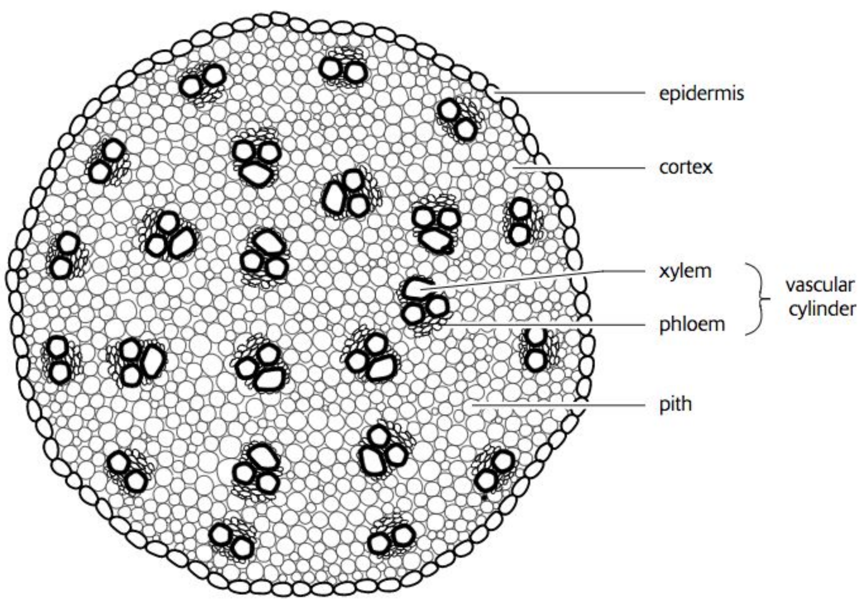


Monocot Root

- <u>Primary Structure of Stems</u>
    - Similar to the root, except the casparian strip and endodermis are usually missing (they are specialized for water absorption which only takes place in the root).
    - Epidermis
        - Contans epidermal cells which are covered with the waxy **cutin** substance, which forms the **cuticle**
        - Contains guard cells (around stomata) and stinging cells
    - Cortex
        - Ground tissue (containing chloroplasts)
        - Bulk of substance lying between epidermis and vascular cylinder
    - Vascular Cylinder
        - Contains Xylem, Phloem, and Pith
        - A single layer of cells between the xylem and phloem may remain undifferentiated and later become the vascular cambium.



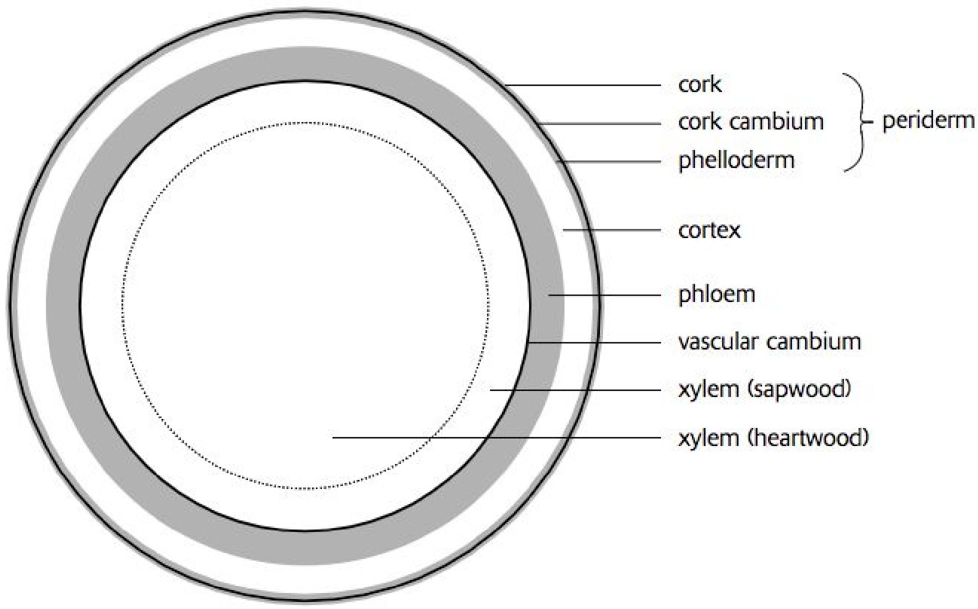
Dicot Stem



Monocot Stem

- <u>Secondary Structure of Stem and Roots</u>
  - The Vascular Cambium
    - Originates between xylem and phloem
    - This layer is <u>meristematic</u>, producing cells on both sides
      - Cells on the inside are secondary xylem cells
      - Cells on the outside are secondary phloem cells

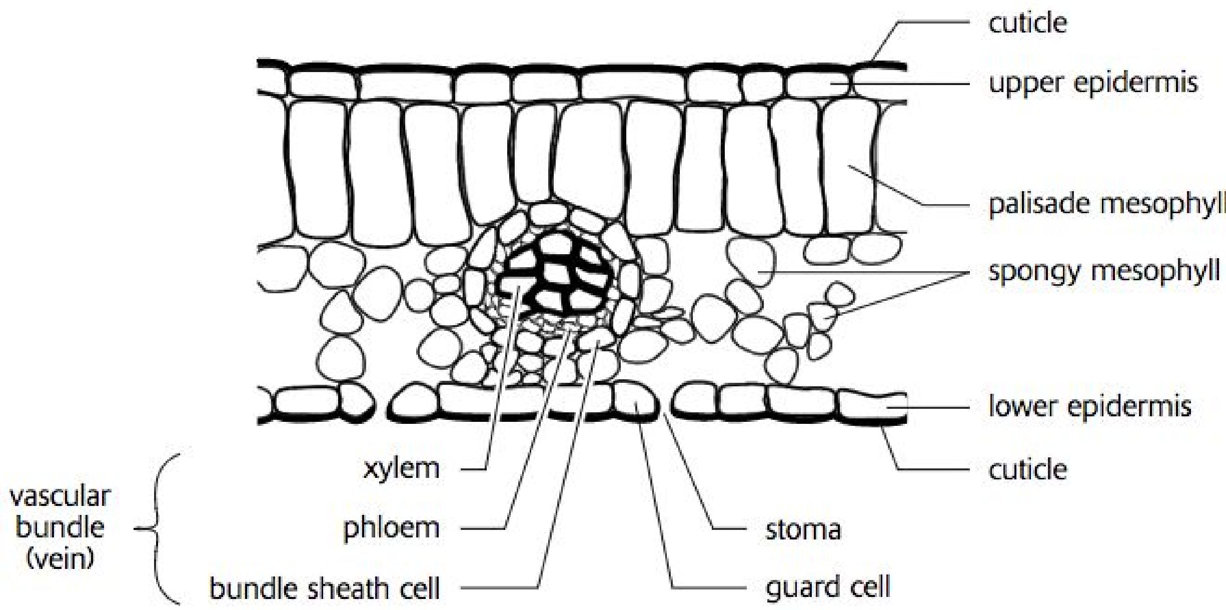
        - The xylem tissue (dead at maturity) is the actual wood of the plant. The sapwood is the active xylem (more recently produced) that still transports water. The heartwood is older and just acts as mechanical support.
        - During seasons of growth, the vascular cambium actively divides. When the seasons come to an end, the growth phase is halted. This alteration of growth → dormancy → growth produces annual rings in the secondary xylem tissue which can help us determine the age of the tree. The size of the ring corresponds to the amount of water available during the year, also allowing us to provide a history of the rainfall in that region.



    - The outer layer of the plant is sloughed off as the secondary xylem and phloem grow outwards. These cells are then replaced by the **cork cambium**.
        - It produces cells on the outside mostly, but sometimes on the inside
        - Phelloderm is made on the inside, cork cells on the outside
    - The **Periderm** is the Cork, Cork Cambium and the Phelloderm

- <u>Structure of the Leaf</u>
    - Epidermis
        - Protective covering
        - Covered by the cuticle, which reduces transpiration (loss of water)
        - Specialized epidermal cells can contain trichomes
    - Palisade Mesophyll
        - Parenchyma cells containing chloroplasts (sites of photosynthesis)
    - Spongy Mesophyll
        - Parenchyma cells more loosely arranged underneath the palisade mesophyll
        - Contains air chambers that can provide CO_2 to photosynthesizing cells and O_2 to respiring cells

- Guard Cells
    - Epidermal cells that contain opening and closing of stomata, which allow gas exchange between the leaf and the outside environment
- Vascular Bundles
    - Xylem and Phloem tissue
    - Mesophyll cells called Bundle Sheath cells surround these vascular bundles so that the vascular tissue is not exposed to intercellular spaces
        - They also provide the anaerobic environment in C4 plants to fix CO_2



Structure of a Leaf

- <u>Transport of Water</u>
    - Water and minerals enter root hairs via osmosis, and then the water moves towards the center of the root in one of two ways:
        - *1)* ***<u>Apoplastic</u>***
            - Water moves through the cell walls
            - They never actually enter the cell, only the "non-living" portions
        - *2)* ***<u>Symplastic</u>***
            - Water moves through one cell to the other
            - Moves from one cytoplasm to the next via plasmodesmata (tubes that connect the cytoplasms)
        - Once water reaches the endodermis, it can only enter the vascular cylinder through the symplast pathway, because the apoplast pathway is blocked by casparian strips
        - Water can enter, but the endodermis is selective to which minerals can enter (K^+ can, Na^+ cannot)

- There are three things that contribute to the water movement and distribution throughout the entire plant:
  - 1) Osmosis
    - There is a concentration gradient from the soil to the inside of the root allowing osmosis to occur. This is because water is continuously moving from the root into the xylem, leaving behind a buildup of minerals that cannot pass.
    - The water moving into the root helps push the water up the xylem to a certain extent. This osmotic force is called **root pressure**. The pressure is minimal compared to the others.
    - Responsible for **guttation** (build up of water droplets on plants).
  - 2) Capillary Action
    - Results from the **adhesive** properties of water and the capillary tube.
    - Water forms a continuous column up the xylem <u>without a meniscus</u>, indicating that the effect of capillary action is also minimal.
  - 3) Cohesion-Tension Theory
    - Transpiration
      - Water evaporates from the leaves of plants causing a **negative pressure** build up in the leaves.
    - Cohesion
      - Water is cohesive, causing it to act like a single polymer unit as it moves up the xylem.
    - Bulk Flow
      - Bulk flow of water through the plant is caused by the water evaporating from the leaf surface, pulling the water behind it.
      - Since transpiration is caused by the heating action of the sun, the sun, then, is the driving force for the ascent of sap through plants.

- Stomata
  - The opening and closing of the stomata influence gas exchange, transpiration, the ascent of sap, and photosynthesis.
    - When stomata are closed, CO_2 is not available, and photosynthesis cannot occur.
    - In contrast, when stomata are open, CO_2 can enter the leaf, but the plant risks desiccation from excessive transpiration.
    - A mechanism that controls the opening and closing of stomata must, therefore, balance these two states and provide a means to optimize photosynthesis while minimizing transpiration.
  - Guard Cells
    - Each stomata has two guard cells surrounding it

            - The cell walls in these guard cells do not have uniform thickness
            - Water diffuses into the guard cell causing it to expand, causing the thinner portion of the cell wall to bulge out, ultimately opening the stoma
            - Water diffusing out of the guard cells closes the stoma
            - When they open and close:
                - Stomata close during high temperatures to decrease water loss (but it also stops photosynthesis because CO_2 cannot enter)
                - Stomata open when [CO_2] is low in the leaf
                - Stomata close at night and open during the day because it uses CO_2 during the day for photosynthesis, but CO_2 builds up at night due to a lack of photosynthesis and an occurrence of respiration
- <u>Transport of Sugars</u>
    - **<u>Translocation</u>** (movement from source → sink)
    - Pressure Flow Hypothesis:
        - Sugars enter sieve-tube members
            - Soluble carbohydrates move from their source of production (palisade mesophyll) to phloem sieve-tube members via active transport
            - A concentration of solutes develops in the sieve-tube members at the source that is higher than that at the sink
        - Water enters sieve-tube members.
            - Because of the sugars moving into the cell, there is less water concentration inside the sieve-tube member cells
            - Water diffuses into these cells
        - Pressure in sieve-tube members at the source moves water and sugars to sieve-tube members at the sink through sieve tubes.
            - The cell walls in sieve-tube members do not expand when water enters, so pressure builds up
            - The water and sugar moves via bulk flow through sieve-tube cells (from cell to cell through channels called sieve plates)
        - Pressure is reduced in sieve-tube members at the sink as sugars are removed for utilization by nearby cells.
            - Pressure begins to build up at the sink
            - The sink uses up the carbohydrates (transports them out via active transport) causing a buildup of water
            - Water diffuses out of the cell to relieve the pressure
    - Also note that sugars can be stored as starch, which is NOT soluble. Essentially this means a cell can decrease its sugar concentration by storing sugars as starch (having the same effect as if the cell utilized the sugars for energy). Any cell can also break down the starch, and thus it becomes a source.

- <u>Plant Hormones</u>
    - Auxin (IAA)

        - Promotes plant growth via elongation of developing cells
        - **Phototropism** - Auxin is produced in the tips of shoots and roots, influencing the plants response to light (if there is a barrier inbetween the plant and the sun, the plant will release auxin on the more shaded side allowing it to grow around the barrier)
    - Gibberellins
        - Also promote cell growth
        - Involved in the promotion of fruit development seed germination
        - High concentrations can cause bolting (rapid increase of length by stems, such as when rice was bolted in response to fungi containing the hormone)
    - Cytokinins
        - Stimulate cell division
        - Influence organ development (determines whether or not roots/shoots will develop)
        - Delay aging of leaves and are often added to prolong the plant's usefulness
    - Ethylene
        - A gas that promotes fruit ripening
        - Also involved in stimulating flower production
        - Influences leaf abscission,the aging and dropping of leaves.
    - Abscisic Acid (ABA)
        - A growth inhibitor
        - Maintains dormancy in seeds

- Plant Response to Stimuli (Tropism)
    - 1) **Phototropism**
        - Plant growth in response to light (achieved by auxin hormone)
        - Auxin is produced in the apical meristem, and then moves to the zone of elongation to stimulate elongation
        - If all sides of a steam are illuminated by light equally, then growth is equal resulting in a straight stem
        - When the stem is unequally illuminated, auxin concentrates on the shady side of the stem causing differential growth
    - 2) **Gravitropism**
        - Plant growth in response to gravity (not well understood)
    - 3) **Thigmotropism**
        - Response to touch (not well understood)
        - Vines wrapping around a fence
- Photoperiodism
    - Response of plants to photoperiod (length in daylight and night)
    - Plants maintain a circadian rhythm (internal clock) to measure the length of day and night

- Phytochrome is a key protein involved. There are two kinds:
  - P_r (or P_{600})
  - P_{fr} (or P_{730})
- When P_r is exposed to sunlight, it is converted into P_{fr}. When P_{fr} is exposed to far-red light, it is converted back to P_r.
- These two are in equilibrium during the daylight.
- P_r accumulates at night, and then is rapidly converted into P_{fr} at daybreak.
- Types of Flowering Plants:
  - Long-day
    - Flower in the spring and early summer when daylight is increasing
  - Short-day
    - Flower in late summer and early fall when daylight is decreasing
  - Neutral-day
    - Do not flower in response to changes in daylight

Animal Form and Function

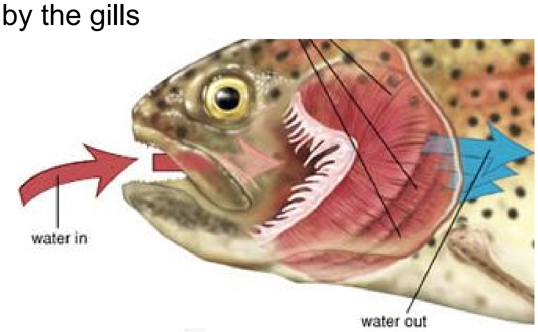
- The functions of animals is often Homeostasis (maintaining stable, internal conditions despite the changing environment). Cells within organisms are organized in the following ways to achieve this:
  - 1) Tissues
    - Tissues are groups of similar cells that work together to perform a common function. Types of tissues are:
      - **Epithelial**
        - Shape based (Squamous, cuboidal, columnar, etc.)
        - Layer based (Simple, Stratified, Pseudostratified)
      - **Nervous**
        - Neurons, Glial Cells
      - **Connective**
        - Loose, Dense, Fibrous, Cartilage, Bone, Blood, Adipose
      - **Muscle**
        - Smooth, Striated, Cardiac
  - 2) Organs
    - Groups of tissues functioning together
    - The heart is an organ that contains ALL FOUR tissues that work together
  - 3) Organ Systems
    - Groups of organs that work together
    - The digestive system is one example
- Negative Feedback
  - Negative feedback is commonly used within animals to achieve homeostasis.
  - A **receptor** (*sensing* mechanism) detects when conditions change beyond the limits that are allowed. So these are what monitor the conditions

- An **integrator** (*control center* - usually the brain) then can activate a second mechanism called an effector. So the integrator is what evaluates the conditions detected by the receptor.
- An **effector** corrects the conditions in response to the control center.

- Thermoregulation
  - Two groups of animals: (differing in how they regulate their body temperature)
    - Ectotherms
      - These organisms obtain body heat from the environment
      - Includes invertebrates, amphibians, reptiles, and fish
      - Also called **poikilotherms**
      - Also called **cold-blooded** animals, because they often feel cold to the touch (note they can become warmer than the environment by basking in the sun)
    - Endotherms
      - These organisms generate their own body heat
      - Also called **homeotherms**
      - Also called **warm-blooded** animals, because their temperature is relatively warm (compared to ectotherms)
  - How animals regulate their body temperature:
    - 1) Cooling by Evaporation
      - Many can lose heat by sweating
      - Liquid → Gas is a **endergonic** reaction (requires heat)
      - Note this includes evaporation out of the respiratory system (like when dogs pant)
    - 2) Warming by Metabolism
      - Metabolic activities generate heat
      - This includes contracting muscles (this is why we shiver when we are cold!)
    - 3) Adjusting Surface Area
      - Our extremities, such as arms, legs, ears, etc. add a considerable amount of surface area to our body
      - Our body can adjust the amount of blood flow to certain areas of the body, to either warm us or keep us cool
        - Elephants in hot climates have increased blood flow to their large ears, allowing their body to remain cool
        - When we are freezing cold, we will have reduced blood flow in our hands, etc.
      - This occurs via **vasodilation** or **vasoconstriction**
      - Also, when blood is flowing towards an extremity, there is blood moving alongside it in the opposite direction. Here, we have **countercurrent exchange** which allows the warmer blood to pass the heat over to the colder blood returning to the body

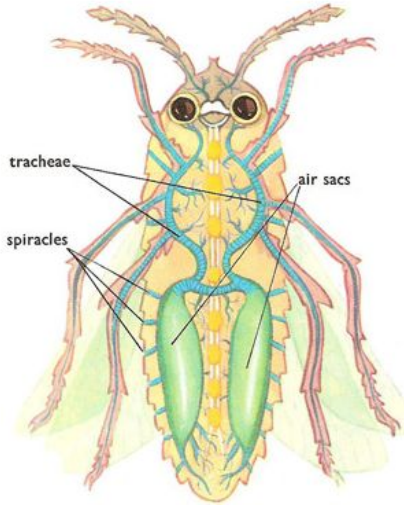
- Besides physiological means of maintaining proper body temperature, many animals use physical means, such as staying in the shade, only coming out at night, hibernating when it's cold, or some have evolutionary traits that benefit them such as fur, blubber, or feathers.

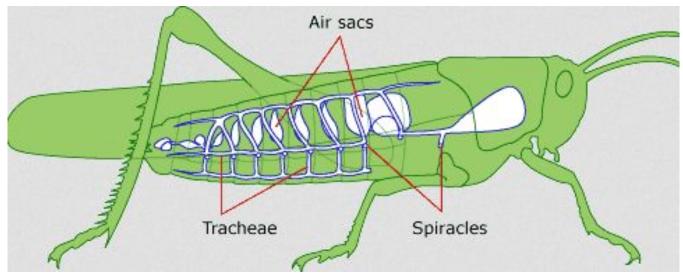
- **<u>The Respiratory System</u>**
  - Most cells in animals require O_2 to function (aerobic respiration). Since most cells are not directly exposed to the environment, the respiratory system provides a mechanism to provide gas exchange to internal cells (delivering O_2 as well as removing CO_2).
    - The word **respiration** describes this movement of gases.
  - Gas Exchange Mechanisms in Animals:
    - 1) <u>Environment</u>
      - Some very small animals have gas exchange occurring directly with the environment. Most of their cells are either exposed to the environment, or close enough that the O_2 can easily diffuse through to them
        - This includes flatworms (platyhelminthes)
      - In some larger animals, the gas that diffuses through the skin can then be distributed throughout the animal by a distribution system
        - This includes segmented worms (annelida)
    - 2) <u>Gills</u>
      - Gills are **evagenated** structures (outgrowths) from the animals body. They create a large amount of surface area allowing for gas exchange
      - The gills contain a circulatory system that can remove the oxygen, creating the waste CO_2.
      - There are internal (protected) gills which are common in fish, but some organisms have external (unprotected) gills. In fish, water enters the mouth, and exits the gill cover, the **operculum**, after passing by the gills



      - Countercurrent exchange occurs here via the water and oppositely moving blood. This maximizes the amount of O_2 that enters the blood, as well as the amount of CO_2 that enters the water
    - 3) <u>Tracheae</u>

- Tracheae are **tubes lined with chitin** found within insects
- They permeate throughout the entire insect's body!





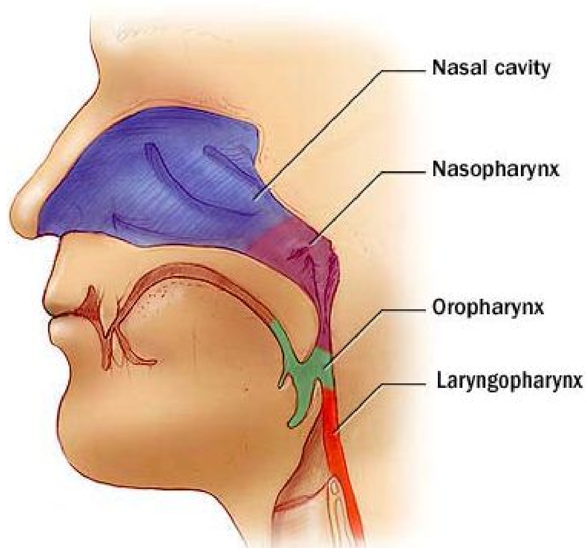
- O_2 comes in, and CO_2 leaves through openings in the tracheae called **spiracles**.

■ 4) <u>Lungs</u>

- Lungs are **invaginated** structures/cavities within an animal.
- **Book lungs** are a unique stack of membranes within a structure, common in many types of spiders

○ Process of Gas Exchange in Humans:

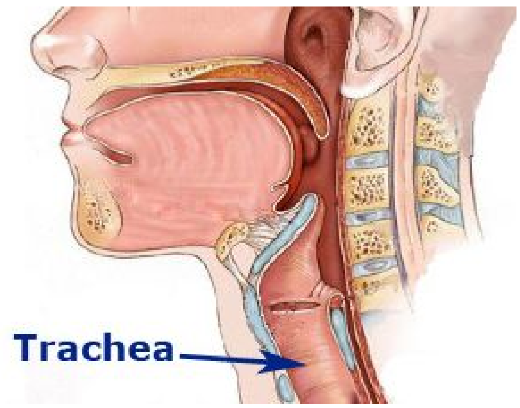
■ 1. O_2 enters through the nose, passing through the **nasal cavity → pharynx → larynx**

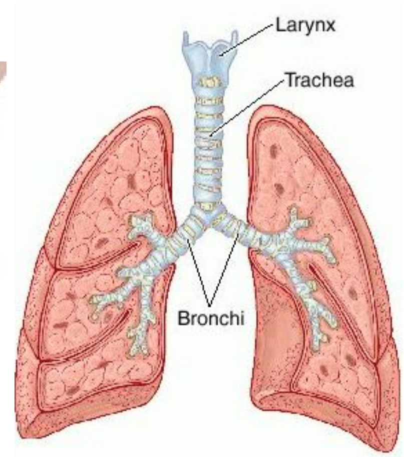


- Note that the larynx is the "voice box" containing vocal cords

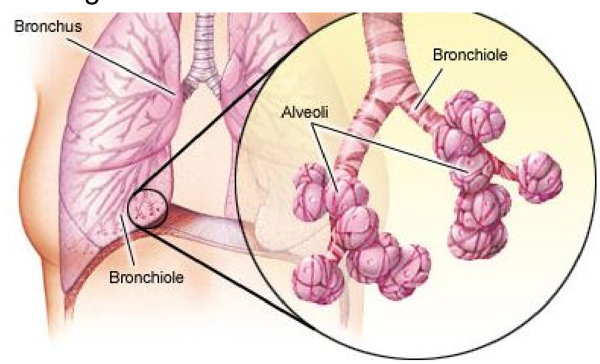
■ 2. The O_2 passes through the larynx and into the **trachea** (a tube lined with cartilage).

    - Note the epiglottis structure covers the trachea when you swallow





- 3. The trachea then branches into **two bronchi** (singular = bronchus).
    - The bronchi enter the lungs, and then branch repeatedly (see above) forming even narrower tubes called **bronchioles**.



- 4. Each branch of the bronchioles end in a small sac called an **alveolus**, each one being densely surrounded by blood carrying capillaries.
    - Diffusion takes place between the alveoli and blood. The alveolar sacs are moist, and the O_2 diffuses from the alveolus, into the moisture around the membrane through the alveolar wall, into the capillary, and finally into the blood cells. CO_2 goes in the opposite direction.
- 5. The O_2 is then transported via the circulatory system throughout the body by the red blood cells.
    - The RBCs have an iron-containing protein called **hemoglobin** which allows O_2 to bind
- 6. Blood capillaries permeate throughout the entire body, allowing diffusion between the blood and the cells of the body. The O_2 diffuses out of the RBC, across the capillary walls, into the **interstitial fluids** (which is what surrounds cells), and finally across the membranes of the cells. As always, CO_2 goes in the opposite direction.
- 7. Most of the CO_2 in our bodies travels through the blood plasma, but **it actually travels as bicarbonate ions** (**HCO_3-**). Although it travels

through the blood plasma (the liquid part in the blood), the bicarbonate is formed within the RBCs.

- First, within the RBC, is the formation of **Carbonic Acid** (H_2CO_3). This is catalyzed by the enzyme **Carbonic Anhydrase**.

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3^-$$

  - Once the HCO_3- is formed in the RBC, it diffuses into the plasma.
- Note that this does not happen with all of the CO_2 (just most of it). Some of it just simply dissolves in the blood plasma as CO_2 gas, or binds to the amino groups in hemoglobin.

■ 8. The Mechanics of Air Movement: Air is moved into and out of the lungs simply by changing their volume. The **diaphragm** is a muscle underneath the lungs. When the diaphragm contracts, it increases the volume of the lungs. The **intercostal muscles** also help with this.

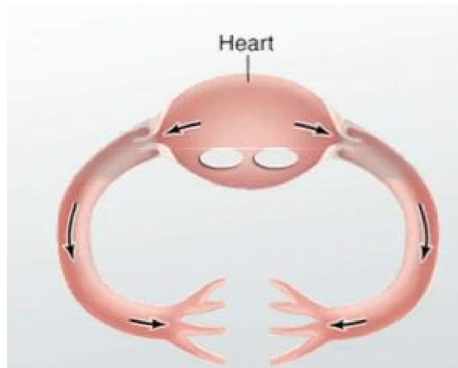
- When the lung volume increases, pressure inside of the lungs decreases
- The pressure difference between the inside of our lungs and the outside air causes air to rush into the lungs via bulk flow
- The diaphragm and intercostal muscles relax, decreasing the volume in the lungs, which raises the pressure on the air causing it to move out of the lungs.

■ 9. Control of Respiration - We have **chemoreceptors** in our **carotid arteries** (the arteries supplying our brain with blood). These chemoreceptors *monitor the pH of our blood*.

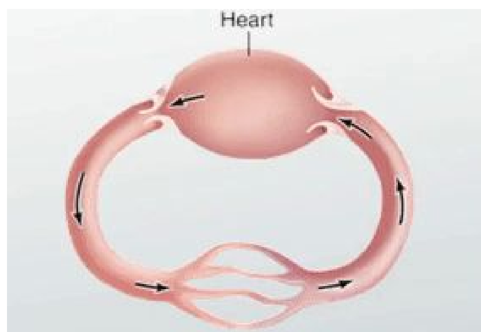
- When you are very active, the amount of CO_2 increases. This causes your blood to become more acidic (lower pH) due to it being converted to carbonic acid (H_2CO_3) as explained above.
- In response to the low pH, the chemoreceptors send nerve impulses **directly to the diaphragm** to increase the respiratory rate
- This increases the rate of gas exchange, returning the blood pH back to normal (negative feedback - homeostasis)

- **The Circulatory System**
  - The circulatory system is what moves blood and lymph throughout an organism. Larger organisms have a circulatory system to assist in distribution of nutrients and oxygen, as well as to remove wastes/CO_2. There are two types of circulatory systems:
    - ■ 1) Open Circulatory Systems [Video]
      - Mostly in insects/mollusks
      - These organisms do not contain isolated blood like humans do, but rather their blood mixes with the interstitial fluid and is called **hemolymph**.

- Blood is pumped into the **hemocoel** (an internal cavity/sinus) where the organs sit. This hemocoel directly bathes the organs with oxygen/nutrient rich fluid called **hemolymph**. The hemolymph then returns to the heart through holes called **ostia**.



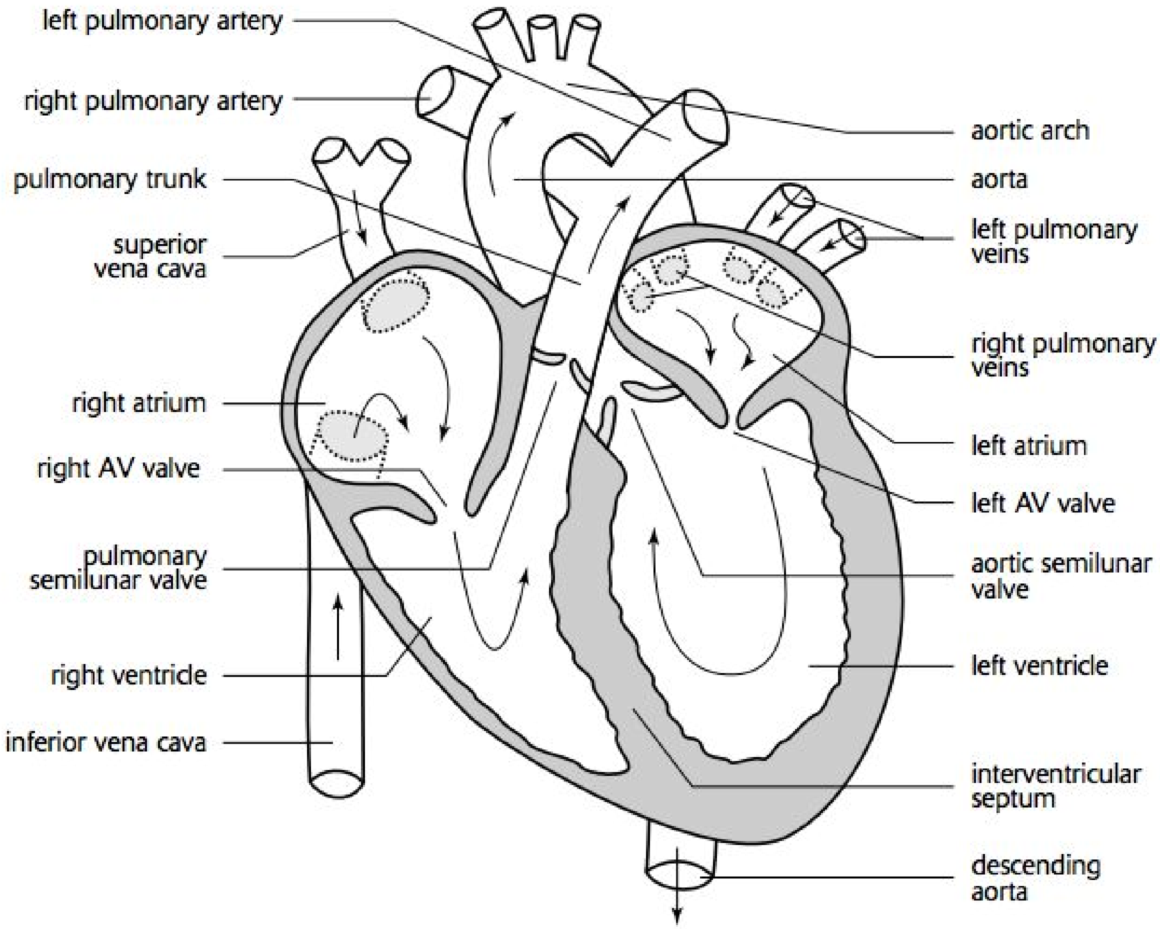
- 2) Closed Circulatory Systems
  - Found in Annelids (earthworms, for example), certain mollusks (octopuses and squids), and vertebrates.
  - Here, blood carries nutrients, oxygen, and wastes, and it does not mix with interstitial fluid of the body as it is a closed system. The blood is instead confined to vesicles.



  - Vesicles that move blood away from the heart are called **arteries**
    - These branch into smaller vesicles called **arterioles**, and then into **capillaries**
    - Gas/nutrient exchange occurs across the capillary walls into the interstitial fluid and finally into the cells.
    - Wastes move from the cells into the capillaries in the opposite direction.
  - Vesicles that move blood towards the heart are called **veins**
    - Deoxygenated blood starts in a capillary after it drops the oxygen off at the cells/tissues. It returns to the heart through **venules**, which eventually merge into the larger veins.
  - The deoxygenated blood arrives at the heart, and is then pumped out again through arteries, and into the lungs (or gills). These

        - arteries again branch into capillaries in the lungs where gas exchange can occur, allowing the blood to pick up more oxygen.
        - The re-oxygenated blood returns to the heart through veins. It is then pumped again throughout the body to provide the oxygen to the tissues.

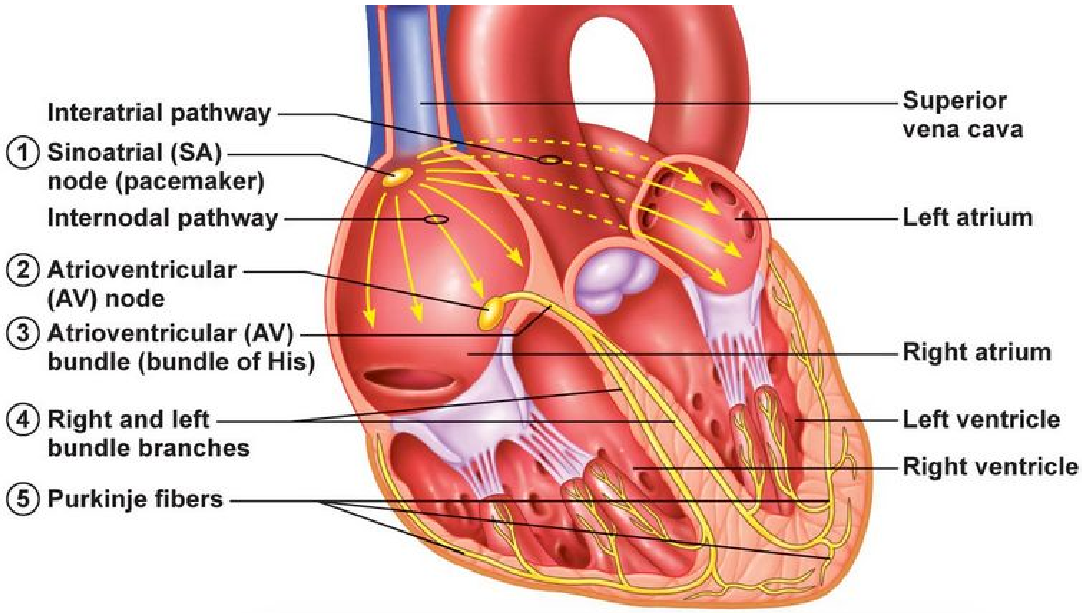
- <u>Blood Flow Through the Heart</u>:
    - 1. Right Atrium
        - Deoxygenated blood enters here through either the superior or inferior vena cava
    - 2. Right Ventricle
        - Blood moves from the right atrium through the **right AV valve/tricuspid valve** into the right ventricle
        - The ventricles have much thicker/stronger walls than the atrium, allowing them to contract and pump the blood.
        - The right ventricle pumps blood into the pulmonary artery through the **pulmonary semilunar valve** towards the lungs.
        - Contraction of the ventricle closes the AV valve to prevent the blood from flowing back into the atrium. As the ventricle relaxes, it closes the semilunar valve to prevent backflow into the ventricle.
    - 3. Left Atrium
        - The blood is oxygenated in the lungs, and then it returns to the heart through the pulmonary veins.
        - The pulmonary veins dump the blood into the left atrium of the heart
    - 4. Left Ventricle
        - Blood passes from the left atrium through the **left AV valve/bicuspid valve/mitral valve** into the left ventricle.
        - The left ventricle contracts, pumping the blood into the aorta through the **aortic semilunar valve**. Similar to the right ventricle, contraction causes the left AV valve to close and relaxation causes the aortic semilunar valve to close, preventing backflow.
        - From here, the blood goes up through the aortic arch and out throughout the rest of the body!
    - The blood pathway between the right side of the heart, to the lungs, and back to the left side of the heart is called **the pulmonary circuit**.
    - The circulation pathway throughout the body (between the left and right sides of the heart) is **the systemic circuit**.



The Heart

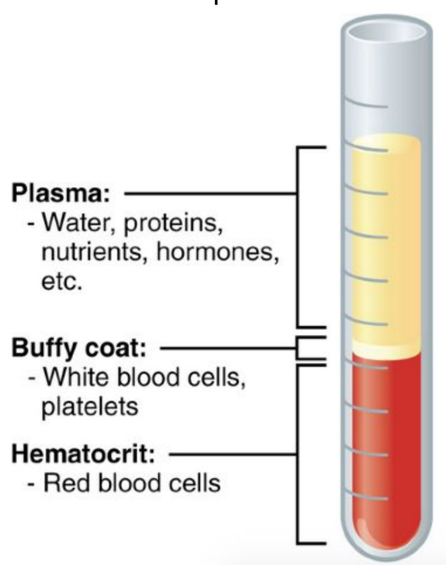
- <u>The Cardiac Cycle/Heart Cycle</u>
  - The cardiac cycle refers to the rhythmic contraction/relaxation of the heart muscles. This is regulated by **autorhythmic cells**, which do not need help from nerves or anything else...they function completely on their own.
  - The Cycle Steps:
    - 1. **The SA node** (sinoatrial node) or **pacemaker** is located in the upper wall of the right atrium.
      - This node stimulates the cycle by contracting BOTH atria at the same time (simultaneously), and then sending a delayed impulse to stimulate the AV node.
    - 2. **The AV node** is in the lower wall of the right atrium.
      - This node sends an impulse through the **bundle of his**, which passes between both ventricles, and also branches into the ventricles via **purkinje fibers**.
      - This is what causes contraction of the ventricles.

- 3. The ventricles contract (**systole phase**) forcing blood through the pulmonary arteries and the aorta. Remember, when the ventricles contract, both AV valves close.
  The ventricles relax (**diastole phase**), and a small amount of backflow into the ventricles causes the semilunar valves to close.
    - The closing of the AV valves, followed by the closing of the semilunar valves, causes the “lub-dup” sound made by the heart!



        - **Hydrostatic pressure** in the heart is what causes the movement of blood through the arteries. As you go from artery → arteriole → capillary, the blood pressure drops and is ultimately zero in the venules. However, **blood still continues to move through the veins, <u>NOT</u> DUE TO CONTRACTIONS OF THE HEART**, but rather due to the contraction of skeletal muscles which squeeze on the veins. This squeezing pushes the blood towards the heart because veins contain valves which prevent backflow.
    - The Lymphatic System
        - Although most waste/interstitial fluid enters the circulatory system by diffusing into the capillaries, a lot of it doesn’t.
        - There is a second network of capillaries and veins...the lymphatic system, where some interstitial fluid and waste enter.
        - **Lymph** is the fluid that circulates throughout the lymphatic system. The lymph is formed when the interstitial fluid (the fluid which lies in the interstices of all body tissues) is collected through lymph capillaries. It is then transported through lymph vessels to lymph nodes before emptying ultimately into the right or the left subclavian vein, where it mixes back with blood.

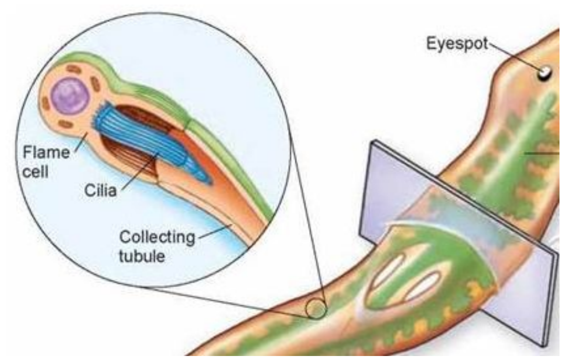
        - Similar to veins, the fluid (called lymph) travels due to adjacent skeletal muscle contractions. They also have valves that prevent backflow.
        - The lymph returns to the blood circulatory system via two ducts in the shoulder area
      - The lymphatic system, in addition to returning fluids back into the circulatory system, it also acts as a filter
        - **Lymph nodes** act as filters and defend against infections
  - Blood is composed of:
    - Erythrocytes (RBCs)
      - Transporters of oxygen
      - Catalyze the conversion of $CO_2 \rightarrow H_2O + H_2CO_3$
      - Mature RBCs do not have a nucleus (giving them more room for hemoglobin, allowing a greater efficiency in oxygen transport)
    - Leukocytes (WBCs)
      - Disease fighting cells
      - Fight against infections
    - Platelets
      - These are fragments of cells involved in blood clotting.
      - **Fibrinogen** (the main agent involved in clotting) is normally inactive. The platelets release factors that activate it, turning fibrinogen into the active form, **fibrin**. These fibrin proteins form a network thread that stops blood flow.
    - Plasma
      - Liquid portion of the blood
      - Contains various proteins/dissolved substances



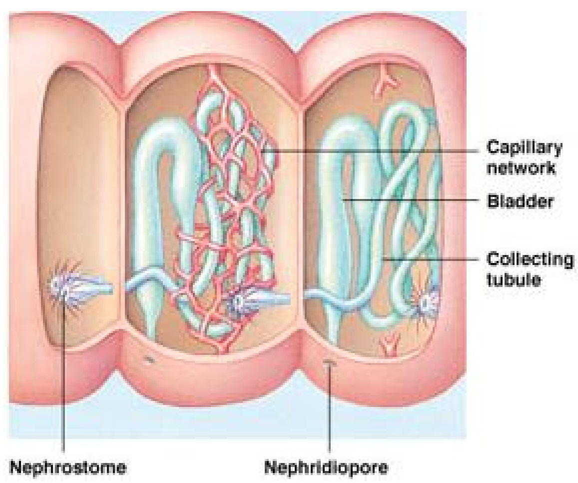
- **The Excretory System**
  - Regulates water balance and removes harmful substances

- **Osmoregulation** is the maintenance of constant osmotic pressure in the fluids of an organism by the control of water and salt concentrations.
    - Marine Fish (Saltwater fish)
        - These are **hypoosmotic** in comparison to their environment (*hypo* meaning less salty). Because of this, water is constantly loss via osmosis (water moving from low → high concentration)
        - To maintain homeostasis, marine fish must drink constantly and rarely urinate, as well as secreting the accumulated salts that come in from drinking the salty water.
    - Freshwater Fish
        - These are **hyperosmotic** in comparison to their environment (hyper meaning more salty than the water they are in).
        - Water diffuses from low → high concentration of salt, meaning it diffuses inside of the fish. Opposite of the saltwater fish, this means that freshwater fish rarely drink water, they constantly urinate, and they absorb salts lost through the urine through their gills.
- There are many different mechanisms in different types of organisms that are involved in excreting toxic substances:
    - **Contractile Vacuoles**
        - These are simply vacuoles found in protists that accumulate water, and release it into the cytoplasm

    - **Flame Cells** (protonephridia)
        - Found in Platyhelminthes (flatworm)
        - Function like a kidney does - removing waste materials. The fluids of the body are filtered across the flame cells, moved by the cilia.
        - Wastes are excreted through pores that exit the body.

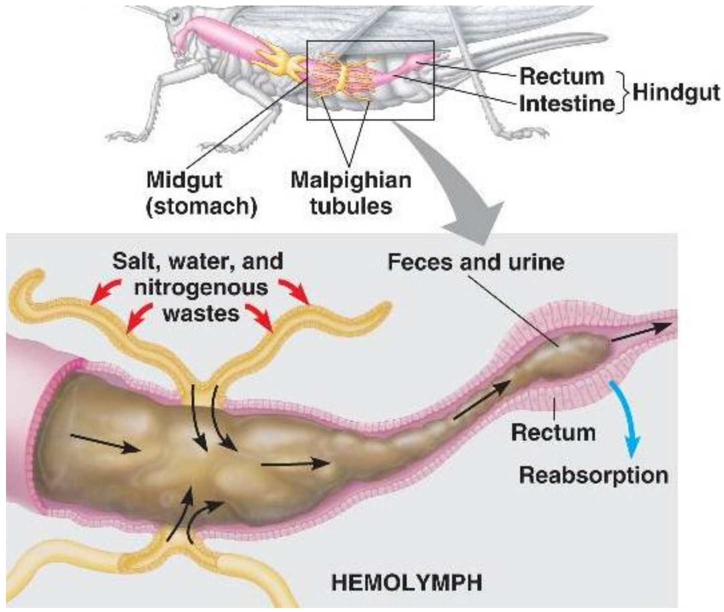


- **Nephridia** (or metanephridia)
  - Found in annelids (segmented worms)
  - Interstitial fluid enters the nephridium through a ciliated opening (called a **nephrostome**). As the fluid passes through the collecting tubule, it increases in concentration due to many of the salts/materials being selectively secreted into the coelomic fluid. There are blood capillaries that then reabsorb the materials the organism needs.
  - At the end of the collecting tubule, the waste exits through an **excretory pore**.
  - Nephridia exemplify a tube-type excretory system, where body fluids are selectively filtered as they pass through the tube. Materials to be retained are secreted back into the body fluids, while concentrated wastes continue through the tube to be excreted at the far end.

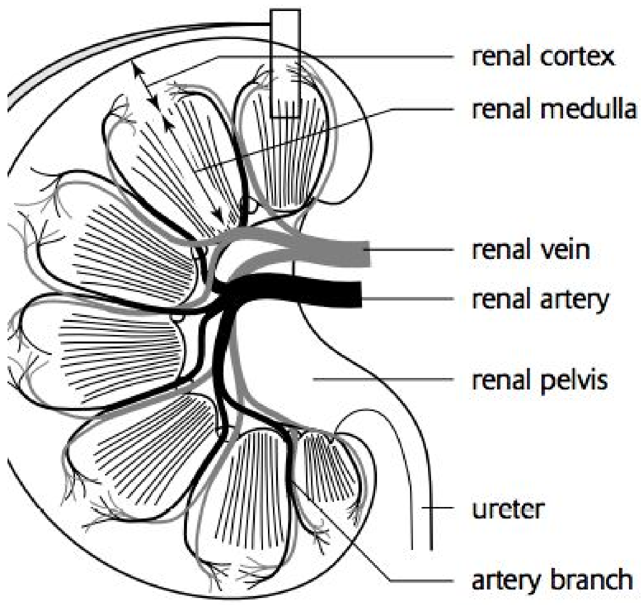


- **Malpighian Tubules**
  - Found in arthropods (insects, spiders, crustaceans)
  - There are tubes attached to the midgut of the digestive tract that collect body fluid from the hemolymph (the fluid contains wastes and necessities).

- The fluid (as well as the food they ate) passes through the digestive tract. Once it reaches the hindgut, needed materials are passed back out so that they can be retained.
- The wastes continue through and are excreted through the anus.



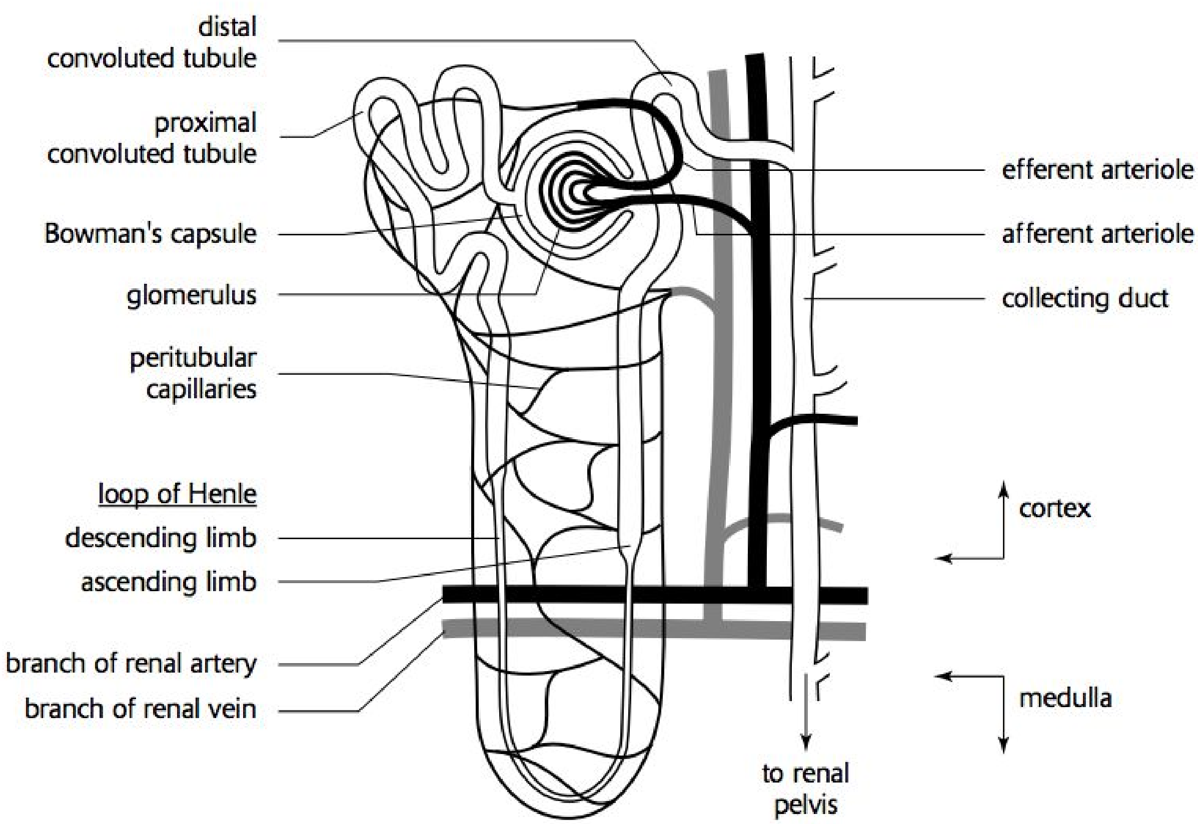
- **The Kidney**
  - The kidney contains millions of **nephrons**, which are the filtering tubes.
  - The waste fluids produced in the kidneys is called **urine**, and travels through **ureters** to the **bladder**. The urine is stored in the bladder and excreted through the **urethra**.



Kidney

- The Nephron (of the kidney)
  - Consists of a tube with blood vessels closely associated to it.
  - The tube winds from the cortex of the kidney deeper into the medulla, back up to the cortex, then back to the medulla. It drains in the **renal pelvis** (the center of the kidney).
  - The Nephron is made up of:
    - Bowman's Capsule
      - Beginning of the nephron tube
      - The afferent arteriole (part of the renal artery) enters the capsule and forms a dense ball of vessels called the **glomerulus**.
      - The vessels then exit out of the capsule, and it becomes the efferent arteriole.
    - Convoluted Tubule
      - The proximal convoluted tubule begins at bowman's capsule, where filtrate is absorbed from the blood moving through the glomerulus.
      - It ends with the distal convoluted tubule which joins up with the collecting duct to send out the waste.
      - **The Loop of Henle** is found in the middle of the convoluted tubule
        - Descending Limb descends down from the proximal convoluted tubule

        - <u>Ascending Limb</u> ascends upwards towards the collecting duct
    - The efferent arteriole has branching capillaries that surrounds the convoluted tubule. These capillaries eventually dump into the renal vein as they exit the nephron.
- Collecting Duct
    - The distal convoluted tubule dumps into the collecting duct, which descends toward the center of the kidney.
    - Multiple nephrons share a single collecting duct.
    - The collecting duct dumps contents into the **renal pelvis**, which then drains into the ureter.

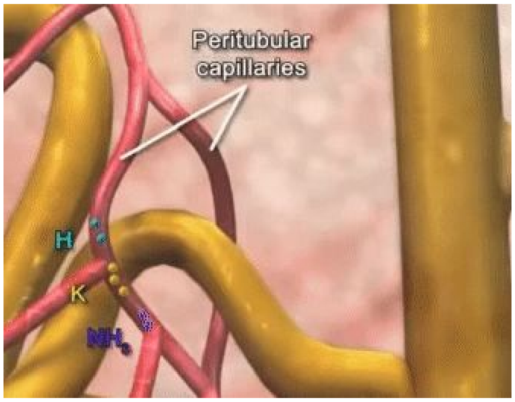


Nephron

- The processes of the nephron are:
    - 1. **Filtration**
        - Blood enters the glomerulus, and a high amount of pressure forces the water/solutes to exit the capillary walls, and enter bowman's capsule.
            - Salts and sugars can pass through

- Larger proteins and RBCs are too big to pass, so they continue through the artery
- The filtrate then goes from bowman's capsule → proximal convoluted tubule

- 2. **Secretion**
  - Additional fluids/substances can be secreted INTO the convoluted tubule as the filtrate passes through. These fluids are secreted from the capillaries of the efferent arteriole.
  - These materials are *selectively secreted* via active and passive transport from the capillary network



- 3. **Reabsorption**
  - The filtrate moves down the loop of henle, becoming more and more concentrated due to water flowing outwards.
    - Descending Limb = High Concentration
  - The filtrate then moves up the loop of henle, where salts/materials are *actively* and *passively transported* out, causing the solution to become more dilute.
    - After the filtrate has passed the loop of henle, the outside interstitial fluids are highly concentrated due to this passing of salt
    - The filtrate itself is LESS concentrated and MORE dilute.
  - The filtrate enters and descends down the collecting duct, towards the renal pelvis. As it moves down, it passes by the the area where there is a high concentration of salt in the outside interstitial fluid. This causes water to diffuse out of the collecting duct.
    - By the time it gets to the renal pelvis, the filtrate is highly concentrated urine.

- Hormone Influence
  - The concentration of the filtrate is regulated by two hormones:

- **Antidiuretic Hormone (ADH)**
  - Also called vasopressin
  - Increases water reabsorption by the body (anti-diarrhea), which in turn increases the concentration of salts in the urine.
  - It works by increasing **the permeability of the collecting duct** before it dumps into the renal pelvis. This allows for more water absorption.
- **Aldosterone**
  - Increases the reabsorption of **sodium (Na^+)**, which naturally causes the reabsorption of water along with it.
  - It works by **increasing the permeability of the distal convoluted tubule and collecting duct** to Na^+. When Na^+ is reabsorbed by the body, it increases the concentration of salt causing water to passively follow.

- Nitrogen Waste
  - Nitrogen is a major waste product in animals due to the breakdown of amino acids and nucleic acids.
  - The NH_3 (ammonia) produced is toxic to the animals, and there are different mechanisms to get rid of it:
    - Aquatic animals/fish excrete the NH_3/NH_4^+ directly into the water
    - **Mammals convert NH_3 → Urea in the liver**
      - They do this because it allows them to excrete the NH_3 without getting rid of lots of water. This is because urea is much less toxic, so does not require as much water to go along for the ride.
    - **Birds, insects, and reptiles convert urea → uric acid**
      - Uric acid is <u>insoluble</u> in water, so it precipitates out forming a solid. This allows the organism to excrete nitrogen as a solid, rather than a liquid, conserving water.
      - Eggs have a special sac called an **allantois** that separates this solid nitrogen toxic waste from the developing embryo.

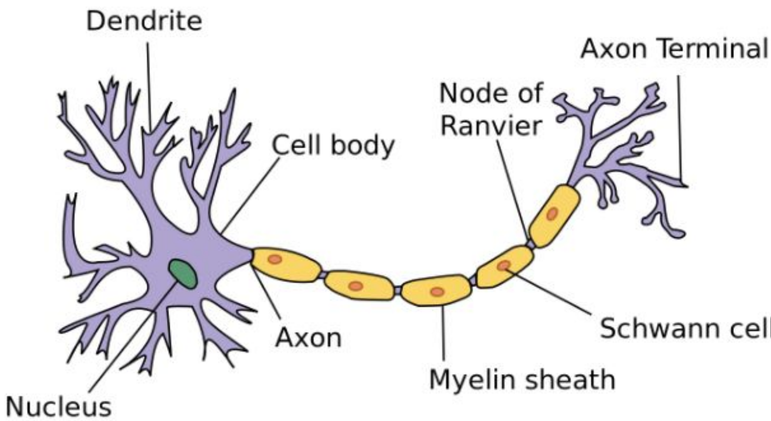
- **<u>The Digestive System</u>**
  - Digestion occurs both on a small scale (cellular lysosome) as well as a large scale (gastrovascular cavity). It usually occurs first on the large scale, allowing smaller pieces to enter the cell.
  - The types of molecules that are digested include:
    - Starches (sugars)
      - Broken into glucose
    - Proteins
      - Broken into amino acids
    - Lipids
      - Broken into glycerol/fatty acids

        - Nucleic Acids
            - Broken down into nucleotides
- Digestive Areas and Enzymes involved:
    - <u>Mouth</u>
        - **Salivary Amylase** begins the breakdown of starch → maltose
        - Food is shaped into a bolus and swallowed
    - <u>Pharynx</u>
        - When food enters here, the **epiglottis** blocks it from entering the trachea
    - <u>Esophagus</u>
        - **Peristalsis** is the muscular contractions that moves the bolus through the esophagus and digestive tract.
    - <u>Stomach</u>
        - **Gastric juice** is secreted (a mixture of enzymes and HCl).
        - Storage - the stomach walls contain folds allowing a large amount of storage (2-4L)
        - **Chyme** is produced as water and gastric juice mix with the food
        - Muscles churn the content in the stomach causing it to breakdown into smaller particles.
        - HCl in the gastric juice unfolds proteins and kills bacteria.
        - **Pepsin** is an enzyme that chemically breaks down proteins
            - **Pepsinogen** is the secreted, inactive form of pepsin. Because this enzyme has an inactive form, it prevents the stomach cells from digesting themselves with it.
            - **Pepsinogen is activated → Pepsin when it comes in contact with the HCl**. Because of this, proteins are only digested after pepsinogen has been secreted, and not before!
        - A **protective mucous** in the stomach lining is secreted by stomach cells to prevent damage when protein digestion begins. If this mucous fails to form, **ulcers** are a result.
        - The **pyloric sphincter** is a valve that releases the chyme into the small intestine
    - <u>Small Intestine</u> (Duodenum, Jejunum, Ileum)
        - The duodenum is the first 25ft of the small intestine. It continues to digest proteins and starches, as well as other food types such as fats and nucleotides.
            - **Proteases** (proteolytic enzymes) come from the wall of the small intestine.
            - **Maltase and Lactase** also come from here
            - **Phosphates** (digestion of nucleotides) as well
        - The pancreas produces digestive enzymes which enter the duodenum through the pancreatic duct. These enzymes include:

                - **Trypsin and Chymotrypsin** (proteases)
                - **Lipase** (fat digestion)
                - **Pancreatic Amylase** (starch digestion)
            - The liver makes bile, which **emulsifies fats** (breaking fat into very small droplets) which allows for much greater surface area for lipases to digest them. Bile is not an enzyme, as it does not chemically change anything in the fats.
                - Bile is stored next to the liver, in the gallbladder, and released through the **bile duct**.
                - The bile duct merges with the pancreatic duct
            - The rest of the small intestine absorbs the breakdown products from the previous process. Amino acids/sugars are absorbed into the blood, and fats are absorbed into the lymphatic system.
                - **Villi** and **Microvilli** allow for absorption
                - These increase the surface area for absorption by their finger-like projections
        - <u>Large Intestine</u> (colon)
            - The colon functions to **reabsorb water** to form feces.
            - Feces are stored in the rectum (the end of the large intestine), and excreted through the anus.
            - Humans have a useless **appendix** that branches off at the beginning of the large intestine.
                - This same organ is called a **cecum** in herbivores and is useful for harboring bacteria that help digest cellulose.
    - Hormone Influence
        - **Gastrin**
            - When food enters the stomach, gastrin is produced by stomach cells
            - It is also produced when we smell or see food (via the nervous system in preparation for eating)
            - Gastrin enters the bloodstream and stimulates other cells to release gastric juices
        - **Secretin**
            - Produced in the duodenum when food enters from the stomach
            - Stimulates the pancreas to make bicarb which in turn reduces the acidity of the chyme (chyme is acidic from HCl and is neutralized by bicarbonate)
        - **Cholecystokinin**
            - Produced by the small intestine **in response to fats**
            - This hormone **stimulates bile release** from the gallbladder
            - It also **stimulates the pancreas** to release digestive enzymes.

- **<u>The Nervous System</u>**

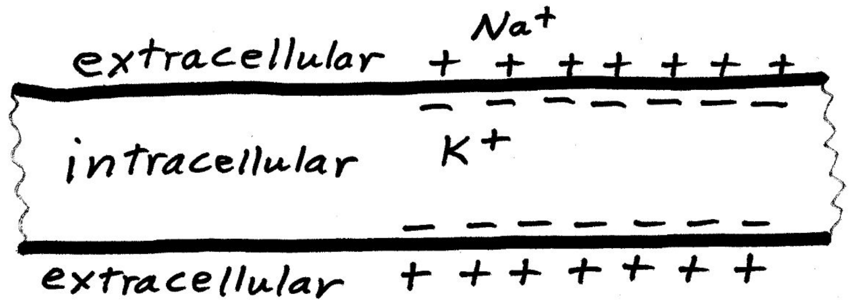
- A neuron is composed of:
  - **Cell Body**
    - Contains nucleus/organelles
  - **Dendrite**
    - An extension of the cell body that receives stimuli
  - **Axon**
    - Long extension of the body that sends nerve impulses



- Process of stimuli:
  - Impulse at dendrites → cell body → axon → axon branches (terminates)
- Types of Neurons:
  - **Sensory Neurons** (Afferent)
    - Receive (sense) the stimulus
    - Allow you to feel when you touch things.
    - Sensory neurons in your eyes allow you to see
  - **Motor Neurons** (Efferent)
    - Stimulate target cells called **effectors** which then produce a response
    - Stimulate muscles for movement, stimulate stomach cells to release gastrin, stimulate sweat glands to cool the body, etc.
  - **Association Neurons** (Interneurons)
    - In the spinal cord or brain
    - Intermediates between sensory and motor. They receive the impulses from sensory neurons, and send impulses to motor neurons.
    - Called **integrators**, as they evaluate impulses for appropriate responses
- How neurons work:
  - <u>Neuron Polarity</u>:
    - The membrane of a neuron (an unstimulated, resting neuron) is *polarized*! The **inside of the neuron is negative**, and the **outside is positive**
      - Na^+ is on the outside

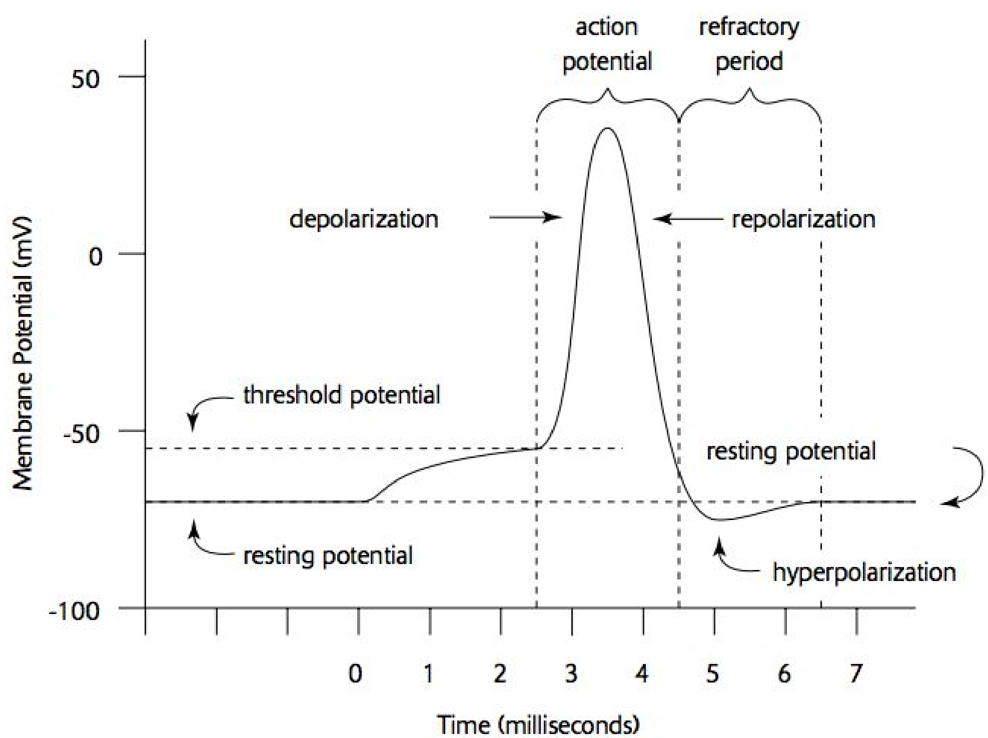
- K^+ is on the inside
- Negatively charged proteins and nucleic acids cause the inside of the cell to be negative.

- These two ions are always diffusing across the membrane due to their concentration gradient (high → low) but there are ion pumps in the neuronal membrane which prevent this by pumping the Na^+ back outside and the K^+ back inside. This retains the polarity (charge difference) of the neuron.



- <u>Transmission of Nerve Impulses</u>
  - **Resting Potential**
    - When the neuron is resting and un-stimulated
    - ~ -70 millivolts
  - **Action Potential**
    - The cell body receives a stimulus, and in response Na^+ channels in the membrane open, allowing an influx of Na^+ (rushes from outside ⇒ inside the cell).
    - This causes the membrane to become depolarized (~ 0 millivolts)
    - There is a threshold level that must be reached for the signal to continue. If threshold is reached, more Na^+ gates open, allowing even more sodium in, which causes the action potential (complete depolarization, ~ +30 millivolts).
    - More and more Na^+ channels open like a domino effect down the neuron axon.
    - The action potential is “all or nothing”. Either complete depolarization occurs, or there is no action potential.
  - **Repolarization**
    - K^+ channels in the membrane now open, allowing an outflux of K^+ (rushes from inside ⇒ outside the cell)
    - This restores the original polarization of the membrane.
    - Soon after opening of these K^+ gates, the Na^+ channels will close so that no more sodium rushes into the cell.
  - **Hyperpolarization**

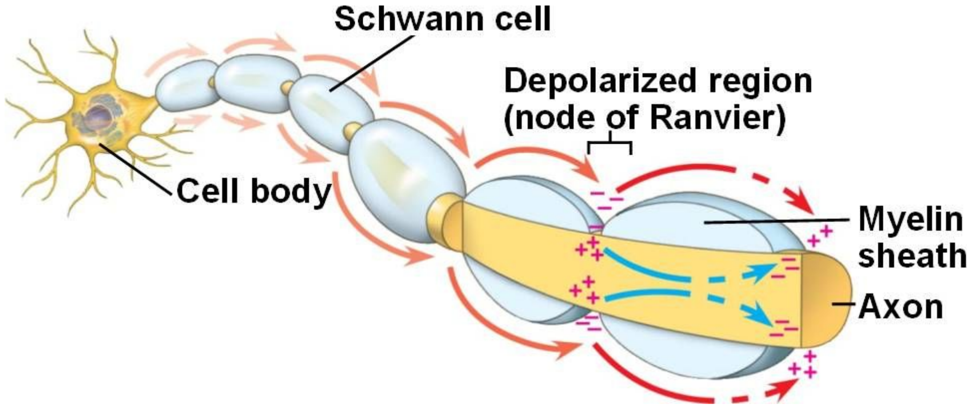
    - For a brief moment, there is more K^+ on the outside then necessary. This causes the hyperpolarization at about -80 millivolts, but it is quickly restored.
- **Refractory Period**
    - This period is from the end of the action potential, until it is restored to resting potential once more.
    - After the impulse has finished, the K^+ and Na^+ are on the wrong sides of the membrane (K^+ is outside, but should be inside. Na^+ is inside, but should be outside). During this time (the refractory period) the neuron cannot respond to an additional stimulus.
    - The membrane restores itself back to normal by using Na^+/K^+ pumps to pump the ions back to their proper side. When this process is complete, the neuron can once again respond to a stimulus.



Action Potential in a Neuron

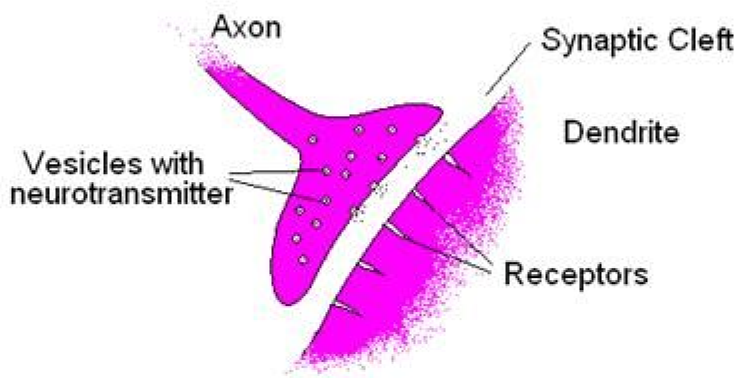
- Movement of the impulse down the Axon
    - Many neurons contain a **myelin sheath** which wraps around the axon, keeping it insulated.
        - The myelin sheath is a series of **Schwann Cells**.

- There are gaps inbetween each schwann cell called **Nodes of Ranvier**. These nodes allow the signal to "jump" down the axon from node to node, rather than going along the entire axon (which would be slower). This process is called **saltatory conduction**.



■ <u>The Synaptic Cleft</u>

- The synapse/synaptic cleft is a gap separating two adjacent neurons
- The signal/impulse travels across the cleft, from the axon terminal of one neuron to the dendrite of another neuron, or in other words from presynaptic cell ⇒ postsynaptic cell.
  - Transmission of the signal may be electrical or chemical, though it is usually chemical.
  - Note that electrical signals would travel through gap junctions in the cell (this occurs in the heart).

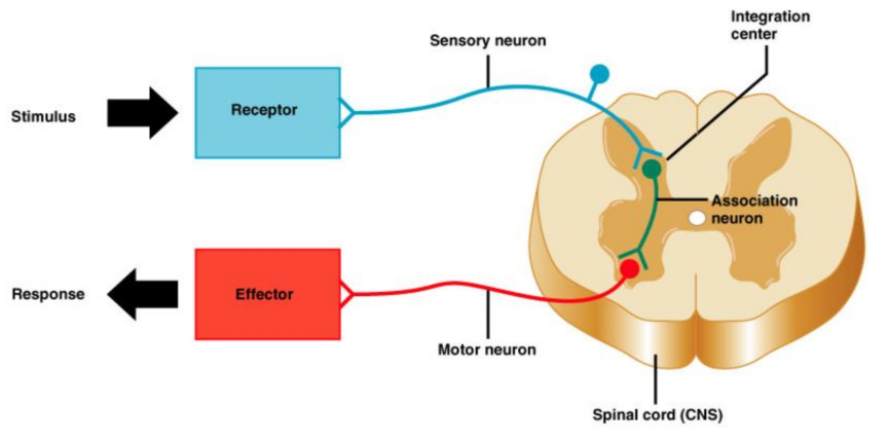


- **Calcium (Ca^{++}) Gates Open**
  - There are **voltage gated Ca^{++} channels** at the end terminus (of the presynaptic neuron). When the AP gets there, it causes these to open.
  - Ca^{++} is much higher OUTSIDE of the cell than inside, so when it opens, Ca^{++} rushes into the cell (into the end terminus).
- **Synaptic Vesicles Release the Neurotransmitter**

        - The Ca^{++} causes a protein that is blocking vesicles (containing neurotransmitters) to change formation, and this in turn causes the synaptic vesicles to release their cargo (such as acetylcholine) into the synaptic cleft.
    - **Neurotransmitter binds with postsynaptic receptors**
        - The neurotransmitters make there way across the cleft via diffusion, bind to a receptor on the postsynaptic membrane, and create a "Post Synaptic Potential" (which can either be EPSP or IPSP).
        - There are different receptors for different types of neurotransmitters.
    - **The postsynaptic membrane is excited or inhibited**
        - The type of outcome from a neurotransmitter binding depends on what kind of neurotransmitter it was, as well as what kind of receptor it bound too. The outcome can be either an:
            - **Excitatory postsynaptic potential (EPSP)**
                - This is when Na^+ gates open, causing depolarization, leading to another action potential being generated in the postsynaptic neuron.
            - **Inhibitory postsynaptic potential (IPSP)**
                - This is when K^+ gates open, causing hyperpolarization, which makes it very difficult to form an action potential on the postsynaptic neuron.
    - **The neurotransmitter is degraded and recycled**
        - The neurotransmitter is broken down by enzymes in the synaptic cleft so that it does not continue triggering an AP in the neuron. These are then recycled in the presynaptic cell.
        - **Cholinesterase** is an enzyme that breaks down acetylcholine.
- <u>Common Neurotransmitters</u>
    - **Acetylcholine**
        - Common in neuromuscular junctions (between neurons and muscle cells). Where it stimulates muscle contraction
        - Often inhibitory in places besides the neuromuscular junction
    - **Epinephrine, norepinephrine, dopamine, and serotonin**
        - All of these neurotransmitters are derived from amino acids
        - Secreted between neurons the central nervous system (brain+spinal cord)

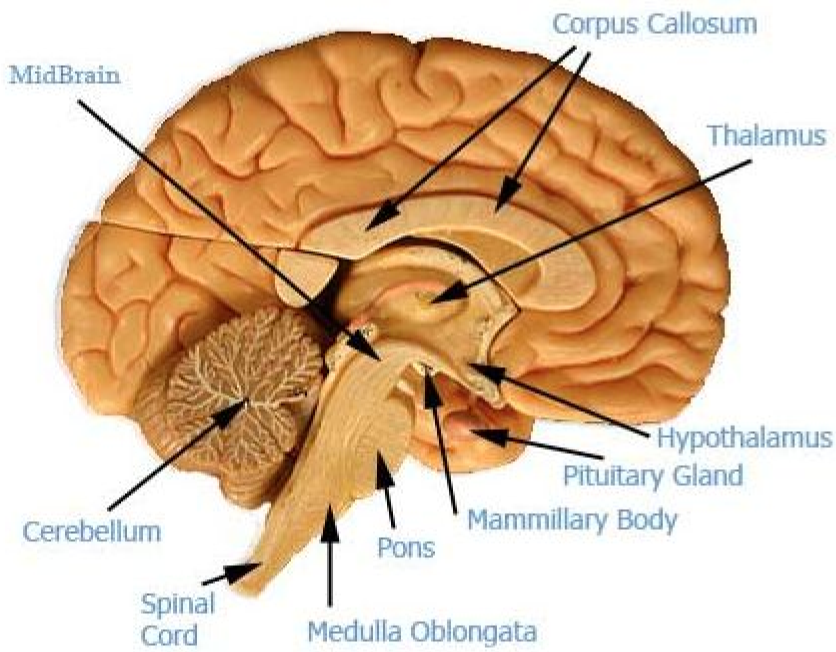
- **Gamma aminobutyric acid (GABA)**
  - Inhibitory neurotransmitter in the brain

- Nervous Systems
  - **Central Nervous System (CNS)**
    - Brain + spinal cord
  - **Peripheral Nervous System (PNS)**
    - Sensory neurons which send impulses to the central nervous system, and motor neurons that send impulses from the central nervous system to effectors
    - The PNS includes:
      - **Somatic Nervous System** (skeletal muscles)
        - Directs the contraction of skeletal muscles
      - **Autonomic Nervous System** (involuntary muscles/organs)
        - Sympathetic
          - "Fight or flight"
          - The sympathetic nervous system is involved in preparing the body for action. This includes increasing heart rate, releasing sugar from the liver → blood, etc.
        - Parasympathetic
          - "Rest and digest"
          - Stimulates secretion of saliva or digestive enzymes in the stomach, etc.
          - Slows down heart rate
        - These two systems work on the same areas/organs of the body, but they work antagonistically to each other.
        - A **reflex arc** is an involuntary, rapid response to a stimulus. This involves a sensory, motor, and interneuron. It it not regulated by the brain.

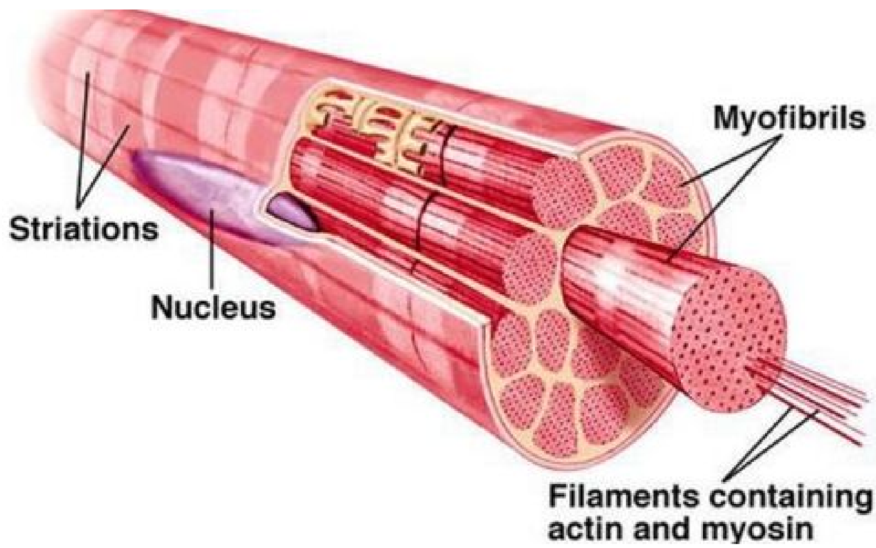


  - Functions of the Brain

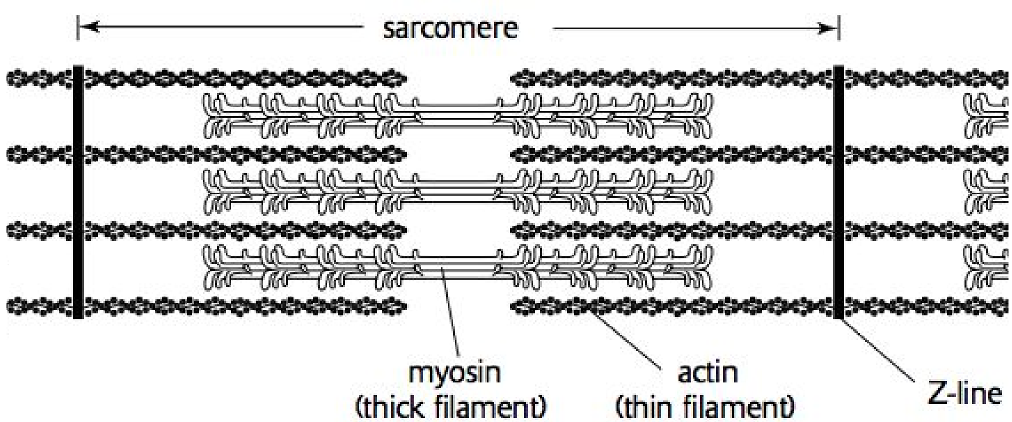
- Frontal Lobe
  - Part of the cerebral cortex
  - Reasoning, planning, problem solving (on the DAT)
- Parietal Lobe
  - Part of the cerebral cortex.
  - Orientation, recognition, perception.
- Occipital Lobe
  - Part of the cerebral cortex.
  - Visual processing.
- Temporal Lobe
  - Part of the cerebral cortex.
  - Recognition of auditory stimuli, memory, and speech.
- Corpus Callosum
  - Bundle of axons that connect the two brain hemispheres.
- Cerebellum
  - Coordinates movement, balance, posture.
- Hypothalamus
  - Part of the limbic system.
  - Produces ADH, regulates homeostasis, thirst, hunger, temperature, autonomic nervous system, and controls hte pituitary gland.
- Hippocampus
  - Part of the limbic system.
  - Associated with learning and memory.
- Medulla
  - Maintains vital body functions such as breathing and heart rate.



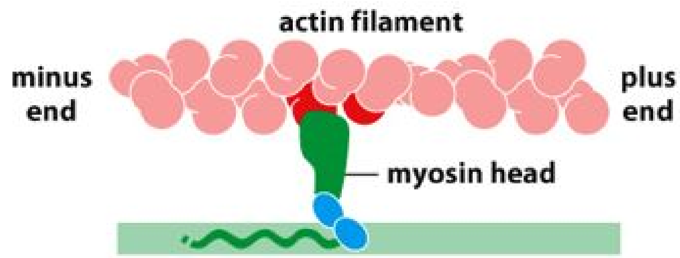
- **The Muscular System**
  - The cell in a muscle is called a **muscle fiber**. These cells are multinucleated, having the nuclei like along the periphery of the cell (see below). The muscle fiber consists of the following:
    - **Sarcolemma**
      - The plasma membrane of a muscle cell
      - Invaginated by T-Tubules (transverse tubules)
    - **Sarcoplasm**
      - The cytoplasm of the muscle cell
      - Contains the sarcoplasmic reticulum (the ER of a muscle cell) which store calcium ions.
    - **Myofibrils**
      - Myofibrils fill nearly the entire volume of a muscle cell.
      - There are two types of filaments contained in a myofibril:
        - Actin (thin filaments)
          - Two strands of the globular actin protein are arranged in a double helix.
          - Troponin and tropomyosin are also contained here. These are proteins that sit on top of the actin proteins, covering up the binding sites
        - Myosin (thick filaments)
          - Myosin is a filamentous protein that has a protruding head on one end.
          - The filaments are laid together in such a way that there are numerous protruding heads on both ends



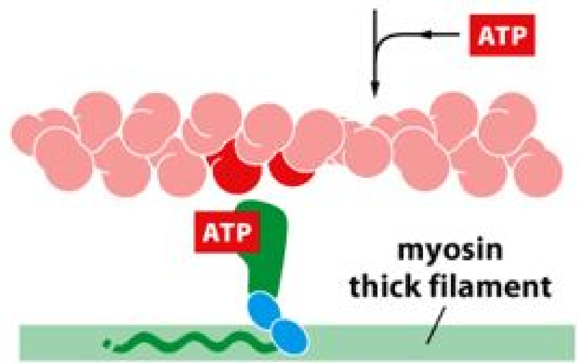
- Sarcomere:
    - Within a myofibril, the actin and myosin filaments run parallel to each other (they are side by side). These filaments overlap, giving skeletal muscles the appearance of being striated.
    - Each repeating unit is called a **sarcomere**, and is shown below. One sarcomere is separated from the next by the **Z-line** (where actin is attached). The myosin are not attached to the z-line.



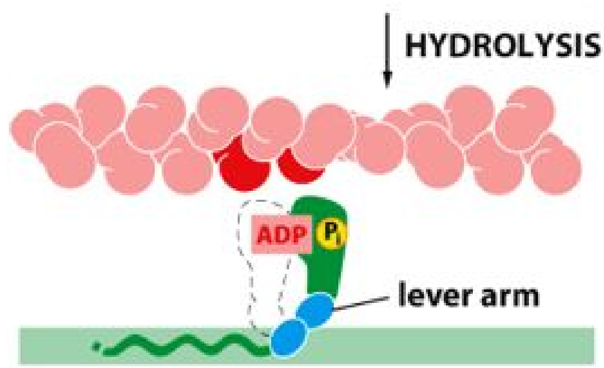
- Sliding Filament Model (describes the process of muscle contraction)
    - 1) **Attached**
        - The myosin head is attached to the actin filament when nothing is bound to the myosin head (no ATP or anything)



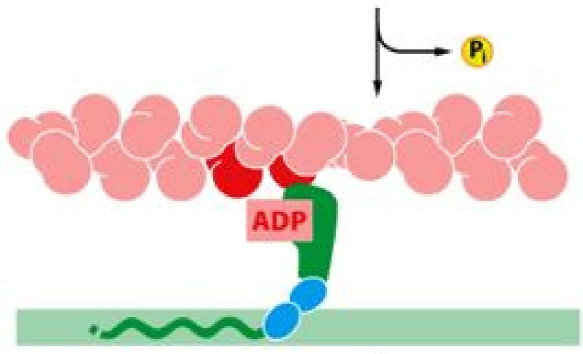
- 2) **Released**
    - A molecule of ATP binds myosin, causing it to release from actin.



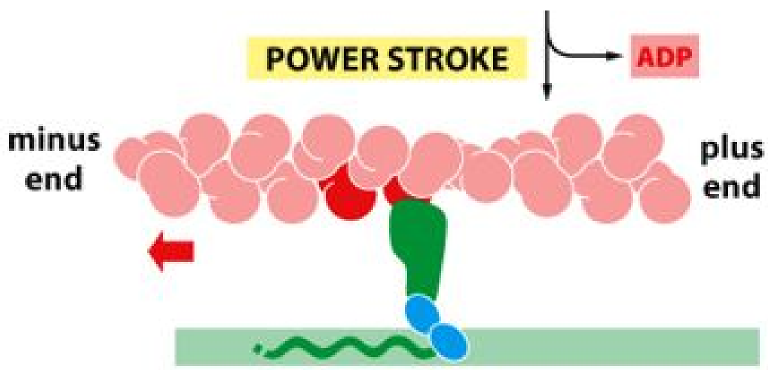
- 3) **Cocked**
    - The ATP is hydrolyzed to ADP+Pi, which pushes the myosin head forward into the “cocked” position.
    - Note the ADP + Pi are still attached to the myosin head.



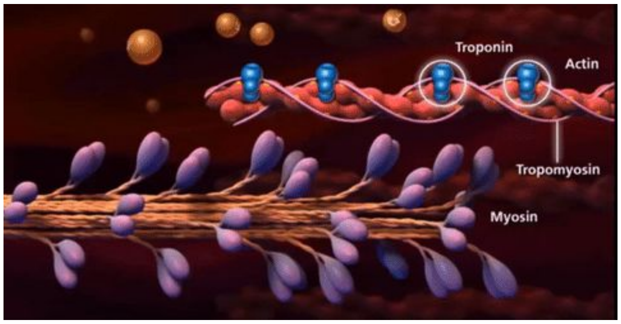
- 4) **Binding Sites Exposed by Calcium**
    - Ca^{++} binds to troponin, causing tropomyosin to expose positions on the actin filament for the myosin heads to attach too.
- 5) **Formation of Cross Bridges**
    - Cross bridges are formed between the myosin filaments and the actin filaments
    - Cross bridges are simply actin bound to myosin.

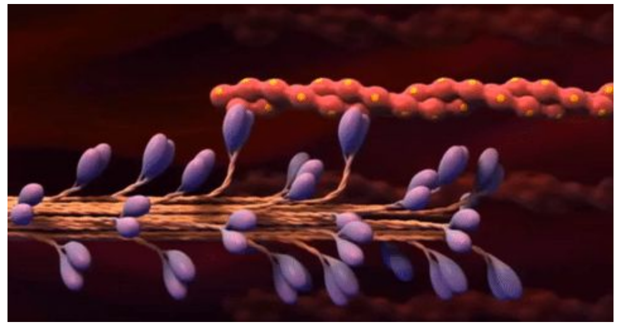


- 6) **ADP and Pi are released and sliding motion of actin results**
  - When the cross bridges form between actin and myosin, the ADP and Pi is released
  - The myosin then released like a spring, generating a sliding movement of the actin towards the center of the sarcomere. The two Z-lines are pulled together, which effectively contracts the entire muscle fiber.

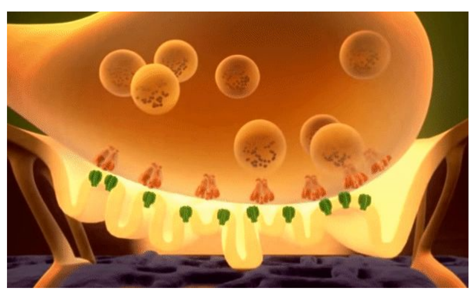


- Note that ATP will then bind to the myosin, releasing it from the actin and the cycle continues.
- If there is no more ATP generated in the body (such as after death), then there is nothing left to bind the myosin and release it from the actin. This causes the stiffness of corpses, and the eventual degradation of the ATP causes rigor mortis.
- In the below gif, note the **Ca^{++}** ions which bind **troponin**, causing **tropomyosin** to move out of the way, exposing the **binding sites** on actin. The cross bridge then forms between myosin and actin, and myosin drags actin, causing contraction.



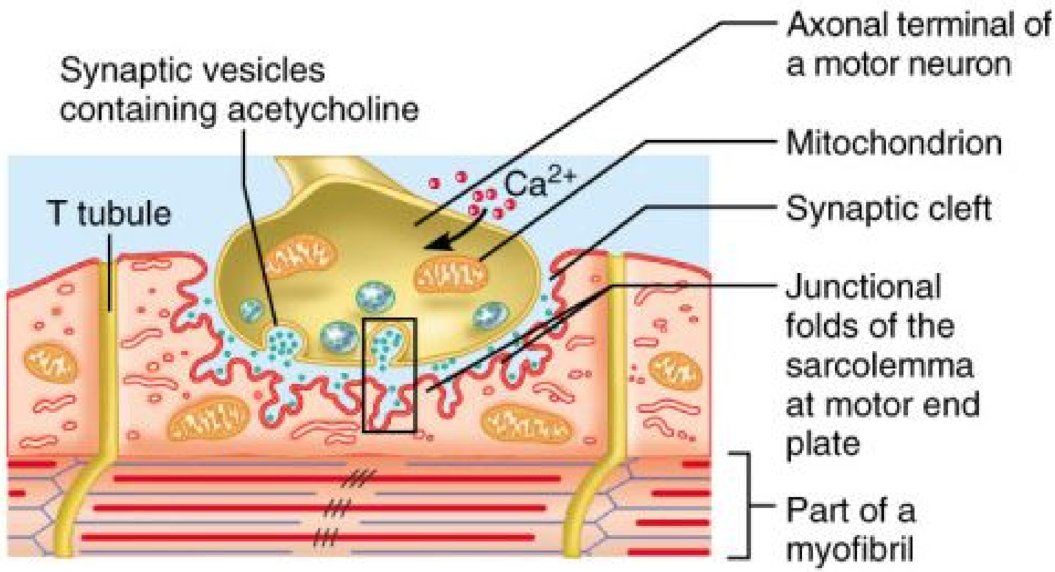


- Neuromuscular Junctions
  - Neurons form special synapses with muscle cells called **neuromuscular junctions**. These junctions are what allow the nerves to stimulate muscle contractions. The process is as follows:
    - 1. **Action potential generates release of acetylcholine**
      - The action potential of a neuron reaches the neuromuscular junction (just like it happens in neuron-neuron junctions)
      - The neuron releases the neurotransmitter acetylcholine, which diffuses across the synaptic cleft.
    - 2. **Action potential is generated on sarcolemma and throughout the T-tubules**
      - Receptors on the sarcolemma (the membrane of the muscle cell) bind the acetylcholine and open Na^+ channels (causing an influx of sodium) to initiate a depolarization event.
      - This causes an action potential that spreads throughout the system of t-tubules.

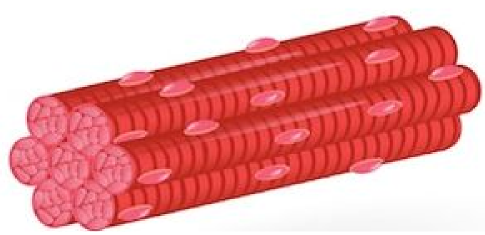


    - 3. **Sarcoplasmic reticulum releases Ca^{++}**
      - In response to the action potential, the sarcoplasmic reticulum (the ER of the muscle cell) releases Ca^{++} ions. These are the calcium ions that bind to troponin.
    - 4. **Myosin cross bridges form**
      - The Ca^{++} binds troponin on the actin filaments, moving tropomyosin out of the way, which allows the myosin heads to attach to the actin binding sites.

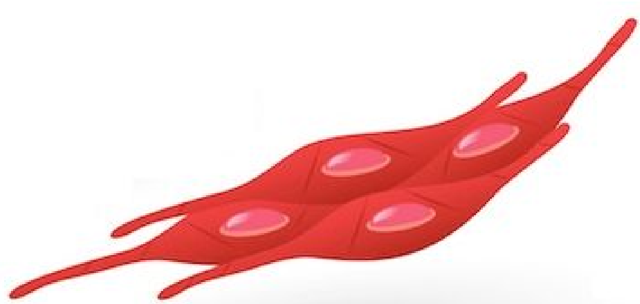
- If ATP is available, then muscle contraction begins.



- <u>Muscle Types</u>:
  - **Skeletal Muscle**
    - Causes movements of the body
    - Attached to bones
    - <u>Striated</u>
    - <u>T-Tubule System</u>
    - Voluntary



  - **Smooth Muscle**
    - Lines the walls of blood vessels
    - Lines the digestive tract
    - <u>Not striated</u>
    - <u>No T-tubule system</u>. Contraction is slow and highly regulated

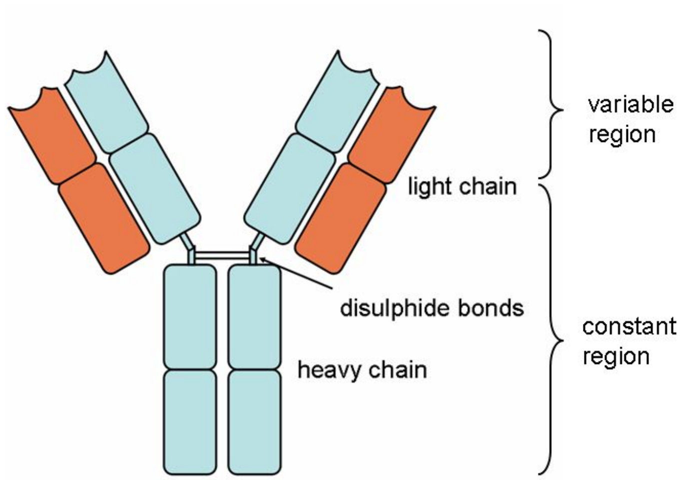


- **Cardiac Muscle**
    - Involved in the rhythmic contractions of the heart
    - <u>Striated</u> and <u>branched</u>
    - <u>Cells connected by gap junctions</u>
    - Cardiac muscle generates its own action potential, which spreads rapidly throughout muscle tissue by electrical synapses across the gap junctions.

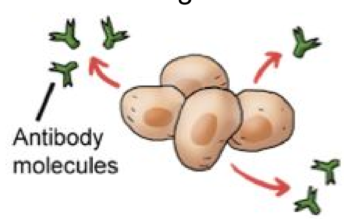
- **<u>The Immune System</u>**
  - First line of defense:
    - The first line of defense is a *nonspecific* way to prevent invaders/pathogens from entering the body. It is the skin and mucous membranes, etc. and has the following characteristics:
      - **Skin**
        - Physical Barrier
        - pH 3-5 due to oily secretions
      - **Antimicrobial Proteins**
        - One example is a lysozyme which breaks down the cell walls in bacteria
        - These proteins are found in saliva, sweat, and tears.
      - **Cilia**
        - Cilia are found in the lungs and function to sweep out harmful bacteria
      - **Gastric Juice**
        - Acidic juice in the stomach that functions to kill many microbes
      - **Symbiotic Bacteria**
        - Found in the digestive tract and vagina
        - Outcompete other bacteria that could be harmful
  - Second line of defense:
    - Another nonspecific way of defending invaders, including the following characteristics:
      - **Phagocytes**
        - Phagocytes engulf harmful particles via phagocytosis.
        - <u>White blood cells</u> (WBCs or leukocytes)
          - Neutrophils

        - Monocytes
            - These enlarge further into macrophages
    - Natural Killer cells (NKs)
        - Attack tumors or pathogen infected cells
- **Complement**
    - These are proteins that "complement" other defenses.
    - These attract phagocytes where they are needed
    - They also promote cell lysis (breaking the cell open) if the cell is a threat.
- **Interferons**
    - Cells that are infected by a virus secrete interferons to promote the neighboring cells to produce virus fighting proteins
- **Inflammatory Response**
    - A series of events (nonspecific) that occurs in response to a pathogen (if bacteria enters the body, if the skin becomes damaged, etc). The inflammatory response includes:
        - **Histamine**
            - This protein is released by **basophils** (a type of WBC) during the inflammatory response
            - Histamine increases the permeability of the capillaries to white blood cells to allow them to engage pathogens in the infected tissues
        - **Vasodilation**
            - Vasodilation (dilation of the blood vessels) occurs in response to histamine.
            - This results in an increased blood supply to the affected area, and allows WBCs to more easily access where they are needed.
            - This is what causes redness, swelling, increased temperature, etc. (when you get a fever)
        - **Phagocytes**
            - Attracted to the injured area to engulf the pathogens
        - **Complements**
            - Complements leave chemical gradients, allowing phagocytes to follow them to the injury/infected area.
            - These help phagocytes engulf pathogens

            - They also stimulate basophils to release histamine
            - They also assist in the lysis of foreign cells when necessary.
- Third line of defense:
    - The immune response is the third line of defense, and is a *specific* way of defending against invaders (as opposed to the nonspecific inflammatory response)
    - **Antigens** are molecules/proteins that can be detected as foreign. The immune response detects specific antigens in the body.
    - The Major Histocompatibility Complex (MHC)
        - This is the system of glycoproteins on the membranes of all cells that allows the immune system to determine the difference between foreign cells and self cells.
        - MHC molecules are different/unique for everybody (having about 20 genes, and 50+ alleles involved)
    - **Lymphocytes** are the major component of the immune response. These are WBCs originating in the bone marrow, and spending most of their time in the lymph nodes, thymus gland, and spleen. Lymphocytes include:
        - 1) **B-Cells**
            - Originate AND mature in the bone marrow
            - The plasma membranes of b-cells contain **antibodies**, which are just membrane receptors for different antigens.
            - Antibodies:
                - Proteins that are specific to a certain antigen
                - Also called immunoglobulins
                - **1 Constant Region**
                    - These are the same for antibodies in the same class and species
                    - They are *recognized by receptors* on some cells (i.e. macrophages)
                - **2 Variable Region**
                    - This is the business end
                    - Responsible for *recognizing antigen*
                - When antibodies bind an antigen, it inactivates the antigen until it is phagocytosed by a macrophage.
                - When antibodies bind a surface antigen of a cell, it stimulates the complement proteins to come and lyse the cell.



- Once the antibody on the B-cell binds its specific antigen, it causes the b-cell to proliferate into two different types of daughter cells:
  - <u>Plasma Cells</u>
    - These daughter cells release the antibodies into the bloodstream, allowing them to circulate throughout the body allowing them to bind to antigens.



  - <u>Memory Cells</u>
    - Memory cells keep their antibodies bound to their membranes.
    - These cells hang around (they are long lived) after you come in contact with a certain type of antigen. This is why one can become immune to many diseases after being exposed to it once.

- 2) **T-Cells**
  - Originate in the bone marrow, but mature in the thymus gland (hence the name T-Cell)

- T-Cells also have antigen receptors on their surface, but they are <u>not antibodies</u>. The receptors recognize molecules on foreign cells in the following way:
  - MHC Markers distinguish between foreign and self cells
  - The t-cell looks for displays of a mixture of self and foreign markers on a cell. This is a typical type of expression for a cell infected with a virus.
  - Cancerous or transplanted cells are recognized as foreign
- Once recognition of a foreign marker has taken place, it causes the T-cell to divide and produce two types of daughter cells:
  - <u>Cytotoxic T-cells</u> (killer T-cells)
    - Recognize and puncture foreign cells, causing them to lyse
  - <u>Helper T-cells</u>
    - These stimulate the proliferation of cytotoxic t-cells, as well as b-cells.

- **Clonal Selection**
  - When an antigen binds to a B-cell, or when a foreign cell binds to a T-cell, causing proliferation into identical daughter cells.
  - It is called clonal selection because the cell bound to the antigen was "selected" for, and cells that are not bound will not divide.

- Immune System Response:
  - **Cell-Mediated Response**
    - Uses T-cells to respond to either foreign cells, or cells invaded by pathogens
    - Initiates the process of t-cells ⇒ cytotoxic t-cells (which destroy foreign cells)
    - Also initiates the process of t-cells ⇒ helper t-cells (which bind to macrophages that have already engulfed pathogens, marking them for destruction. They also produce **interleukins**, which stimulate the proliferation of t-cells/b-cells).
  - **Humoral Response** (humor = body fluid)
    - Uses antibodies to respond to the antigens on pathogens that circulate in the blood or lymph.
    - The process of B-cells ⇒ plasma cells (which release antibodies to bind to the antigens/pathogens)
    - The process of B-cells ⇒ memory cells (which provide future immunity to repeating pathogens)
    - Also involves macrophages and helper t-cells stimulating the production of more b-cells. Sometimes, the antigen binding to a

b-cell does not directly stimulate the production of additional b-cells. Instead, the pathogen (bearing the antigen) must be engulfed by a macrophage. The helper t-cells can then bind the macrophage, release **interleukins**, which then stimulates b-cell production.

- Medical Treatment
  - **Antibodies**
    - Chemicals that are obtained from fungi or bacteria
    - Harmful to invasive microorganisms in our body
  - **Vaccines**
    - Vaccines stimulate the production of memory cells
    - Sometimes vaccines are either inactivated viruses, fragments of a virus, or another microorganism/bacteria.
    - The immune system quickly responds before any disease can take over
  - **Passive Immunity**
    - Passing antibodies from a previously infected individual to someone else who is newly infected with a disease.
    - This is the process by which newborn infants are protected (antibodies passed through both the placenta and breast milk)

- **Endocrine System**
  - The endocrine system produces hormones, which are chemical signals created in one part of the body, dumped into the bloodstream, and ultimately affecting other cells in different parts of the body. The hormones are involved in regulating homeostasis, reproduction, development, etc.
    - Hormones always travel through the blood
    - Some hormones are steroids, some are proteins or modified amino acids. Either way, it is some type of chemical signal.
    - Small amounts of a hormone can have great effects!
  - The hypothalamus in the forebrain is involved in monitoring the conditions of both the external environment, as well as the internal environment of the body. When necessary (either for homeostasis or for developmental purposes), the brain can secrete hormones into the blood.
    - Neurosecretory cells link the hypothalamus to the pituitary gland. These cells are built/structured like neurons, but they secrete hormones into the blood (instead of neurotransmitters onto other neurons).
  - The Pituitary Gland
    - Two halves:
      - Anterior Pituitary
        - Many different tropic hormones are released from here (hormones that directly affect other endocrine glands)
        - Releasing hormones are made in the hypothalamus and released in the blood which flows directly to the anterior

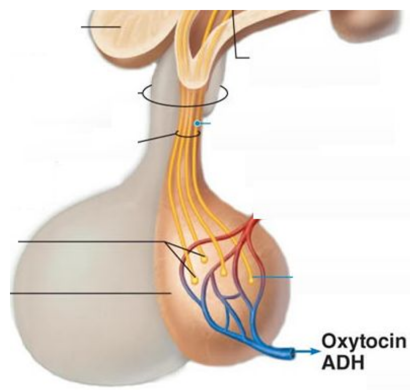
pituitary. These cause the release of the tropic hormones into the blood.

- Posterior Pituitary
    - ADH and Oxytocin are produced in the hypothalamus (by neurosecretory cells), but they are stored here in the posterior pituitary.
    - These hormones do not affect other glands like the anterior pituitary does, they directly affect tissues.
- The pituitary gland is controlled by the hypothalamus, and the pituitary gland controls most of the other glands in the body.

- Example of Hormone Homeostasis:
    - The pancreas has bundles of cells called islets of Langerhans, which are a combination of α-alpha cells and β-beta cells.
        - β-Cells
            - Secrete insulin
            - With high blood glucose (after eating) insulin is released from these cells.
            - Insulin stimulates the liver and other body cells to take up glucose, lowering the glucose levels of the blood.
            - The Liver and Muscles can convert glucose → glycogen (a glucose polymer for storage)
            - Adipose cells convert glucose into fat
        - α-Cells
            - Secrete glucagon
            - When low blood glucose (after exercise) glucagon is released from these cells.
            - Glucagon stimulates the liver to release the glucose stores into the bloodstream. Note that the liver also produces and releases glucose by converting amino acids/fatty acids into glucose when needed.
- How Hormones Work
    - <u>Steroid Hormones</u>
        - The hormone diffuses through the plasma membrane of a cell and goes directly into the nucleus (this is true for steroid hormones).
        - There is a receptor in the nucleus where the hormone binds, which then activates gene transcription.
    - <u>Peptide Hormones</u>
        - The peptide hormone cannot diffuse through the plasma membrane, so it instead binds to a receptor on the membrane. This is termed **receptor mediated endocytosis**.
        - The receptor protein then stimulates the production of a second messenger inside of the cell to continue carrying the message. **Secondary messengers** include:

- Cyclic AMP (cAMP)
  - Made from ATP
  - Triggers an enzyme to make changes in the cell.
- Inositol triphosphate (IP_3)
  - Produced from membrane phospholipids
  - Triggers the release of Ca^{++} from the ER, which in turn activate enzymes to cause changes in the cell

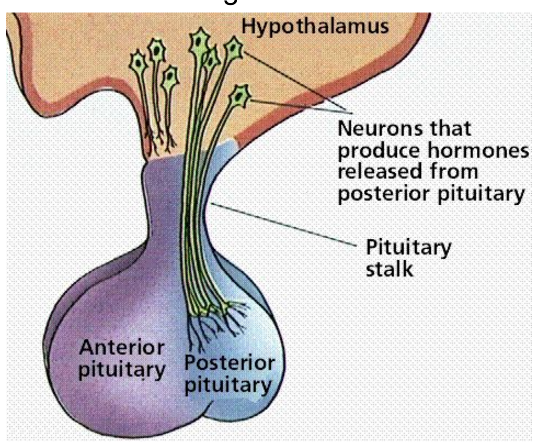
- List of Hormones
  - Posterior Pituitary
    - **Antidiuretic Hormone (ADH)**
      - Targets the kidneys
      - Causes an increase in water reabsorption (prevents diarrhea)
    - **Oxytocin**
      - Targets mammary glands
      - Stimulates milk release



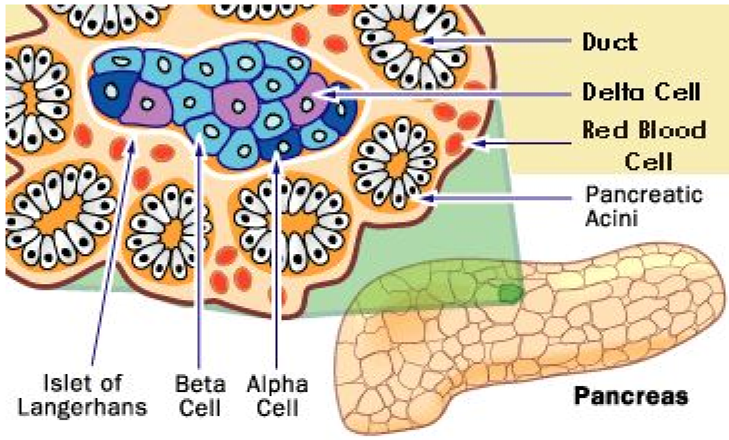
  - Anterior Pituitary
    - Tropic Hormones
      - **Thyroid Stimulating Hormone (TSH)**
        - Targets the thyroid gland
        - The thyroid then secretes T_3 and T_4
      - **Adrenocorticotropic Hormone (ACTH)**
        - Targets the adrenal cortex
        - The adrenal cortex then secretes glucocorticoids (steroid hormones)
      - **Follicle Stimulating Hormone (FSH)**
        - Targets the follicles, aka the ovaries and testis
        - These then regulates oogenesis and spermatogenesis
        - In females, FSH stimulates the maturation of ovarian follicles to secrete estrogen.
        - In males, it stimulates maturation of the seminiferous tubules and sperm production.

- **Luteinizing Hormone (LH)**
  - Also targets ovaries and testis
  - These then also regulate oogenesis and spermatogenesis
  - During the follicular phase of the ovarian cycle, estrogen levels spike upward, which in turn stimulates the hypothalamus to produce a surge of LH (luteinizing hormone). It is this surge of LH that triggers ovulation.
  - In females, LH stimulates formation of the corpus luteum.
  - In males, it stimulates interstitial cells of the testes to produce testosterone.

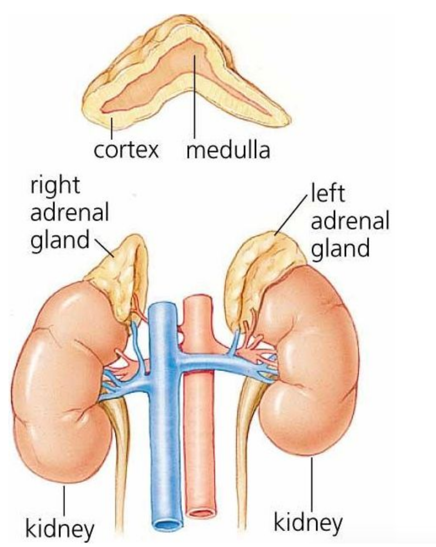
- Normal Hormones
  - **Prolactin (PRL)**
    - Targets the tissues in the mammary glands
    - Stimulates milk production
  - **Growth Hormone (GH)**
    - Targets bone and muscles
    - Stimulates growth



- <u>Pancreas</u>
  - Alpha Cells
    - **Glucagon**
      - Targets the liver
      - Causes increase in blood glucose levels
  - Beta Cells
    - **Insulin**
      - Targets liver, muscle, and fat cells
      - Causes decreased blood glucose levels

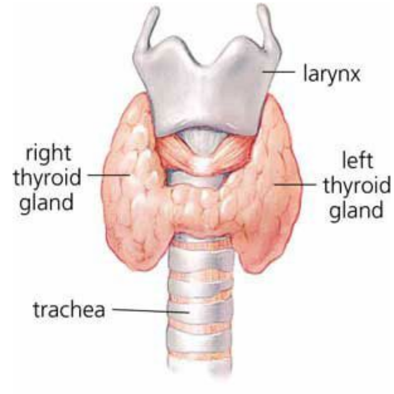


- Adrenal Gland
    - Medulla
        - **Epinephrine & Norepinephrine**
            - Targets blood vessels, heart, and liver
            - Increases blood glucose
            - Constricts blood vessels (fight or flight)
    - Cortex
        - **Cortisol** (a Glucocorticoid)
            - Increases blood glucose
            - Increases absorption of sodium (Na^+)
            - Increases excretion of potassium (K^+)
        - **Aldosterone** (a Mineralocorticoid)
            - " "

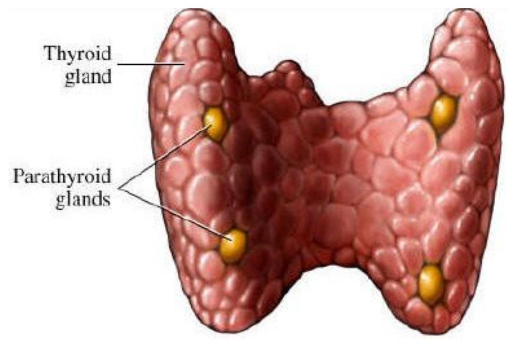


- Thyroid
    - **Triiodothyronine (T_3)** and **Thyroxin (T_4)**
        - Increases cellular metabolism
    - **Calcitonin**
        - Targets the bone

- Decreases blood Ca^{++}, increases bone Ca^{++}

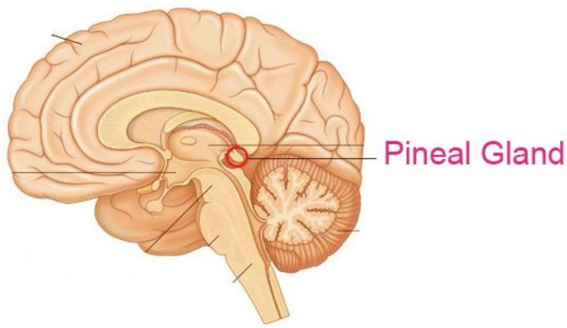


- <u>Parathyroid</u>
  - **Parathyroid Hormone (PTH)**
    - Targets the bone
    - Increases blood Ca^{++}, decreases bone Ca^{++}



- <u>Testis</u>
  - **Testosterone**
    - Targets the testis and other general areas
    - Spermatogenesis
    - Secondary sex characteristics
- <u>Ovary</u>
  - **Estrogen**
    - Targets the uterus and other general areas
    - Menstrual cycle
    - Secondary sex characteristics
    - While rising levels of estrogen do stimulate the hypothalamus to produce an LH surge (which then triggers ovulation), estrogen itself is not directly responsible for ovulation.
    - In females, estrogen plays an important role in the <u>menstrual cycle</u> and in the development of secondary sexual characteristics.
  - **Progesterone**
    - Targets the uterus

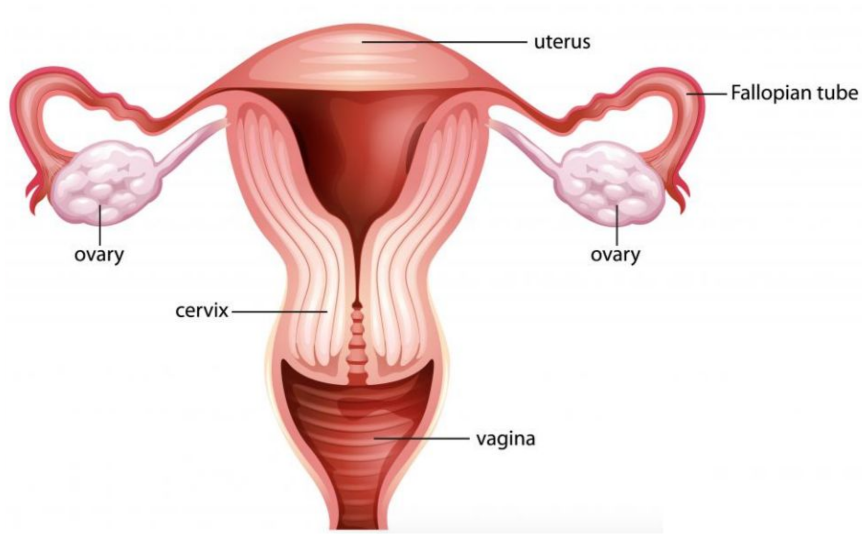
        - Menstrual cycle
        - Pregnancy
    - <u>Pineal</u>
      - **Melatonin**
        - Targets the body in general
        - Regulates circadian rhythm



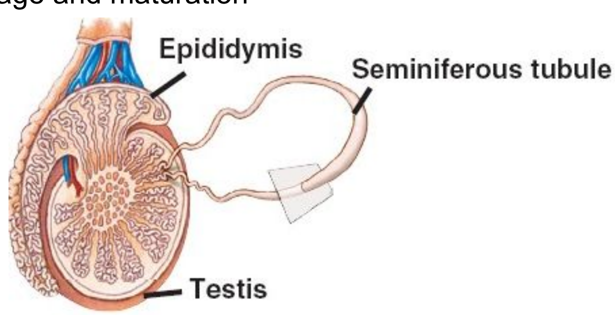
Animal Reproduction and Development

- Primary and Secondary Sex Characteristics
  - Primary Sex Characteristics
    - Structures directly involved in reproduction
    - Uterus and Ovaries
    - Testes
  - Secondary Sex Characteristics
    - Structures that indicate sexual maturity, or structures that are used to attract the opposite sex or compete for a mate
    - Body hair (beards, pubic hair)
    - Breasts
    - Voice
    - Fat distribution
    - Deer Antlers, Lion Manes, Peacock tails
- Human Reproductive Anatomy
  - Females
    - <u>Ovary</u>
      - Organ where eggs (**Ova**) are made
      - Females have two ovaries
    - <u>Oviduct</u> (Fallopian Tube)
      - Eggs travel from the ovary to the uterus through the oviduct
    - <u>Uterus</u>
      - The fertilized egg implants itself in the **endometrium** of the uterus (the uterine wall)
      - This is where development of the embryo occurs

- ■ Vagina
    - The baby passes through the cervix and then the vagina during birth

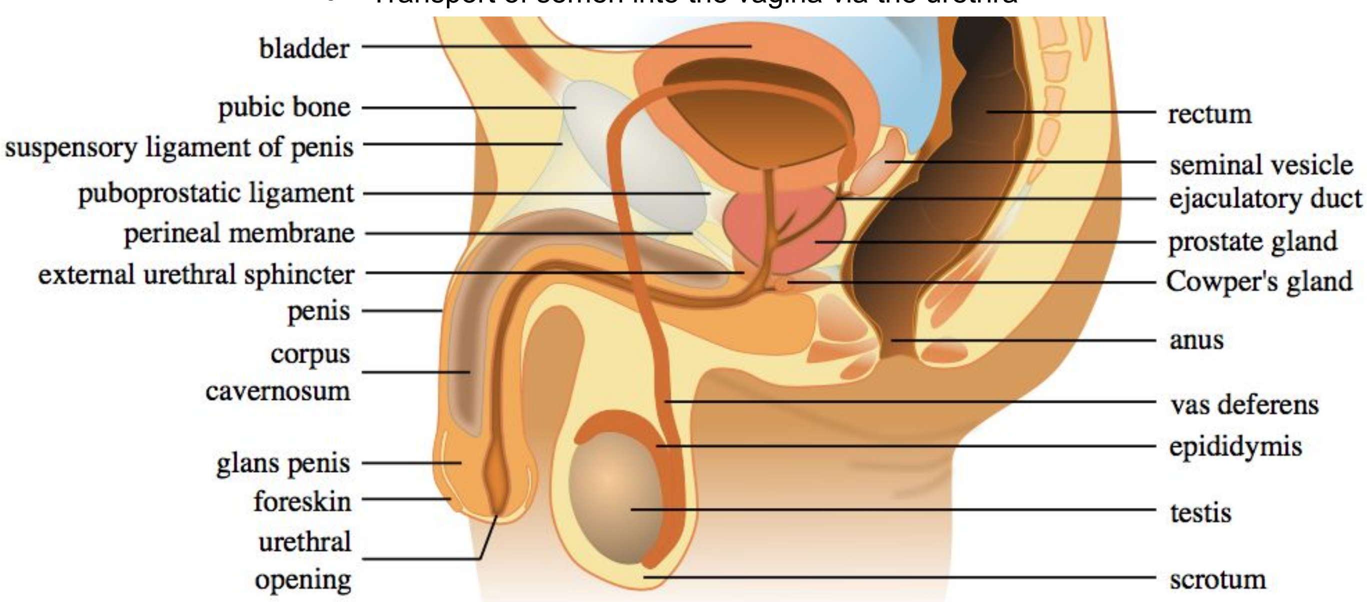


- ○ Males
  - ■ Testes
    - **Seminiferous tubules** are found within the testes. This is where sperm development takes place
    - **Interstitial cells** in the testes produce hormones (testosterone & androgens)
    - The testes hang in the **scrotum**, which is outside the body. The scrotum keeps the testes 2° colder in order for sperm development to occur.
  - ■ Epididymis
    - A coiled tube attached to the testis
    - Sperm storage and maturation



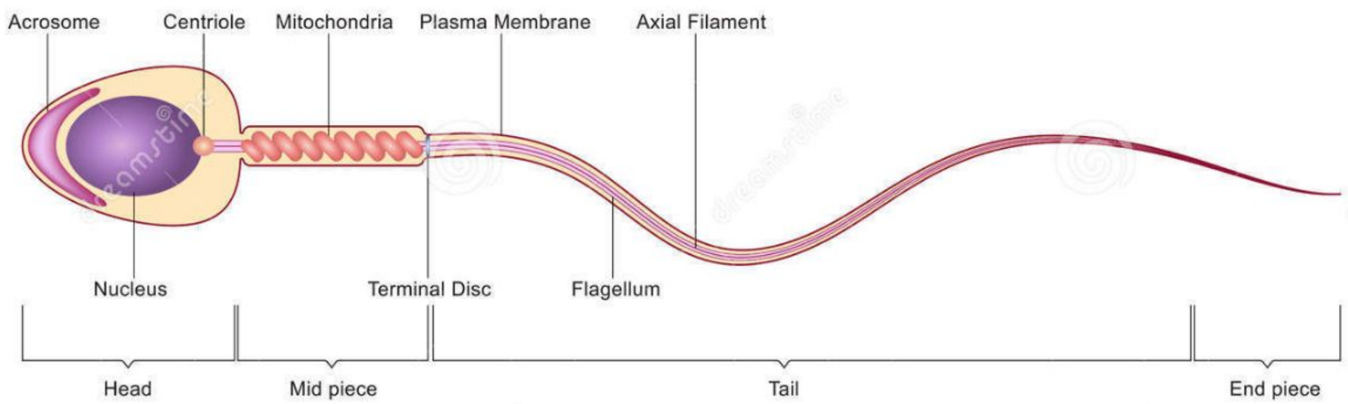
  - ■ Vas Deferens
    - Transfers sperm from the epididymis to the urethra of the penis

- Seminiferous Vesicles
    - Glands that secrete mucus into the vas deferens during ejaculation, allowing the sperm to move in a liquid medium.
    - The glands also secrete fructose to provide energy for the sperm.
    - They also secrete prostaglandins which stimulate uterine contractions, ultimately allowing the sperm to effectively move into the uterus.
- Prostate Gland
    - Secretes alkaline fluid to neutralize the acidity of the vagina
    - Can also neutralize any urine left over in the urethra
- Bulbourethral glands (Cowper's glands)
    - Secrete a fluid in the urethra
- Penis
    - Transport of urine outside the body via the urethra
    - Transport of semen into the vagina via the urethra



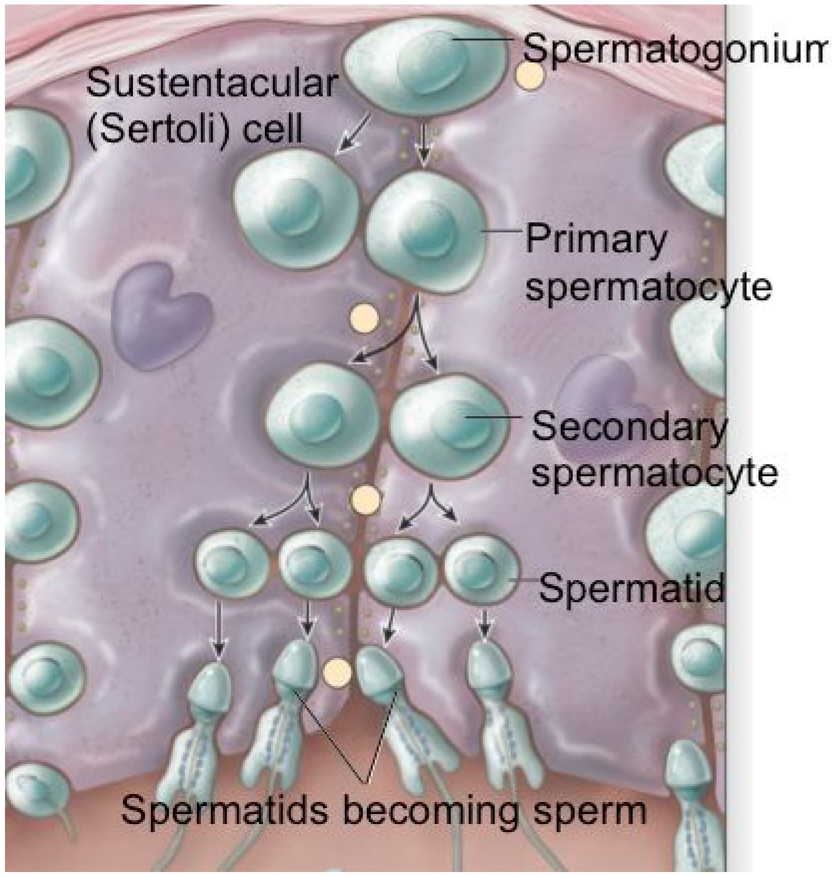
- Sperm

            - Sperm are basically compact packages full of the male's DNA, which deliver the male genome to the egg during fertilization.
            - The Sperm Head
                - Contains the haploid nucleus (23 chromosomes).
                - The **acrosome** (the tip of the sperm head) contains enzymes that are used to penetrate the egg (the acrosome is a lysosome).
            - Midpiece
                - Contains mitochondria
                - The first part of the flagellum
            - Tail
                - Remainder of the flagellum
                - Sperm movement propelled by the tail



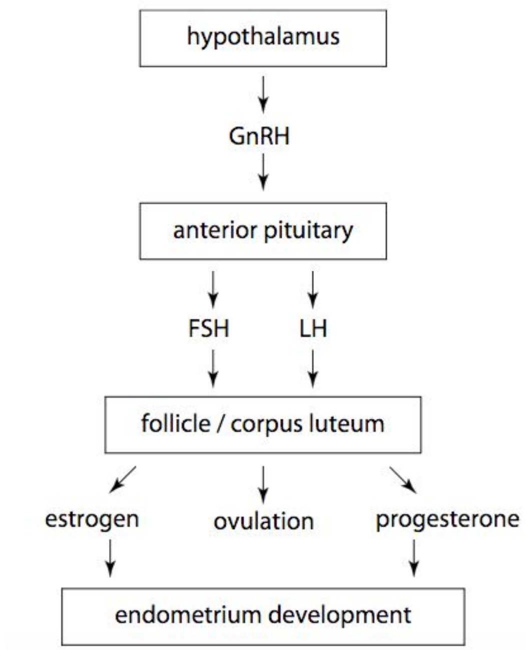
- Gametogenesis
    - Gametogenesis is the formation of gametes.
        - Oogenesis in females (meiotic divisions making eggs)
        - Spermatogenesis in males (meiotic divisions making sperm)
    - Females
        - Oogenesis
            - The production of eggs begins during embryonic development (in other words, women start making eggs before they are born!)
            - **Oogonia** are cells which go through mitosis to produce **primary oocytes.**
            - The primary oocytes then go through meiosis, but they stop once they get to prophase 1. Nothing else happens until years later during puberty.
            - After reaching puberty, the primary oocyte continues meiosis again (note this happens for one primary oocyte every menstrual cycle, which is about once per month).
            - Development of the oocyte occurs within a **follicle** cell, which provides protection and nourishment for the oocyte.

                - During meiosis, the division is unequal, giving the majority of the cytoplasm to one daughter cell rather than splitting it amongst both of them.
                - The unequal cytokinesis results in two cells: a **secondary oocyte** (containing the majority of the cytoplasm) and a **polar body** (with very little cytoplasm). This occurs to assure that one cell has the most nutrients, mitochondria, ribosomes, etc. in order to assist in development of an embryo.
                - Note that the division is once again frozen, as the oocyte does not yet enter meiosis 2.
        - Ovulation
            - Ovulation is when the secondary oocyte is released (breaks free) from the follicle.
            - The secondary oocyte makes its way through the oviduct, where it has the opportunity to be fertilized by a sperm cell.
            - If fertilized, the egg will begin meiosis 2. The daughter cell will once again be a polar body (which is useless and disintegrates).
    - Males
        - Spermatogenesis
            - Begins during puberty inside the seminiferous tubules of the testes
            - **Spermatogonia** are cells that repeatedly undergo mitosis. This produces primary spermatocytes.
            - **Primary spermatocytes** can then undergo meiosis. After meiosis 1 there are two secondary spermatocytes.
            - The two **secondary spermatocytes** then undergo meiosis 2 and turn into four **spermatids**.



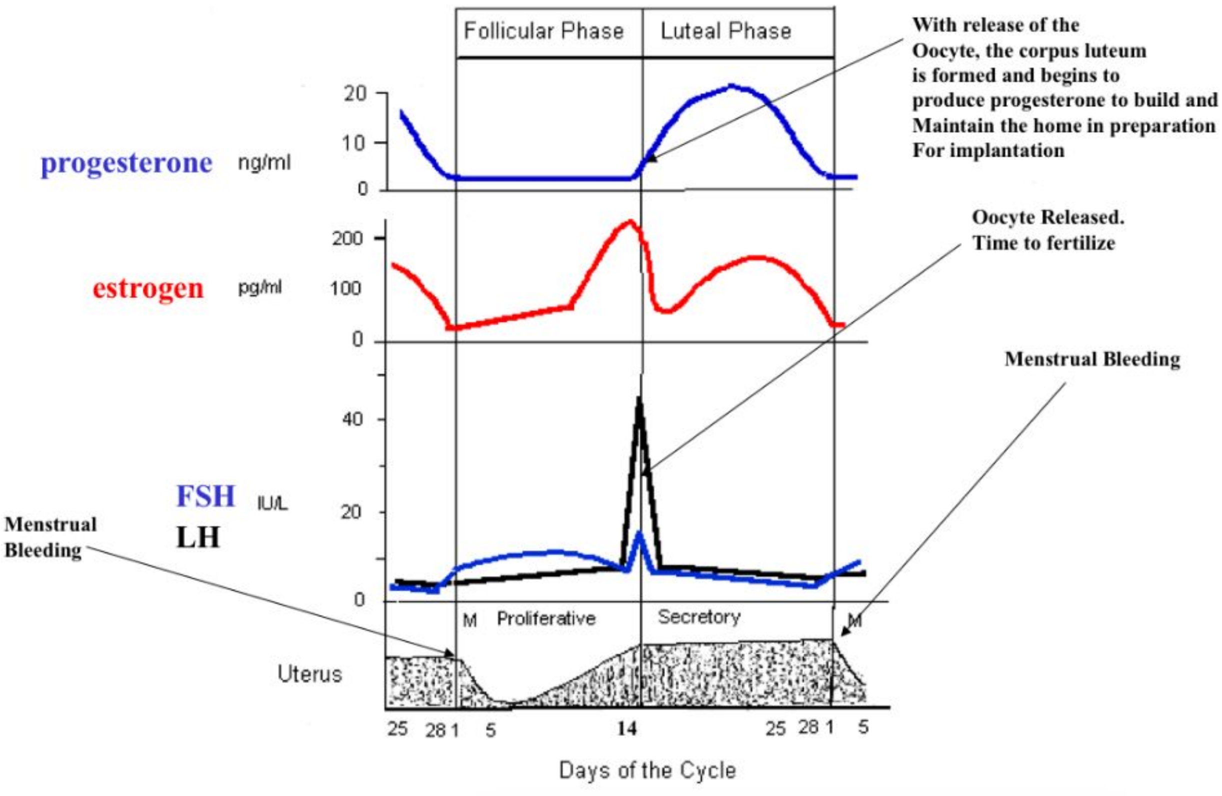
- **Sertoli cells** then provide nourishment for the maturing spermatids, allowing them to grow and mature into sperm cells.
- The sperm then travel to the **epididymis**, where they complete their maturation. The sperm stay here until they are needed.

- Hormones involved in Reproduction
    - Human females have a reproductive cycle, which consists of a series of events in the ovaries (**the ovarian cycle**), as well as a series of events in the uterus (**uterine/menstrual cycle**). These cycles occur in order to:
        - Produce an egg
        - Prepare the uterus for implantation
    - The ovarian and uterine cycles are coordinated together by hormones which use both positive and negative feedback systems. These hormones include:
        - Gonadotropin Releasing Hormone (GnRH)
        - Follicle Stimulating Hormone (FSH)
        - Luteinizing Hormone (LH)
        - Estrogen
        - Progesterone



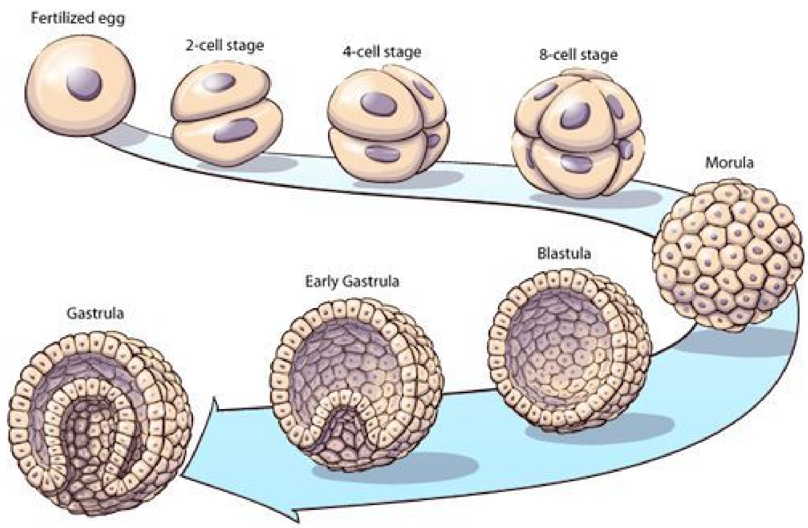
- The Menstrual Cycle
  - Three phases:
    - Menstrual Phase
    - Proliferative Phase
    - Secretory Phase
  - The hypothalamus and anterior pituitary initiate the reproductive cycle.
  - The hypothalamus monitors the estrogen/progesterone levels in the blood. When these levels are low, the hypothalamus secretes GnRH, stimulating the anterior pituitary gland. Note that this is a negative feedback system.
  - In response, the anterior pituitary secretes FSH and LH, resulting in the development of the follicle and oocyte.
  - FSH then causes the follicle to secrete estrogen
  - Blood levels of estrogen begin to rise, stimulating the hypothalamus to release GnRH, which stimulates the anterior pituitary to release a huge amount of LH (the LH surge).
  - The high levels of LH in the blood trigger ovulation.
  - Following ovulation, the follicle, now empty of an oocyte, is called the **corpus luteum**. The corpus luteum continues to develop, and secretes estrogen and progesterone to prepare the uterus for implantation.
  - The endometrium of the uterus begins to thicken (with nutrients and blood vessels) in response to the progesterone and estrogen. This is how the uterus prepares for implantation of a fertilized egg.
  - The high blood levels of progesterone and estrogen then stimulate the hypothalamus (via negative feedback) to cease producing FSH and LH.

        - Without FSH and LH, the corpus luteum disintegrates, stopping the release of progesterone and estrogen. This causes the endometrium to stop growing as well, and it is then sloughed off during the flow phase of the menstrual cycle.
        - If a fertilized egg was implanted during this process, then it begins to secrete a hormone called **human chorionic gonadotropin** (HCG). This hormone sustains the corpus luteum, causing it to continue to produce estrogen and progesterone (which are essential for the maintenance of the endometrium).
            - Note that pregnancy checks test for HCG to determine if you are pregnant
        - Later in development, HCG is no longer needed because the placenta begins to produce progesterone.
        - In summary, the menstrual cycle consists of the thickening of the endometrium of the uterus in preparation for implantation of a fertilized egg and the shedding of the endometrium if implantation does not occur.
    - The Ovarian Cycle
        - Follicular Phase
            - Development of the egg
            - Secretion of estrogen from the follicle
        - Ovulation
            - The release of the egg
        - Luteal Phase
            - The secretion of estrogen and progesterone from the corpus luteum.



- The Male Cycle
  - Just like in females, GnRH is released by the hypothalamus, which causes a release of FSH and LH from the anterior pituitary gland.
  - LH stimulates cells in the testes (interstitial cells) to produce testosterone and androgens.
  - FSH and LH together cause the sertoli cells to promote the production and development of sperm cells.
  - Hormones and gametes are constantly produced during a male's lifetime, whereas in women the gametes are only made during embryonic development, and the hormones change depending on the phase of the cycle.

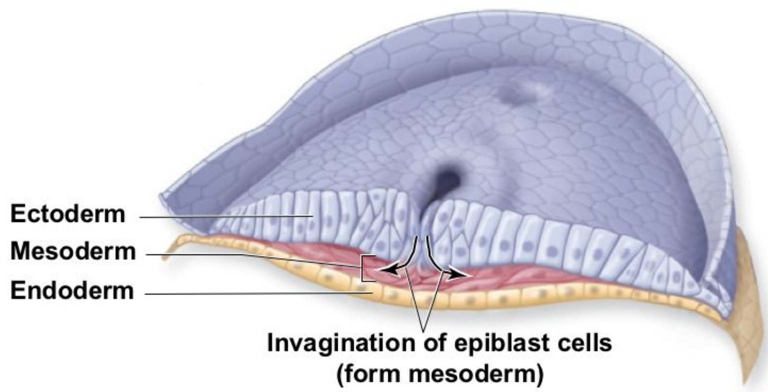
- Embryonic Development
  - There are different forms of embryonic development, depending on the organism. Some examples follow.



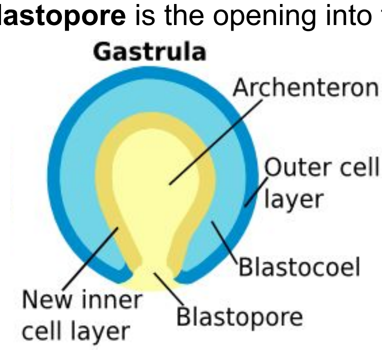
- 1. Fertilization
  - Recognition - The oocyte has a special glycoprotein coat on its plasma membrane called a **vitelline** (in humans it is called the **zona pellucida**). The sperm secretes a protein which binds to receptors on this coat, assuring that fertilization only occurs between egg and sperm of the same species.
  - Penetration - The plasma membranes of sperm and oocyte are fused together. The nucleus of the sperm cell enters the egg.
  - The vitelline layer then forms a membrane to prevent any additional sperm from entering.
  - Meiosis 2 Completes - In humans, when the sperm penetrates the egg, meiosis 2 is triggered in the oocyte. This produces the ovum (egg) as well as a polar body (which is discharged).
  - The two nuclei are then fused together to form the zygote. In humans, the zygote consists of 23 pairs (46 total) chromosomes. The chromosomes are then each replicated.
- 2. Cleavage
  - The zygote undergoes a series of divisions, but remains the same size. Each of the newly formed cells are called **blastomeres**, and they are each smaller and smaller than the previous.
  - The dense areas within the zygote are naturally separated from the less dense. This forms two poles on opposite ends of the embryo:
    - Animal Pole
    - Vegetal Pole (yolk/food)
  - The early cleavages are polar (they include both poles), and later divisions become parallel with the equator.
  - A cleavage is indeterminate if it produces blastomeres that, if separated, can individually complete normal development. In

contrast, blastomeres produced by a determinate cleavage cannot develop into a complete embryo if separated from other blastomeres.

- 3. Morula
  - After multiple divisions, the resulting ball of cells is called a morula.
- 4. Blastula
  - Cell divisions continue, and liquid fills the morula, which pushes the middle cells outward to form a circular cavity called the **blastocoel**. The entire structure is called the blastula.
- 5. Gastrula
  - Gastrulation then occurs (the process of forming the gastrula) when a group of cells invaginate into the blastula.
  - The gastrula has three germ layers, which all other tissues are derived from:
    - **Ectoderm**
    - **Mesoderm**
    - **Endoderm**

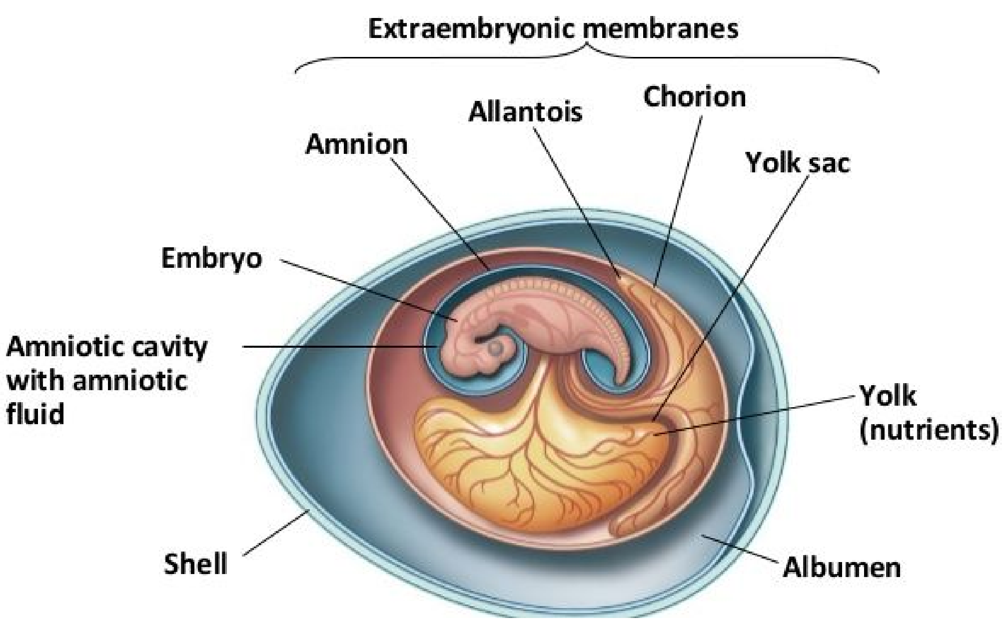


  - The **archenteron** is the cavity resulting from the invagination.
  - The **blastopore** is the opening into the archenteron.

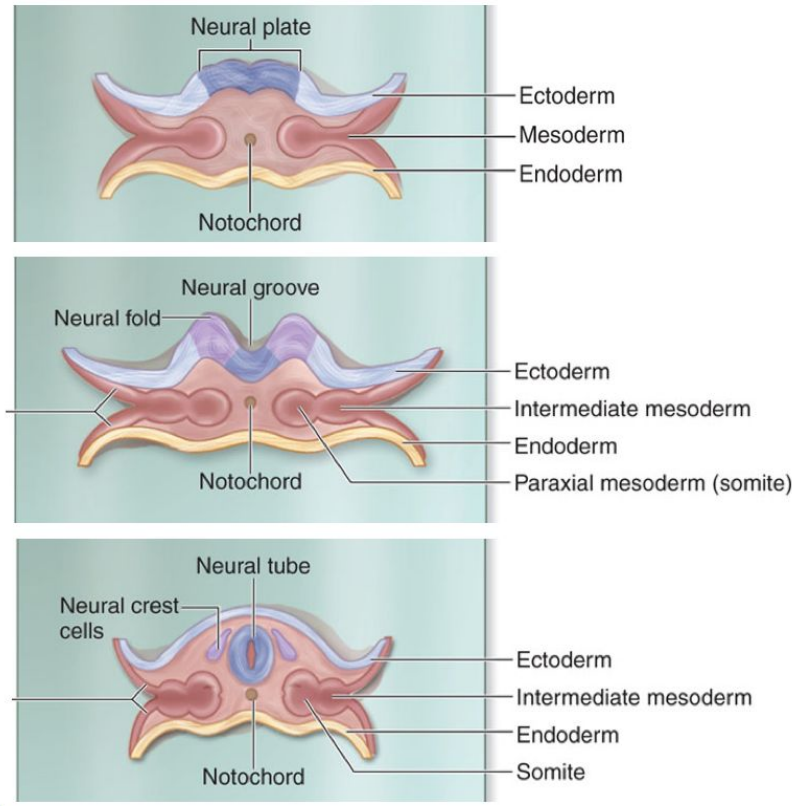


- 6. Extraembryonic Membrane Development
  - Extraembryonic membranes develop only in birds, reptiles, and humans (**amniotes**).
  - The **chorion** is the outer membrane

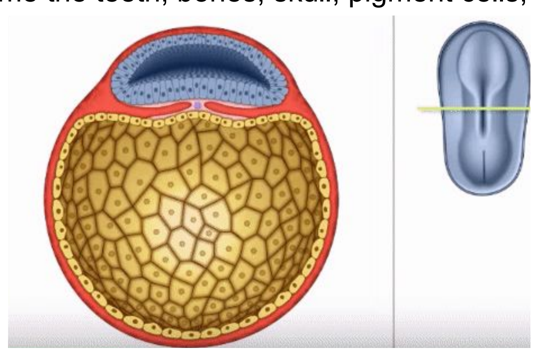
        - In birds and reptiles, it is for gas exchange
        - In mammals, the chorion implants into the endometrium, and later forms the placenta (where gases, nutrients, and water are exchanged between embryo and mother)
        - Understand that the **chorion** and **endometrium** are the two structures that form the placenta.
    - The **allantois** is a sack that branches off of the archenteron, eventually encircling the embryo and forming a layer beneath the chorion.
        - In birds and reptiles, it first acts as waste storage (uric acid) later fusing with the chorion.
        - In mammals, the allantois transports wastes to the placenta. It eventually **forms the umbilical cord** (which transports wastes, nutrients, and gases between the embryo and placenta).
    - The **amnion** encloses the amniotic cavity. The amniotic cavity is filled with fluid, allowing a cushion for the developing embryo.
    - The **yolk sac** is used for nutrients in birds and reptiles, but in placental mammals it is mostly empty.



- 7. <u>Organogenesis</u>
    - After gastrulation, cells begin to differentiate from one another, allowing the formation of different tissues and organs.
    - **The Notochord**
        - Cells on the upper (dorsal) mesoderm from the notochord
        - The notochord provides support



- **Neural Tube**
  - Neural plate → Neural Groove → Neural Tube
  - Develops into the central nervous system (CNS)
  - More cells roll off of the top of the neural tube, which become the teeth, bones, skull, pigment cells, and nerves.



- [Most of the above processes are typical from a sea urchin, a common organism used to study the process of development. There are slight differences in other organisms, some of which are:]()
  - Frogs
  - Birds
  - Humans (or other mammals)
- Factors that Influence Development
  - ..

Animal Behavior (Ethology)

- Animal behavior can either be:
    - Genetic (innate)
        - Molded by evolution
        - Because of this, most of the genetically inherited behavior is typically beneficial for the overall fitness of the animal (**behavioral ecology**)
    - Learned
        - Through the environment/experiences
- Types of Animal Behavior
    - Instinct
        - Inherited (genetic) behavior.
        - An example is in mammals, the mother cares for the offspring.
    - Fixed Action Patterns (FAP) (Modal Action Pattern)
        - Another inherited (instinctive) type of behavior. This is a behavior that almost always *inevitably runs to completion*.
        - There is a "**sign stimulus**" involved which ultimately stimulates the behavior to occur.
            - An example of this stimulus is found in male stickleback fish. These fish build a nest to entice females to come lay their eggs. The males will attack any male who comes into their territory. The stimulus that promotes this aggression is the red belly on other males (they will also show aggression and attack when researchers show the fish a red card, hence the red color is the stimulus).
        - An example of this behavior is in greylag goose. These animals will retrieve an egg that becomes lost from their nest (the lost egg is the stimulus). They will then roll the egg back to the nest. If the egg is lost during this process, they will continue the motion of rolling an imaginary egg back to the nest.
    - Imprinting
        - Another inherited behavior that can be "imprinted" on the animal only during a specific phase during their lifetime. If this **critical period** is missed, the behavior cannot be learned. Once learned, it is irreversible.
        - An example is greylag goose babies who will, on the first day of their life only, accept any moving object to be their mother. After this has occurred, they will reject anything else (even the real mother).
        - Another example is salmon hatching in freshwater and then leaving to the ocean to feed. The salmon, when ready to mate, return to the exact same spot where they hatched. This area was imprinted on them when they were young.

- Associative Learning
  - When an animal learns that two or more events are connected (associated)
  - One example is **classical conditioning** (Pavlov's dogs). The real stimulus (food) is replaced by the substitute stimulus (the bell).
- Trial and Error Learning (Operant Conditioning)
  - Another form of associative learning where the animal connects its behavior to some sort of response it receives.
  - This can be when the animal performs a certain behavior and has positive reinforcement (aka a good result causing the animal to repeat the behavior). It can also be when the animal performs a certain behavior and has a negative reinforcement (aka it causes pain, so the animal ceases to perform that particular behavior).
  - When a behavior no longer elicits the same response, it can be unlearned (**extinction**).
- Spatial Learning
  - Another form of associative learning where the animal connects a specific location (landmarks) to a reward it receives, causing the animal to return to that location.
  - An example is wasps that use landmarks to find their nest. These landmarks can be something such as a pinecone. If the pinecones are removed, the wasp will no longer be able to find where the nest is.
- Habituation
  - This is a learned behavior that allows the animal to disregard meaningless stimuli.
  - An example is sea anemones ignoring things that bump into them that aren't food (like sticks). When actual food bumps into their tentacles they will pull it into their mouth.
- Observational Learning
  - When an animal observes the behavior of another animal, and then copies this behavior without ever having any positive reinforcement for it.
  - An example is monkees brushing sand from a potato. Normally they just brush it off with their hands, but when one monkey from the group found it was more effective to clean it in the water, the rest of the monkeys observed this behavior and copied it.
- Insight
  - This behavior is when an animal gains insight into a new behavior that will result in a positive outcome.
  - An example is a monkey finding bananas that are out of reach (never having been in this position before). The monkey gains insight to build a tower of boxes in order to reach the bananas.

- Animal Movement
  - 1. Kinesis

        - An **undirected** change in speed in response to a stimulus.
        - When a log is lifted up, animals inside respond to the stimulus by scurrying about.
    - 2. <u>Taxis</u>
        - A **directed** movement in response to a stimulus (the movement is directed *towards* or *away* from the stimulus).
        - Phototaxis is when light is the stimulus (movement *towards* the light).
    - 3. <u>Migration</u>
        - Long distance, seasonal movement of animals.
        - Birds, whales, and other animals that migrate to warmer climates during specific seasons (for food, weather, etc.)
- Animal Communication
    - <u>Chemical</u>
        - **Pheromones** are chemicals that animals use to communicate. These can be smelled or eaten.
            - **Releaser pheromones** cause immediate and specific changes in behavior (they release or "trigger" the behavior to occur).
            - **Primer pheromones** cause physiological changes
        - Examples include:
            - Queen bees, termites, or ants secrete a primer pheromone that is eaten by the workers. This prevents the workers from being able to reproduce.
            - Dogs urinate in their territory to warn others.
            - Female moths attract male moths by secreting a releaser pheromone in the air.
    - <u>Visual</u>
        - Visual communication is often used to entice a mate, or to show aggression (agonistic behavior).
        - The red belly of stickleback fish is again a valid example of how these fish communicate. This color attracts females, and is also used to stimulate aggression between males.
    - <u>Auditory</u>
        - Animals use sounds to communicate through long distances, through water, and at night (in the dark).
        - Whales produce "songs" that can be heard for hundreds of miles by other males (at a frequency that humans cannot hear).
    - <u>Tactile</u>
        - Animals use physical touching in social bonding, infant care, grooming, and mating.
        - Wolves greet the dominant male in the pack by licking his muzzle.
- Foraging Behaviors

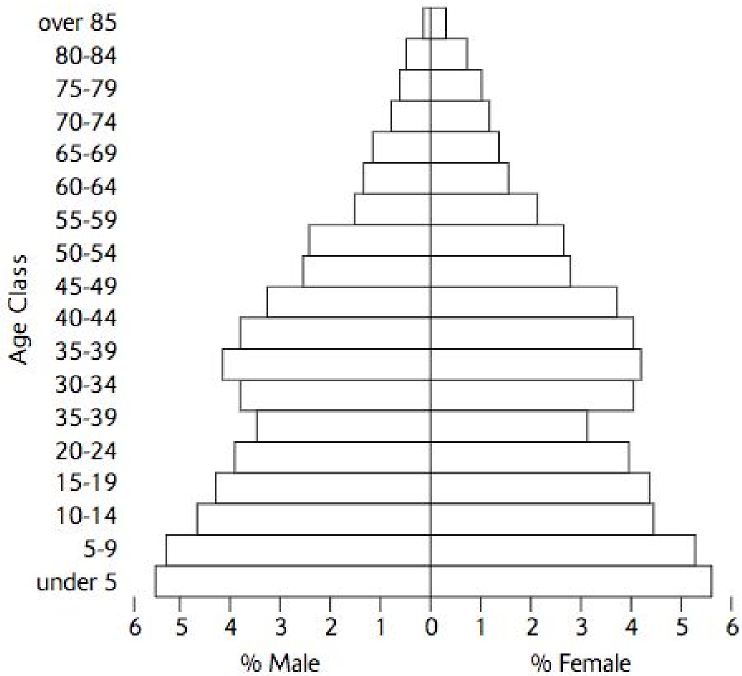
- This type of behavior explains the goal for animals to maximize feeding, while minimizing the amount of energy expended to obtain the food (as well as minimizing the risks they take to obtain the food).
- Animals can form herds, flocks, and schools where they group together in large amounts. This makes it so the majority of animals are hidden away from view (concealment).
- Animals can form packs, allowing them to corner their prey.
- Animals use **search images** to find food (the same technique that humans use, associating an image of a black and white car with a police car).

- Social Behavior
    - Some animals live in groups, while some are solitary. Regardless, at some point animals must engage in social activity to reproduce. Animals can interact in the following ways:
        - <u>Agonistic Behavior</u>
            - Aggression or Submission
            - This behavior comes from the competition for food, mate, or territory.
            - This behaviors are often ritualized.
        - <u>Dominance Hierarchies</u>
            - This indicates the power or status of certain animals.
            - Established hierarchies minimize competition for food or mates.
        - <u>Territoriality</u>
            - When animals (or groups of animals) defend the territory in which they live.
            - Territories are important as they are places to reproduce, raise young, and find food.
        - <u>Altruistic Behavior</u>
            - When animals risk their own safety to defend other animals.
            - This behavior may appear to reduce the fitness, but it actually increases the fitness of the individual and the relatives (**inclusive fitness**).
            - **Kin selection** is a form of natural selection. It is the evolutionary strategy that favours the reproductive success of an organism's relatives, even at a cost to the organism's own survival and reproduction.
            - Kin altruism is altruistic behaviour whose evolution is driven by kin selection. Kin selection is an instance of inclusive fitness, which combines the number of offspring produced with the number an individual can produce by supporting others, such as siblings.

Ecology

- Ecology is the relations of organisms to one another and to their physical surroundings.
    - Population
        - A group of individuals of the same species in an area.
    - Community
        - A group of populations in an area.
    - Ecosystem
        - A community of interacting organisms and their physical environment.
    - Biosphere
        - Any region of the earth that contains living things.
        - The regions of the surface, atmosphere, and hydrosphere of the earth (or analogous parts of other planets) occupied by living organisms.
    - Habitat
        - The type of place where a certain organism usually lives.
        - A habitat may explain the temperature, soil type, water salinity, or other organisms living there.
    - Niche
        - Any biotic or abiotic resource used by an organism in their environment. The environment or resources of an environment will, in some way, change as a result of the niche of an organism living their.
        - A niche is the evolutionary result of a species' morphological (morphology refers to an organism's physical structure), physiological, and behavioral adaptations to its surroundings.

- **<u>Population Ecology</u>** (growth, abundance, and distribution of populations)
    - <u>Size</u>
        - The total number (N) of individuals living in a population.
    - <u>Density</u>
        - The number of organisms per area or volume occupied.
    - <u>Dispersion</u>
        - The way that individuals are distributed in a population.
        - Clumped (humans in cities), uniform (orchard trees), or random (forest trees)
    - <u>Age Structure</u>
        - Describes the amount of individuals of a species at each age.
        - See diagram below:



Age Structure

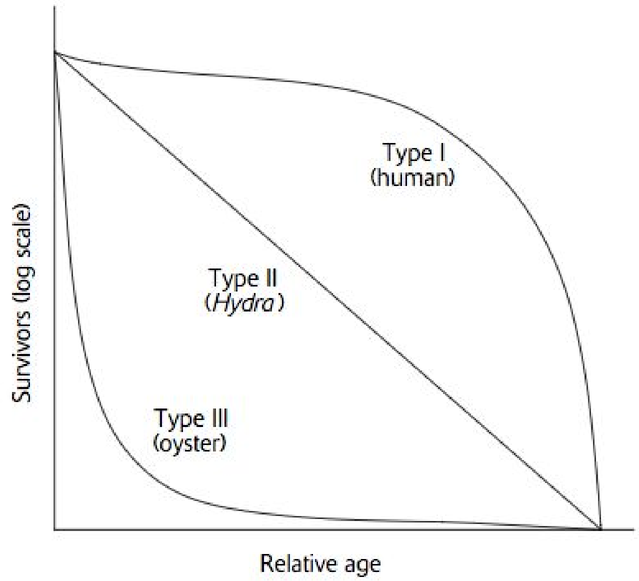
- Horizontal Bars:
    - The frequency of individuals in that particular age group.
- Vertical Line:
    - Divides males and females.

■ A pyramid shaped diagram would indicate a rapidly growing population because of the high frequency of young individuals.

■ If the tiers all have relatively equal width, this indicates a stable population, aka a population with “zero population growth” or ZPG.

○ Survivorship Curves

■ Describes the varying mortality (death) of individuals of a species over their lifetime. See diagram below:



Survivorship Curves

        - Type I
            - A species in which most of the organisms survive to their middle age, and then the majority die afterwards (humans).
        - Type II
            - Organisms have random rates of survival. This means the likelihood of mortality is the same at every age.
        - Type III
            - Majority of individuals die young, with very few surviving to adulthood.
            - This is common in species with larvae (marine plankton) where most of them are eaten and don't survive to adulthood.
- Population Growth is determined by:
    - <u>Biotic Potential</u>
        - This describes the maximum growth rate of a species under perfectly ideal conditions (unlimited resources, no restrictions).
        - The biotic potential of a species depends on their age at reproductive maturity, the amount of offspring made during each reproductive event, how frequently the organism reproduces, and the survivorship of the offspring.
        - Examples:
            - Elephants can only have a single baby every two years. Even still they have a great biotic potential, because after 2,000 years a single couple could have enough descendents to outweigh the earth.
            - Some bacteria can divide every twenty minutes, with the potential of making 10 trillion offspring in 10 hours.

- Carrying Capacity
  - The maximum number of organisms in a population that are able to be sustained by their habitat.
- Limiting Factors
  - These factors include anything that prevents a species from reaching their biotic potential. These factors are categorized in two ways:
    - **Density Dependent**
      - These limiting factors are density dependent, meaning that the bigger the population size of the organism, the greater effect the limiting factor has (more organisms = increased limitations).
      - Transmission rates of parasites and diseases increase as a population increases.
      - Competition for food and resources increases with an increase in population size.
      - More toxic waste is produced with larger populations.
    - **Density Independent**
      - Opposite to the above, these limiting factors are completely independent of population size.
      - Natural disasters (fires, earthquakes, etc.) or extreme climates (storms).

- The growth of a population can be determined mathematically:

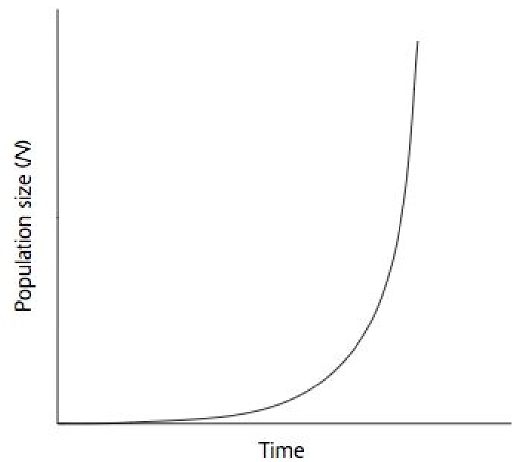
$$R = \frac{Births - Deaths}{N}$$

    - R = reproductive rate (growth rate)
    - N = population size at the beginning of the interval
    - (Births - Deaths) = the net increase of individuals
    - The equation can also be expressed as:

$$\frac{\Delta N}{\Delta t} = rN = \text{Births - Deaths}$$

    - This represents the change in the number of individuals over time.
  - **Intrinsic Rate of Growth**
    - When the reproductive rate (r) is at a maximum (aka the biotic potential) then it is called the intrinsic rate of growth.

- Types of Population Growth:
  - 1. Exponential Growth
    - Exponential growth occurs whenever the reproductive rate is greater than zero (it can be smaller than zero if deaths exceed births).

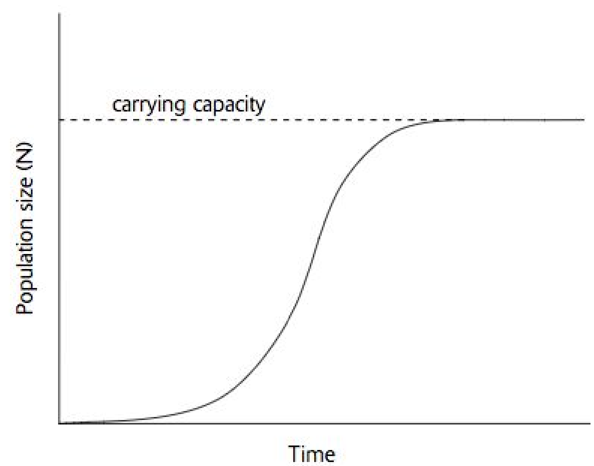


Exponential Population Growth

- Graph of Population Size vs. Time
- Note the growth of the population rises very quickly.

■ 2. Logistic Growth

- This type of population growth occurs when there is some type of limiting factor preventing exponential growth. Ultimately this causes the population size to be restricted to its carrying capacity in that habitat.



Logistic Population Growth

- This type of growth is represented by:

$$\frac{\Delta N}{\Delta t} = rN\left(\frac{K-N}{K}\right)$$

- K = Carrying Capacity
- When N = K it means the population has reached its carrying capacity in the habitat. Note how the population size increases, and its reproductive rate decreases. Once N = K, the reproductive rate is zero and so the size of the population stabilizes.

○ Population Cycles

        - These cycles describe the fluctuations of the size of populations in response to limiting factors.

- **Human Population Growth**
    - ...