AP Biology Notes

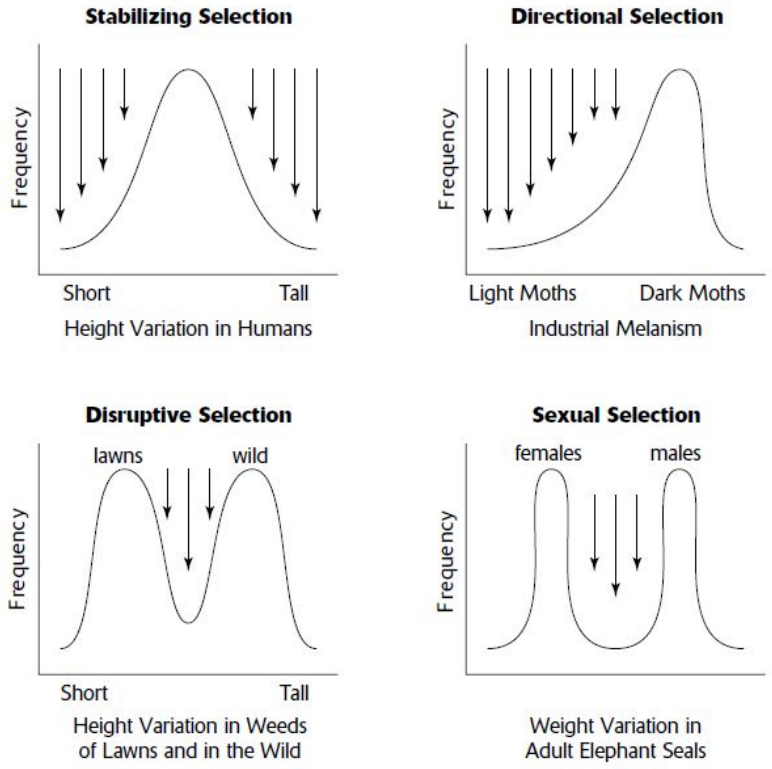
Evolution

1. **Evolution**
    a. Evolutionary biologists know evolution occurs; the question they want to answer is how it occurs. For this they propose theories. **Lamarck** theorized, incorrectly, that evolution occurs through the inheritance of acquired characteristics. **Darwin's** theory, which is most widely accepted, was that evolution progresses through natural selection.
    b. **Evolution** is defined as a *change in allele frequencies in a population over time.*

2. **Evidence for Evolution**
    a. **Paleontology**: Fossil deposits are often found among sediment layers, where the deepest fossils represent the oldest specimens. For example, fossil oysters removed from successive layers of sediment show gradual changes in the size of the oyster shell alternating with rapid changes in shell size.
    b. **Biogeography**: Geography reveals that unrelated species in different regions of the world look alike when found in similar environments, which suggest natural selection at work.
    c. **Embryology**: Reveals similar stages in development among related species. These similarities help demonstrate evolutionary relationships.
    d. Comparative anatomy:
        i. **Homologous structures** are body parts that resemble one another in different species because they have evolved from a common ancestor.
        ii. **Analogous structures** are body parts that resemble one another in different species, not because they have evolved from a common ancestor, but because they evolved independently as adaptations to their environments.
    e. Molecular biology: More than 98% of the nucleotide sequences in humans and chimpanzees are identical. This supports evolution of different species through modification of genetic information.

3. **Natural Selection**
    a. Darwin observed through his travels that **variation** naturally exists within populations. These small variations in traits can influence an individual's ability to survive and reproduce successfully, he reasoned.

b. He realized that more offspring are born to a species than can possibly survive, leading to **competition** among members of the same species for existence. Those offspring with the most advantageous adaptations, differences allowing an individual to become better suited to its environment, would be better able to survive and reproduce, thus ensuring their traits would be passed on.
c. In a sense, nature "selects" traits more helpful for survival. This is called **natural selection**, and it is the process by which Darwin proposed new species evolve.
d. **Artificial selection** is a form of directional selection carried out by humans when they sow seeds or breed animals that possess desirable traits.
e. Different types of natural selection act on populations in different ways. Four kinds of selection with examples are shown below.
f.



4. Sources of Variation

a. **Mutations**: Introduce new alleles that never before existed into gene pool.
b. **Sexual reproduction:** Creates individuals with new combinations of alleles
c. **Diploidy**: Presence of two copies of each chromosome in a cell. Recessive alleles can be "stored" for future generations
d. **Outbreeding**: Random mating increases possibility of mixing different alleles
e. **Balanced Polymorphism**: Coexistence of two or more phenotypes, as a result of:
    i. Heterozygote advantage
    ii. Hybrid Vigor

iii. Minority Advantage

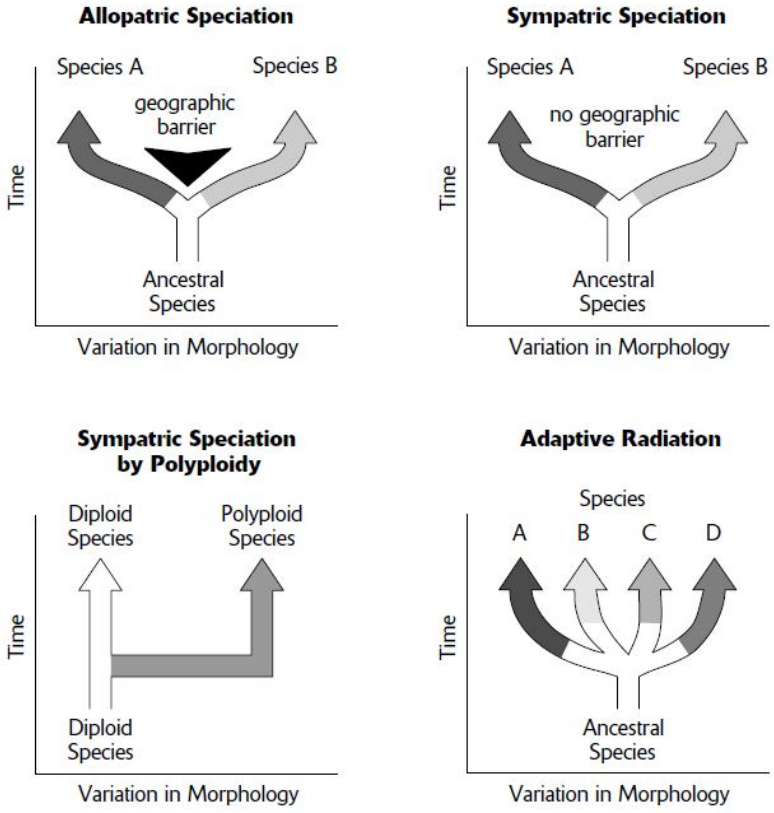
5. **Causes of Evolution**
    a. **Natural Selection:** increase or decrease in allele frequencies due to the impact of the environment.
    b. **Mutations:** mutations in DNA occur frequently during the replication process; it cannot be stopped. Even exposure to sunlight can cause mutations in an organism's DNA.
    c. **Gene Flow:** introduction or removal of alleles from the population when individuals leave (emigration) or enter (immigration) the population.
    d. **Genetic Drift:** random increase or decrease of alleles particularly strong in small populations
        i. **Founder Effect** allele frequencies in a group of migrating individuals are, by chance, not quite the same as that of their population of origin.
        ii. **Bottleneck** population undergoes a dramatic decrease in size
    e. **Nonrandom Mating:** individuals choose mates based upon their particular traits.
        i. **Inbreeding**
        ii. **Sexual Selection**

6. **Genetic Equilibrium**
    a. When allele frequencies are constant from generation to generation, the population is in **genetic equilibrium**, or **Hardy-Weinberg equilibrium**.
    b. Five conditions must be met for this to occur:
    1. All traits are selectively neutral (no natural selection).
    2. Mutations do not occur.
    3. The population must be isolated from other populations (no gene flow).
    4. The population is large (no genetic drift).
    5. Mating is random.
    c. This never occurs in nature!
    d. If p = frequency of dominant allele and q = frequency of recessive allele (assuming Hardy-Weinberg equilibrium), then
        i. **$p + q = 1$** (all alleles sum to 100%)
        ii. **$p^2 + 2pq + q^2$** = 1 (all individuals sum to 100%)

7. **Speciation**: the formation of new species occurs by any of the following processes
    a. **Allopatric Speciation**: population is divided by a geographic barrier so that interbreeding between the two resulting populations is prevented.

b. **Sympatric Speciation:** formation of new species without the presence of a geographic barrier.

c. Adaptive Radiation: relatively rapid evolution of many species from a single ancestor. It occurs when the ancestral species is introduced to an area where diverse geographic or ecological conditions are available for colonization.



8. **<u>Reproductive Isolation</u>** If species are not physically separated by a geographic barrier, mechanisms exist to maintain reproductive isolation and prevent gene flow from occurring.

a. **Habitat isolation** occurs when species do not encounter one another.

b. **Temporal isolation** occurs when species mate or flower during different seasons or at different times of the day.

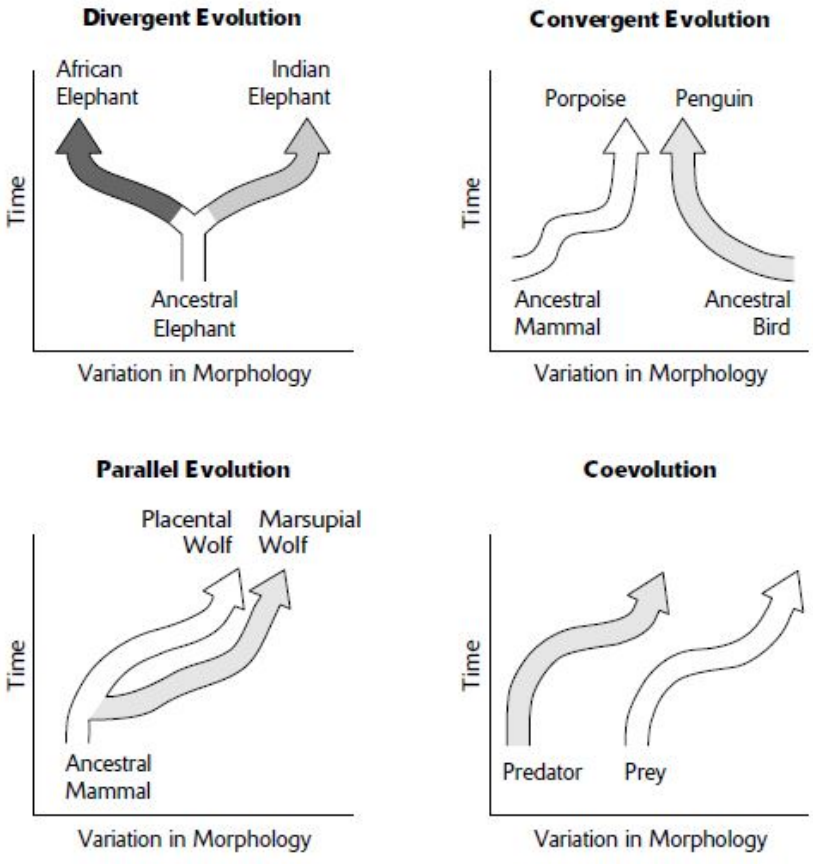
c. **Behavioral isolation** occurs when a species does not recognize another species as a mating partner because it does not perform the correct courtship rituals, display the proper visual signals, sing the correct mating songs, or release the proper chemicals.

d. **Mechanical isolation** occurs when male and female genitalia are structurally incompatible or when flower structures select for different pollinators.

e. **Gametic isolation** occurs when male gametes do not survive in the environment of the female gamete.
f. **Hybrid inviability** occurs when the zygote fails to develop properly and aborts, or dies, before reaching reproductive maturity.
g. **Hybrid sterility** occurs when hybrids become functional adults, but are reproductively sterile (eggs or sperm are nonexistent or dysfunctional). Ex: mule
h. **Hybrid breakdown** occurs when hybrids produce offspring that have reduced viability or fertility.

9. Patterns of Evolution There are four patterns of evolution, which are

a. **Divergent Evolution**: two or more species that originate from a common ancestor and become increasingly different over time.
b. Convergent Evolution: describes two unrelated species that share similar traits.
c. **Parallel Evolution:** describes two related species or two related lineages that have made similar evolutionary changes
d. Coevolution: evolution of one species in response to new adaptations that appear in another species.

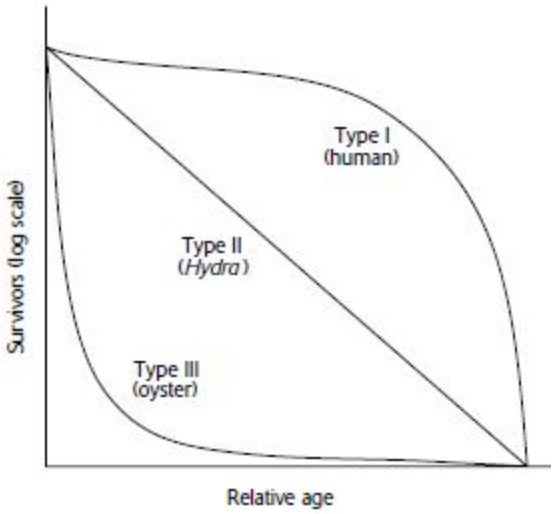


10. Origin of Life

- **a.** Earth and atmosphere formed
- **b.** Primordial seas formed
- **c.** Complex molecules were synthesized
    - **i. Miller-Urey experiment** demonstrates that organic molecules can come from abiotic compounds under early-Earth conditions!
- **d.** Polymers and self-replicating molecules were synthesized
- **e.** Organic molecules were isolated into protobionts (precursors of cells)
- **f.** Primitive prokaryotes form
- **g.** Prokaryotes gain ability to make food through mutation in DNA
- **h.** Oxygen layer forms
- **i.** Eukaryotes form through **endosymbiosis:** According to endosymbiotic theory, eukaryotic cells originated from a mutually beneficial association among various kinds of prokaryotes. Evidence for endosymbiosis include
    i. Mitochondria and chloroplasts possess their own (circular) DNA.
    ii. Ribosomes of mitochondria and chloroplasts resemble those of bacteria and cyanobacteria, with respect to size and nucleotide sequence.
    iii. Mitochondria and chloroplasts reproduce independently of their eukaryotic host cell by a process similar to the binary fission of bacteria.
    iv. Mitochondria and chloroplasts have two membranes (both phospholipid bilayers).

Ecology & Animal Behavior

1. **Ecology:** the study of the distribution and abundance of organisms, their interactions with other organisms, and their interactions with their physical environment.
    a. **Population:** group of individuals all of the same species living in the same area
    b. **Community:** group of populations living in the same area
    c. **Ecosystem:** interrelationships between the organisms in a community and their physical environment
    d. **Biosphere:** all the regions of the earth that contain living things
    e. **Habitat:** place where organism lives
    f. **Niche**: all biotic and abiotic resources in environment used by an organism
2. **Population Ecology:** the study of the growth, abundance, and distribution of populations. Population abundance and distribution can be described by:
    a. **Size (N)** total number of individuals in the population
    b. **Density:** Size divided by volume occupied
    c. **Distribution:** dispersion of individuals in a population
        i. **Uniform** (trees in an orchid)
        ii. **Clumped** (human cities)
        iii. **Random** (forests)
    d. **Survivorship Curve:** describes how mortality of individuals in a species varies during their lifetimes
        i. **Type I** curves describe species in which most individuals survive to middle age. After that age, mortality is high.
        ii. **Type II** curves describe organisms in which the length of survivorship is random, or equally likely across all ages.
        iii. **Type III** curves describe species in which most individuals die young, with only a relative few surviving to reproductive age and beyond.



3. **Growth Rates**
    a. The **carrying capacity** is the maximum number of individuals of a population that can be sustained by a particular habitat.
    b. Limiting Factors
        i. **Density-dependent** (disease, competition, predation, pollution)
        ii. Density-independent (climate, earthquakes, fires, rainfall)
    c. The growth rate of a population is equal to

$$r = \frac{births - deaths}{N}$$

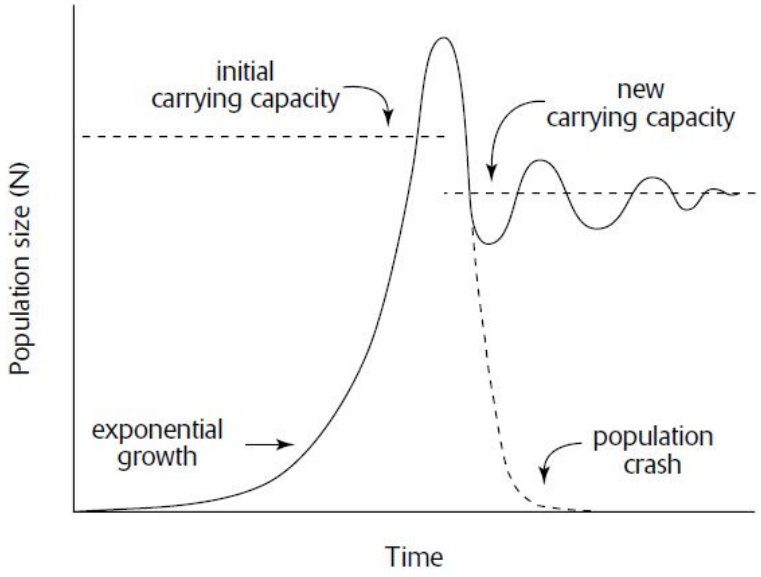
where N is the population size.

    d. There are two kinds of population growth patterns:
        i. **Exponential Growth** occurs whenever the reproductive rate is greater than zero. On a graph where population size is plotted against time, a plot of exponential growth rises quickly, forming a J-shaped curve.
        ii. **Logistic Growth** occurs when limiting factors restrict the size of the population to the carrying capacity of the habitat. The plot forms an S-shaped curve.
            1. The equation for logistic growth is

$$\frac{dN}{dt} = rN(\frac{K - N}{K})$$

where K is the carrying capacity.

    e. A typical growth pattern is shown in the graph below.



The population may continue to fluctuate about the carrying capacity as limiting factors exert negative feedback on population growth when population size is large. When population size is small, limiting factors exert little negative feedback, and population growth renews.

f. Growth patterns are connected to two kinds of **reproductive strategies:**

i. An **r-selected** species exhibits rapid growth (J-shaped curve). This type of reproductive strategy involves quickly maturing, quickly reproducing, and then dying. Offspring require little or no parental care.

ii. A **K-selected** species is one whose population size remains relatively constant. Species of this type, such as humans, produce a small number of relatively large offspring that require extensive parental care until they mature.

4. **<u>Community Ecology</u>**

Competition is resolved by

a. **Competitive exclusion principle (Gause's principle):** no two species can sustain coexistence if they occupy the same niche

b. **Resource Partitioning:** pursuing slightly different resources or securing their resources in slightly different way

c. **Realized niche:** both species may be able to coexist by occupying their realized niches, that part of their existence where niche overlap is absent, that is, where they do not compete for the same resources.

d. **Symbiosis:** two species that live together in close contact during a portion (or all) of their lives.

Mutualism (+,+) Both species benefit
Commensalism (+,0) One benefits and one isn't harmed
Parasitism (+,-) Parasite benefits at expense of host

5. **<u>Coevolution</u>**

a. **Camoflauge (Cryptic Coloration):** color, pattern, shape, or behavior that enables an animal to blend in with its surroundings.

b. **Aposematic Coloration:** conspicuous pattern or coloration of animals that warns predators that they sting, bite, taste bad, or are otherwise to be avoided.

c. **Mimicry**

i. **Mullerian Mimicry:** several animals, all with some special defense mechanism, share the same coloration. Müllerian mimicry is an effective strategy because a single pattern, shared among several animals, is more

easily learned by a predator than would be a different pattern for every animal.

ii. **Batesian Mimicry:** occurs when an animal without any special defense mechanism mimics the coloration of an animal that does possess a defense.

6. **Succession** describes how one community with certain species is gradually and predictably replaced by another community consisting of different species.
    a. The **Climax community** is a final successional stage of constant species composition
    b. The plants and animals that are first to colonize a newly exposed habitat are called **pioneer species**.
    c. **Primary succession** occurs on substrates that never previously supported living things. For example, primary succession occurs on volcanic islands, on lava flows, and on rock left behind by retreating glaciers.
    d. **Secondary succession** begins in habitats where communities were entirely or partially destroyed by some kind of damaging event. For example, secondary succession begins in habitats damaged by fire, floods, insect devastations, overgrazing, and forest clear-cutting

7. **Ecosystems**
    a. Plants and animals are organized into trophic levels that reflect their main energy source.
        i. **Primary producers** are autotrophs that convert sun energy into chemical energy. They include plants, photosynthetic protists, cyanobacteria, and chemosynthetic bacteria.
        ii. **Primary consumers**, or herbivores, eat the primary producers.
        iii. **Secondary consumers**, or primary carnivores, eat the primary consumers.
        iv. **Tertiary consumers**, or secondary carnivores, eat the secondary consumers.
        v. **Detritivores** are consumers that obtain their energy by consuming dead plants and animals (detritus). The smallest detritivores, called **decomposers**, include fungi and bacteria.
    b. Ecological efficiency describes the proportion of energy represented at one trophic level that is transferred to the next level. The relative sizes of tiers in an energy pyramid (or pyramid of productivity) indicate the ecological efficiency of the ecosystem. On average, the efficiency is only about 10 percent.

8. **<u>Biogeochemical Cycles</u>** describe the flow of essential elements from the environment to living things and back to the environment.
    a. **Hydrologic cycle**
        i. Reservoirs: oceans, air (as water vapor), groundwater, glaciers. (Evaporation, wind, and precipitation move water from oceans to land.)
        ii. Assimilation: plants absorb water from the soil; animals drink water or eat other organisms (which are mostly water).
        iii. Release: plants transpire; animals and plants decompose.
    b. **Carbon cycle**
        i. Reservoirs: atmosphere (as CO_2), fossil fuels (coal, oil), peat, durable organic material (cellose, for example).
        ii. Assimilation: plants use CO_2 in photosynthesis; animals consume plants or other animals.
        iii. Release: plants and animals release CO_2 through respiration and decomposition; CO_2 is released when organic material (such as wood and fossil fuels) is burned.
    c. Nitrogen cycle
        i. Reservoirs: atmosphere (N_2); soil (NH_4^+ or ammonium, NH_3 or ammonia, NO_2^- or nitrite, NO_3^- or nitrate).
        ii. Assimilation: plants absorb nitrogen either as NO_3^- or as NH_4^+; animals obtain nitrogen by eating plants or other animals. The stages in the assimilation of nitrogen are as follows:
            1. Nitrogen fixation: N_2 to NH_4+ by nitrogen-fixing prokaryotes (in soil and root nodules); N_2 to NO_3^- by lightning and UV radiation.
            2. Nitrification: $NH4^+$ to NO_2^- and NO_2^- to NO_3^- by various nitrifying bacteria.
        iii. Release: denitrifying bacteria convert NO_3^- back to N_2 (denitrification)
    d. Phosphorus cycle
        i. Reservoirs: rocks and ocean sediments. (Erosion transfers phosphorus to water and soil; sediments and rocks that accumulate on ocean floors return to the surface as a result of uplifting by geological processes.)
        ii. Assimilation: plants absorb inorganic PO_4^{3-} (phosphate) from soils; animals obtain organic phosphorus when they eat plants or other animals.
        iii. Release: plants and animals release phosphorus when they decompose; animals excrete phosphorus in their waste products.

9. **<u>Animal behavior</u>**

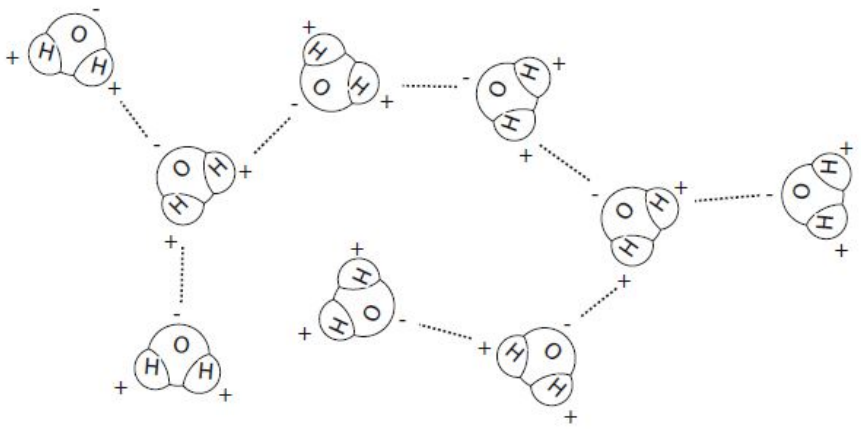
a. **Innate Behavior**
    i. Behavior patterns that animals are "born" with.
b. **Fixed Action Patterns**
    i. A sequence if behavior triggered by a single stimulus.
c. **Imprinting**
    i. Making close connection to another organism during a critical period
    ii. A critical period is an important period early in the organism's life during which they have the ability to learn something quickly.
d. **Classical Conditioning**
    i. Association learning; learning to associate a stimulus with another action.
e. **Operant Conditioning**
    i. Learning based on punishment and reinforcement
f. **Habituation**
    i. Learning to ignore a stimulus from repeated exposure
g. **Observational Learning**
    i. Behaviors gained from observing others display this behavior

10. **<u>Human Impact on Biosphere</u>**
    a. **Global Climate Change:** The burning of fossil fuels and forests increases CO_2 in the atmosphere. Increases in CO_2 cause more heat to be trapped in the earth's atmosphere.
    b. **Ozone Depletion:** The ozone layer forms in the upper atmosphere when UV radiation reacts with oxygen (O2) to form ozone (O3). The ozone absorbs UV radiation and thus prevents it from reaching the surface of the earth where it would damage the DNA of plants and animals.
    c. **Acid Rain:** The burning of fossil fuels (such as coal) and other industrial processes release into the air pollutants that contain sulfur dioxide and nitrogen dioxide. When these substances react with water vapor, they produce sulfuric acid and nitric acid that rain down and kill plants.
    d. **Desertification:** Overgrazing of grasslands that border deserts transform the grasslands into deserts.
    e. **Deforestation:** Clear-cutting of forests causes erosion, flooding, and changes in weather patterns.

Biochemistry

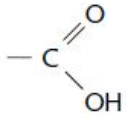
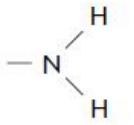
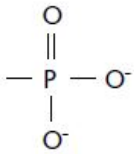
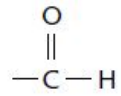
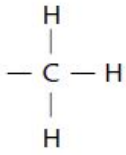
1. **Atoms and Molecules**
    a. An **atom** consists of a dense, positively charged nucleus of protons and neutrons surrounded by a cloud of negatively-charged electrons.
    b. **Molecules** are groups of two or more atoms held together by chemical bonds.
    c. The **electronegativity** of an atom is a measure of the ability of an atom to attract electrons, and it plays a part in determining the kind of bond that forms.

2. **Bonds** Three of the most important kinds of chemical bonds in organic molecules are:
    a. **Ionic** bonds form between two atoms when one or more electrons are transferred from one atom to the other. The atom that gains electrons has an overall negative charge, and the atom that loses electrons has an overall positive charge. Because of their positive or negative charges, these atoms are ions. The attraction of the positive ion to the negative ion constitutes the ionic bond.
    b. **Covalent bonds** form when electrons between atoms are shared.
        i. **Nonpolar Covalent** bonds form when electrons are shared equally.
        ii. **Polar Covalent:** bonds form when electrons are shared unequally. Atoms in this kind of bond have electronegativities that are different which causes an unequal distribution of electrons.
        iii. Covalent bonds can be **single**, **double**, or **triple**, depending on the number of pairs of electrons being shared.
    c. **Hydrogen** bonds are weak bonds *between* molecules. They form when a positively charged hydrogen atom in one covalently bonded molecule is attracted to a negatively charged area of another covalently bonded molecule.
        i. Hydrogen bonding in water is shown below.



3. **Properties of Water** The hydrogen bonds in water give rise to water's unique properties, which are essential to life on Earth
    a. **Water is a strong solvent:** Ionic substances are soluble in water because the poles of the water molecules interact with the charged ionic substances and separate them into ions. Polar substances are also soluble because of the interaction of their poles with those of water. Substances that dissolve in water are called **hydrophilic** ("water loving") while nonpolar covalent substances that do not dissolve in water are called **hydrophobic** ("water fearing").
    b. **Water has a high heat capacity:** Water has a high heat capacity, changing temperature very slowly with changes in its heat content. The temperatures of large bodies of water are very stable in response to the temperature changes of the surrounding air, which is why coastal cities are so cool.
    c. **Ice floats**: Water expands as it freezes, becomes less dense than its liquid form, and, as a result, floats in liquid water. This is important to aquatic life in cold areas; the ice layer atop a frozen lake insulates the life beneath.
    d. **Water is cohesive:** Cohesion, or the attraction between like substances, occurs in water because of the hydrogen bonding between water molecules. The strong cohesion between water molecules produces a high surface tension, creating a water surface that is firm enough to allow many insects to walk upon it without sinking.
    e. **Water is adhesive:** Adhesion is the attraction of unlike substances. When water adheres to the walls of narrow tubing or to absorbent solids like paper, it demonstrates **capillary action** by rising up the tubing or creeping through the paper.

4. **Organic Molecules**
    a. Organic molecules are made of carbon atoms. In living systems, large organic molecules, called macromolecules, may consist of hundreds or thousands of atoms. Most macromolecules are **polymers**, molecules that consist of a single unit (**monomer**) repeated many times.
    b. Many organic molecules share similar properties because they have similar clusters of atoms, called functional groups. Each **functional group** gives the molecule a particular property, such as acidity or polarity.
    c. Complex molecules can be formed by stringing carbon atoms together in a straight line or by connecting carbons together to form rings.
    d. A table of the most common functional groups in biochemistry is shown below:

Functional Group		Class Name	Examples	Characteristics
— OH	hydroxyl	alcohols	ethanol, glycerol, sugars	polar, hydrophilic
	carboxyl	carboxylic acids	acetic acid, amino acids, fatty acids, sugars	polar, hydrophilic, weak acid
	amino	amines	amino acids	polar, hydrophilic, weak base
	phosphate	organic phosphates	DNA, ATP, phospholipids	polar, hydrophilic, acid
	carbonyl	ketones	acetone, sugars	polar, hydrophilic
	carbonyl	aldehydes	formaldehyde, sugars	polar, hydrophilic
	methyl	——	fatty acids, oils, waxes	nonpolar, hydrophobic

5. Carbohydrates

a. **Carbohydrates** are mainly used in organisms as a *source of energy*. They are classified as simple sugars (monosaccharides or disaccharides) or complex sugars (polysaccharides).

b. The simple sugars themselves all share the molecular formula $C_nH_{2n}O_n$. They link up via glycosidic bonds through the process of condensation synthesis.

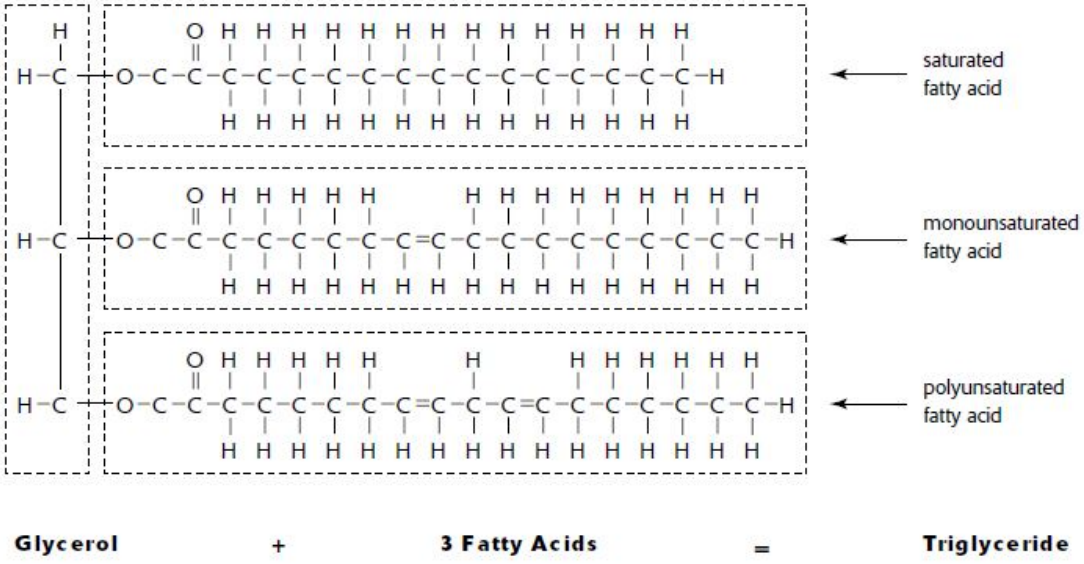
c. **Glycosidic bonds** are the oxygen bridges between glucose molecules. The process of forming them is known as **condensation synthesis,** or dehydration synthesis, because water is lost through the joining of an H+ ion from one monomer and an OH- ion from another.

d. The decomposition of disaccharides or polysaccharides, which occurs during digestion, is the opposite process known as **hydrolysis**. This occurs only in the presence of water and enzymes.

e. Plants produce them via photosynthesis to be used a reservoir of fuel before being converted into energy via aerobic respiration.
f. The structure of carbohydrates makes this a quick and efficient process so that the animal can quickly absorb the glucose into the blood and gain energy from it.

6. <u>Lipids</u>

a. **Lipids** are important to cells because they are the basis of all cell membranes, store energy, and control cholesterol and sex hormones. The three main types of lipids are fats, phospholipids, and steroids.
b. **Fats**, the most common lipids, are used for storing energy. The two types of fats are **saturated** (Ex: solid, animal fats) and **unsaturated** (Ex: fish oil, olive oil, etc.) The only difference between the two is that saturated fats have only single covalent bonds in the fatty acid chains while unsaturated fats have one or more double covalent bonds between fatty acid chains.

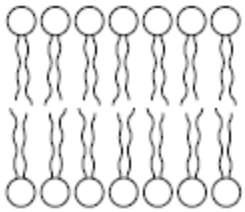


c. The second type of lipids is **phospholipids**, which will be discusses later.
d. The final type of lipid is **steroids**, which are used to determine the cholesterol and sex of an individual. Steroids are composed of four fused rings at all times.

7. <u>Phospholipids</u>

a. Phospholipids make up the cell membrane. Each phospholipid has a hydrophilic head and two hydrophobic tails.
b. A phospholipid looks just like a lipid except one of the fatty acid chains is replaced by a phosphate group.

c. In order to form the cell membrane, phospholipids create a phospholipid bilayer composed of two stacked layers of phospholipids, oriented with the tails on the inside.
d. This structure allows the bilayer to be semi-permeable, with only water able to pass through.
e. A phospholipid is termed an **amphipathic** molecule because it has both polar (hydrophilic) and nonpolar (hydrophobic) regions.
f. The orientation of phospholipids in the cell membrane is shown to the right.



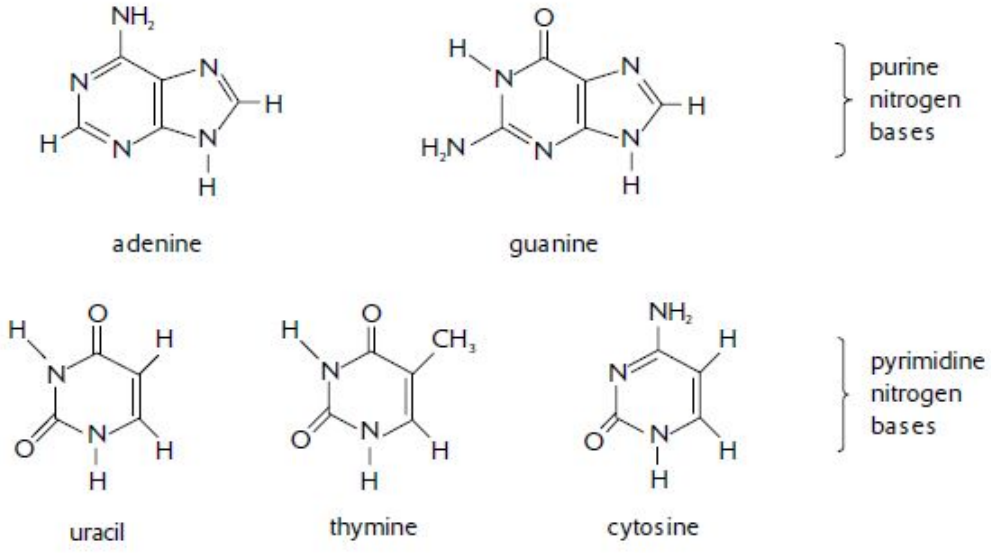
8. <u>Proteins</u>

a. Proteins are made up of **amino acids** which contain carbon, hydrogen, oxygen, and nitrogen atoms. There are 20 different amino acids commonly found in proteins, but all amino acids have a central carbon to which an amino group (-NH2), a carboxyl group (-COOH), a Hydrogen, and an R group are attached.
b. The **R group**, also called the side chain, is what gives each amino acid its identity since each amino acid has its own particular R group. The R group could be as simple as a hydrogen atom (as in glycine) or as complex as a carbon skeleton (as in arginine).
c. The single amino acids join together with **peptide** bonds, where the N from the amino group bonds with the C of the carboxyl group of the amino acid before it. Water is released as a result of this bond (the -OH group leaves the carboxyl end and an H leaves the amino end to make water).
d. In addition to the variety of proteins that can be created from different R groups, there is also enormous variety from the arrangement of proteins.
    i. The **primary structure** refers to the unique sequence of amino acids in the protein.
    ii. The **secondary structure** is the coiling or bending of the polypeptide, or a string of amino acids, into sheets. Alpha helix or beta pleated sheets are examples of this.
    iii. **Tertiary structure** is the folding back of a molecule upon itself and is held together by disulfide bridges and hydrogen bonds. This increases the protein's stability.
    iv. **Quaternary structure** is a complex structure involving the interaction of several polypeptide chains. At this point, the polypeptide chains are finally considered proteins.

9. Nucleic Acids

a. DNA is a polymer of nucleotides. A DNA nucleotide consists of three parts—a nitrogen base, a five-carbon sugar called deoxyribose, and a phosphate group.

b. The nitrogen bases are:



c. A strand of DNA or RNA consists of nucleotides linked together by phosphodiester bonds.

d. A phosphodiester bond exists between the phosphate of one nucleotide and the sugar 3' carbon of the next nucleotide. This forms a backbone of alternating sugar and phosphate molecules known as the "sugar-phosphate backbone".

e. In nucleic acids, hydrogen bonding occurs between the nitrogen bases of DNA and RNA and holds the strands together. The double helix structure of DNA is caused by this interaction.

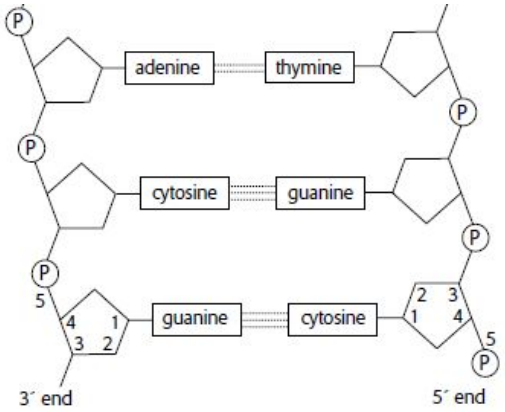
f. RNA differs from DNA in that:

1. The sugar in the nucleotides that make an RNA molecule is ribose, not deoxyribose as it is in DNA.

2. The thymine nucleotide does not occur in RNA. It is replaced by uracil. When pairing of bases occurs in RNA, uracil (instead of thymine) pairs with adenine.

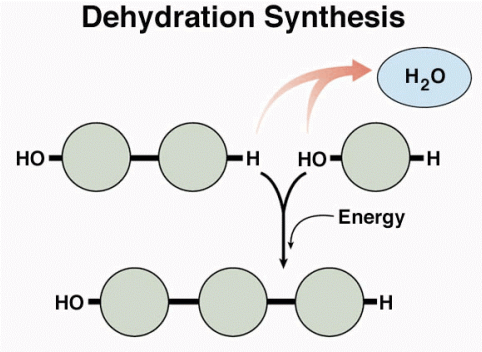
3. RNA is usually single-stranded and does not form a double helix as it does in DNA.

g. The two strands of a DNA helix are antiparallel, as shown to the right.



10. <u>Chemical Reactions</u>

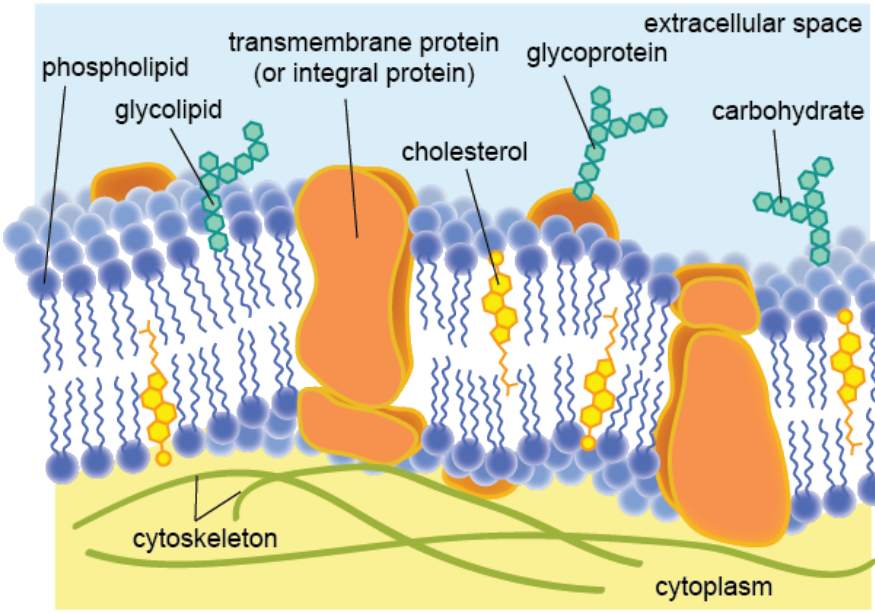
a. The process of forming bonds between proteins, carbohydrates, or fatty acids to glycerol is known as condensation synthesis, or dehydration synthesis, because water is lost through the joining of an H+ ion from one monomer and an OH- ion from another.



b. The decomposition of disaccharides or polysaccharides, which occurs during digestion, is the opposite process known as hydrolysis. This occurs only in the presence of water and enzymes.

Cells, Membranes, & Mechanics

1. **Cell Membrane Structure and Function**



   a. **FUNCTION** The plasma membrane serves to separate the internal cellular environment from the external environment and mediate the movement of materials into and out of the cell.
   b. **STRUCTURE** The membrane itself is a double phospholipid **bilayer** with polar hydrophilic heads forming the outer faces and the nonpolar hydrophobic tails pointing towards the inside of the membrane.
      i. Its structure gives the cell fluidity as well as allowing it to be selectively **permeable**, meaning only small uncharged molecules can freely pass the membrane.
   c. **Proteins** are embedded into the plasma membrane and exist as channel proteins, **aquaporins** *(channel proteins for water),* transport proteins, receptor proteins, recognition proteins, or carrier proteins.
      i. Some of their functions include providing open passageways for hydrophilic substances, allowing the passage of ions, transporting materials across the membrane with the use of ATP (called active transport), provide binding cites for hormones, attaching to neighboring cells, giving each cell a unique identification, and binding to specific molecules.
   d. **Cholesterol** molecules are steroids with ring-like structures. Embedded in the bilayer, they provide some rigidity and moderate the fluidity of the plasma membranes of animal cells.

e. The **glycocalyx** is a carbohydrate coat that covers the outer face of the cell wall of some bacteria and the outer face of the plasma membrane of certain animal cells. It consists of various oligosaccharides that are attached to membrane phospholipids (**glycolipids**) and proteins (such as the **glycoproteins** of recognition proteins).

2. <u>Movement of Substancess</u>

a. Movement of substances may occur from higher to lower concentrations (down the concentration gradient) or the reverse (up or against the gradient).
b. Solute concentrations between two areas may be compared. A solute may be **hypertonic** (a higher concentration of solutes), **hypotonic** (a lower concentration of solutes), or **isotonic** (an equal concentration of solutes) relative to another region.
c. The movement of substances may be passive or active. **Active** movement requires the expenditure of energy and usually occurs up a gradient.
d. **Passive** transport processes describe the movement of substances from regions of higher to lower concentrations (down a concentration gradient) and do not require expenditure of energy.
    i. Diffusion: net movement of substances from an area of higher concentration to an area of lower concentration.
    ii. **Osmosis:** diffusion of water molecules across a selectively permeable membrane.
    iii. **Facilitated Diffusion:** diffusion of solutes or water through channel proteins in the plasma membrane.
e. Water potential is the sum of the pressure potential (from any externally applied force) and the solute potential (osmotic potential)
    i. Water always moves from an area of higher water potential to an area of lower water potential.
    ii. $\Psi = \Psi_p + \Psi_s$

3. <u>Transport Across the Membrane</u>

a. Vesicular transport uses vesicles or other bodies in the cytoplasm to move macromolecules or large particles across the plasma membrane.
    i. **Exocytosis** describes the process of vesicles fusing with the plasma membrane and releasing their contents to the outside of the cell. This is common when a cell produces substances for export.

ii. **Endocytosis** describes the capture of a substance outside the cell when the plasma membrane merges to engulf it. The substance subsequently enters the cytoplasm enclosed in a vesicle.

4. <u>Structure of the Cell</u>

a. **Organelles** are bodies within the cytoplasm that serve to physically separate the various metabolic reactions that occur within cells.

i. **Nucleus:** contains **DNA** (deoxyribonucleic acid), the hereditary information of the cell. Normally, the DNA is spread out within the nucleus as a threadlike matrix called **chromatin**. When the cell begins to divide, the chromatin condenses into rod-shaped bodies called **chromosomes**, each of which, before dividing, is made up of two long DNA molecules and various histone (protein) molecules. The histones serve to organize the lengthy DNA, coiling it into bundles called nucleosomes.

1. Also visible within the nucleus are one or more **nucleoli**, concentrations of DNA in the process of manufacturing the components of ribosomes.

ii. **Ribosomes:** subunits manufactured in the nucleus that synthesize proteins.

iii. **Endoplasmic Reticulum:** consists of stacks of flattened sacs involved in the production of various materials. In cross section, they appear as a series of maze-like channels, often closely associated with the nucleus.

iv. **Golgi Body:** group of flattened sacs arranged like a stack of bowls. They modify and package proteins and lipids into vesicles, small, spherically shaped sacs that bud from the outside surface of the Golgi apparatus.

1. Vesicles often migrate to and merge with the plasma membrane, releasing their contents to the outside of the cell.

v. **Lysosome:** vesicles from a Golgi apparatus that contain digestive enzymes. They break down food, cellular debris, and foreign invaders such as bacteria. A low pH (acidic), favorable to the activity of the enzymes, is maintained inside the lysosome.

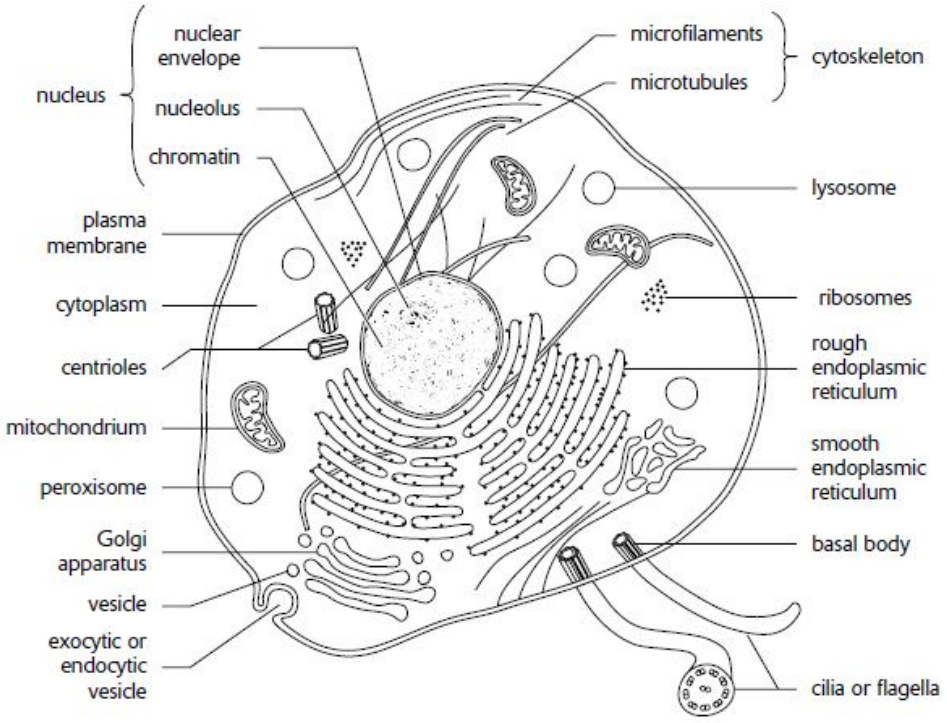
vi. **Peroxisome:** Peroxisomes break down various substances, including hydrogen peroxide (H2O2) (forming H2O and O2.), fatty acids, and amino acids. Peroxisomes are common in liver and kidney cells where they break down toxic substances.

vii. **Mitochondria:** carry out aerobic respiration to gain ATP from carbohydrates.

viii. **Vacuoles**: fluid-filled, membrane-bound bodies that store food, provide rigidity to the cell, or pump excess water out of the cell.

ix. **Cytoskeleton:** the internal structure of the cytoplasm; a network of fibers including microtubules, intermediate filaments, and microfilaments.

x. **Chloroplasts:** carry out photosynthesis in plant cells.



An Animal Cell

5. The Cytoskeleton and Cellular Junctions

a. Microtubules, intermediate filaments, and microfilaments are three protein fibers of decreasing diameter, respectively. All are involved in establishing the shape of or in coordinating movements of the cytoskeleton, the internal structure of the cytoplasm.

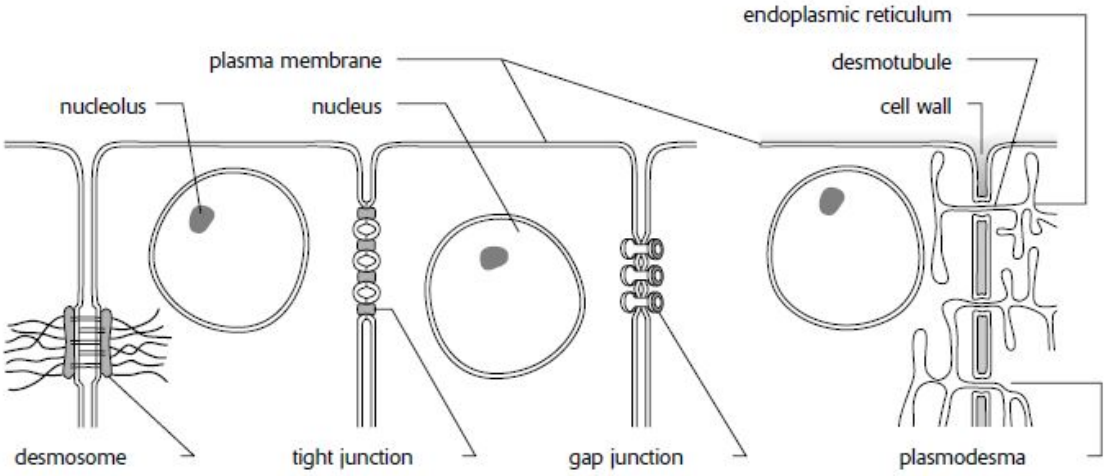
i. **Microtubules** are made of the protein tubulin and provide support and motility for cellular activities. They are found in the spindle apparatus, which guides the movement of chromosomes during cell division, and in flagella and cilia (described in the following section), structures that project from the plasma membrane to provide motility to the cell.

ii. **Intermediate filaments** provide support for maintaining the shape of the cell.

iii. **Microfilaments** are made of the protein actin and are involved in cell motility. They are found in muscle cells and in cells that move by

changing shape, such as phagocytes (white blood cells that wander throughout the body attacking bacteria and other foreign invaders).

b. **Flagella** and **cilia** are structures that protrude from the cell membrane and make wavelike movements.
    i. Flagella and cilia are classified by their lengths, by their numbers per cell, and by their movement: Flagella are long, few, and move in a snakelike motion; cilia are short, many, and move with a back-and-forth movement.
    ii. A single flagellum propels sperm, while the numerous cilia that line the respiratory tract sweep away debris.
    iii. Structurally, both flagella and cilia consist of microtubules arranged in a "9 + 2" array—nine pairs (doublets) of microtubules arranged in a circle surrounding a pair of microtubules.
c. **Cell junctions** serve to anchor cells to one another or to provide a passageway for cellular exchange of substances.



Cell Junctions

    i. **Anchoring Junctions:** protein attachments between adjacent animal cells.
    ii. **Tight Junctions:** tightly stitched seams between animal cells.
    iii. **Communication Junctions:** passageways between cells that allow the transfer of chemical or electrical signals.
        1. **Gap Junctions:** communication between cells through the exchange of materials or through the transmission of electrical impulses.
        2. **Plasmodesmata:** narrow channels between plant cells.

6. **Endomembrane System**
    a. **ER** - When ribosomes are present, the ER (called **rough ER**) creates **glycoproteins** by attaching polysaccharide groups to polypeptides as they are assembled by the ribosomes.
    b. **Smooth ER**, without **ribosomes**, is responsible for various activities, including the synthesis of lipids and hormones, especially in cells that produce these substances for export from the cell. In liver cells, smooth ER is involved in the breakdown of toxins, drugs, and toxic by-products from cellular reactions.
    c. **GOLGI BODY** – It modifies and packages proteins and lipids into **vesicles**, small, spherically shaped sacs that bud from the outside surface of the Golgi apparatus. Vesicles often migrate to and merge with the plasma membrane, releasing their contents to the outside of the cell.
    d. **LYSOSOMES** – Unique to animals cells, lysosomes are membrane-bound sacs of enzymes that digest macromolecules. The fuse with food vacuoles to break polymers to monomers and clean up dead organelles.
        i. **Apoptosis** occurs when lysosomes burst open and kill the cell. Tay-Sachs disease is a a disease arising from lysosomes filling up with undigested material and is always fatal.
    e. **PEROXISOME** - Peroxisomes break down various substances, including hydrogen peroxide (H2O2) (forming H2O and O2.), fatty acids, and amino acids. Peroxisomes are common in liver and kidney cells where they break down toxic substances.

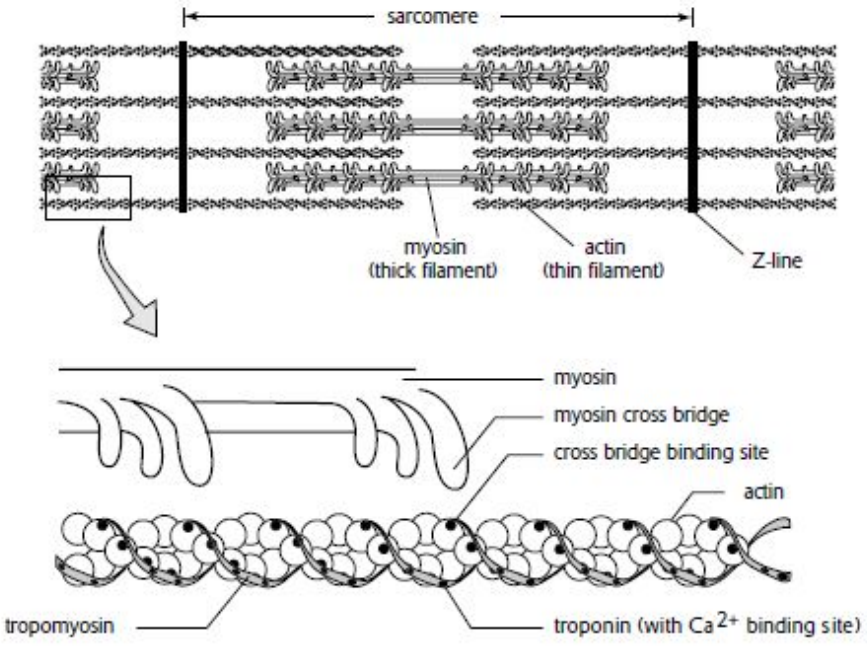
7. **Muscle Contraction**
    a. There are three kinds of muscles.
        i. **Skeletal muscle** is attached to bones and causes movements of the body.
        ii. **Smooth muscle** lines the walls of blood vessels and the digestive tract where it serves to advance the movement of substances. Due to its arrangement of actin and myosin filaments, smooth muscle does not have the **striated** appearance of skeletal muscle.
        iii. **Cardiac muscle** is responsible for the rhythmic contractions of the heart. Although **striated**, cardiac muscle differs from skeletal muscle in that it is highly branched with cells connected by gap junctions. In addition, cardiac muscle generates its own action potential, which spreads rapidly throughout muscle tissue by electrical synapses across the gap junctions.
    b. Muscle cells have special terminology for cellular components. The **sarcolemma** is the plasma membrane of the muscle cell and is sheathed by transverse tubules, or **T-tubules**. The **sarcoplasm** is the cytoplasm of the muscle cell and

contains a calcium-storing **sarcoplasmic reticulum**, which is a specialized endoplasmic reticulum.

i. The process of muscle contraction begins when a motor neuron releases **acetylcholine**, a neurotransmitter. The acetylcholine binds to receptors leading to depolarization of the neuron as Na^{+} moves in through membrane channels. The action potential then propagates along the sarcolemma and T-tubules. As a result, the sarcoplasmic reticulum changes permeability and releases Ca^{2+}.

ii. Ca^{2+} binds to troponin molecules (thin filaments consisting of the protein actin arranged in a double helix), prompting tropomyosin molecules to expose binding sites for myosin cross –bridge formation. Provided ATP is available, muscle contraction begins.

iii. Meanwhile, motor neurons reuptake Ca2+ via active transport and repolarize the membrane potential with the Na+/K+ pump. Myosin head detachment requires ATP as well.

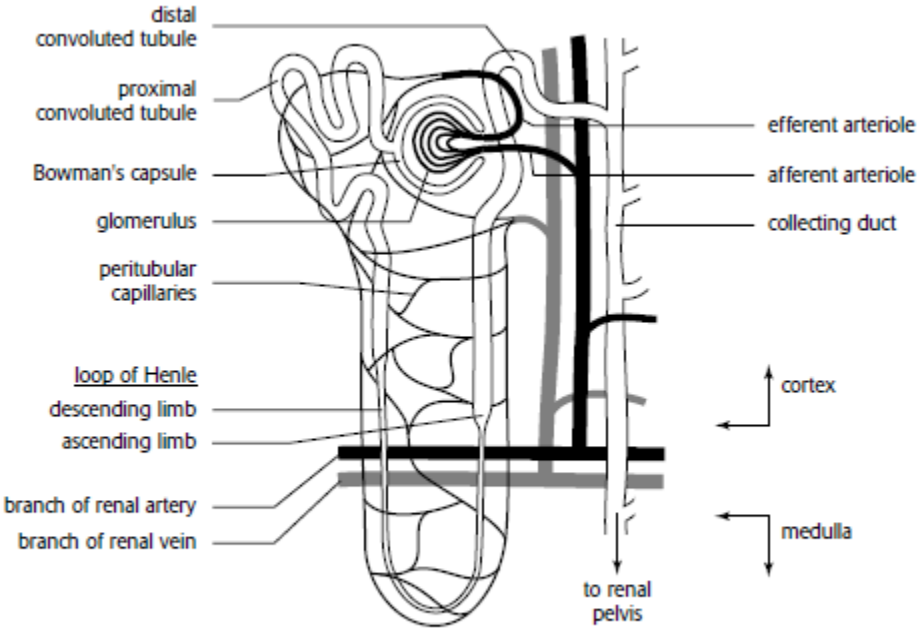


Sliding-Filament Model of Muscle Contraction

8. The Human Kidney

a. The function of the kidney is to filter wastes out of the blood and concentrate them into a filtrate that can be excreted from the body.

b. **Nephrons** are the functional unit of the excretory system, meaning that each nephron is capable of concentrating wastes into filtrate. Each nephron is made of a single long tubule, with different regions modified to transport different ions and wastes into or out of the filtrate.



Nephron

i. The nephron tube begins with a bulb-shaped body at one end, the **Bowman's capsule.** A branch of the renal artery (the afferent arteriole) enters into the Bowman's capsule, branches to form a dense ball of capillaries called the **glomerulus**, and then exits the capsule (efferent arteriole). When blood enters the glomerulus, a dense ball of capillaries, pressure forces water and solutes through the capillary walls into the Bowman's capsule. Solutes include glucose, salts, vitamins, nitrogen wastes, and any other substances small enough to pass through the capillary walls. The material that enters the Bowman's capsule, or filtrate, flows into the convoluted tubule.

ii. The **convoluted tubule** is a winding tube that begins with the **proximal** convoluted tubule at the Bowman's capsule and ends with the **distal** convoluted tubule where it joins with the collecting duct. Many small molecules and solutes are reabsorbed in the proximal tubule.

iii. The middle of the tubule, called the **loop of Henle**, is shaped like a hairpin and consists of a descending and ascending limb. As the filtrate moves down the loop of Henle (descending limb), it becomes more

concentrated due to passive flow of H2O out of the tube through **aquaporins** in the cell membrane.

iv. As the filtrate moves up the loop of Henle (ascending limb), it becomes more dilute due to passive and active transport of salts out of the tubule to maintain the osmotic gradient.

v. The distal convoluted tube empties into the collecting duct which descends in the same direction as the descending limb toward the center of the kidney. A single collecting duct reabsorbs water and is shared by numerous nephrons and empties into the renal pelvis.

9. <u>Neurons and Action Potentials</u>

a. A nerve impulse begins at the tips of the **dendrite** branches, passes through the dendrites to the cell body, then through the **axon**, and finally terminates at branches of the axon.

b. The membrane of an unstimulated neuron is **polarized**, which means there is a difference in electrical charge between the outside and inside of the membrane. The inside is negative (-70mV) with respect to the outside.

i. Polarization is established by maintaining an excess of sodium ions (Na+) on the outside and an excess of potassium ions (K+) on the inside.

ii. A certain amount of Na+ and K+ is always leaking across the membrane, but Na+/K+ pumps in the membrane actively restore the ions to the appropriate side.

c. In response to a stimulus, ion channels in the membrane open and permit the Na+ on the outside to rush into the cell.

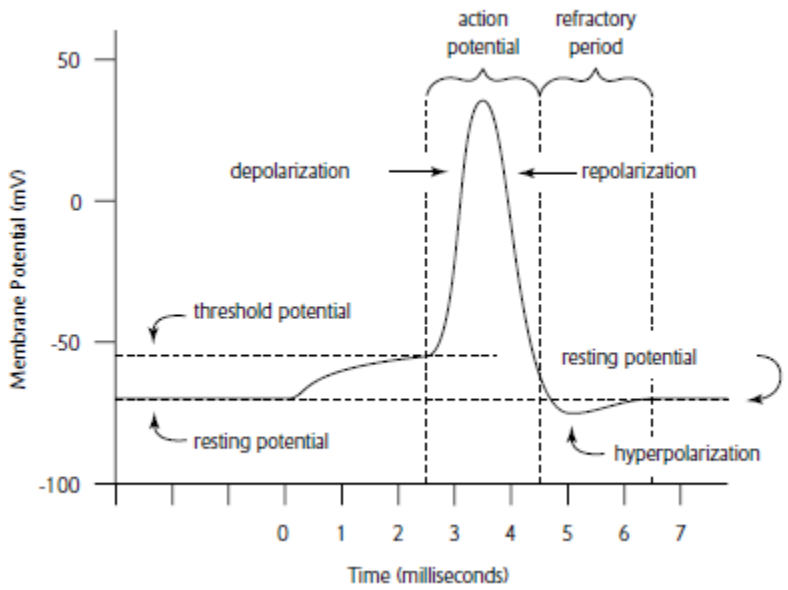
i. As the charged Na+ rush in, the charge on the cell membrane becomes **depolarized** or more positive on the inside. If the stimulus is strong enough, more Na+ gates open, increasing the inflow of Na+ even more, causing an action potential.

ii. This stimulates neighboring Na+ gates, further down the neuron, to open. The action potential travels down the length of the neuron as opened Na+ gates stimulate neighboring Na+ gates to open.

iii. The **action potential** is an all-or-nothing event: when threshold potential is exceeded, complete depolarization occurs.

iv. In response to the inflow of Na+, another kind of gated channel opens, this time allowing the K+ on the inside to rush out of the cell. The movement of K+ out of the cell causes repolarization by restoring the original membrane polarization. Soon after the K+ gates open, the Na+ gates close.

v. By the time the K+ gated channels close, more K+ have moved out of the cell than is actually necessary to establish the original polarized potential. Thus, the membrane becomes **hyperpolarized**.



vi. During the **refractory period**, the neuron will not respond to a new stimulus. To reestablish the original distribution of these ions, the Na+ and K+ are returned to their resting potential location by Na+/K+ pumps in the cell membrane.

d. Some neurons possess a myelin sheath, which consists of a series of Schwann cells that encircle the axon. The Schwann cells act as insulators and are separated by gaps of unsheathed axon called **nodes of Ranvier**. Instead of traveling continuously down the axon, the action potential jumps from node to node (**saltatory conduction**), thus speeding the propagation of the impulse.

e. A **synapse**, or synaptic cleft, is the gap that separates adjacent neurons. In most animals, most synaptic clefts are traversed by chemicals.
   i. Calcium (Ca2+) gates open.
   ii. Synaptic vesicles release neurotransmitter.
   iii. Neurotransmitter binds with postsynaptic receptors.
   iv. The neurotransmitter is degraded and recycled. After the neurotransmitter binds to the postsynaptic membrane receptors, it is broken down by enzymes in the synaptic cleft.

10. <u>Nitrogenous Waste</u>

a. Nitrogen forms a major waste product in animals. When amino acids and nucleic acids are broken down, they release toxic ammonia (NH3).
b. To rid the body of this toxin, several mechanisms have evolved, each appropriate to the habitat or survival of the animal.
    i. Aquatic animals excrete **NH3** (or NH4+) directly into the surrounding water.
    ii. Mammals convert NH3 to **urea** in their livers. Urea is significantly less toxic than NH3 and thus requires less water to excrete in the urine. Urea is produced in the liver by a metabolic cycle that combines ammonia with carbon dioxide.
    iii. Birds, insects, and many reptiles convert urea to **uric acid**. Since uric acid is mostly insoluble in water, it precipitates and forms a solid. This allows important water conservation by permitting the excretion of nitrogen waste as a solid. In birds, the precipitation also allows the nitrogen wastes to be isolated in a special sac in the egg apart from the vulnerable developing embryo.

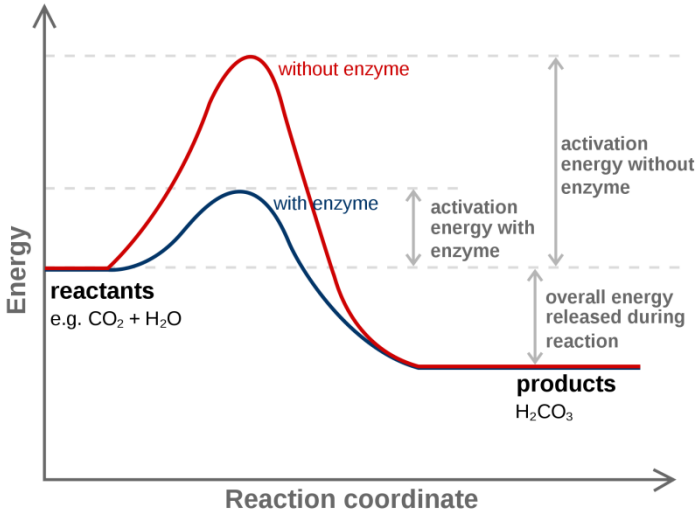
Metabolism and Digestion

1. **Reactions**
    a. **Exergonic** reactions release energy while **endergonic** reactions consume energy.
    b. Metabolic processes operate by coupling exergonic reactions with endergonic reactions.
        i. In order for a chemical reaction to take place, the reacting molecules (or atoms) must first collide and then have sufficient energy (**activation energy**) to trigger the formation of new bonds.
        ii. Although many reactions can occur spontaneously, the presence of a **catalyst** accelerates the rate of the reaction because it lowers the activation energy required for the reaction to take place.
            1. A catalyst is any substance that accelerates a reaction but does not undergo a chemical change itself.
            2. Since the catalyst is not changed by the reaction, it can be used over and over again.
            3. A catalyst lowers the activation energy in both the forward and reverse direction of the reaction. Most reactions are reversible like this.

2. **Metabolism**
    a. Chemical reactions that occur in biological systems are referred to as **metabolism**. They include all the chemical reactions of life.
        i. Metabolism includes the breakdown of substances (**catabolism**), the formation of new products (**synthesis** or **anabolism**), or the transferring of energy from one substance to another.
    b. Life's reactions are organized into **metabolic pathways**, or a series of chemical reactions that either builds a complex molecule or breaks down a complex molecule into simpler compounds.
    c. The efficient management of metabolic pathways is critical to a cell's survival. It must, for example, produce large amounts of energy when it is needed or produce structural materials when there is an energy surplus.
    d. Reactions occur to maintain **homeostasis**.

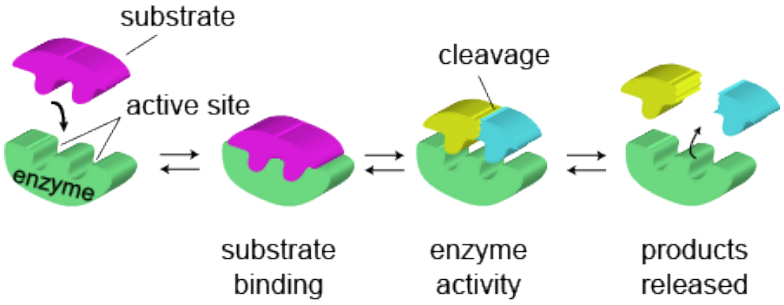
3. **Enzymes**

a. **Enzymes** are globular proteins that catalyze metabolic reactions. This means they lower the activation energy of metabolic processes:



i. The **substrate** is the substance upon which the enzyme acts on. For example, the enzyme amylase catalyzes the breakdown of the substrate amylose (starch).

ii. Enzymes are substrate specific. The enzyme amylase, for example, catalyzes the reaction that breaks the α-glycosidic linkage in starch but cannot break the β-glycosidic linkage in cellulose.



b. An enzyme is unchanged as a result of a reaction. It can perform its enzymatic function repeatedly.

i. An enzyme catalyzes a reaction in both forward and reverse directions.

4. Optimal Conditions

a. The efficiency of an enzyme is affected by temperature and pH. The human body, for example, is maintained at a temperature of 98.6°, near the **optimal temperature** for most human enzymes. Above 104°, these enzymes begin to lose their ability to catalyze reactions as they become **denatured**, that is, they lose

their three-dimensional shape as **hydrogen bonds** and **peptide bonds** begin to break down.

i. At even higher temperatures, enzymes become fully denatured and lose their ability to bind to substrates.
ii. The enzyme pepsinogen, which digests proteins in the stomach, becomes active only at a low pH (very acidic).

b. The **induced-fit model** describes how enzymes work. Within the protein (the enzyme), there is an **active site** with which the reactants readily interact because of the shape, polarity, or other characteristics of the active site. The interaction of the reactants (substrate) and the enzyme causes the enzyme to change shape into a favorable site for bonding.

5. Important Digestive Enzymes

a. Amylase is a digestive enzyme that acts on starch in food, breaking it down into smaller carbohydrate molecules.

i. The enzyme is made in two places. First, salivary glands in the mouth make salivary amylase, which begins the digestive process by breaking down starch during chewing, converting it into maltose, a smaller carbohydrate.
ii. Pancreatic amylase completes digestion of carbohydrate, producing glucose, a small molecule that is absorbed into blood and carried throughout the body.

b. Protease is a general term for any enzyme that breaks down protein into amino acids. The digestive tract produces a number of these enzymes, but the three main proteases are pepsin, trypsin and chymotrypsin.

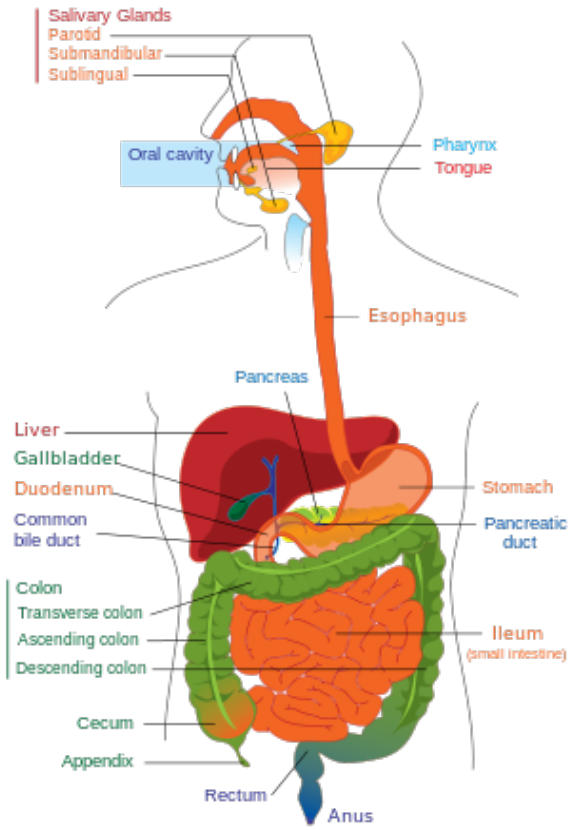
i. Pepsin breaks certain chemical bonds in proteins, producing smaller molecules called peptides and beginning protein digestion.
ii. The pancreas makes trypsin and chymotrypsin, enzymes that are released into the intestine through the pancreatic duct. When partially digested food moves from the stomach into the intestine, trypsin and chymotrypsin complete protein digestion, producing simple amino acids that are absorbed into circulation.

c. Lipase is an enzyme that breaks down dietary fats into smaller molecules called fatty acids and glycerol.

i. The main source of lipase in your digestive tract is the pancreas, which makes pancreatic lipase that acts in the small intestine.
ii. Bile is made by the liver and stored by the small intestine.

6. **Enzyme Regulation**
    a. **Cofactors** are nonprotein molecules that assist enzymes.
        i. **Coenzymes** are organic cofactors (often vitamins) that usually function to donate or accept some component of a reaction, often electrons.
        ii. Inorganic cofactors are often metal ions, like Fe2+ and Mg2+.
    b. **Allosteric** enzymes have two kinds of binding sites—one an active site for the substrate and one an allosteric site for an allosteric effector. Allosteric means "other" site, which is anywhere but the active site.
    c. **Feedback inhibition** involves an end product of a series of reactions acting as an allosteric inhibitor, shutting down one of the reactants in the beginning so that the reaction can be stopped.
        i. This is a very important energy-saving trick because it prevents the unnecessary accumulation of excess product.
    d. In **competitive inhibition**, a substance that mimics the substrate inhibits an enzyme by occupying the active site, preventing the substrate from being broken down.

7. **Digestion of Macromolecules**
    a. The human digestive system is a complex process that consists of breaking down large organic masses into smaller particles that the body can use as fuel.
    b. The breakdown of the nutrients requires the coordination of several enzymes secreted from specialized cells within the mouth, stomach, intestines, and liver.
    c. The four macromolecules broken down are:
        i. **Starches** are broken down into glucose molecules.
        ii. **Proteins** are broken down into amino acids.



iii. **Fats** (or lipids) are broken down into glycerol and fatty acids.
iv. **Nucleic** acids are broken down into nucleotides.

8. <u>The Mouth through the Stomach</u>

a. Mouth

i. Salivary amylase, secreted into the mouth by the salivary glands, begins the breakdown of starch into maltose. Chewing mechanically breaks down food particles to allow more surface area to be exposed.

b. Pharynx

i. Food is swallowed and passed into the throat, or pharynx, a flap of tissue, into the esophagus.

c. Esophagus

i. Food moves through the esophagus, a tube leading to the stomach, by muscular contractions called **peristalsis**.

d. Stomach

i. The stomach secretes gastric juice, a mixture of digestive enzymes and hydrochloric acid (HCl), and serves a variety of functions.
ii. Proteins are chemically broken down by the enzyme **pepsin**. Stomach cells producing pepsin are protected from self-digestion because they produce and secrete an inactive form, **pepsinogen**. Pepsinogen is activated into pepsin by HCl, which is produced by other stomach cells.
iii. **Ulcers** are caused by failure of the mucus to protect the stomach, and are caused by bacteria.

9. <u>The Small Intestine and Secreted Enzymes</u>

i. The first part of the small intestine, the **duodenum**, continues the digestion of starches and proteins as well as all remaining food types (including fats and nucleotides).
    1. <u>Pancreas Enzymes</u>
        a. The pancreas produces various enzymes, including **trypsin**, **lipase** (digestion of fats), and **pancreatic amylase** (digestion of starch). These also neutralize HCl.
    2. <u>Liver</u>
        a. The liver produces **bile**, which functions to emulsify fats.
        b. **Emulsification** is the breaking up of fat globules into smaller fat droplets.

ii. An adult's small intestine is about 23 feet long and is divided into three sections: the first 10 to 12 inches are the duodenum; the next 10 feet are the jejunum; and the final 12 feet are the ileum.
    1. The remainder of the small intestine absorbs the breakdown products of food. It is characterized by **villi** and **microvilli**, fingerlike projections of the intestinal wall that increase its total absorptive surface area.
    2. Amino acids and sugars are absorbed into blood capillaries, while most of the fatty acids and glycerol are absorbed into the lymphatic system.
    3. Most absorption in the small intestine occurs in the jejunum. The products of digestion enter cells of the villi, move across the cells, and enter blood vessels called capillaries.
    4. Diffusion accounts for the movement of many nutrients, but active transport is responsible for the movement of glucose and amino acids.

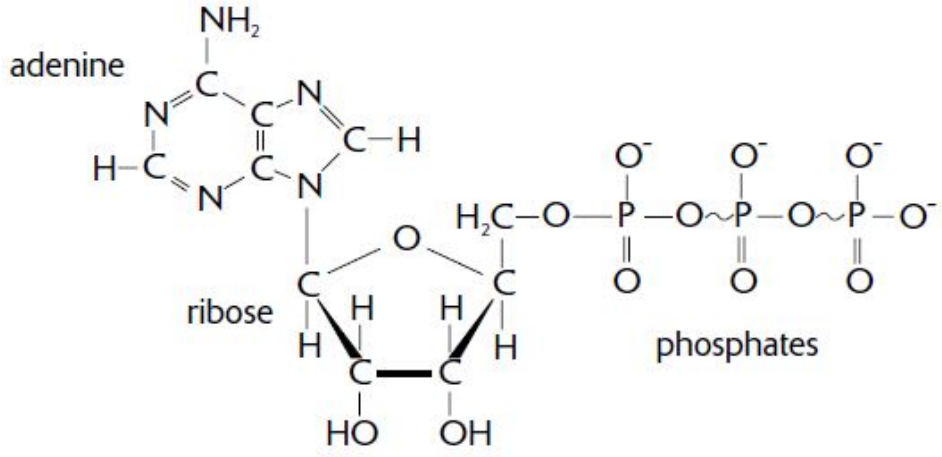
10. **Large intestine and Beyond**
    i. The small intestine joins the large intestine in the lower right abdomen of the body. The two organs meet at a blind sac called the cecum and a small fingerlike process called the appendix.
        1. Evolutionary biologists believe the appendix is a vestige of larger organs that may have been functional in human ancestors.
    ii. The main function of the large intestine, or **colon**, is the reabsorption of water to form solid waste, or feces. Feces are stored at the end of the large intestine, in the rectum, and excreted through the anus.
    iii. The large intestine also contains harmless bacteria that are useful to digestion. They break down remaining undigested food and provide certain essential vitamins, like Vitamin K, in the process.

Cellular Respiration

1. **Cellular Respiration Overview**
    a. **Cellular respiration** is an ATP-generating process that occurs within cells.
        i. Energy is extracted from energy-rich glucose to form ATP from ADP and P_i.
        ii. The chemical equation describing this process is
        iii. *C6H12O6 + 6 O2 → 6 CO2 + 6 H2O + energy*
    b. The goal of **cellular respiration** and metabolism in animals and plants is, ultimately, the conversion of one type of energy source to another. The original energy source animals consume comes in a form that cannot be immediately used to support cellular activities.
    c. For humans, our external energy sources are the foods we eat. Once we ingest and digest the food, our cells metabolic processes convert the energy contained within the food into a form of energy that can function in our cells. These constant conversions are what allow us to perform our day-to-day activities.
    d. Cellular respiration in the presence of O_2 is called **aerobic respiration**. Aerobic respiration is divided into three components: **glycolysis**, the **Krebs cycle**, and **oxidative phosphorylation** (which includes **chemiosmosis** by **electron transport chains**).
        i. Only glycolysis can occur without oxygen.
    e. Energy harvesting works through **redox** reactions (reduction and oxidation reactions)
        i. **Oxidation**: losing electrons
        ii. **Reduction**: gaining electrons

2. **ATP**
    a. **ATP** (adenosine triphosphate) is a common source of activation energy for metabolic reactions.
        i. It is often called the “energy currency” of the cell, because it is needed in almost every endergonic process.
        ii. For example, nerve impulses and muscle contraction need ATP to power protein pumps.

b. ATP is essentially an RNA **adenine nucleotide** with two additional phosphate groups.



3. **ATP synthesis**
    a. The formation of ATP is opposite to the process by which ATP is broken down to produce energy: phosphate groups are brought in contact with either ADP or AMP. While this process is not as favorable, it is able to occur with the energy derived from metabolizing foods.
        i. In addition to ATP, there are a number of other reactive molecules that are involved in the production of cellular energy. These are called coenzymes and their role is to help transfer other chemical groups like hydrogens.
        ii. Coenzymes work in conjunction with metabolic enzymes to drive metabolic reactions. Among these are nicotinamide adenine dinucleotide (NADH) and acetyl coenzyme A.
    b. When ATP supplies energy to a reaction, it is usually the energy in the last bond that is delivered to the reaction.
        i. In the process of giving up this energy, the last phosphate bond is broken and the ATP molecule is converted to **ADP** (adenosine diphosphate) and a phosphate group (indicated by Pi).
        ii. New ATP molecules are assembled by **phosphorylation** when ADP combines with a phosphate group using energy from glucose.

4. Glycolysis
    a. **Glycolysis** is the decomposition of glucose to pyruvate (or pyruvic acid).
        i. Glucose is a six- membered ring molecule found in the blood and is usually a result of the breakdown of carbohydrates into sugars. It enters

cells through specific transporter proteins that move it from outside the cell into the cell's cytosol.

b. Nine intermediate products, which will be ignored, are formed, each one catalyzed by an enzyme. In six of the steps, magnesium ions (Mg2+) are cofactors that promote enzyme activity.
    i. 2 ATP are added. The first several steps require the input of energy. This changes glucose in preparation for subsequent steps.
    ii. 2 NADH are produced. NADH, a coenzyme, forms when NAD+ combines with two energy-rich electrons and H+ (obtained from an intermediate molecule during the breakdown of glucose). As a result, NADH is an energy rich molecule.
    iii. 4 ATP are produced.
    iv. 2 pyruvate are formed.
c. In summary, glycolysis takes 1 glucose and turns it into 2 pyruvate, 2 NADH, and a net of 2 ATP (made 4 ATP, but used 2 ATP). The process occurs in the cytosol.
d. Glycolysis uses **Substrate level phosphorylation** which occurs when a phosphate group and its associated energy is transferred to ADP to form ATP. The substrate molecule (the molecule with the phosphate group) donates the high energy phosphate group.

5. <u>After Glycolysis</u>

a. Glycolysis is an anaerobic process. None of its nine steps involve the use of oxygen.

b. However, immediately upon finishing glycolysis, the cell must continue respiration in either an aerobic or anaerobic direction; this choice is made based on the circumstances of the particular cell.
    i. A cell that can perform aerobic respiration and which finds itself in the presence of oxygen will continue on to the aerobic citric acid cycle in the mitochondria.
    ii. If a cell able to perform aerobic respiration is in a situation where there is no oxygen (such as muscles under extreme exertion), it will move into a type of anaerobic respiration called lactic acid fermentation.
    iii. Some cells such as yeast are unable to carry out aerobic respiration and will automatically move into a type of anaerobic respiration called alcoholic fermentation.

c. In both aerobic and anaerobic respiration, the NADH molecule is part of the enzyme complex and must be restored to its NAD, oxidized state.

i. If there are aerobic conditions, meaning oxygen is available, the NADH molecule can be transported to the mitochondria where it can be immediately converted back to NAD and plays a role in the electron transport chain.
ii. However, under anaerobic, oxygen-deficient conditions, NADH gets converted back to NAD through anaerobic mechanisms.

6. Anaerobic Respiration

a. If oxygen is not present, no electron acceptor exists to accept the electrons at the end of the electron transport chain. If this occurs, then NADH accumulates. The Krebs cycle and glycolysis both stop (both need NAD+ to accept electrons). When this happens, no new ATP is produced, and the cell soon dies.
b. There are two methods to produce ATP without oxygen, which operate by producing NAD+ for glycolysis:
    i. **Alcohol fermentation** occurs in plants, fungi (such as yeasts), and bacteria. A pyruvate is broken into 1 CO2 and 1 acetaldehyde. The acetaldehyde makes 1 ethanol and 1 NAD+.
    ii. **Lactic Acid Fermentation** occurs in humans and other mammals. A pyruvate is converted to lactate (or lactic acid) and in the process, NADH gives up its electrons to form NAD+.

7. Krebs Cycle

a. The pyruvate made from glycolysis enters the Krebs cycle (AKA citric acid cycle) to make more ATP and electron carriers.
    i. The **Krebs cycle** begins when acetyl CoA combines with OAA (oxaloacetate) to form citrate. There are seven intermediate products.
    ii. Along the way, 3 NADH and 1 FADH2 are made, and CO2 is released. FADH2, like NADH, is a coenzyme, accepting electrons during a reaction.
    iii. Because the first product made from acetyl CoA is the 3-carbon citrate (citric acid), the Krebs cycle is also known as the citric acid cycle or the tricarboxylic acid (TCA) cycle.
b. The Krebs cycle occurs in the mitochondrial matrix.

8. Mitochondrial Structure

a. The mitochondria is a double membrane-bound organelle found in nearly all eukaryotic cells. It plays a critical role in the conversion of energy through metabolism, and is composed of an outer and inner membrane that divide the structure into two distinct regions--the inner membrane space and the matrix.

i. The enzymes that help catalyze oxidative phosphorylation are embedded in the inner mitochondrial membrane.
ii. The events of the citric acid cycle and oxidative phosphorylation take place in the matrix.

b. There are four distinct areas of a mitochondrion
   i. **Outer membrane:** This membrane, like the plasma membrane, consists of a double layer of phospholipids.
   ii. **Intermembrane space:** This is the narrow area between the inner and outer membranes. H+ ions (protons) accumulate here.
   iii. **Inner membrane:** This second membrane, also a double phospholipid bilayer, has folds called cristae. Oxidative phosphorylation occurs here. **Matrix:** The matrix is the fluid material that fills the area inside the inner membrane. The Krebs cycle and the conversion of pyruvate to acetyl CoA occur here.

c. The outer membrane of the mitochondria is largely permeable and allows many molecules to freely diffuse across it.
d. The inner membrane, on the other hand, is highly impermeable, only allowing water, carbon dioxide, and oxygen to freely cross it.

9. Chemiosmosis and Electron Transport Chain

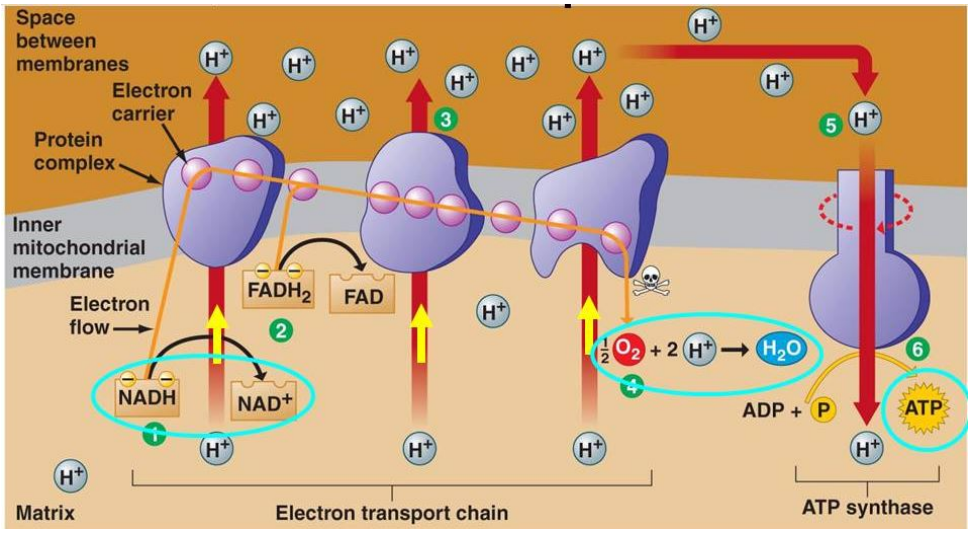
a. **Chemiosmosis** is the mechanism of ATP generation that occurs when energy is stored in the form of a proton concentration gradient across a membrane.
   i. The Krebs cycle produces NADH and FADH2 in the matrix.
   ii. Protein complexes in the inner membrane remove electrons from **NADH** and **FADH2**. The electrons move along the **electron transport chain**, from one protein complex to the next.

b. The final electron acceptor of the electron transport chain is **oxygen**. The 1⁄2 O2 accepts the two electrons and, together with 2 H+, forms water.
   i. The ten NADH that enter the electron transport originate from each of the earlier processes of respiration: two from glycolysis, two from the transformation of pyruvate into acetyl-CoA, and six from the citric acid cycle. The two FADH2 originate in the citric acid cycle.

10. Oxidative Phosphorylation

a. As a result of the electron transport chain, an electrochemical gradient is formed on either side of the inner mitochondrial membrane.
   i. The outside of the membrane is positive while the inside is negative. The positive hydrogen ions are allowed to flow back across the membrane

through specialized channels manned by proton **ATP synthase**.



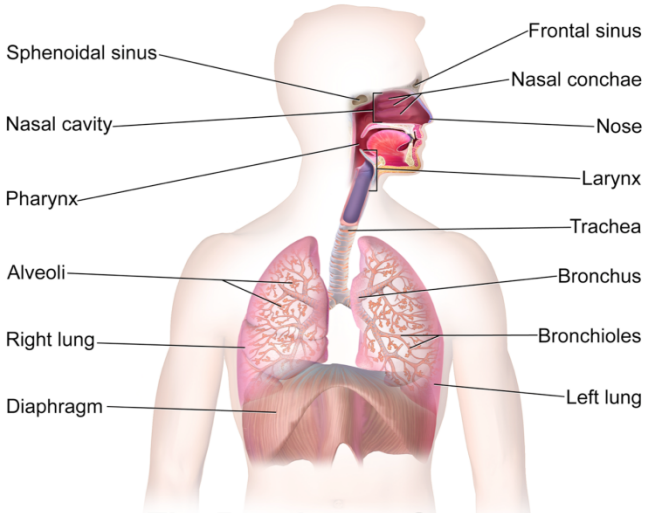
ii. **ATP synthase**, a channel protein in the inner membrane, allows the protons in the intermembrane compartment to flow back into the matrix. The protons moving through the channel generate the energy for ATP synthase to generate ATP.

iii. The transport of just two electrons through the electron transport chain generates enough free energy in the form of electrochemical gradient to drive the synthesis of one molecule of ATP.

b. In total, the process started through the glycolysis of one glucose molecule yields about 32 ATP in oxidative phosphorylation. In total, oxidative phosphorylation accounts for around 90 percent of the body's total ATP.

Animal Systems

1. **Respiratory System: Structure & Function**
    a. The respiratory system is needed to transport O2 and CO2, the reactant and product of cellular respiration, respectively, into and out of internal cells that are not exposed not exposed to the outside environment.
    b. The rate of respiration is monitored by the medulla in the brainstem. Chemoreceptors in the carotid and aortic bodies detect changed in pH of the blood.
        i. When the CO2 that enters the plasma is converted to HCO3– and H+, the blood pH drops (becomes more acidic). In response, the chemoreceptors send nerve impulses to the diaphragm and intercostal muscles to increase respiratory rate.
        ii. This results in a faster turnover in gas exchange, which, in turn, returns blood pH to normal.
    c. As the diaphragm contracts, the lungs expand; this is called inspiration, or breathing in.
        i. The expansion of the lungs causes the pressure in the lungs (and alveoli) to become slightly negative relative to atmospheric pressure. As a result, air moves from an area of higher pressure (the air) to an area of lower pressure (lungs & alveoli.
    d. Expiration is the opposite of inspiration; as the diaphragm and intercostal muscles relax, the volume within the thoracic cavity decreases.
        i. This decrease in volume causes an increase in pressure above atmospheric pressure which forces air out up the airway.
    e. Human Respiratory System Structure
        i. Air enters the nose and passes through the nasal cavity, pharynx, and larynx. The larynx ("voice box") contains the vocal cords.
        ii. After passing through the larynx, air enters the trachea, a cartilage-lined tube.



The Respiratory System

When the animal is swallowing, a special flap called the epiglottis covers the trachea, preventing the entrance of solid and liquid material.

iii. The trachea branches into two bronchi (singular, bronchus), which enter the lungs and then branch repeatedly, forming narrower tubes called bronchioles.

iv. Each bronchiole branch ends in a small sac called an alveolus (plural, alveoli).

2. <u>Respiratory System: Gas Exchange and Blood Transport</u>

a. Each alveolus is densely surrounded by blood-carrying capillaries.

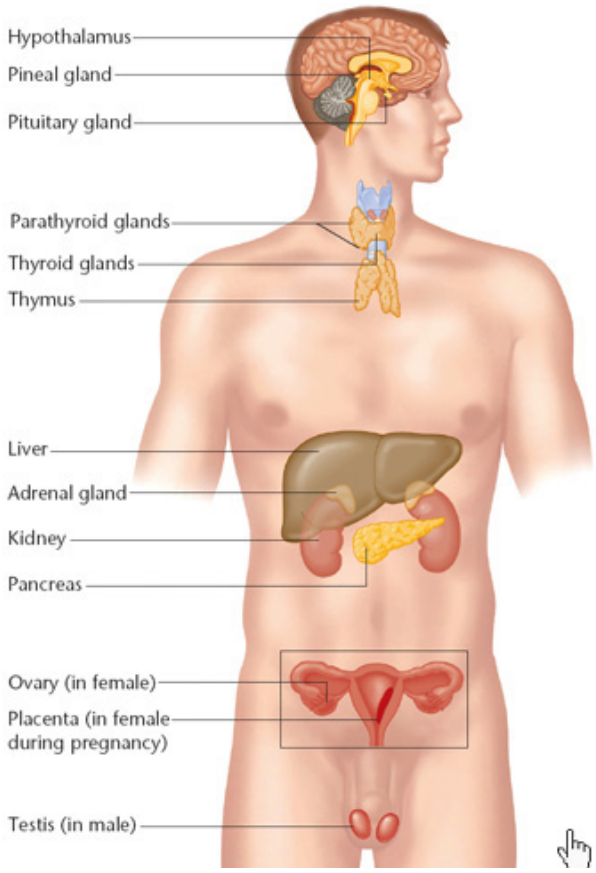
i. Gas exchange occurs by diffusion across the sac membranes of the alveoli. Oxygen diffuses into the moisture covering the membrane, through the alveolar wall, through the blood capillary wall, into the blood, and into red blood cells. Carbon dioxide diffuses in the opposite direction.

b. The circulatory system transports O2 throughout the body within red blood cells. Red blood cells contain **hemoglobin**, iron-containing proteins to which O2 bonds.

c. Blood capillaries permeate the body. Oxygen diffuses out of the red blood cells, across blood capillary walls, into interstitial fluids (the fluids surrounding the cells), and across cell membranes. Carbon dioxide diffuses in the opposite direction. Most CO2 is transported as dissolved **bicarbonate** ions (HCO3–) in the plasma, the liquid portion of the blood.

d. Gills are outgrowths from the body that create a large surface area over which gas exchange occurs.

i. Countercurrent exchange between the opposing movements of water and the underlying blood through blood vessels maximizes the diffusion of O2 into the blood and CO2 into the water.



3. <u>Endocrine System</u>

a. The endocrine system produces hormones that help maintain

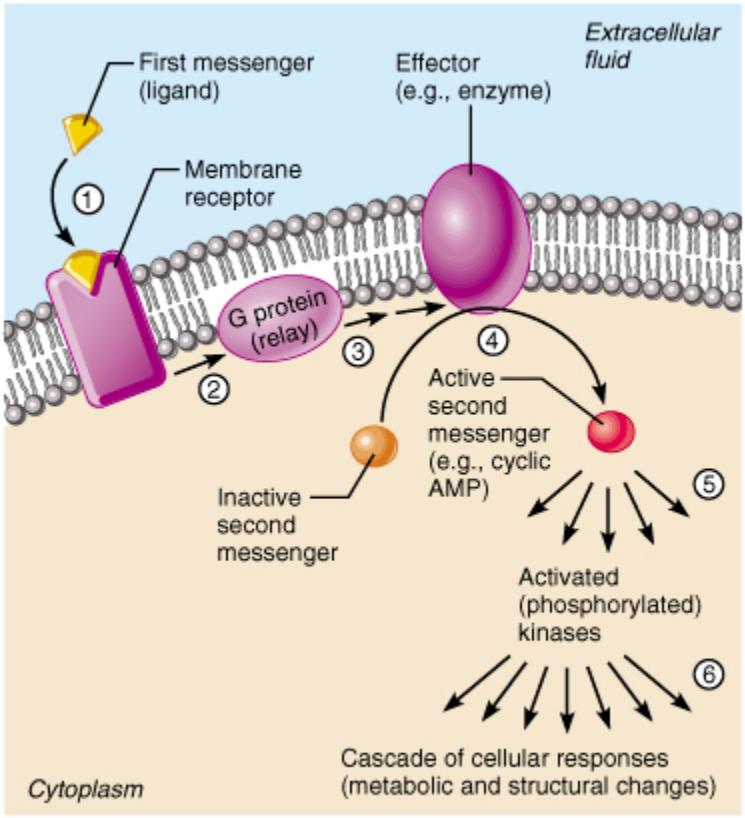
homeostasis and regulate reproduction and development.

b. An endocrine gland releases hormones directly into the bloodstream, carrying them throughout the body.
c. Hormones are chemical messengers that affect target cells in other parts of the body.
    i. All hormones are transported throughout the body in blood.
    ii. Hormones are steroids, peptides, or modified amino acids.
d. Common Organs & Effect of their Hormones
    i. Anterior Pituitary: FSH (stimulates activities in ovaries/testes) , LH (stimulates release of ovum/production of testosterone), Growth Hormone (stimulates bone and muscle growth), TSH (stimulates thyroid to secrete thyroxine) , Prolactin (causes milk secretion)
    ii. Posterior Pituitary: Oxytocin (causes uterus to contract), Vasopressin (causes kidney to reabsorb water)
    iii. Thyroid: Thyroid hormone (regulates metabolic rate), calcitonin (lowers blood calcium)
    iv. Parathyroid: Parathyroid hormone (increases blood calcium)
    v. Adrenal Cortex: Aldosterone (increases Na+ and H2O reabsorption in kidneys)
    vi. Adrenal Medulla: Epinephrine, Norepinephrine (both increase blood sugar and heart rate)
    vii. Pancreas: Insulin (decreases blood sugar) , Glucagon (increases blood sugar)
    viii. Ovaries: Estrogen (promotes female secondary characteristics), Progesterone (endometrial lining)
    ix. Testes: Testosterone (promotes male sex characteristics)

4. Hormones & Signal Transduction

a. Unlike lipid-based hormones, protein-based hormones cannot diffuse across the cell membrane.
b. The hormone binds to a receptor protein in the cell membrane of the target cell instead. The binding of a hormone to a receptor initiates a series of events which leads to generation of second messengers within the cell (the hormone is the first messenger).
    i. The second messengers then trigger a series of molecular interactions that alter the state of the cell.
c. Cyclic AMP (cAMP), a secondary messenger, triggers various enzyme activity.

i. Bound receptors interact with and, through a set of G proteins, turn on adenylate cyclase, which is also an integral membrane protein.
ii. Activated adenylate cyclase begins to convert ATP to cyclic AMP, resulting in an elevated intracellular concentration of cAMP.
iii. High levels of cAMP in the cytosol make it probable that protein kinase A will be bound by cAMP and therefore catalytically active.
iv. Active protein kinase A runs around the cell adding phosphates to other enzymes, thereby changing their conformation and modulating their catalytic activity.



5. <u>Immune System: First & Second Lines of Defense</u>

a. The skin and mucous membranes provide a nonspecific first line of defense against invaders entering the body. They are *physical barriers*.
   i. **Skin** is a physical and hostile barrier covered with oily and acidic secretions from sweat
   ii. Antimicrobial proteins (such as **lysozyme**) are found in tears and other secretions on mucous membranes.
   iii. **Cilia** lines the lungs to sweep invaders out.

iv. **Gastric juice** in the stomach kills most microbes with its high acidity.

b. The second line of defense involves nonspecific mechanisms within the body.
   i. **Phagocytes** are leukocytes (white blood cells) that engulf pathogens via phagocytosis.
   ii. **Macrophages** are large phagocytic cells.
   iii. **Natural killer cells** are other white blood cells that attack abnormal body cells or pathogen-infected body cells.
   iv. **Complement** is a group of about twenty proteins that "complement" defense reactions. These proteins help attract phagocytes to foreign cells.

c. The inflammatory response is nonspecific and occurs on response to pathogens.
   i. When injured, basophils, white blood cells found in connective tissue, release their histamine to trigger dilation of blood vessels which increases permeability of nearby capillaries.
   ii. Activated macrophages and other cells discharge additional signals that further promote blood flow. The increase in blood supply causes the redness and heat of inflammation to occur, making the environment inhospitable to pathogens.

6. <u>Immune System: Third Line of Defense</u>

a. The third line of defense is the immune response.
b. The invading microbe or pathogen is called an antigen.
   i. It is regarded as a threat by the immune system and is capable of stimulating an immune response. Antigens are proteins that are found on the surface of the pathogen. They are unique to that pathogen.
c. In the **humoral response**, Specific B cells (lymphocytes that mature in the bone marrow) that recognize an antigen proliferate (a process called clonal selection), producing two kinds of B cells: plasma cells and memory cells.
   i. Memory cells provide protection against future invasions of the same virus.
   ii. The plasma cells release antibodies, proteins that bind with and inactivate antigens (the virus in this case).
   iii. Antibodies are always Y-shaped. A type of white blood cell called a lymphocyte recognizes the antigen as being foreign and produces antibodies that are specific to that antigen.
   iv. Each antibody has a unique binding site shape which locks onto the specific shape of the antigen. The antibodies destroy the antigen (pathogen) which is then engulfed and digested by macrophages.

d. T cells are lymphocytes that originate in the bone marrow, but mature in the *thymus gland.* The plasma membranes of T cells have antigen receptors. However, these receptors are not antibodies, but recognition sites for molecules displayed by nonself cells.
    i. Nonself cells are identified by MHC markers on the plasma membrane. Foreign cells or viruses display a combination of self and nonself markers, which T cells interpret to be nonself.
    ii. When T cells encounter nonself cells, they divide and produce two kinds of cells:

        Cytotoxic T cells (or **killer T cells**) recognize and destroy nonself cells by puncturing them.
    iii. **Helper T cells** stimulate the proliferation of B cells and cytotoxic T cells.
e. The **cell-mediated response** is used when viruses infect body cells. Here is a summary:
    i. A normal, uninfected cell is identified as a "self" cell by special molecular markers called the histocompatibility complex, or MHC.
    ii. However, when a virus is actively replicating inside a cell (during the lytic cycle of viral reproduction), both self and nonself markers are displayed.
    iii. Specific T cells (lymphocytes that mature in the thymus) recognize these markers, proliferate by clonal selection, and produce killer T cells and helper T cells.
        1. The killer T cells destroy the infected cells.
        2. Helper T cells, in cooperation with macrophages (that attack and engulf the infected cells), produce chemical signals called interleukins that stimulate the proliferation of B cells and more T cells.

7. <u>Immune System: Vaccinations, Antibodies, and Disorders</u>

a. Antibiotics are chemicals derived from bacteria or fungi that are harmful to other microorganisms.
b. Vaccines are substances that stimulate the production of memory cells. Inactivated viruses or fragments of viruses, bacteria, or other microorganisms are used as vaccines.
    i. The second time the same antigen is exposed, the response is faster. The memory B cells remember the microbe which caused the disease and rapidly make the correct antibody if the body is exposed to infection again.
c. HIV is a deadly and unique virus because it attacks helper T cells.

i. As the name suggests, helper T-cells help B-lymphocytes proliferate and make antibodies.
ii. The decrease in B cell proliferation leads to the decrease of overall immunity. Eventually there is a cell disruption which leads to the death or impaired function of the cell.
iii. As T cells are destroyed, the proliferation of opportunistic diseases occurs, such as pneumonia and skin cancer.

8. <u>Circulatory System</u>

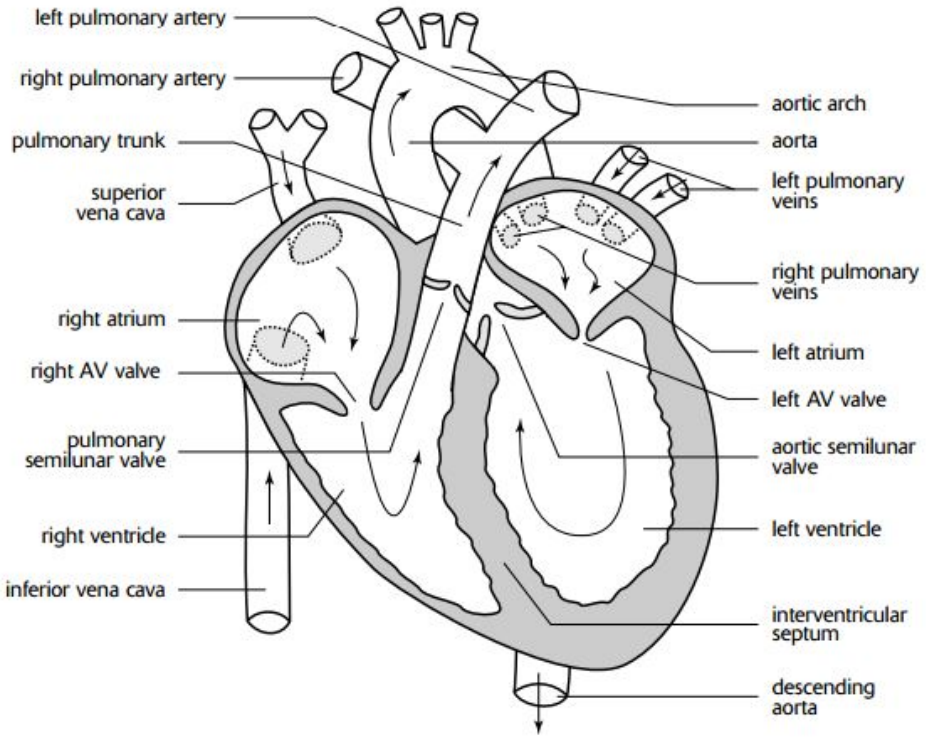
a. Large organisms require a transport system to distribute nutrients and oxygen and to remove wastes and CO2 from cells distributed throughout the body.
b. There are two types of circulatory systems.
    i. An **open circulatory system** is a system in which open-ended blood vessels spill blood into the body cavity. Blood flows into an interconnected system of sinuses (internal cavities) so that the tissues receive nutrients, fluid and oxygen directly. This causes the blood vessels to literally bathe the organs in blood, and blood pressure is low.
    ii. In a **closed circulatory system**, the blood in the body flows through a system of arteries, veins and capillaries. Each organ in the body is surrounded by capillaries that provides nourishment, oxygen as well as takes away waste products.
        1. The **pulmonary** circulation helps carry deoxygenated blood from the organs to the lungs and the **systemic** circulation helps in carrying the oxygenated blood from the lungs to the various parts of the body.
        2. The blood moves through the veins and arteries due to a difference in pressure.
        3. This system suits larger animals well as there is more area to be covered.
c. **Arteries** are thick, elastic muscle layers that can handle high pressures. They carry blood away from the heart. They branch into smaller vessels, the **arterioles**, and then branch further into the smallest vessels, the **capillaries**.
    i. Gas and nutrient exchange occurs by diffusion across capillary walls into interstitial fluids and into surrounding cells.
d. Blood returns to the heart through **venules**, which merge to form larger veins. **Veins** are thin, elastic muscle layers with semilunar valves that prevent blood from flowing in the opposite direction. They carry blood to the heart.

i. The structure of veins and arteries are adapted to the tissue they serve. When blood is pumped out of the heart, it happens with great force, meaning that the muscles must be stronger to endure the force. Veins however, carry blood toward the heart, which does not require so much force.

9. <u>The Heart</u>

a. Humans have a 4-chambered heart. A 4-chambered heart has an adaptive advantage for large animals because it completely separates oxygenated blood returning to the heart from deoxygenated blood returning to the heart.

i. When oxygenated blood is permitted to mix with deoxygenated blood, as it does in the ventricle of the 3-chambered heart, some of this blood will be sent to the respiratory structures, which is inefficient.



b. <u>Path of the human heart</u>

i. Deoxygenated (CO_2-rich) blood enters through the superior and inferior vena cava into the right atrium of the heart. The right atrium contracts and pumps the blood through the tricuspid valve and into the right ventricle.

ii. The right ventricle then pumps blood through the pulmonary artery into the lungs. In the lungs, capillaries absorb carbon dioxide from the blood and replace it with oxygen.

iii. Oxygenated blood then flows through the pulmonary vein and into the left atrium. From there it is pumped through the mitral valve and into the left ventricle.
iv. The left side of the heart contracts the strongest to send blood out the left ventricle and through the aortic arch on its way to all parts of the body.

c. The SA node, or **pacemaker**, located in the upper wall of the right atrium, spontaneously initiates the cardiac cycle by simultaneously contracting both atria and also by sending a delayed impulse that stimulates the AV node.
d. When the ventricles contract (the **systole** phase), blood is forced through the pulmonary arteries and aorta. Also, the AV valves are forced to close.
e. When the ventricles relax (the **diastole** phase), backflow into the ventricles causes the **semilunar valves** to close. This produces the characteristic "lub-dub" sounds of the heart.

10. <u>Pathway and Composition of Blood</u>

a. <u>The Lymphatic System</u>
    i. Wastes and excess interstitial fluids enter the circulatory system when they diffuse into capillaries. However, not all of the interstitial fluids enter the capillaries. Some interstitial fluids and wastes are returned to the circulatory system by way of the **lymphatic system**, a second network of capillaries and veins.
        1. The fluid in these lymphatic veins, called lymph, moves slowly through lymphatic vessels by the contraction of adjacent muscles. Valves in the lymphatic veins prevent backflow.
        2. Lymph returns to the blood circulatory system through two ducts located in the shoulder region.
        3. The lymphatic system also functions as a filter. Lymph nodes act as cleaning filters that defend against infection.
b. After passing through the aortic arch on its way to all parts of the body, there are a few options for the blood flow.
    i. Blood can be pumped through the carotid artery and into the brain, through the auxiliary arteries and into the arms, or through the aorta and into the torso and legs.
    ii. Blood capillaries permeate the body. When the oxygen-containing red blood cell crosses a muscle cell in need of oxygen, oxygen diffuses out of the red blood cells, across blood capillary walls, into interstitial fluids (the

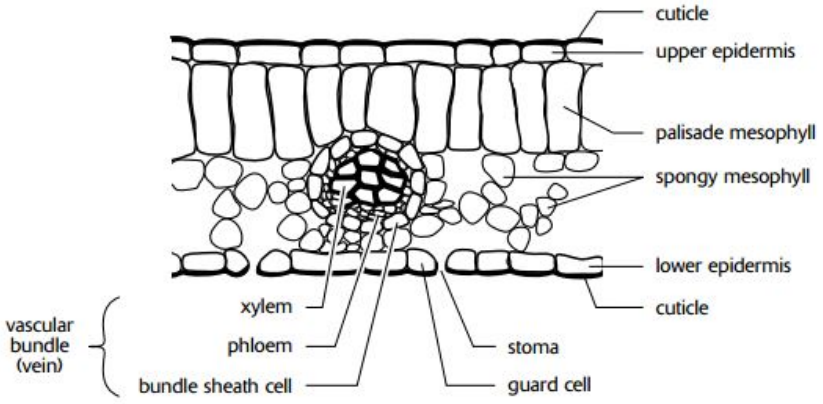
fluids surrounding the cells), and across cell membranes. Carbon dioxide diffuses in the opposite direction.

iii. After moving from the arteries to the capillaries, deoxygenated blood returns through venules before entering the vena cava again.

c. Blood is composed of
    i. Red blood cells that transport oxygen (attached to hemoglobin) and catalyze the conversion of CO_2 and H_2O to H_2CO_3. They lack a nucleus in order to maximize hemoglobin capacity.
    ii. White blood cells consisting of five major groups of disease-fighting cells that defend the body against infection.
    iii. Platelets that are cell fragments involved in blood clotting.
    iv. Plasma, the liquid portion of the blood that contains various dissolved ions.

Plants

1. **Structure of Plants**
    a. **Roots** anchor a plant, store food, absorb water and mineral, and transport these materials to all parts of the plant.
        i. Root hairs increase the absorbing surface area.
        ii. **Mychorrhizae** are fungi that benefit plants by increasing absorbing surface era.
    b. **Stems** support the plant above the ground and transport water, minerals, and sugars to the top part of the plant.
    c. **Leaves** exist for photosynthesis.
        i. The **epidermis** is a protective covering of one or more layers of cells.
        ii. The epidermis is covered by the **cuticle**, a protective layer consisting of the waxy material cutin. The cuticle reduces **transpiration**, or the loss of water through evaporation.
        iii. The **palisade mesophyll** consists of parenchyma cells equipped with numerous chloroplasts and large surface areas.
        iv. The **spongy mesophyll** contains numerous intercellular spaces provide air chambers that provide CO2 to photosynthesizing cells.
        v. **Guard cells** are specialized epidermal cells that control the opening and closing of stomata. **Stomata** are openings in the epidermis that allow gas exchange between the inside of the leaf and the external environment.
        vi. Vascular bundles consist of xylem and phloem tissues. **Xylem** delivers water for photosynthesis, while **phloem** transports sugars and other carbohydrate by-products of photosynthesis to other areas of the plant.



    d. **Flowers** are the reproductive parts of a plant, where gametes and produced and fertilization occurs.

2. **<u>Control of stomata</u>**
    a. The opening of stomata begins with blue-light sensing in the chloroplast. H+ is actively pumped out of the guard cells by proton pumps. This establishes an electrical gradient across the cell membrane.
    b. The electrical gradient drives the uptake of potassium and chloride ions into the guard cells, creating s solute gradient driving osmosis.
    c. Water enters the guard cells, making them turgid, and the stomata open.
    d. When these ions exit, so does water, and the guard cells become flaccid again.

3. **<u>Transport in Plants & Transpiration (mention symplastic/apoplastic)</u>**
    a. Water enters from the soil near the tip of a growing root, where root hairs grow. Water diffuses into the root, where it can take at least three different pathways through the root cortex to eventually reach the **xylem**, *the channel in the interior of the root that carries the soil water to the leaves.*
        i. One path is the **apoplastic path** where the *water molecule stays between cells in the cell wall region, never crossing membranes or entering a cell*.
        ii. The other two routes, called cellular pathways, require the water molecule to move across a membrane.
            1. The first cellular pathway is the **transmembrane path** where *water moves from cell to cell across membranes; it will leave one cell by crossing its membrane and will re-enter another cell by crossing its membrane*.
            2. The second cellular path is the **symplastic path** which takes the *water molecule from cell to cell using the intercellular connections called the **plasmodesmata** which are membrane connections between adjacent cells.*
    b. Regardless of the pathway, once water has crossed the cortex, it must now cross the endodermis.
        i. The **endodermis** is a *layer of cells with a waxy inlay* called the **Casparian strip** that *stops water movement between cells*, forcing it to instead move through the membranes of endodermal cells.
        ii. Once in the endodermal cells, the water freely enters the xylem cells where it joins the fast moving column of water or transpiration stream, headed to the leaves.
            1. The xylem is the longest part of the pathway that water takes on its way to the leaves of a plant.

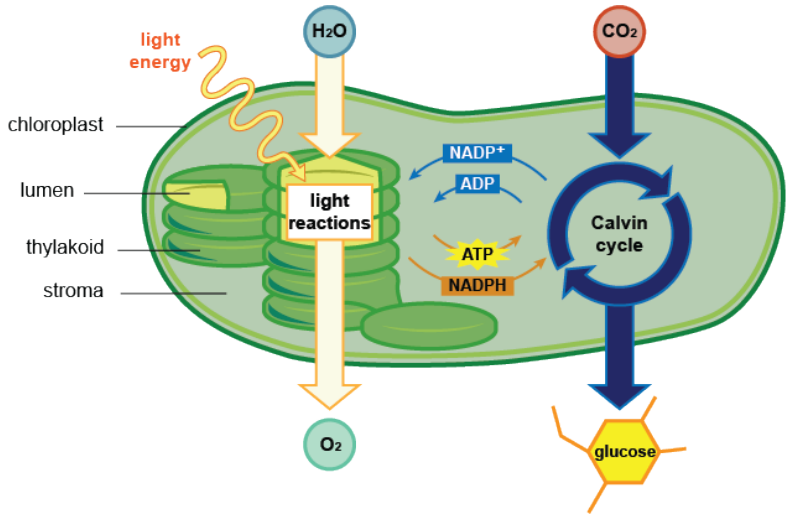
2. It is also the path of least resistance, with about a billion times less resistance than cell to cell transport of water. Xylem cells contain no membranes and are considered dead.

c. The moist air in the **stomata**, or *small openings in the leaf surface which open into air spaces that surround the mesophyll cells*, has a higher water potential than the outside air, so water tends to evaporate.

d. **Transpiration** thus causes a negative tension creating an upward pull on the column of water molecules existing in the xylem all the way from the leaves to the roots.

i. This pull is caused by the cohesion of water molecules to each other by hydrogen bond formation and adhesion of the water molecules to the walls of the xylem.

4. Photosynthesis: Light-Dependent Reactions



a. When chlorophyll absorbs light energy, an electron gains energy and is 'excited'. Different pigments, capable of absorbing different wavelengths, act together to maximize absorption of the spectrum. These pigments include the green **chlorophyll a** and **chlorophyll b.**

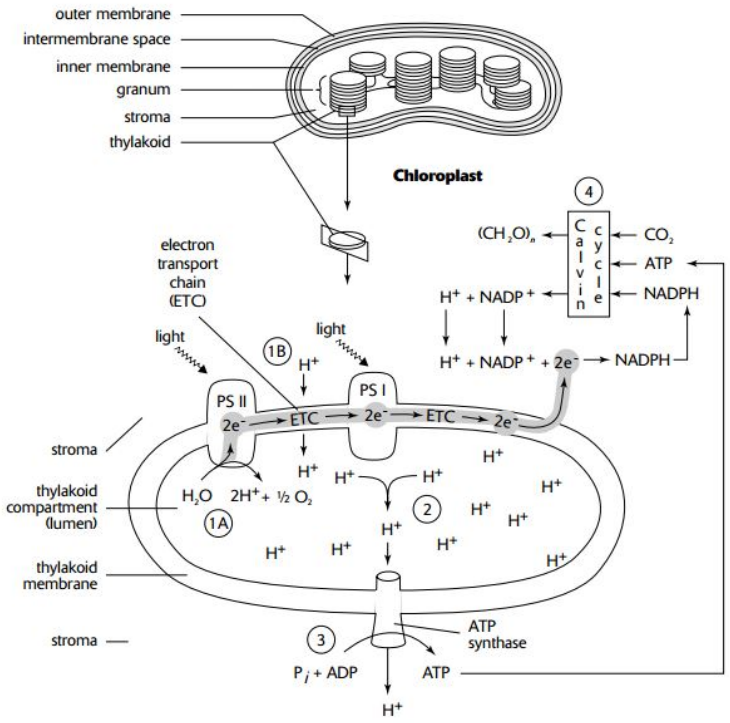
b. Electrons are energized by light in **Photosystem II**, the first protein complex in the electron transport chain, and passed on to a primary electron acceptor.

c. Electrons pass through an **electron transport chain**, losing energy as they move through it. The energy lost is used to phosphorylate a few ATP molecules.

i. But how was the ATP generated? Chemiosmosis

1. H+ are released into the lumen of the thylakoid when water is split by PS II. This creates a pH and electrical gradient across the thylakoid membrane.

2. Channel proteins called ATP synthases allow the H+ to flow through the thylakoid membrane and out to the stroma. The energy generated by the passage of the H+ provides the energy for the ATP synthases to phosphorylate ADP to ATP by the addition of phosphates.



d. The ETC ends with **Photosystem I**, where they are again energized by sunlight and passed to another electron acceptor.
e. They pass through another short electron transport chain. At the end, the electrons combine with **NADP+** and **H+** to form **NADPH**.
f. The electrons lost originally in PS II are replaced when **water** splits into 2 electrons, 2 H+, and ½ O2. The H+ provides the H in NADPH and the ½ O2 is a waste product.
g. A second photophosphorylation sequence occurs when electrons energized in PS I are recycled. The electrons are returned to PS I, generating some more ATP. This is called **cyclic phosphorylation**.

5. Photosynthesis: Calvin Cycle

a. The Calvin cycle, which does not require the presence of light, takes CO2 from the atmosphere and the energy in ATP and NADPH to create a glucose molecule. The pathway involves over a dozen products and must repeat six times, using 6 CO2s to create one glucose molecule.

i. Step 1 is carbon fixation. 6 CO_2 combine with 6 RuBP (ribulose bisphosphate) to produce 12 PGA. (It is called C3 photosynthesis because PGA has 3 carbon atoms). The enzyme Rubisco catalyzes this reaction.
ii. Step 2 is reduction. 12 ATP and 12 NADPH are used to convert 12 PGA to 12 G3P.
iii. Step 3 is regeneration. 6 ATP are used to convert 10 G3P to 6 RuBP, allowing the cycle to continue.
iv. Step 4 is carbohydrate synthesis. The remaining 2 G3P are used to build glucose.

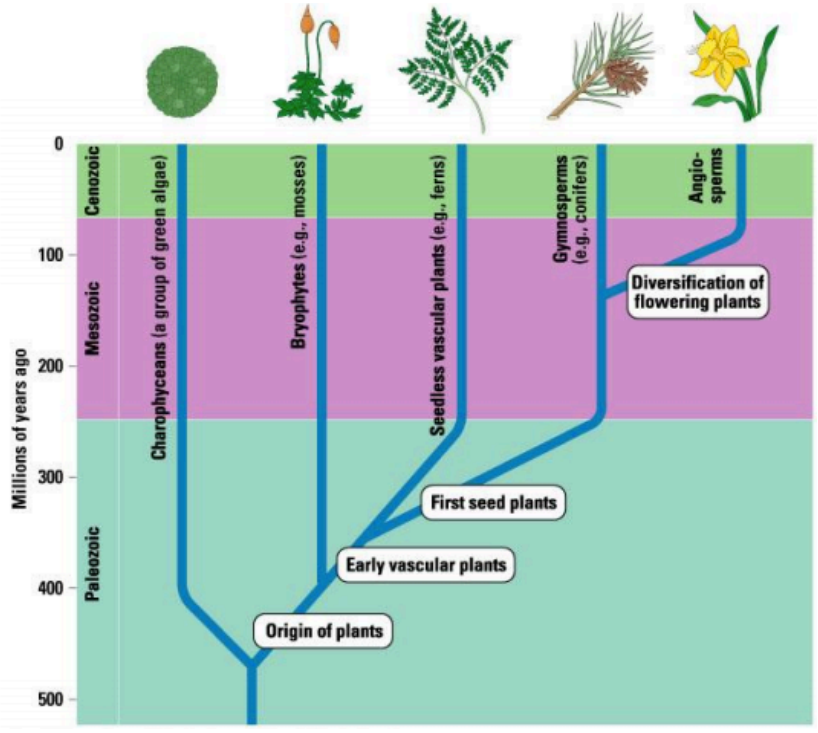
6. <u>Types of Photosynthesis</u>

a. **C3 photosynthesis** is the typical photosynthesis that most plants use, and was described above in #4 and #5. C4 and CAM photosynthesis are both adaptations to arid conditions because they result in better water use efficiency.
b. Under high light and high heat, the enzyme rubisco that grabs carbon dioxide for photosynthesis may grab oxygen instead, causing respiration to occur instead of photosynthesis (This is bad!) This is called **photorespiration**.
c. Some plants have evolved an adaptive mechanism that minimizes photorespiration. These plants use a different pathway called **C4 photosynthesis** that first incorporates carbon dioxide into a four-carbon compound before it enters the Calvin cycle. PEP Carboxylase delivers the CO_2 directly to rubisco for photosynthesis, not allowing it to grab oxygen and undergo photorespiration.
d. In **CAM photosynthesis**, stomata open at night and close during the day. The CO_2 is converted to an acid and stored during the night. During the day, the acid is broken down and the CO_2 is released to rubisco for photosynthesis. The advantage of CAM is that photosynthesis can proceed during the day while the stomata are closed, greatly reducing H_2O loss.

7. <u>Plant Diversity</u>

a. All plants undergo a life cycle that takes them through both haploid and diploid generations.
    i. The multicellular diploid plant structure is called the **sporophyte**, which produces spores through meiotic (asexual) division.
    ii. The multicellular haploid plant structure is called the **gametophyte**, which is formed from the spore and give rise to the haploid gametes.
    iii. The fluctuation between these diploid and haploid stages that occurs in plants is called the **alternation of generations**.

b. **Bryophytes** are non-vascular plants, meaning they have no water or sugar transport system. They also lack roots.
    i. The dominant generation is haploid, so that the gametophyte comprises what we think of as the main plant.
    ii. They have spores for reproduction and swimming sperm.
c. **Pteridophytes** have vascular systems, including roots and leaves. They also have swimming sperm and spores.
d. **Gymnosperms** have pollen; this adaptation eliminated the need for water in reproduction. Their lifecycle is dominated by the sporophyte stage.
e. **Angiosperms** are flowering plants with fruit and seeds. Their life cycle is dominated by the sporophyte stage as well.
    i. A **seed** offer protection for the embryo and stores nutrients for growth.
    ii. **Cotyledons** are the buds of the first leaves of the plant within the seed.
    iii. **Dicots** (like trees, shrubs, woody plants) have 2 cotyledons and leaves with vein networks.
    iv. **Monocots** (like grasses, palm trees) have 1 cotyledon and leaves with parallel veins.



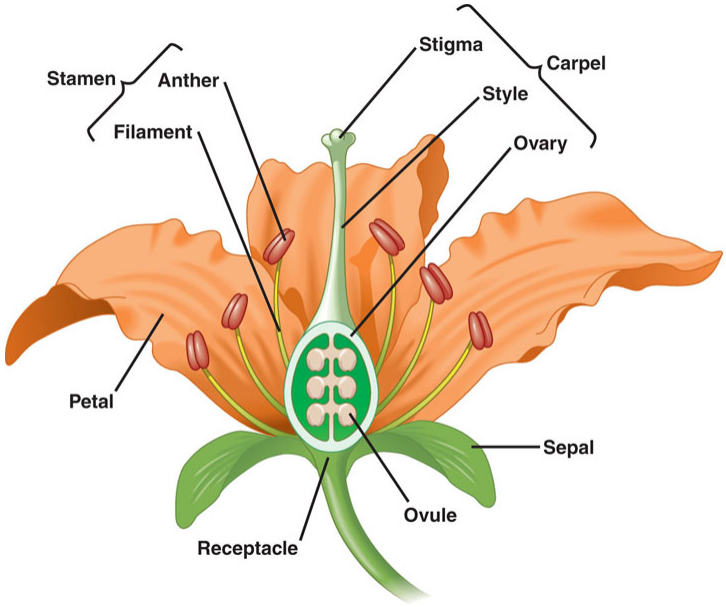
8. Plant Reproduction

a. Most angiosperms have flowers with both male and female parts.
    i. The **stamens** are the male reproductive organs, containing filaments with **anthers** that carry pollen.

1. **Pollen** is the gametophyte the makes sperm.

ii. The **carpels** are the female reproductive organs. At their base is the **ovary**, which houses numerous **ovules**.

1. Ovules contain the **embryo sac**, a gametophyte that makes eggs.



b. **Fertilization** occurs when pollen is carried by wind or insects to land on **stigma**, the outermost part of the carpel. To prevent self-pollination, stamens and carpels are self-incompatible and may mature at different times.

i. One cell of a pollen grain divides by mitosis to form two sperm. The other cell from the pollen grain grows into a **pollen tube**, which the sperm travel down through.

ii. One sperm fertilizes the egg while the other combines with the polar nuclei in the embryo sac to create a cell with a triploid nucleus. It will become the **endosperm**, a food supply for the developing embryo.

1. The process by which one sperm fertilizes the egg and the other forms a triploid cell is called **double fertilization**.

iii. The **ovules** turn into seeds and **ovary** develops into a **fruit** containing the ovules.

c. Angiosperms and animals have shaped one another's evolution. Natural selection reinforced the interactions because the improved the reproductive success of both species.

9. <u>Photoperdiods</u>

a. **Photoperiodism** is the reaction of plants to changes in the **photoperiod**, or the length of daylight and night. Plants maintain a circadian rhythm, a clock that

measures the length of daylight and night that can be reset by environmental cues.

b. **Phytochrome**, a protein modified with a light-absorbing chromophore, is involved.
    i. There are two forms of phytochrome, P_r (or P660) and P_{fr} (or P730). P_r absorbs red (wavelength 660 nm) and P_{fr} absorbs far-red (730 nm).
    ii. When P_r is exposed to red light, it is converted to P_{fr} and when P_{fr} is exposed to far-red light, it is converted back to P_r.
    iii. By measuring the red to far-red light ratio, the phytochrome system evaluates the quality of light reaching the plant.
c. **Long-day plants** flower in the spring and early summer when daylight is increasing.
d. **Short-day plants** flower in late summer and early fall when daylight is decreasing. These plants flower when daylight is less than a critical length.
e. **Day-neutral plants** do not flower in response to daylight changes.

10. <u>Plant Hormones and Tropism</u>

a. Plant hormones are small molecules, capable of passing through cell walls, that affect the division, growth (elongation), or differentiation of the cells. Very small quantities of hormones are required to alter cell physiology.
    i. **Auxin** promotes plant growth by facilitating the elongation of developing cells.
        1. It does this by increasing the concentration of H+ in primary cell walls, which, in turn, activates enzymes that loosen cellulose fibers. The result is an increase in cell wall plasticity. In response, turgor pressure causes the cell wall to expand, thus generating growth.
    ii. **Cytokinins** are a group of hormones that stimulate cytokinesis (cell division).
        1. They have a variety of effects depending upon the target organ and, sometimes, the presence (and concentration) of auxin.
            a. For example, the relative amounts of cytokinins and auxin determine whether roots or shoots will develop.
        2. Cytokinins stimulate the growth of lateral buds, thus weakening apical dominance (the dominant growth of the apical meristem).
    iii. **Gibberellins** are a group of plant hormones that, like auxin, promote cell growth.

1. Gibberellins are also involved in the promotion of fruit development and of seed germination, and the inhibition of aging in leaves.
2. High concentrations of GA can cause the rapid elongation of stems (called bolting).

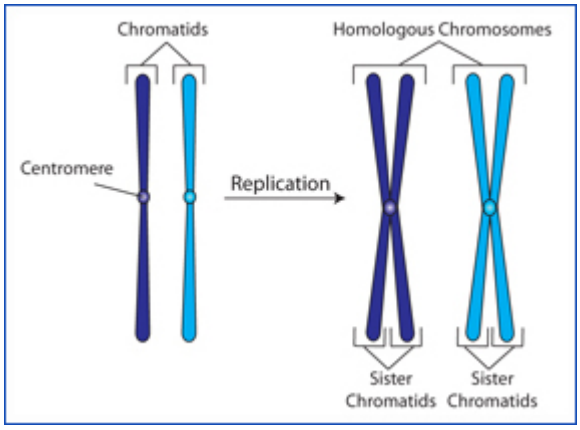
iv. **Ethylene** is a gas that promotes ripening by enzymatic breakdown of cell walls.
1. Ethylene is also involved in stimulating the production of flowers.
2. In addition, ethylene (in combination with auxin) inhibits the elongation of roots, stems, and leaves and influences leaf abscission, the aging and dropping of leaves.

v. **Abscisic acid** is a growth inhibitor.
1. In many species of plants, ABA maintains dormancy in seeds.
2. Dormancy in these seeds is broken by an increase in gibberellins or by other mechanisms that respond to environmental cues such as temperature or light.

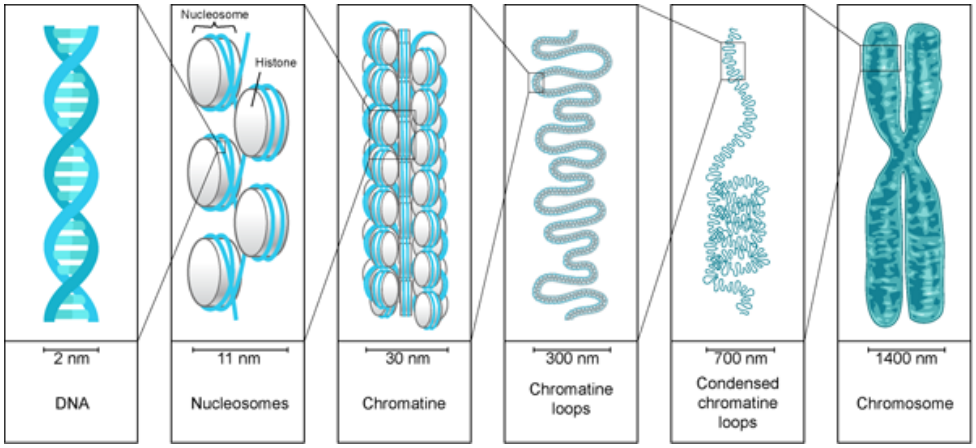
b. **Phototropism**, the response to light, is achieved by the action of the hormone auxin. Auxin accumulates on the shady side of the stem, causing more growth than on the sunny side, making the stem bend towards the light.
c. **Thigmotropism** is a response to touch. Some vines, for example, respond to contact by wrapping around the object.
d. **Gravitropism** is the response to gravity by stems and roots. Both auxin and gibberellins are involved, but their action depends on their relative concentrations.
i. It is thought that specialized starch-storing plastids called statoliths, which settle at the lower ends of cells, somehow influence the direction of auxin movement.

Cell Division, Reproduction & Development

1. **Genetic Material**
    a. The first step in either kind of cellular division (mitosis or meiosis) involves the packing of genetic material, **chromatin**, into coiled structures of chromosomes.
        i. **Chromosomes** are made of two identical halves called **sister chromatids** joined at the **centromere**.



        ii. In **diploid cells**, there are two copies of every chromosome, forming a pair, called **homologous chromosomes**. One came from the mother and one came from the father.
        iii. Humans have 46 chromosomes, 23 homologous pairs, and 92 chromatids.

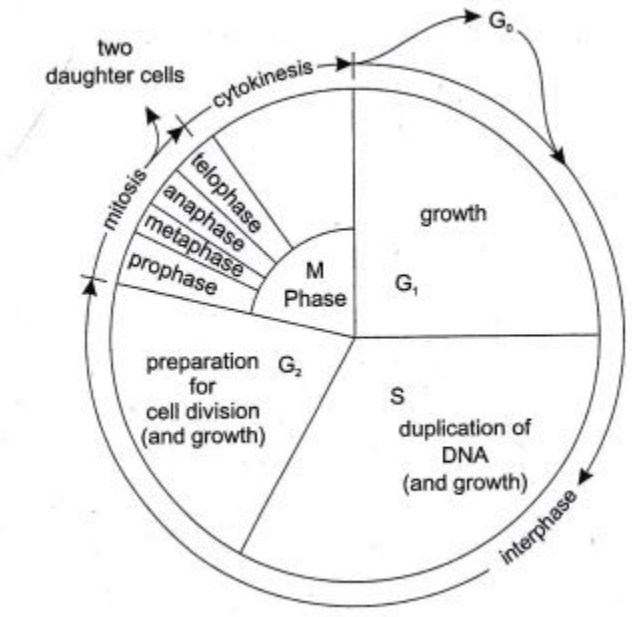


2. **The Cell Cycle**
    a. The **cell cycle** describes the sequence of events that occurs during the life of most eukaryotic cells.
        i. Cellular division consists of **nuclear division** and **cytokinesis**. Nuclear division divides the genetic material in the nucleus while cytokinesis divides the cytoplasm.

1. **Mitosis** divides the nucleus into identical daughter cells while **meiosis** divides the nucleus into genetically variable daughter cells containing half of the genetic information of the parent cell.

ii. **Interphase** is the stage that makes up about 90% of the cells life cycle. During this period, when the cell is not dividing, the cell is growing, respiring, synthesizing DNA, RNA, and proteins, and whatever other specialized task it has.

1. The chromatin is enclosed within a clearly defined nuclear envelope. **Nucleoli** are visible. Collectively, the mass of chromosomes is called **chromatin**.
2. Interphase is divided into three phases:
    a. **G1**: 1st gap where cells perform normal tasks
    b. **S**: The 2nd DNA molecule for chromosomes are synthesized
    c. **G2**: 2nd gap where cells prepare for dividing by duplicating chromosomes and organelles



3. Mitosis

a. Prophase

i. The nuclear membrane and nucleoli break down.

ii. Chromatin condenses into chromosomes.

iii. The mitotic spindle develops as **centrosomes** (pair of centrioles) move apart to the poles of the cell.

1. As they move apart, microtubules develop from each centrosome.

2. Microtubules from each centrosome connect to a specialized region in the centromere called a **kinetochore**.
3. Microtubules tug on the kinetochore, moving the chromosomes back and forth, toward one pole, then the other.

b. Metaphase

i. The chromosomes move to the equatorial plane of the cell and line up.

ii. Microtubules, still attached to the kinetochores, pull each chromosome apart into two chromatids.

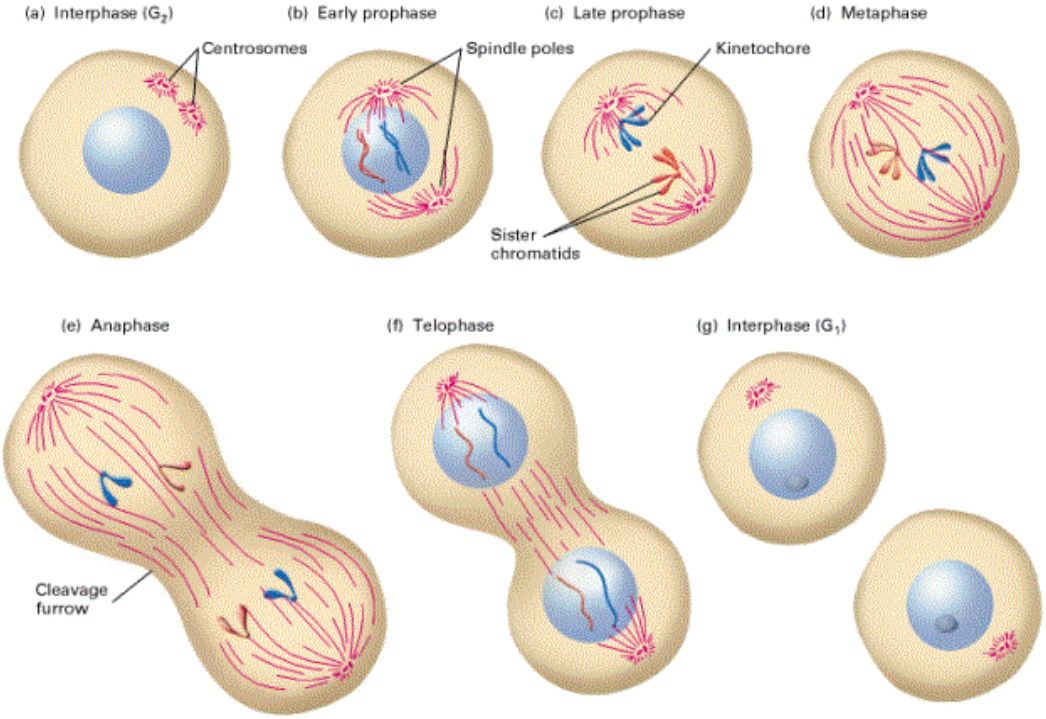
c. Anaphase

i. Centromeres holding sister chromatids together split apart and they move away from each other towards the poles of the cell.

d. Telophase

i. A nuclear envelope develops around each pole, forming two nuclei. The chromosomes within each of these nuclei disperse into chromatin, and the nucleoli reappear.

e. Some cells grow and mature only to never divide again, such as neurons and muscle cells. They are considered to be in the G0 phase.



4. <u>Cytokinesis</u>

a. Cytokinesis divides the cytoplasm to form two cells. It begins during telophase.

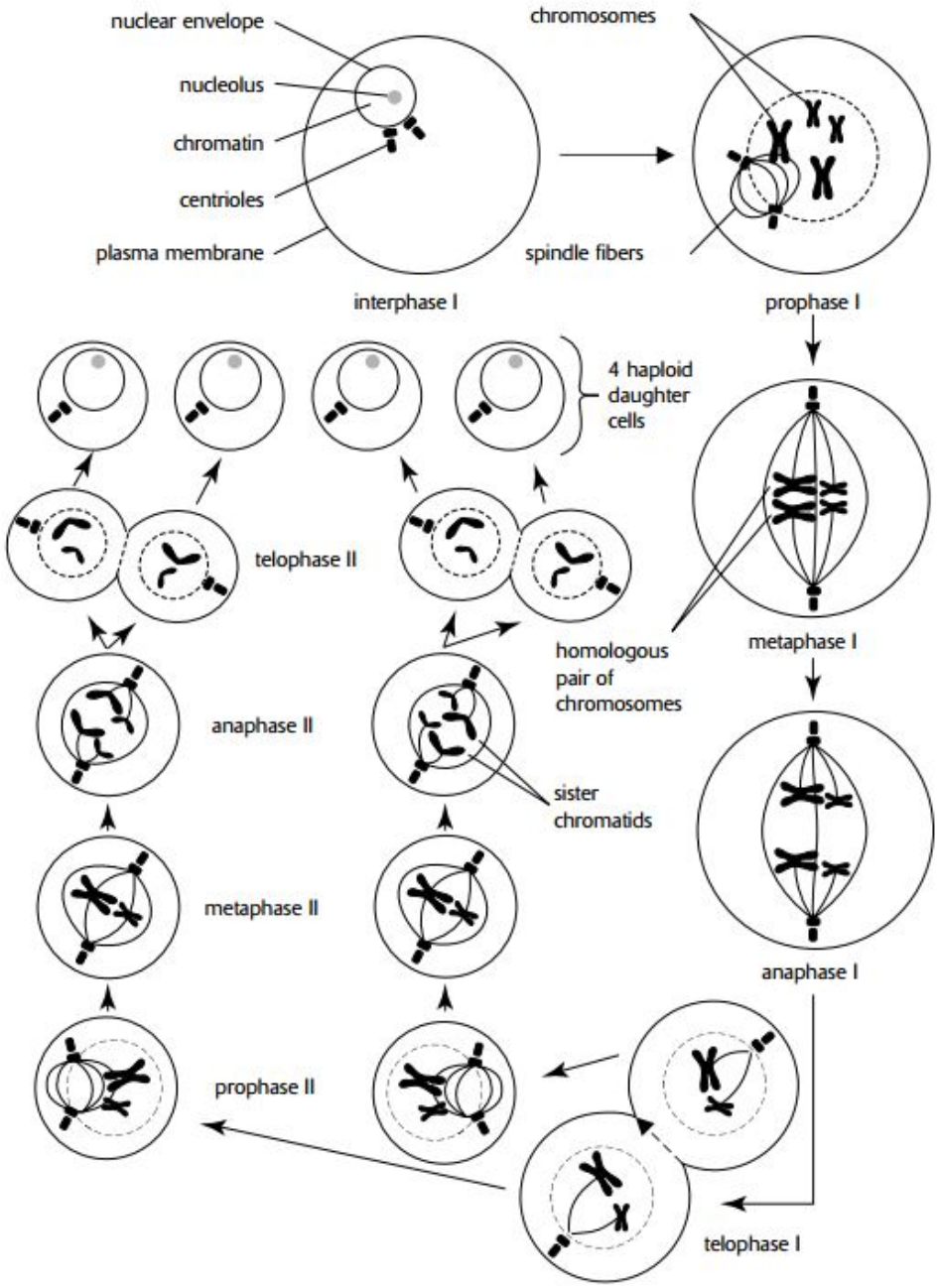
b. It occurs by the formation of two kinds of structures:

i. In plants, vesicles originating from Golgi bodies migrate to the plane between the two newly forming nuclei. The vesicles fuse to form a **cell plate**, which later becomes the plasma membranes for the two daughter cells. Cell walls develop between the membranes.
ii. In animals, microfilaments form a ring inside the plasma membrane between the two newly forming nuclei. As the microfilaments shorten, they pull the plasma membrane into the center, dividing the cell into two daughter cells. The groove that forms as the purse strings are tightened is called a **cleavage furrow**.

5. <u>Meiosis</u>

a. Meiosis consists of two groups of divisions, meiosis I and meiosis II.
b. In meiosis I, *homologous chromosomes* pair at the metaphase plate and move to opposite poles.
    i. **Prophase I** is similar to prophase in mitosis. The nucleolus disappears, chromatin condenses into chromosomes, the nuclear envelope breaks down, and the spindle apparatus develops.
        1. This time, however, homologous chromosomes pair up with each other. During the process, corresponding regions along nonsister chromatids form close associations. These associations are sites for genetic material to be exchanged in a process called **crossing over**.
    ii. In **Metaphase I**, homologous pairs of chromosomes are spread across the metaphase plate. Microtubules extending from one pole are attached to the kinetochore of one member of each homologous pair.
    iii. In **Anaphase I**, homologues uncouple from each other as they are pulled to opposite poles.
    iv. In **Telophase I**, chromosomes have reached their respective poles, and a nuclear membrane develops around them. Since daughter nuclei will have half the number of chromosomes, cells that they eventually form will be haploid.
c. In meiosis II, *chromosomes* spread across the metaphase plate and sister chromatids separate and move to opposite poles. It is just like mitosis.
    i. In **prophase II**, the nuclear envelope disappears and the spindle develops.
    ii. In **metaphase II**, the chromosomes align on the metaphase plate.
    iii. In **anaphase II**, each chromosome is pulled apart into two chromatids by the microtubules of the spindle apparatus.
    iv. In **telophase II**, the nuclear envelope reappears and cytokinesis occurs. Later in interphase, a second chromatid in each chromosome is

replicated, but the cell will still have only half the number of chromosomes.



6. Comparing Meiosis and Mitosis

a. Mitosis

i. Mitosis ends with two diploid daughter cells, each with a complete set of chromosomes; they are clones of the original.

ii. Mitosis occurs during growth and development of multicellular organisms and for repair (replacement) of existing cells.

iii. It occurs in all cells except for those that make eggs and sperm, or pollen.

b. Meiosis
    i. Meiosis ends with four haploid daughter cells, each with half the number of chromosomes. It must first combine with a second haploid cell to create a diploid cell, known as fertilization.
    ii. One copy of each chromosome is of maternal heritage, while the second copy is of paternal heritage.
    iii. Meiosis is thus genetically variable and serves to produce gametes for sexual reproduction.
c. The number of chromosomes in diploid and haploid cells is indicated by 2n and n, respectively.

7. Regulation of the Cell Cycle

a. Functional limitations, including the surface-area-to-volume ration and the genome-to-volume ratio, place limits on cell growth. The surface area is eventually unable to exchange enough substances with the outside environment to service the large volume of the cell.
b. The cell cycle is also controlled by internal factors:
    i. Checkpoints

    At specific points during the cell cycle, the cell evaluates internal and external conditions to determine whether or not to continue through the cell cycle. There are three checkpoints:

    a. **G1 checkpoint:** occurs near the end of the G1 phase. If conditions are not appropriate or if the cell is genetically programmed not to divide, the cell remains in an extended G1 phase (or G0 phase).
    b. **G2 checkpoint**: occurs at the end of the G2 phase. It evaluates the accuracy of DNA replication and signals whether or not to begin mitosis.
    c. **M checkpoint**: occurs during metaphase. It ensures that microtubules are properly attached to all kinetochores before division continues with anaphase.

    ii. Cyclin-dependent kinases (Cdks)

    1. Cdks are kinase enzymes which activate proteins that regulate the cell cycle by attaching a phosphate group to them (phosphorylation).
    2. Cdk's are themselves activated by the protein cyclin, a protein whose presence varies during the different phases of the cell cycle.

c. The cell cycle is also controlled by external factors:
    i. **Growth Factors**
        1. Plasma membranes of cells have receptors for external molecules, or growth factors, that stimulate a cell to divide.
            a. Example: Platelets are cell fragments that contribute to clotting in the blood. When they come across damaged tissue, they release PDGFs (platelet-derived growth factors) which bind to plasma membranes of connective tissues and cause them to divide.
        2. Most cells only divide when they are attached to an external surface.
        3. Many cells stop dividing when the surrounding cell density reaches a certain maximum.
d. Cancer is a disease of the cell cycle characterized by uncontrolled cell growth and division. Transformed cells, cells that have become cancerous, proliferate without regard to cell cycle checkpoints or other regulatory mechanisms.

8. <u>Genetic Variation & Chromosomal Abnormalities</u>

a. The source of genetic variation comes from re-assortment of genetic material during three events in the reproduction cycle:
    i. **Crossing over:** Nonsister chromatids of homologous chromosomes exchange pieces of genetic material during prophase I. No homologue represents an entire single parent.
    ii. **Independent assortment:** Which chromosome goes to which pole in metaphase I is up to the orientation of the chromosome pair at the plate. This orientation and subsequent separation is random.
    iii. **Random fertilization:** Which sperm fertilizes which egg is a mostly random event, but may be affected by the strength and swiftness of the sperm.
b. A chromosome abnormality reflects an abnormality of chromosome number or structure.
    i. Number abnormalities: An individual can be missing a chromosome from a pair, called monosomy, or having three chromosomes of a pair, called trisomy.
        1. An example is Down syndrome, where the person has three copies of chromosome 21, rather than two.
    ii. Structural abnormalities:
        1. **Deletions**: Portion of the chromosome is missing.

2. **Duplication**: A portion of the chromosome is duplicated.
3. **Translocation**: A portion of one chromosome is transferred to another chromosome.
4. **Inversion**: A portion of the chromosome has broken off, turned upside down and reattached.

iii. In nondisjunction, chromosomes failed to separate properly during Meiosis I. The end result is two cells that have an extra copy of one chromosome and two cells that are missing that chromosome.

9. <u>Reproduction</u>

a. Difference between sexes
   i. The **primary sex characteristics** are the structures directly involved in reproduction.
      1. The uterus and ovaries in females and the testes in males are examples.
   ii. The **secondary sex characteristics** are used to indicate sexual maturity, sexual readiness, or to attract mates.
      1. Deer antlers, lion manes, and peacock tails are examples.

b. Gametogenesis consists of the meiotic cell divisions that produce eggs in females (oogenesis) and sperm in males (spermatogenesis).
   i. Spermatogenesis
      1. The male testes have tiny tubules containing diploid cells called spermatogonium that mature to become sperm. Spermatogenesis turns each one of the diploid spermatogonium into four haploid sperm cells by meiosis.
      2. Starting at puberty, a male will produce millions of sperm every day for the rest of his life.
   ii. Oogenesis
      1. Oogenesis involves the formation of haploid cells from an original diploid cell, called a primary oocyte.
      2. Oogenesis only leads to the production of one final ovum, or egg cell, from each primary oocyte, in contrast to the four sperm that are generated from every spermatogonium.
      3. Of the four daughter cells produced by meiosis, three of them come out smaller than the fourth. These cells, called polar bodies, disintegrate. The production of one egg occurs once a month from puberty to menopause.
   iii. Hormones

1. In females, the ovary and the uterus are regulated by negative and positive feedback loops involving gonadotropin releasing hormone (GnRH) from the hypothalamus, follicle stimulating hormone (FSH) and luteinizing hormone (LH) from the anterior pituitary, and estrogen and progesterone from the follicle and corpus luteum.
    a. **FSH** causes the follicle (secretory sac) to develop, which secretes estrogen causing the endometrium to thicken.
    b. **LH** triggers ovulation, or the release of the ovum into the uterine tubes.
    c. The remnants of the follicle are now called the corpus luteum, which secretes **progesterone**, causing thickening of the endometrium to continue. Progesterone also inhibits FSH and LH production so no other follicles develop.
    d. Decline in **estrogens** causes the sloughing off of the endometrium.
2. The **menstrual cycle**, as described above, is the thickening of the endometrium of the uterus in preparation for the fertilized egg and shedding if it doesn't occur.
3. The male reproductive cycle is similar, except LH stimulates the production of **testosterone** to make sperm.

10. <u>Development</u>

a. There are four stages in the growth and development of animals.
    i. The first is gametogenesis, the formation of sperm and eggs.
    ii. The second includes embryonic development, which begins with fertilization of the egg and continues to birth.
    iii. The third stage is the process leading to reproductive maturity (puberty).
    iv. The fourth is the aging process to death.
b. Early developmental stages
    i. <u>Fertilization</u>
        1. The plasma membranes of the **sperm** and **oocyte** fuse, and the sperm nucleus enters the oocyte (female gametocyte). A membrane forms to prevent the entrance of additional sperm.
        2. Sperm penetration triggers meiosis II in the oocyte, producing an **ovum** (egg) and **polar body**. The polar body is discharged through the plasma membrane.

3. The sperm and ovum nuclei fuse, forming a **zygote** nucleus.

ii. Cleavage
1. The zygote now begins a series of **cleavage** divisions (rapid cell divisions without cell growth). As a result, each of the resulting cells, called **blastomeres**, contains substantially less cytoplasm than the original zygote.
2. Successive cleavage divisions result in a solid ball of cells called a **morula**.

iii. Blastula
1. As cell divisions continue, liquid fills the morula and pushes the cells out to form a circular cavity surrounded by a single layer of cells. This hollow sphere of cells is called the **blastula**, and the cavity is the **blastocoel**.

iv. Gastrula
1. Formation of the gastrula (**gastrulation**) occurs when a group of cells move inward into the blastula forming a two-layered embryo with an opening from the outside into a center cavity. This opening becomes the mouth.
2. A third cell layer forms between the outer and inner layers of the invaginated embryo. These three cell layers, the **ectoderm**, **mesoderm**, and **endoderm** (outside, middle, and inside layers) are the primary germ layers from which all tissue develops.
3. Extraembryonic membranes, like yolk sacs and placentas, develop.

v. Organogenesis
1. Cells begin to differentiate and form organs.
2. Cells along the surface of the mesoderm germ layer form the **notochord**, a stiff rod that provides support in lower chordates.
3. A layer of cells forms the neural plate in the ectoderm layer. The plate indents, forming the neural groove, then rolls up into a cylinder, the **neural tube**. The neural tube develops into the central nervous system.

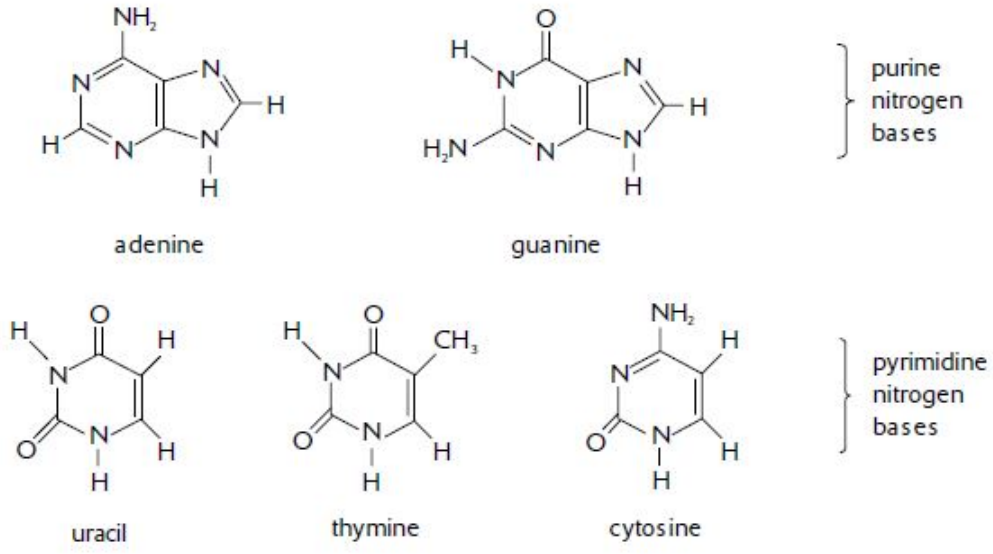
c. Birth

i. After labor begins the baby's head puts pressure on the cervix, causing the cervix to stretch. This stimulates receptors that trigger the mother's hypothalamus to release **oxytocin**, which increases uterine contractions, causing the cervix to stretch further. It is an example of **positive feedback**.

DNA & Biotechnology

1. **Early Experiments with DNA**
    a. Frederick **Griffith** experimented with pneumonia-causing strains of bacteria in mice to discover that genetic information can be transferred from dead to living bacteria. This is called **transformation**; the ability of bacteria to absorb genetic information from the surroundings. DNA was discovered to be the transforming agent.
    b. **Avery**, **MacLeod**, and **McCarty** used experiments with disease-causing bacteria to discover DNA as the hereditary information (not RNA or other proteins).
    c. **Hershey** and **Chase** also concluded that DNA was the hereditary material with experiments involving radioactive phages to determine whether the proteins or DNA would enter the bacteria.
    d. **Wilkins** and **Franklin** used X-rays to reveal the structure of DNA. **Watson** and **Crick** proposed a twisted ladder structure of DNA.

2. **DNA Structure**
    a. DNA is a polymer of nucleotides. A DNA nucleotide consists of three parts—a nitrogen base, a five-carbon sugar called deoxyribose, and a phosphate group.
    b. The nitrogen bases are:



    c. A strand of DNA or RNA consists of nucleotides linked together by phosphodiester bonds.
    d. A phosphodiester bond exists between the phosphate of one nucleotide and the sugar 3' carbon of the next nucleotide. This forms a backbone of alternating sugar and phosphate molecules known as the "sugar-phosphate backbone".

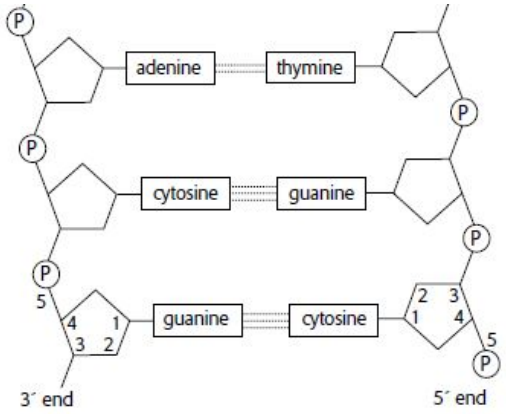
e. In nucleic acids, hydrogen bonding occurs between the nitrogen bases of DNA and RNA and holds the strands together. The double helix structure of DNA is caused by this interaction.
    i. There are 2 Hydrogen bonds between adenine and thymine
    ii. There are 3 Hydrogen bonds between guanine and cytosine

f. RNA differs from DNA in that:

    1. The sugar in the nucleotides that make an RNA molecule is ribose, not deoxyribose as it is in DNA.

    2. The thymine nucleotide does not occur in RNA. It is replaced by uracil. When pairing of bases occurs in RNA, uracil (instead of thymine) pairs with adenine.

    3. RNA is usually single-stranded and does not form a double helix as it does in DNA.



g. The two strands of a DNA helix are antiparallel, as shown to the right.

h. Chargaff observed that the amount of A, T, G, and C varied from species to species. The amount of adenine was equal to the amount of thymine, however, and the amount of guanine was always equal to the amount of cytosine (base pairing rules).

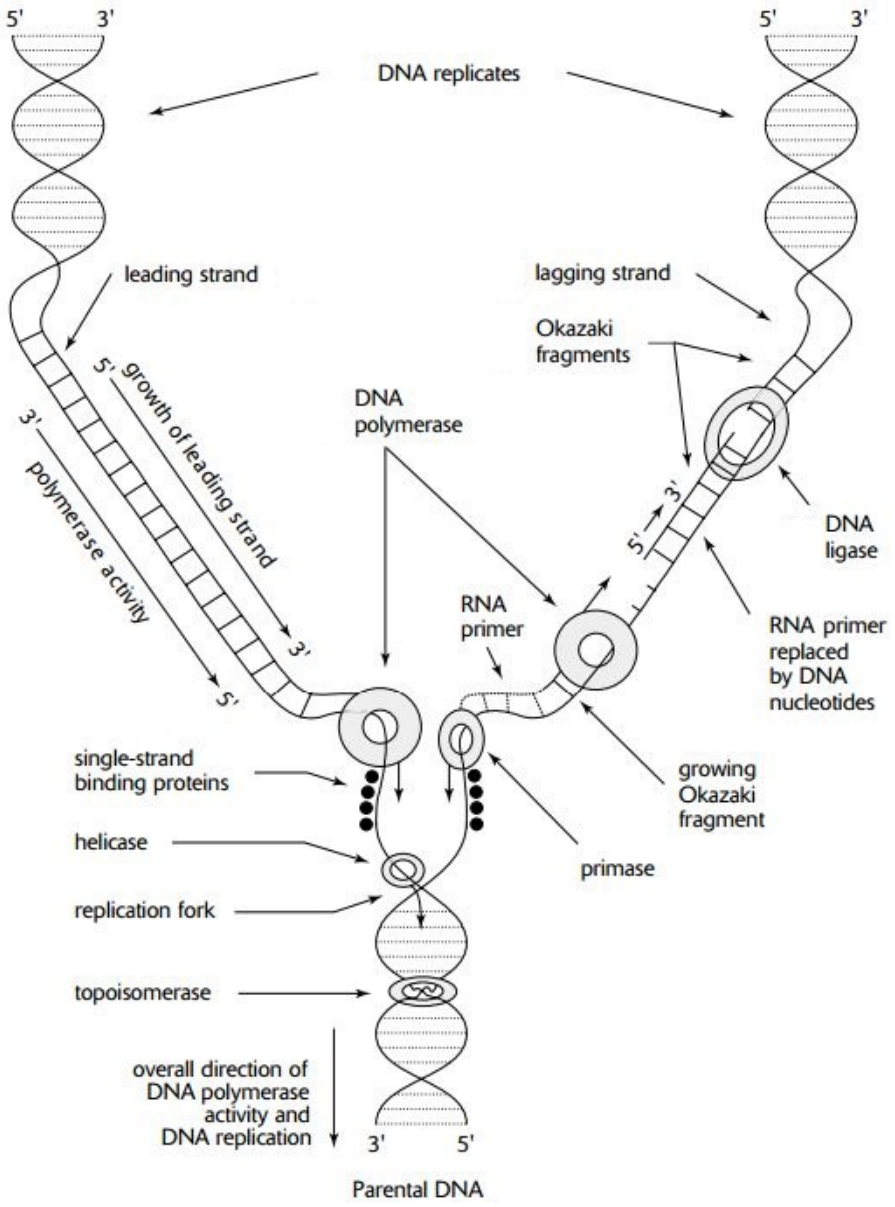
3. DNA Replication and Repair

a. DNA Replication occurs during the S phase of interphase in the cell cycle. A second chromatid containing a copy of the DNA molecule is assembled when the DNA molecule is unzipped into two strands, each of which serving as a template to assemble a new, complementary strand. The process is called **semiconservative** for this reason.

b. The Process:

    1. **Helicase** unzips DNA, creating a **replication fork**. Single-strand binding proteins prevent the single strands of DNA from recombining.
        a. **Topoisomerase** removes twists and knots that form in the double stranded template as a result of the unwinding induced by helicase.

2. **Primase** starts DNA replication at special nucleotide sequences, called origins of replication, with short segments of RNA nucleotides called **RNA primers**.
3. **DNA polymerase** attaches to the RNA primers and begins **elongation**, the adding of DNA nucleotides to the complement strand.
4. The **leading strand** is assembled continuously as the double-helix DNA uncoils.
5. Replication of the **lagging strand** occurs in short **Okazaki fragments**, which are binded by the enzyme **ligase**. Each Okazaki segment begins with an **RNA primer**. The RNA primer is subsequently removed, and a DNA polymerase attaches to the 3' end of the next **Okazaki segment** and works backward toward the earlier segment (5' → 3') to fill the space left by the RNA primer.
6. The RNA primers are replaced by DNA nucleotides.



c. There are various mechanisms to repair replication errors
    i. **Proofreading**: DNA polymerase checks to make sure that each newly added nucleotide correctly base pairs with the template strand.
    ii. **Mismatch Repair Enzymes**: Enzymes repair errors that escape the proofreading ability of DNA polymerase.
    iii. Excision repair: Enzymes remove nucleotides damaged by mutagens by using the complementary strand as a template to fix the error.

d. A special situation occurs at the ends of eukaryotic chromosomes, called **telomeres**.
    i. Often not enough template strand remains to which primase can attach. If there is no next Okazaki segment to which DNA polymerase can attach, the empty space left by the removal of the primer is left unfilled.
    ii. The enzyme **telomerase** solves this problem by attaching to the end of the template strand and lengthening it by adding a short sequence of nonsense DNA nucleotides.
    iii. Once telomerase activity declines in older cells, the chromosome becomes shorter with each replication and important DNA starts to get lost until daughter cells are non-viable. This is thought to be what causes aging of cells.

4. <u>Types of RNA</u>

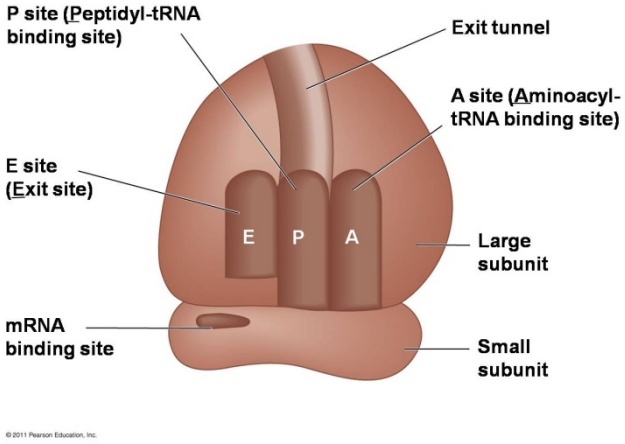
a. <u>mRNA</u>
    i. Messenger RNA is a single strand of RNA that conveys genetic information from DNA to the ribosome, where they specify the amino acid sequence of the protein products of gene expression.
    ii. A triplet group of three adjacent nucleotides on the mRNA, called a **codon**, codes for one specific amino acid. There are 64 codons (but only 20 amino acids).
    iii. The genetic code for humans is a chart used to decode the each codon.

b. <u>tRNA</u>
    i. Transfer RNA is a short RNA molecule that interacts with itself to form a three dimensional molecule. It is used for transporting amino acids to their proper place on the mRNA template.
    ii. The 3' end of the tRNA attaches to an amino acid. Another portion of the tRNA is the anticodon. During translation, the anticodon of the tRNA base pairs with the codon of the mRNA.

c. <u>rRNA</u>
    i. rRNA molecules are the building blocks of ribosomes.

ii. Within the nucleolus, various proteins from the cytoplasm are assembled with rRNA to form ribosome subunits.
    1. Together, two subunits form a ribosome that coordinates the activities of the mRNA and tRNA during translation.
    2. Ribosomes have three binding sites:
        a. One for the mRNA.
        b. One for a tRNA that carries a growing polypeptide chain.
        c. One for a second tRNA that delivers the next amino acid that will be inserted into the growing polypeptide chain.

Schematic model showing binding sites



5. <u>Protein Synthesis: Transcription and mRNA processing</u>

a. DNA contains codes for polypeptides that regulate development, growth, and metabolism. Many polypeptides are enzymes that regulate chemical reactions, and these chemical reactions influence the resulting characteristics of the cell. The flow of information from DNA to RNA to proteins controlling traits is called the **central dogma** of molecular biology.

b. The **gene** is the DNA segment that codes for a particular polypeptide (one-gene-one-polypeptide hypothesis).

c. The Process:
    i. **RNA polymerase** attaches to a **promoter** region on DNA that defines the start of a gene and begins to unzip the DNA. A promoter region often contains the T-A-T-A sequence and tells the polymerase which strand to read and in what direction.
    ii. RNA polymerase unzips the DNA and assembles mRNA nucleotides using one strand of the DNA as a template. Nucleotides are added in the 5' → 3' direction, just like in DNA replication. Only one DNA strand is transcribed, however.
    iii. The RNA polymerase stops when it reaches a special sequence of nucleotides that serve as a termination point.
    iv. Prior to the mRNA leaving the nucleus, a few things happen:

1. A 5' cap made of a guanine with two additional phosphates is added to the 5' end of the mRNA to provide stability.
2. A **poly-A tail** made of 200 adenines is attached to the 3' end of the mRNA. It controls the movement of the mRNA across the nuclear envelope.
3. mRNA contains **exons**, which are sequences that express a code for a polypeptide, and **introns**, which are intervening sequences that are noncoding. Small nuclear ribonucleoproteins delete the introns and splice the exons before leaving.

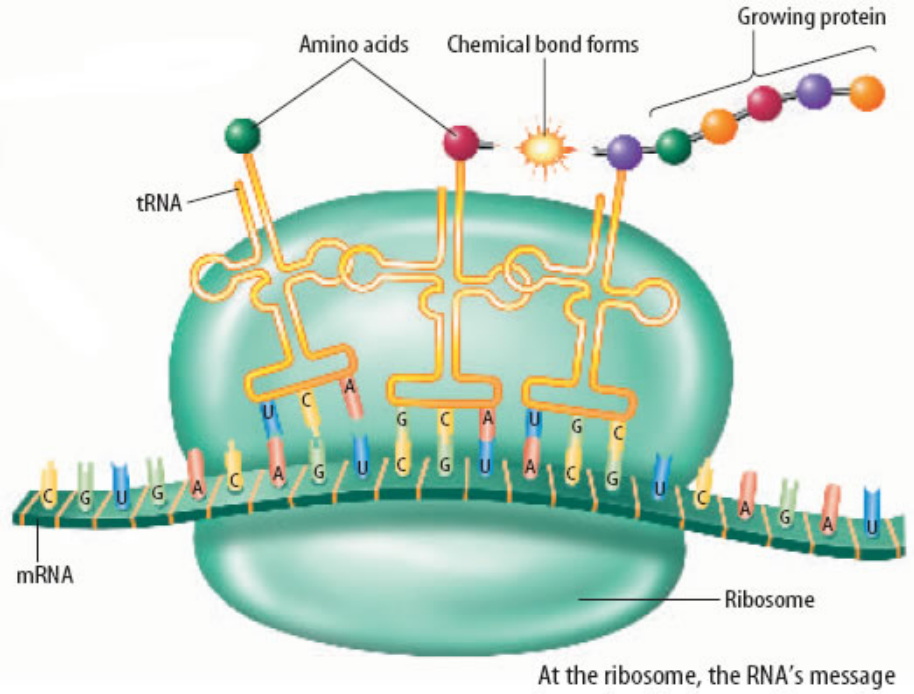
6. Protein Synthesis: Translation

a. The mRNA, tRNA, and ribosomal subunits are transported across the nuclear envelope and into the cytoplasm. Energy for translation is provided by GTP, which works similarly to ATP.

b. mRNA arrives at a ribosome. The codons on the mRNA code for a specific sequence of amino acids to be synthesized. One-by-one, tRNA brings amino acids to the ribosome so that anticodon of the tRNA pairs with the codon on the mRNA. Amino acids are found freely in the cytoplasm by food we eat.

c. The amino acid is attached to the adjacent amino acid with a peptide bond and a tRNA is released from the ribosome. The growing of the polypeptide chain is called elongation.

d. The polypeptide is released for further processing in the Golgi body or endoplasmic reticulum once a stop codon has been reached. Interactions among the amino acids give it its secondary and tertiary structures.



At the ribosome, the RNA's message is translated into a specific protein.

7. Mutations & Viruses

a. A mutation is a sequence of nucleotides in DNA that does not match the original DNA exactly. They are caused by replication errors, radiation or reactive chemicals. They introduce allele variation into the population.
b. A point mutation is a single nucleotide error.
    i. **Substitution**: DNA sequence contains incorrect nucleotide.
    ii. **Deletion**: Nucleotide is omitted.
    iii. **Insertion**: Nucleotide is added.
    iv. **Frameshift**: All subsequent nucleotides are displaced one position as a result of a deletion or insertion.
c. A point mutation causes one of the following when transcribed:
    i. **Silent mutation**: New codon still codes for the same amino acid.
    ii. **Missense mutation**: New codon codes for a new amino acid. The hemoglobin protein that causes sickle-cell anemia is caused by this mutation.
    iii. **Nonsense mutation**: New codon codes for a stop codon.
d. **Transposons** are naturally occurring mutations. They are DNA segments that insert themselves into the genome after copying or deleting themselves from another area. They are responsible for spotted corn.
e. **Viruses** penetrate cells and take over their metabolic processes to assemble hundreds of new viruses that are copies of itself, destroying the host cell in the process.
    i. Viruses consist of DNA or RNA (not both), a protein coat, and an envelope.
    ii. They replicate by penetrating the cell membrane and using the enzymes to produce viral proteins in the lytic cycle, or the viral DNA is incorporated into the DNA of the host cell in the lysogenic cycle.
    iii. Viruses reproduce quickly and thus have a potential for rapid evolution. RNA viruses have high rates of replication errors because they lack repair mechanisms. HIV, the flu, and the common cold are all RNA viruses that evolve and mutate quickly, on a seasonal basis.

8. Prokaryotic vs Eukaryotic Genetics

a. Storage of DNA
    i. In eukaryotes, genetic material (DNA) is stored in the nucleus of the cell. Normally, the DNA is spread out within the nucleus as a threadlike matrix called chromatin. When the cell begins to divide, the chromatin

condenses into chromosomes, each of which is made up of two long linear DNA molecules and various histone molecules.

ii. In prokaryotes, there is no nucleus and the primary genetic material is a single chromosome consisting of a single, circular DNA molecule. The circular DNA twists around itself, known as supercoiling. A bacterial chromosome is called a naked chromosome because it lacks the histones and other proteins that eukaryotic chromosomes have. Prokaryotes can absorb DNA from their surrounds and incorporate it into their genome.

b. DNA Replication
   i. In eukaryotes, DNA replication has multiple points of origin. Also, eukaryotic chromosomes encounter problems replicating their telomeres (ends of chromosomes) because of the loss of segments for DNA polymerase to attach to.
   ii. In prokaryotes, chromosomes are circular, so replication starts at a single origin and moves in both directions until they meet again. Prokaryotic chromosomes are circular, and thus do not have telomeres.
c. Protein Synthesis
   i. Prokaryotes lack introns, or noncoding sections of an RNA transcript that are spliced out before the RNA is translated. Prokaryotes do not have proofreading of transcription. Also, translation is coupled with transcription in prokaryotes. The ribosome attaches to end of the mRNA transcript and begins translation while the mRNA is still being produced at the other end. Both processes occur in the cytoplasm, in contrast to the nucleus in eukaryotes.
d. Gene Regulation
   i. Gene regulation in prokaryotes includes the use of operons, or gene clusters whose enzyme products function sequentially as part of a metabolic pathway while eukaryotes do not. Prokaryotes use positive and negative regulation, meaning both activator and repressor proteins are involved in gene regulation whereas eukaryotes primarily use positive regulation.

9. Gene Expression Regulation

a. All cells contain identical copies of all genetic instructions. Cells take on a wide variety of structures and functions because of differences in the expression of genes during the cell's development.
b. Most genes must be turned off and on at appropriate times. A cell must constantly modify activities to respond to internal and external conditions.

c. Gene Regulation in Prokaryotes

Operons are units of DNA that contain genes for a single metabolic pathway.

i. **Promoter**: Region of DNA that RNA polymerase attaches to.

ii. **Operator**: Engaged by a regulatory protein to block or activate RNA polymerase.

iii. **Structural genes** contain the coding DNA.

iv. **Regulatory genes** outside the operon region produce **regulatory proteins** that engage the operator region.

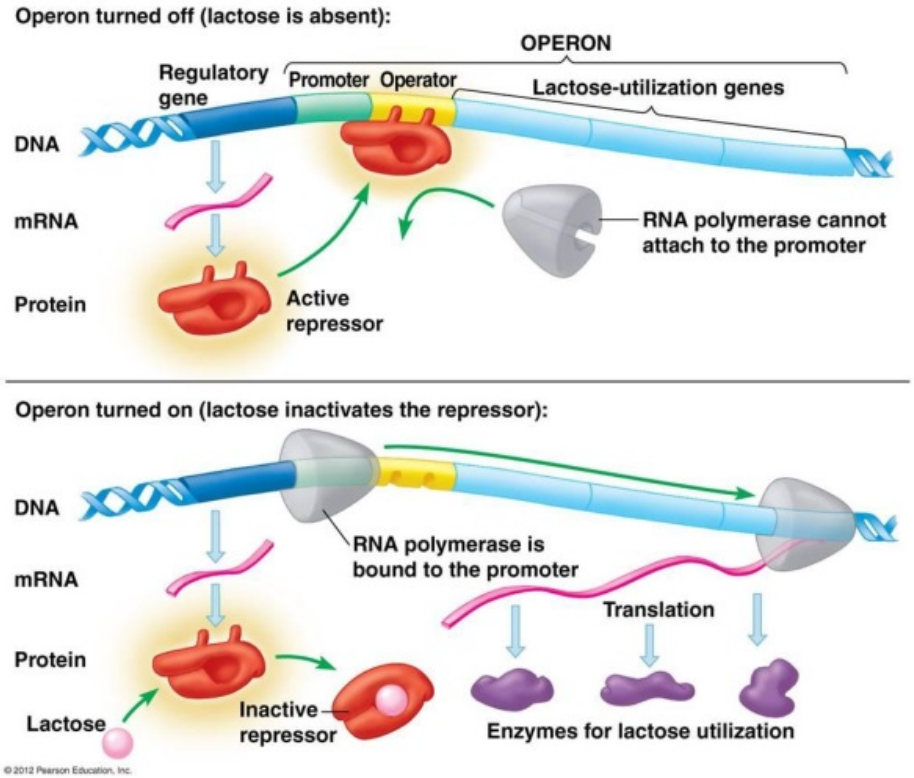
1. **Repressor proteins** block the attachment of RNA polymerase to the promoter in **negative regulation** because they must be inactive for transcription to occur.

*a. An example is the **trp operon**, where rising levels of tryptophan induce the inactive repressor to become active, thus blocking further production of tryptophan.*

i. Since the gene stops producing enzymes in the presence of a repressor, the operon is called a repressible operon.

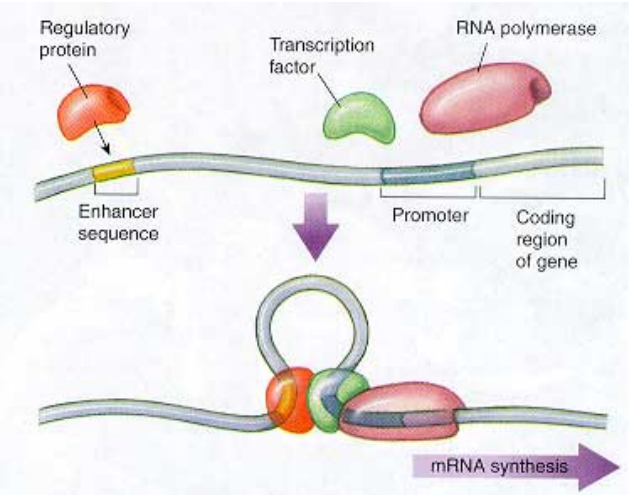
*b. Another example is the **lac operon**, where lactose inactivates repressors to allow RNA polymerase to code for enzymes that break down lactose.*

i. Since a substance is needed to induce the operon, the operon is called an inducible operon.



2. **Activator proteins** promote the attachment of RNA polymerase to the promoter in **positive regulation** because they must be active for transcription to occur.
    a. *An example is glucose repression: when glucose is absent, cAMP levels are up, an activator protein is activated and binds to the operator, promoting RNA polymerase transcription of enzymes that break down lactose.*

d. Gene Regulation in Eukaryotes
    i. Unlike prokaryotic genes, eukaryotic genes have **introns** and large numbers of control elements (noncoding DNA sequences where transcription factors bind).
    ii. Every stage that contributes to the final protein can be subject to some kind of regulation.
        1. The packing of DNA can regulate transcription.
            a. **DNA methylation** occurs when methyl groups attach to DNA and make it hard for transcription factors to access the DNA, leading to gene silencing.
            b. In **acetylation**, histone molecules loosen their grip on DNA when acetyl groups are attached.
    iii. Regulation can also occur for transcription initiation.
        1. Eukaryotic genes have a **promoter** region where **RNA polymerase** binds to start transcription.
            a. RNA polymerase alone cannot initiate the transcription; it is dependent on *general* transcription factors, or binding proteins, to bind to the promoter.
        2. *Specific transcription factors* attach to **enhancers**, DNA binding sites upstream or downstream from a gene. The enhancer is far from the gene it influences, so the DNA with the enhancer folds into a hairpin loop so that it can join the general transcription factors and RNA polymerase on the promoter.



How enhancers work

The enhancer site is located far away from the gene being regulated. Binding of a regulatory protein (*red*) to the enhancer allows the protein to interact with the transcription factors (*green*) associated with RNA polymerase, activating transcription.

a. Transcription starts when the loop of DNA brings the transcription factors on the enhancer sequence in contact with transcription factors on RNA polymerase at the promoter.

iv. Regulation can also occur during **RNA processing** if mRNAs are sliced in different ways.

v. Regulation can also occur through **RNA interferences**, when short RNA molecules bind to mRNA in the cytoplasm and block their translation (siRNA).

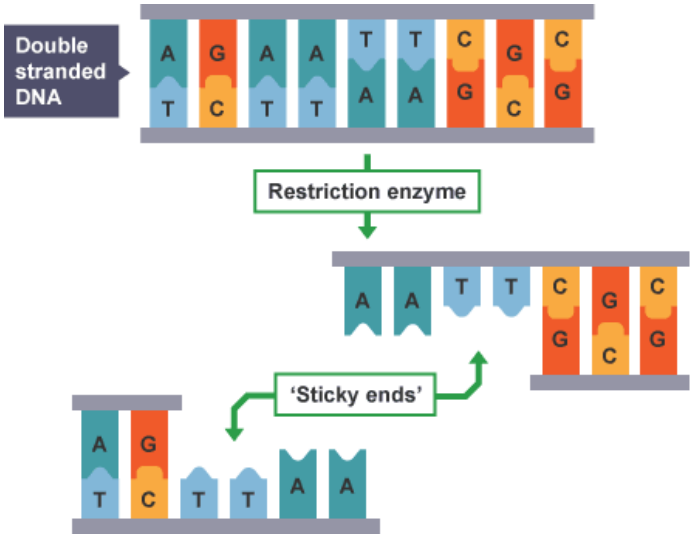
vi. Lastly, regulation occurs by **protein degradation** in which old proteins whose functionality has been lost when their 3D shape falls apart are marked for destruction with the protein **ubiquitin**.

10. Biotechnology (types, procedures, concerns)

Biotechnology involves modifying organisms to produce desired products, and may include a range of procedures from selective breeding to manipulating gene expression.

a. Biotechnology often uses **recombinant DNA**: DNA segments from different sources.
   i. DNA transfer occurs naturally though crossing over, viral transduction, bacterial conjugation (transfer of plasmids between bacteria), or transposons.

b. Recombinant biotechnology uses **restriction enzymes** to cut up DNA into fragments. Such restriction enzymes come from bacteria, where they serve as evolutionary adaptations for killing viral DNA.
   i. Restriction enzymes cut at specific nucleotide sequences, or **restriction sites**, which often result in staggered fragments with one strand of DNA extending farther than its complementary strand (called a sticky end).



c. DNA cloning involves the copying and insertion of recombinant DNA.
    i. A restriction enzyme cuts up the DNA containing the gene to be copied. DNA with the required gene should come directly from the mRNA so that no introns prevent transcription.
    ii. The same restriction enzyme cuts up the DNA of a cloning vector, which is usually a plasmid because they can be introduced to bacteria by transformation.
    iii. The foreign DNA is mixed with cut plasmids so that some foreign fragments will fuse with plasmid fragments.
    iv. DNA Ligase seals the attachments.
    v. The plasmids are mixed or inserted into bacteria, leading to transformation by absorption.
    vi. Often scientists make a point to include genes for ampicillin resistance or fluorescence on the plasmid so that they can easily identify which bacteria have absorbed the plasmid (which have transformed).

d. The **Polymerase Chain Reaction (PCR)** makes large numbers of DNA from a small amount.
    i. DNA is heated, breaking Hydrogen bonds between strands of DNA.
    ii. Two DNA primers are added complementary to the single strands.
    iii. DNA polymerase (a special heat-tolerant kind derived from bacteria adapted to hot springs) attaches to the primers at each end and synthesizes the complementary DNA strand.
    iv. This is repeated to amplify DNA copies to millions of copies very quickly.

e. DNA Fingerprinting uses **gel electrophoresis** to separate restriction fragments into bands of DNA that can be analyzed.
    i. In gel electrophoresis, DNA fragments cut up by restriction enzymes are placed in a gel.
    ii. The DNA is drawn to a positive electrode (since the phosphate groups make DNA negatively charged).
    iii. Short fragments migrate further than heavier fragments.
    iv. Certain parts of the human genome are known to differ between individuals, so the locations of resulting bands of DNA can be used to compare results of DNA found at crime scenes to DNA of suspects.

Heridity

1. **Probability & Standard Deviation**
    a. Genetics Problems require the application of probability rules.
        i. If two events are independent of each other, then the probability of both events occurring is P(A) x P(B).
            1. For example, the probability of HBO finishing Game of Thrones (100%) AND George RR Martin finishing *A Song of Ice and Fire* (0%) is 100% x 0% = 0%
        ii. If two events are mutually exclusive (they cannot occur at the same time), then the probability of either occurring is P(A) + P(B).
            1. For example, the probability of Jon Snow's mother being Lyanna Stark (99%) OR not Lyanna Stark (1&) is 99% + 1% = 100%
    b. **Mode** = value that occurs most frequently in a data set
    c. **Median** = middle value that separates the greater and lesser halves of a data set
    d. **Mean** = sum of all data points divided by number of data points
    e. **Range** = value obtained by subtracting the smallest observation (sample minimum) from the greatest (sample maximum)
    f. **Standard Deviation**:

$$s_x = \sqrt{\frac{\sum_{i=1}^{n}(x_i - \bar{x})^2}{n-1}}$$

$n =$ The number of data points

$\bar{x} =$ The mean of the x_i

$x_i =$ Each of the values of the data

    g. Standard Error: Standard deviation divided by square root of sample size

$$SE_{\bar{x}} = \frac{s}{\sqrt{n}}$$

2. **Chi-Squared Analysis**

Chi-square is a statistical tool that helps determine if the observed ratio is close enough to the expected ration to be acceptable. It can be used in any area.

a. The process involves calculating the chi-squared value, which is done by the formula shown to the right.
b. The O is obtained result, and the E is

$$\chi^2 = \sum \frac{(O-E)^2}{E}$$

the expected result.

c. For example: 100 coins are flipped and there land 62 heads and 38 tails.

$$\frac{(62-50)^2}{50} + \frac{(38-50)^2}{50} = 5.76$$

d. This value is then compared to a Chi-Square table:

CHI-SQUARE TABLE								
Degrees of Freedom								
p	1	2	3	4	5	6	7	8
0.05	3.84	5.99	7.82	9.49	11.07	12.59	14.07	15.51
0.01	6.64	9.32	11.34	13.28	15.09	16.81	18.48	20.09

The **degrees of freedom** is the number of possible outcomes minus one.

The **p value** indicates the probability of the results not being up to chance alone (so the 0.01 obviously has higher standards).

e. If the value exceeds the critical value, we can reject the **null hypothesis,** which states there are no significant differences between observed and expected frequencies.

   i. In the example, then, since 5.76>3.84, we can reject the null hypothesis.

3. <u>Genetics</u>

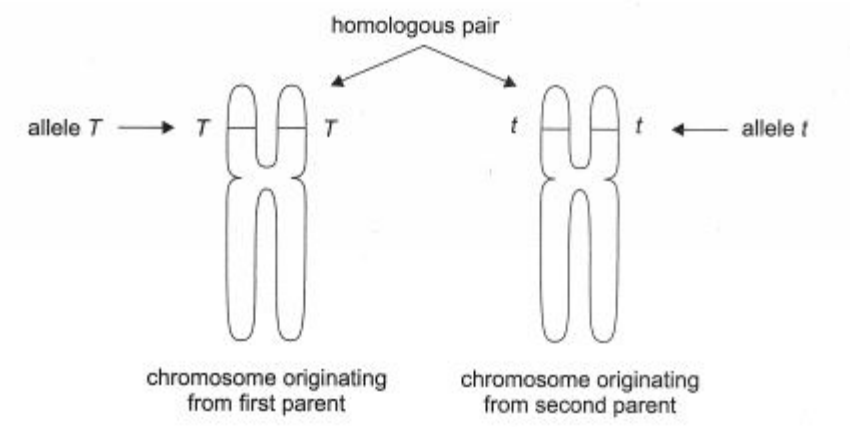
a. A **gene** represents the genetic material on a chromosome that contains the instructions for creating a particular trait.

b. A **trait** is variant of a heritable feature such as hair color.

c. An **allele** is a variety of a gene, such as a tall (T) plant or short (t) plant.

d. A **locus** is the location on a chromosome where a gene is located.

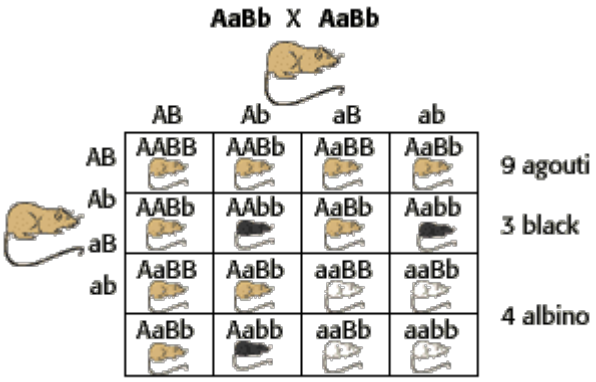
e. Each parent contributed one of the chromosomes in the **homologous pair**. At any one particular locus, the two genes on a pair of homologous chromosomes might represent two different alleles for that gene



f. If the two alleles inherited for a gene (each on one of the two homologous chromosomes) are different, one allele may be **dominant**, while the other is **recessive**. The trait encoded by the dominant allele is the actual trait expressed.
    i. TT – homozygous dominant (true breeding, tall)
    ii. Tt – heterozygous/hybrid
    iii. tt – homozygous recessive (true breeding, short)
g. The **phenotype** is the actual expression of a gene while genotype represents the actual alleles.
h. Mendel was a 19th century monk who made advances in the study of genetics.
    i. **Law of segregation**: Separation of alleles to individual gametes.
    ii. **Law of Independent Assortment**: Alleles assort independently from each other; dominant can combine with recessive.

4. <u>Complete Dominance Crosses</u>

a. Complete dominance (Mendelian genetics) occurs when traits are expressed as if one allele is dominant over a second allele.
    i. Mendel crossed varieties of pea plants to form hybrid offspring. The **P generation** represents the parents, the **F1** generation represents the offspring, and **F2** represents the offspring of the F1 offspring.
        1. A **monohybrid cross** tests one trait only.
            a. In a Punnett square for a monohybrid cross, the gametes from one parent are represented in two spaces at the top of the diagram. The gametes of the second parent are represented at the left side. In the middle are four boxes, each box combining the allele found at the top with the allele found to the left.
        2. A **dihybrid cross** tests two traits. For example, a cross investigating flower color and plant height.
            a. To determine the probability of a particular phenotype in a dihybrid cross, perform each individual monohybrid cross and use the law of multiplication.
            b. To perform a dihybrid cross, determine the possible gametes produced by each parent (by foiling) for both parents and multiply them, like so:



5. **Incomplete Dominance & Codominance**
    a. To determine the genotype for a trait in an organism (whether it is PP or Pp), a **test cross** must be performed. You mate an individual of the unknown genotype with an individual of the known genotype. (For example, P_ x pp). If an offspring shows the recessive phenotype, it must have been Pp. If no offspring show the recessive phenotype, it is likely the individual was PP.
    b. Sometimes the alleles for a gene are not completely dominant or recessive. Instead, the heterozygous condition produces a blending of the individual expressions of the two alleles called **incomplete dominance.**
        i. An example of this in humans is wavy hair, a hybrid between straight hair and curly hair.
    c. Another kind of inheritance is **codominance**, where both inherited alleles are expressed at the same time.

6. **Multiple Alleles (Focus on Blood Type)**

a. Sometimes three or more alleles can control a trait. The most important example is in human blood types.

i. There are three possible blood types (phenotypes): A, B, and O.

ii. There are three possible alleles, represented by I^A , I^B , or i. Superscripts are used because the two alleles, A and B, are codominant. A lower-case i is used for the third allele because it is recessive. This makes six possible genotypes:

1. I^AI^A and I^Ai make A blood type.
2. I^BI^B and I^Bi make B blood type.
3. I^AI^B make AB blood type.
4. ii make O blood type.

iii. The four phenotypes (A, B, AB, and O types) correspond to the presence or absence of an A or B carbohydrate component attached to proteins and lipids of the plasma membrane of red blood cells.

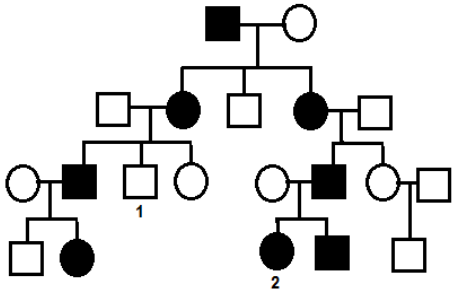
iv. If someone is given a blood transfusion containing an A or B carbohydrate that they don't have, the immune system will identify that antigens as foreign and attack it.

v. Someone with AB blood can take any blood because both A and B are identified as self. Anyone can take O type blood because it doesn't contain any A or B carbohydrates.

Other Non-Mendelian Genetics:

1. **Pleiotropy** is when one gene causes multiple different phenotypic effects on an organism.
    a. For example, the gene in pea plants that expresses the round or wrinkled texture of seeds also influences the phenotypic expressions of starch metabolism and water absorption.
2. **Epistasis** is when one gene affects the expression of another gene.
    a. A common example is when one gene turns on or off production of pigment, while a second gene controls the amount of pigment produced or color of the pigment.
3. In **polygenic inheritance**, there is interaction of many genes to shape a single phenotype.
    a. Human height is an example; there is a continuous variation from short to tall.

7. **Pedigree Analysis**
    a. A pedigree is a visual depiction of inheritance patterns in multiple generations.
    b. To analyze a pedigree, know how to read it:
        i. Males are squares
        ii. Females are circles
        iii. Mating is shown by a connecting line
        iv. Dark circles or squares indicate an affected person



        v. Tips:
            1. If two *affected* people have an *unaffected* child, the trait is *dominant* and both parents are Aa while the unaffected child is aa.
            2. If two *unaffected* people have an *affected* child, the trait is *recessive* and both parents are Aa while the unaffected child is aa.
            3. If there is no skipping of generations (every affected person has an affected parent), the trait is *dominant*. Dominant traits never skip generations while recessive traits can.
        vi. In summary, inheritance patterns can be identified by these factor:
            1. **Autosomal dominant**: No carriers, no skipping of generations, males and females equally affected.
            2. **Autosomal recessive**: carriers present, skipping of generations, males and females equally affected.
            3. **Sex-linked dominant**: All females from affected male are affected.
            4. **Sex-linked recessive**: No male carriers possible, skips generations.

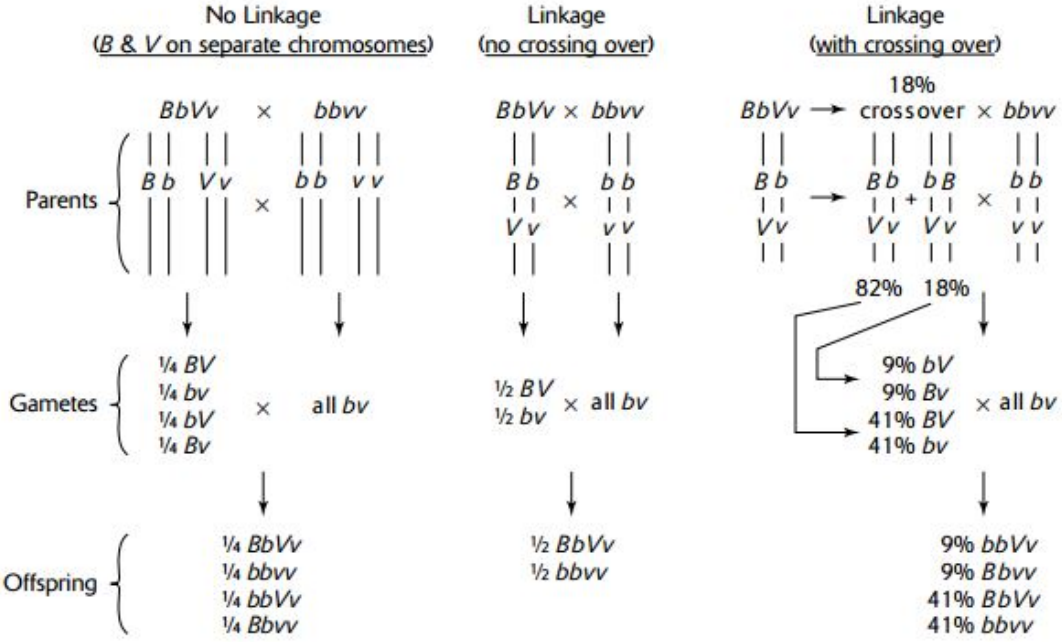
8. **Linked Genes**
    a. Linked genes are genes that reside on the same chromosome and thus cannot segregate independently because they are physically connected. Genes that are linked are inherited together.
    b. Thomas Hunt Morgan did crosses with the fruit fly Drosophila melanogaster. These flies reared in the laboratory occasionally exhibit mutations in their genes.
        i. Two such mutations, affecting body color and wing structure, are linked.
        ii. The normal, or wild, body color is gray (B), while the mutant allele is expressed as black (b). The second mutation, for wing structure, results in vestigial wings (v) which are small and nonfunctional.

iii. If the linkage between these genes were not known, the expected results from a cross between this gray-normal fly (BbVv) and a black fly with vestigial wings (bbvv) would be 1:1:1:1.

iv. However, since the two genes are on the same chromosome and cannot assort independently, the gray-normal fly produces only two kinds of gametes, BV and bv. Dominant alleles cannot pair with recessive alleles. The expected result is then 1:1.

v. But the observed ratio from experimentation is more like 41:41:9:9 because linked genes cross over during Prophase I.

vi. In summary:

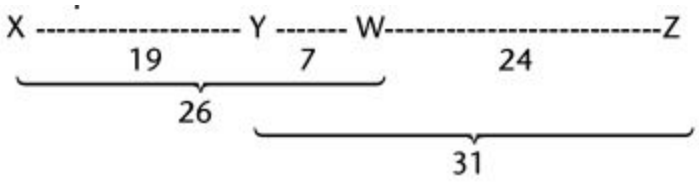


c. The greater the distance between two genes on a chromosome, the more places between the genes that the chromosome can break and thus the more likely the two genes will cross over during synapsis. Recombination frequencies (also called map units) can thus be used to create a picture of the arrangement of genes on a chromosome.

d. For example, if given the following map units for a gene:

W-Y, 7 map units
W-X, 26 map units
W-Z, 24 map units
Y-X, 19 map units
Y-Z, 31 map units

e. Then, the linkage map can be determined:



9. <u>Sex-Linked Inheritance</u>

a. Sex-linked genes are genes on the X-chromosome. All animals have one pair of sex chromosomes; all the rest are autosomes.
   i. XX = female
   ii. XY = male
      1. Y-linked genes are possible, but rarely encountered.

b. The special consideration is that a male will inherit only one copy of the gene because only the X chromosome delivers the gene. There is no similar gene delivered by the Y chromosome. Whichever allele is on the X chromosome of a male is the allele whose trait is expressed.

c. A father always transmits the sex-linked trait to his daughters (not sons) and only females can be carriers of sex-linked traits.

d. Examples of sex-linked traits are hemophilia and muscular dystrophy.

e. This is what a sex-linked cross looks like, for the case of color blindness:

Punnett Square for Color Blindness

	X^B	X^b
X^B	X^BX^B	X^BX^b
Y	X^BY	X^bY

B = Normal
b = Color Blind

f. In **X-Inactivation,** one of the two X chromosomes in a female fails to develop properly. One chromosome remains a coiled compact body called a Barr body. The genes on the other X chromosome will be expressed.

10. <u>Genetic Disorders</u>

a. If nondisjunction occurs in meiosis I, all 4 cells will have abnormal chromosomal numbers. 2 cells will be monosomic (n-1) and 2 cells will be trisomic (n+1). This is called **aneuploidy**.
   i. **Down syndrome** is an example where an egg with an extra 21 chromosome fuses with a normal gamete, producing a zygote with three copies of chromosome 21.
   ii. In **Klinefelter syndrome**, an XY or XX gamete combines with a normal X gamete to produce an XXY individual. These individuals are male, but sterile, and exhibit female characteristics. An XXX individual is a trisomic female without serious problems, but may be tall.

b. **Polyploidy** occurs if all of the chromosomes undergo meiotic nondisjunction and produce gametes with twice the number of chromosomes. Plants are often like this, containing more than 2 sets of chromosomes (like triploid).
c. Identical twins don't appear identical. This is because expression of their genes is influenced by environmental factors. Some examples of the environment on phenotypes are:
    i. Nutrition affects physical development. The availability of calcium or nitrogen can affect the height of an individual.
    ii. Temperature in reptiles influences sex determination; eggs incubated at lower temperatures become males, those at higher temperatures become females. It can also influence the color of fur.
    iii. An increase in exposure to UV radiation in humans stimulates an increase in melanin, a skin-darkening pigment.
    iv. Soil pH can determine the color of flowers in Hydrangeas. (blue in acidic soil, pink in basic soil).
    v. Changes in daylight length influence the expression of hair color from brown to white in snowshoe hares.