# COMPLETE BIOLOGY

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## I. Chemistry

Atoms, Molecules, Ions, Bonds –

- Atom is made up of neutrons, protons, and electrons. Molecules are groups of 2 or more atoms held together by chemical bonds. Chemical bonds are due to electron interactions
- Electronegativity = ability of an atom to attract electrons
- Bond Types:
  - Ionic – transfer of electrons from one atom to another (different electronegativities)
  - Covalent – electrons are shared between atoms (similar electronegativities) – can be single, double, triple
    - Nonpolar = equal sharing of electrons (identical electronegativity)
    - Polar = unequal sharing of electrons (different electronegativity and formation of a dipole)
  - Hydrogen – weak bond between molecules with a hydrogen attached to a highly electronegative atom and is attracted to a negative charge on another molecule (F, O, N)

* Properties of Water:

1. Excellent solvent: dipoles of $H_2O$ break up charged ionic molecules.
2. High Heat Capacity: heat capacity is the degree in which a substance changes temp in response to gain/loss of heat. The temp of large water body are very stable in response to temp changes of surrounding air; must add large amount of energy to warm up water. High heat of vaporization as well.
3. Ice Floats: water expands as it freezes, becomes less dense than its liquid form (H-bonds become rigid and form a crystal that keeps molecules separated).
4. Cohesion/Surface tension: attraction between *like* substances due to H-bonds; the strong cohesion between $H_2O$ molecules produces a high surface tension.
5. Adhesion: attraction of *unlike* substances. (wet finger and flip pages); capillary action: ability of liquid to flow without external forces (e.g. against gravity)

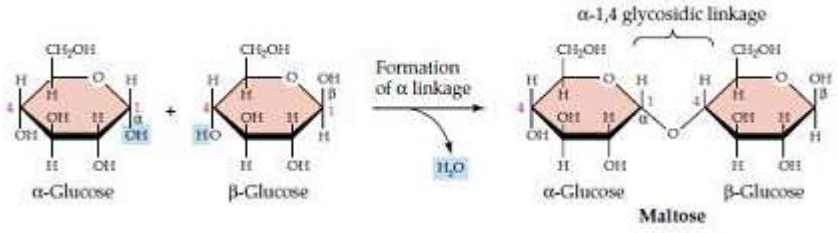
Organic Molecules –

- Have carbon atoms. Macromolecules form monomers (1 unit) which form polymers (series of repeating monomers)
  - 4 of carbon's 6 electrons are available to form bonds with other atoms
- Functional group = particular cluster of atoms, give molecules unique properties
  - Hydroxyl (OH): polar and hydrophilic
  - Carboxyl (COOH): polar, hydrophilic, weak acid
  - Amino ($NH_2$): polar, hydrophilic, weak base
  - Phosphate ($PO_3$): polar, hydrophilic, acid (sometimes shows as $PO_4$?) (y acidic?)

- Carbonyl (C=O): polar and hydrophilic
  - Aldehyde (H-C=O)
  - Ketone (R-C=O)
- Methyl (CH3): nonpolar and hydrophobic

Carbohydrates:

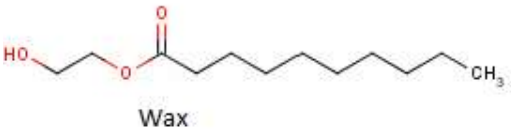
- Monosaccharide = single sugar molecule (e.g. glucose and fructose)
  - Alpha or beta based on position of H and OH on first (anomeric) carbon (down=alpha, up=beta)
- Disaccharide = two sugar molecules joined by a glycosidic linkage (joined by dehydration)
  - E.g. sucrose (glu+fru), lactose (glu+gal), maltose (glu+glu)
- Polysaccharide = series of connected monosaccharides; polymer
  - Bond via dehydration synthesis, breakdown via hydrolysis

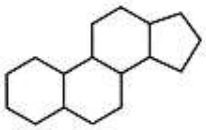


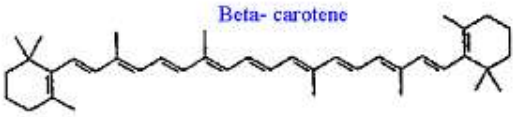

- Starch: a polymer of α-glucose molecules; store energy in plant cells.
- Glycogen: a polymer of α-glucose molecules; store energy in animal cells. (differ in polymer branching).
- Cellulose: a polymer of β-glucose; structural molecules for walls of plant cells and wood.
- Chitin: polymer similar to cellulose; but each β-glucose has a nitrogen-containing group attached to ring. Structural molecule in fungal cell walls (also exoskeleton of insects, etc)

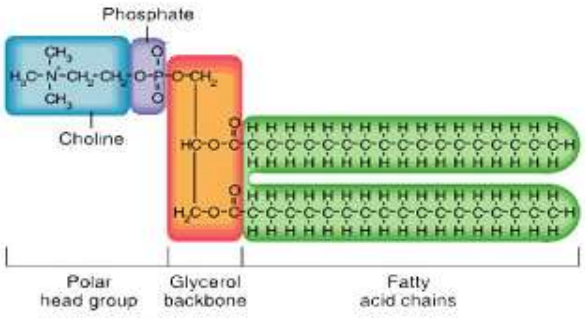
Lipids –

- Hydrophobic molecules. Fxns: Insulation, energy storage, structural (cholesterol and phoslipids in membrane), endocrine
- Triglycerides (triacylglycerols) = three fatty acid chains attached to a glycerol backbone
  - Saturated: no double bonds (bad for health, saturated = straight chain = stack densely and form fat plaques)
  - Unsaturated: double bonds (better for health, unsaturated = double bonds cause branching = stack less dense)
- Phospholipid: two fatty acids and a phosphate group **(+R)** attached to a glycerol backbone
  - Amphipathic = both hydrophilic and hydrophobic properties
- Steroids = three 6 membered rings and one 5 membered ring –hormones and cholesterol (membrane component)
- Lipid Derivatives:
  - Phospholipids (covered above)
  - Waxes – esters of fatty acids and monohydroxylic alcohols. Used as protective coating or exoskeleton (lanolin)
  - Steroids (sex hormones, cholesterol, corticosteroids) – 4 ringed structure
  - Carotenoids – fatty acid carbon chains w/ conjugated double bounds and six membered C-rings at each end. Pigments which produce colors in plants and animals.
    - Carotenes and xanthophylls (subgroups)
  - Porphyrins (tetrapyrroles) – 4 joined pyrrole rings. Often complex w/ metal (e.g. porphyrin heme complexes with Fe in hemoglobin, chlorophyll w/ Mg)

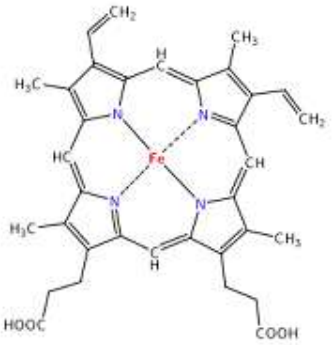



Phospholipid




Porphyrin

**Adipocytes** (img) are specialized fat cells – white fat cells contain a large lipid droplet composed primarily of triglycerides with a small layer of cytoplasm around it, while brown fat cells have considerable cytoplasm, lipid droplets scattered throughout, and lots of mitochondria

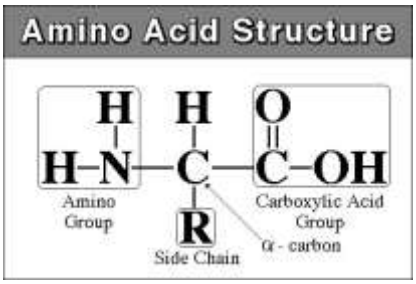
**Glycolipids** are like phospholipids but w/ carb group instead of phos. Note: lipids are insoluble so they are transported in blood via **lipoproteins** (lipid core surrounded by phospholipids and apolipoproteins).

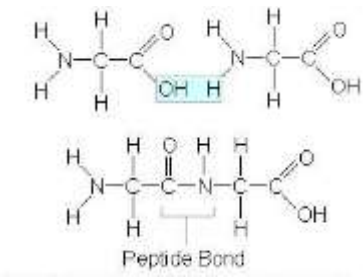
Note on lipids in membranes: Cell membranes need to maintain a certain degree of fluidity and are capable of changing membrane fatty acid composition to do so. In cold weather, to avoid rigidity, cells incorporate more mono and polyunsaturated fatty acids into the membrane (lower melting points and are kinked to increase fluidity). Warm weather climates show the opposite trend. Unsaturated fatty acids have lower melting point compared to saturated fatty acids – there are increased "kinks" in packing of the molecules as a result of the double bonds, which decrease the melting point due to less efficient packing (you can look at this two ways; freezing point: harder to pack into crystal/solid form with kinks so temp has to be lowered more, or melting point: less efficient packing means less intermolecular interactions, so less heat is needed to melt the solid →liquid form). Cholesterol also has a role (see below).

Remember: the above trends are relevant for **fatty acids** as a group, not necessarily molecules in general. Random chemistry note: double/triple bonds tend to have decreased polarity vs single bonds *in the same (already polar) bond*.

Proteins –

- Polymers of amino acids joined by peptide bonds
  - Amino acid structure: H, NH2, COOH bonded to a central carbon and then a variable R group




- Structural, storage, transport, defensive (antibodies), enzymes
  - Storage protein: casein in milk, ovalbumin in egg whites, and zein in corn seeds.
  - Transport protein: Hemoglobin carries oxygen, cytochromes carry electrons
  - **Enzymes**: ATP contains ribose instead of deoxy-ribose (ATP isn't an enzyme, why is this here?).
    - amylase catalyzes the rxn that breaks the α-glycosidic bonds in starch.
    - catalyzes a reaction in both forward and reverse directions based on [substrate].
    - efficiency is determined by temp and pH.
    - **cannot change spontaneity of a rxn**

    **Random note: enzymes are almost always considered to be proteins, but sometimes RNA can act as an enzyme (e.g. ribozymes)**

    - Cofactors are nonprotein molecules that assist enzymes. **Holoenzyme is the union of the cofactor and the enzyme (the enzyme is called apoenzyme/apoprotein when NOT combined w/ cofactor)**; can be organic (called coenzymes e.g. vitamin) or inorganic (metal ions like Fe 2+ and Mg 2+). If cofactor strongly covalent bonds to enzyme = prosthetic group
- Protein structure:
  - Classifications: simple (entirely amino acids), albumins + globulins (functional and act as carriers or enzymes), scleroproteins (fibrous, structural e.g. collagen), conjugated (simple protein + nonprotein), lipoprotein (bound to lipid), mucoprotein (bound to carb), chromoprotein (bound to pigmented molecule), metalloprotein (complexed around metal ion), nucleoprotein (contain histone or protamine, bound to nucleic acid).

- Primary structure = sequence of amino acids
- Secondary structure = 3d shape resulting from hydrogen bonding between amino and carboxyl groups of adjacent amino acids (e.g. alpha helix, beta sheet)
- Tertiary structure = 3d structure due to noncovalent interactions between amino acid R groups (subunit interaction) (factors: H-bonds, ionic bonds, hydrophobic effect [R groups push away from water center], disulfide bonds, van der waals)
- Quaternary structure = 3d shape of a protein that is a grouping of two or more separate peptide chains

Note:All proteins have a primary structure, and most have a secondary structure. Larger proteins can have a tertiary and quarternary structure. There are three main protein categories: **globular proteins** (somewhat water soluble, many fxns: enzymes, hormones, inter and intracellular storage and transport, osmotic regulation, immune response, etc., mostly dominated by 3ary structure), **fibrous/structural proteins** (not water soluble, made from long polymers, maintain + add strength to cellular and matrix structure, mostly dominated by 2ndary structure), and **membrane proteins** (membrane pumps/channels/receptors)
Note: Protein denaturation means the (secondary onward) structure of the protein is basically removed, not necessarily that the protein itself is broken down into individual amino acids. Denaturation is usually irreversible, but in some cases it can be reversed with the removal of the denaturing agent (implies all info needed for protein to assume its native state is encoded in the primary structure)

Nucleic Acids –

- DNA is a polymer of nucleotides
  - Nucleotide: nitrogen base, five carbon sugar deoxyribose, phosphate group
    - Purines (2 rings) – adenine, guanine (double ring)—2 H bonds (AT2, GC3)
    - Pyrimidines (1 ring): thymine, cytosine (singe ring) – 3 H bonds (to remember: CUT the PYE)
    - A nucleoside is just the sugar+base
  - Two antiparallel strands of a double helix
- RNA is a polymer of nucleotides that contain ribose, not deoxyribose
  - Thymine is replaced by uracil (which pairs with adenine)
  - Usually single stranded

**Cell doctrine/theory:** 1. All living organisms are composed of one or more cells. 2. The cell is the basic unit of structure, function, and organization in all organisms. 3. All cells come from preexisting, living cells. 4. Cells carry hereditary information

**RNA world hypothesis** proposes that self-replicating ribonucleic acid (RNA) molecules were precursors to current life (based on deoxyribonucleic acid (DNA), RNA and proteins). RNA stores genetic information like DNA + catalyzes chemical reactions like an enzyme protein →may have played a major step in the evolution of cellular life. **RNA is unstable compared to DNA, so more likely to participate in chemical rxns (due to its extra hydroxyl group).**

**Central dogma of genetics**: biological information cannot be transferred back from protein to either protein or nucleic acid; DNA → RNA → proteins

Know basic microscopy:

-Stereomicroscope (light): Visible light for surface of sample. Can look at living samples, but low resolution vs compound light micro.

-Compound microscope (light): Visible light for thin section of sample. Can look at *some* living samples (single cell layer). May require staining for good visibility.

-Phase-contrast: Uses light phases and contrast. Allows for detailed observation of living organisms (including internal structures) if thin. Good resolution/contrast, but not good for thick samples and produces "Halo effect" around perimeter of samples.

-Confocal laser scanning + fluorescence: Can look at thin slices while keeping sample intact; can look at specific parts of cell via fluorescent tagging. Can look at living cells, but only fluorescently tagged parts. Fluorescence can cause artifacts. Used to observe chromosomes during mitosis. Note: confocal laser scanning microscope can be w/out fluorescence as well. Uses laser light to scan dyed specimen, then displays the image digitally.

-Scanning elctron microscope (SEM): Look at surface of (3D) objects with high resolution. Can't use on living: preparation is extensive (sample needs to be dried and coated). Costly.

-CryoSEM: Like SEM but no dehydration so you can look at samples in more "natural" form. Can't use on living: samples frozen for prep, which can cause artifacts.

-Transmission electron microscope (TEM): look at very thin cross-sections in high detail. Can look at internal structures, very high resolution, but can't be used on living things (preparation is extensive). Costly.

-Electron tomography: 3D model buildup using TEM data. Can look at objects in 3D and see objects relative to one another. Can't be used on living things (see TEM above).

Centrifugation (spins + seperates liquified cell homogenates separate into layers based on density: **(most dense/fastest to pellet out/the bottom is nuclei layer, spin faster→ then mitochondria/chloroplasts/lysosome/peroxisomes, spin faster → then microsomes [internal membranes from ER]/small vesicles, spin faster → then ribosomes/viruses/larger macromolecules). Centrifugation can be differential centrifugation or density centrifugation, the former is density + shape factor based on speed the**

**macromolecule travels at whereas density is just density based. The above described spin pattern is differential centrifugation, we spin and take the dense pellet and then spin again repeat. Density centrifugation is continuous layers of sediment.**

Chemical Reactions in Metabolic Processes –

- Catalysts lower activation energy, accelerating the rate of the rxn
- Metabolism = catabolism + anabolism + energy transfer
- Characteristics of chemical reactions
  - Concentration of reactants and products determines which way a rxn will go
    - Equilibrium: rate of forward and reverse rxns is the same = 0 net production
  - Enzymes are globular proteins that act as catalysts
    - Substrate specific, unchanged during rxn, catalyzes in both forward and reverse directions, temperature and pH affect enzyme function, active site and induced fit is how enzymes bind
  - Cofactors are nonprotein molecules that assist enzymes usually by donating or accepting some component of a rxn like electrons
    - Coenzyme are organic cofactors , usually donate or accept electrons
      - Vitamins
    - Inorganic cofactors are usually metal ions (Fe 2+ and Mg 2+)
    - If binds tightly/covalently, prosthetic group
  - ATP – common source of activation energy. New ATP formed via phosphorylation (ADP + phosphate using energy from energy rich molecule like glucose). Note that ATP contains, but is not itself, potential energy.
- Regulation (more here):
  - Allosteric enzymes – have both an active site for substrate binding and an allosteric site for binding of an allosteric effector (activator, inhibitor)
  - Competitive inhibition – substance that mimics the substrate inhibits the enzyme by binding at the active site. Can be overcome by increasing substrate cxn. Km changed (raised) but Vmax is not
  - Noncompetetive inhibition – substance inhibits enzyme by binding elsewhere than active site, substrate still binds but reaction is prevented from completing. Km unchanged but Vmax is not.
  - Uncompetitive/anti-competitive inhibition: enzyme inhibitor binds only to the formed E-S complex, preventing formation of product (Vmax lowered). Km is also lowered (Le Chetalier's principle: the equilibrium between E-S complexes and ESI (inhibitor attached) complexes is disrupted by this type of inhibition, as it favors the ESI: so ES complexes are depleted. E+S → ES complex is subsequently shifted forward, so the enzyme's apparent affinity for the substrate is raised = lower Km).
  - Cooperativity – enzyme becomes more receptive to additional substrate molecules after one substrate molecule attaches to an active site (e.g enzymes w/ multiple subunits that each have active site [quaternary structure])
    - Example of process: hemoglobin binding additional oxygen (although hemoglobin ≠ enzyme!)
  - Km is the Michaelis constant. It represents the substrate cxn at which the rate is half of Vmax. In a way it indirectly represents binding affinity, inversely: small Km indicates that the enzyme requires only a small amount of substrate to become saturated. Hence, the maximum velocity is reached at relatively low substrate concentrations. A large Km indicates the need for high substrate concentrations to achieve maximum reaction velocity. So raised Km = substrate is binding worse, lowered Km = substrate is binding better.

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## II. Cells

- Membrane proteins: peripheral (loosely attached to one side surface), integral (embeds inside membrane), transmembrane (all the way through, both sides – this is a TYPE of integral)
- Phospholipid membrane permeability – small, uncharged, nonpolar molecules (polar can only if small and uncharged) and hydrophobic molecules can freely pass across the membrane. Everything else requires transporter (large, polar, charged molecules). Another way of saying impermeable is "resistant to".
- Note: peripheral membrane proteins are generally hydrophilic; held in place by H-bonding and electrostatic interaction. Disrupt/detach by changing salt cxn or pH to disrupt these interactions. Integral proteins are hydrophobic; use detergent to destroy membrane and expose these proteins.

* Proteins:
- Channel proteins: provide passageway through membrane for hydrophilic (water-soluble) substances (polar, and charged).
**- Recognition proteins: such as major-histocompatibility complex on macrophage to distinguish between self and foreign; they are *glycoproteins* due to oligosaccharides attached.
- Ion channels: passage of ions across membrane. Called gated channels in nerve and muscle cells, respond to stimuli. Note that these can be voltage-gated (respond to difference in membrane potential), ligand-gated (chemical binds and opens channel), or mechanically-gated (respond to pressure, vibration, temperature, etc).
**- Porins: allow passage of certain ions + small polar molecules. Aquaporins increase rate of H2O passing (kidney and plant root cells). These tend not to be specific, they're just large passages, if you can fit you'd go through.
- Carrier proteins: bind to specific molecules, protein changes shape, molecule passed across. E.g. glucose into cell.(this is a type of transport protein). Carrier seems to be specific to movement across membrane via integral membrane protein.
- Transport proteins: can use ATP to transport materials across (not all transport use ATP). Active transport. E.g. Na+-K+ pump to maintain gradients. Facilitated diffusion as well. Transport protein is a broad category that encompasses many of the above. *Chad's quiz says transport use ATP but other sources contradict: transport can by facilitated diffusion.*
**- Adhesion proteins: attach cells to neighboring cells, provide anchors for internal filaments and tubules (stability)
- Receptor proteins: binding site for hormones + other trigger molecules

- Cholesterol: adds rigidity to membrane of animal cells under normal conditions (but at low temperatures it maintains its fluidity); **sterols** provide similar function in plant cells. Prokaryotes **do not have** cholesterol in their membranes (use hopanoids instead)
**- Glycocalyx: a carbohydrate coat that covers outer face of cell wall of some bacteria and outer face of plasma membrane (some animal cells). It consists of glycolipids (attached to plasma membrane) and glycoproteins (such as recognition proteins). It may provide adhesive capabilities, a barrier to infection, or markers for cell-cell recognition.

* **Organelles**
- Nucleus: **chromatin** is the general packaging structure of DNA around proteins in eukaryotes, the tightness of the packaging varies depending on cell stage; **chromosomes** is tightly condensed chromatin when the cell is ready to divide; **histones** serve to organize DNA which coil around it into bundle **nucleosomes** (8 histones); **nucleolus** inside the nucleus are the maker of ribosomes (rRNA). rRNA is synth'd in nucleolus + ribosomal proteins imported from cytoplasm = ribosomal subunits form; these subunits are exported to the cytoplasm for final assembly into complete ribosome. Nucleus bound by double layer nuclear envelope w/ nuclear pores for transport (mRNA, ribosome subunits, dNTPs, proteins like RNA polymerase + histones, etc) in/out. Note there is no "cytoplasm" in nucleus, there's a nucleoplasm instead.
**- Nuclear Lamina: dense fibrillar network inside nucleus of eukaryotic cells (Intermediate filaments + membrane assoc. proteins). Provides mechanical support; also helps regulate DNA replication, cell division, chromatin organization.
- Nucleoid: irregular shaped region within the cell of prokaryote that contains all/most generic material
- Cytoplasm: **this is an area, not a structure!** metabolic activity and transport occur here. Cyclosis is streaming movement within cell. Doesn't include nucleus, but does included cytosol, organelles, everything suspended w/in cytosol but nucleus
- Cytosol: difference vs cytoplasm here (cytosol doesn't include the stuff suspended within the gel-like substance, it is JUST the gel-like stuff. Think jello vs veggie stew.) **(the cytosol is also known as cytoplasmic matrix)**
- Ribosomes: 60S + 40S = 80S, prokaryote (50S + 30S = 70S); the two subunits produced inside the nucloleus moved into the cytoplasm where they assembled into a single 80S ribosomes (larger S value indicates heavier molecule). Made of rRNA+protein, function to make proteins.
**- ER: rough ER (with ribosomes) creates glycoproteins by attaching polysaccharides to polypeptides as they are assembled by ribosomes. In eukaryotes the rough ER is continuous with the outer nuclear membrane. Smooth ER (no ribosomes) synthesizes lipids and steroid hormones for export. In liver cells, smooth ER has functions in breakdown toxins, drugs, and toxic by-products from cellular rxn. Smooth and striated muscle have smooth ER's called **sarcoplasmic reticulums** that store and release ions, e.g. Ca 2+
**- Lysosomes: vesicles produced from Golgi that contain digestive enzymes (low pH for function); break down nutrients/bacteria/cell debris. Any enzyme that escape from lysosomes remains inactive in the neutral pH of cytosol (other source says autolysis) (lysosomes in plant cell – maybe, but generally taught as none). Functions in apoptosis (releases contents into cell).

- Golgi: transport of various substances in vesicles (cis face is for incoming vesicles, trans face for secretory vesicles). Has flattened sacs known as cisternae.
**- Peroxisomes: break down substances ($H_2O_2$ +$RH_2$ => R + $2H_2O$), fatty acid, and amino acid; common in liver and kidney where they break toxic substances. In plant cell, peroxisomes modify by-products of photorespiration. In germinating seeds, it is called **glyoxysomes** break down stored fatty acids to help generate energy for growth. Peroxisome produce $H_2O_2$ which they then use to oxidize substrates, they can also break down $H_2O_2$ if necessary ($H_2O_2$ => $H_2O$ + $O_2$)
**- Microtubules: made up of protein tubulin, provide support and motility for cellular activities; spindle apparatus which guide chromosomes during division; in flagella and cilia (9+2 array; 9 pairs + 2 singlets in center) in all animal cells and lower plants (mosses, ferns).
**- Intermediate filaments: provide support for maintaining cell shape. E.g. keratin.
- Microfilament: made up of actin and involved in cell motility. (skeletal muscle, amoeba pseudopod, cleavage furrow)
**- Microtubules organizing centers (MTOCs): include **centrioles** and **basal bodies** (are at the base of each flagellum and cilium and organize their development). 9x3 array. **Plant cells lack centrioles and its division is by cell plate instead of cleavage furrow – note that plants DO have MTOC's.**
- Transport vacuoles: move materials between organelles or organelles and the plasma membrane
- Food vacuoles: temporary receptacles of nutrients; merge with lysosomes which break down food.
- Central vacuoles: large, occupy most of plant cell interior, exert turgor when fully filled to maintain rigidity. Also store nutrients, carry out functions performed by lysosomes in animal cells. Have a specialized membrane (**tonoplast**)
**- Storage vacuoles: plants store starch, pigments, and toxic substances (nicotine).
**- Contractile vacuoles: in single-celled organisms that collect and pump excess water out of the cells (prevent bursting). Active transport. Found in Protista like amoeba and paramecia, organisms live in hypotonic environment.
- Cell walls: found in plants, fungi, protists, and bacteria (cellulose in plants; chitin in fungi; peptidoglycans in bacteria, polysaccharides in archea). Provides support. Sometimes a secondary cell wall develops beneath the primary one.
**- Extracellular matrix: found in animals, in area between adjacent cells (beyond plasma membrane and glycocalyx); occupied by fibrous structural proteins, adhesion proteins, and polysaccharides secreted by cells; provide mechanical support and helps bind adjacent cells (collagen is *most common* here, we also see integrin+fibronectin; network of collagen and proteoglycans connected to integrins in the cell membrane via fibronectin). Laminin can be seen as well (acts similar to fibronectin). Images here. Note that cells adhere to the ECM in two ways: focal adhesions (connection of ECM to actin filaments in the cell) and hemidesmosomes (connection of ECM to intermediate filaments **e.g. keratin**).
- Plastids: found in plant cells. Chloroplasts (site of photosynthesis), leucoplasts (can specialize to store starch/lipid/protein as amyloplasts/elaioplasts/proteinoplasts respectively, or serve general biosynthetic fxns), chromoplasts (store carotenoids)
Mitochondria: make ATP, also fatty acid catabolism (B-oxidation)! (fatty acids are made in cytosol). Also have their own circular DNA and ribosomes (gives rise to endosymbiotic theory!). Have a double layered membrane.
**Cytoskeleton: microtubules (ex. flagella & cilia), microfilaments, intermediate filaments. In eukaryotic cells, aids in cell division, cell crawling, and the movement of cytoplasm and organelles.
Note on plant cells: in a hypotonic solution (their normal state), vacuole swells → turgid. In isotonic, the plant cell is flaccid. In hypertonic, the cell is plasmolyzed – cytoplasm is pulled away from the cell wall. Fungal cells also remain turgid due to cell wall, but animal cells will burst (cytolysis).
The **endomembrane system** is the network of organelles and structures, either directly or indirectly connected, that function in the transport of proteins and other macromolecules into or out of the cell.Includes plasma membrane, endoplasmic reticulum, golgi apparatus, nuclear envelope, lysosomes, vacuoles, vesicles, endosomes but **not** the mitochondria or chloroplasts.

* **Circulation:**

- Intracellular Circulation
  - Brownian movement (particles move due to kinetic energy, spreads small suspended particles throughout cytoplasm)
  - Cyclosis/streaming: circular motion of cytoplasm around cell transport molecules
  - Endoplasmic Reticulum: Provides channel through cytoplasm, provides direct continuous passageway from plasma membrane to nuclear membrane
- Extracellular Circulation
  - Diffusion: If cells in close contact with external environment, can suffice for food and respiration needs. Also used for transport of materials between cells and interstitial fluid around cells in more complex animals
  - Circulatory system: complex animals w/ cell too far from external environment require one. Use vessels.

* **Junctions**:
**- Anchoring junctions: **desmosome** (keratin filaments inside attach to adhesion plaques which bind adjacent cells together via connecting adhesion proteins, providing mechanical stability, hold cellular structures together). In animal cells. Present in tissues with mechanical stress – skin epithelium, cervix/uterus. img
- Tight junctions: completely encircles each cell, producing a seal that prevents the passage of materials between cells; characteristic of cells lining the digestive tract where materials are required to pass through cells into blood (They prevent the passage of molecules and ions through the space between cells. So materials must actually enter the cells (by diffusion or active transport) in order to pass through the tissue). In animal cells. img
- Gap junction: narrow tunnels between animal cells (connexins); prevent cytoplasms of each cell from mixing, but allow passage of ions and small molecules; essentially channel proteins of two adjacent cells that are closely aligned (smooth muscle single of spreading action potential). In animal cells. Tissue like heart have these to pass electrical impulses. img
- Plasmodesmata: narrow tunnels between plant cells (narrow tube of endoplasmic reticulum-**desmotubule**; but exchange material through cytoplasms surrounding the desmotubule). img

* **Prokaryotes and Eukaryotes**:
**Eukaryotes include all organisms except for bacteria, cyanobacteria, and archaebacteria. Prokaryotes have a plasma membrane, DNA molecule, ribosomes, cytoplasm, and cell wall. In prokaryotes:

1. No nucleus.
2. Single (circular) naked ds DNA **(no chromatin)**.
3. Prokaryote (50S + 30S = 70S);
4. Cell walls (peptidoglycan); archea (polysaccharides) – many have sticky capsules on wall
5. *Flagella are constructed from flagellin not **microtubules*** in prokaryotes.

- Substance Movement:
  - Hypertonic (higher solute concentration), hypotonic (lower solute concentration), isotonic (equal solute concentration)
  - Bulk Flow = collective movement of substances in the same direction in response to a force or pressure (e.g. blood)
  - Passive Transport –
    - Simple diffusion, osmosis, dialysis (diffusion of different solutes across a selectively permeable membrane), plasmolysis (movement of water out of a cell that results in its collapse), facilitated diffusion, countercurrent exchange (diffusion by bulk flow in opposite directions – blood and water in fish gills). Note: diffusion is **net**, some few particles still move against the gradient because molecule movement is random, but net diffusion is generally what we talk about.
  - Active Transport – movement of transports against their concentration gradients requiring energy. Usually solutes like small ions, amino acids, monosaccharides

* **Endocytosis**: uses ATP (active process) (exocytosis is also active process) (Cliff's FC says bulk flow is active too…?)
- Phagocytosis: *undissolved* material (solid) enters cell; white blood cell engulfs. Plasma membrane wraps outward around.
- Pinocytosis: *dissolved* material (liquid). Plasma membrane invaginates.
- Receptor-mediated: a form of pinocytosis; specific molecules (ligand) bind to receptors; proteins that transport cholesterol in blood (LDL) and hormones target specific cells by this.

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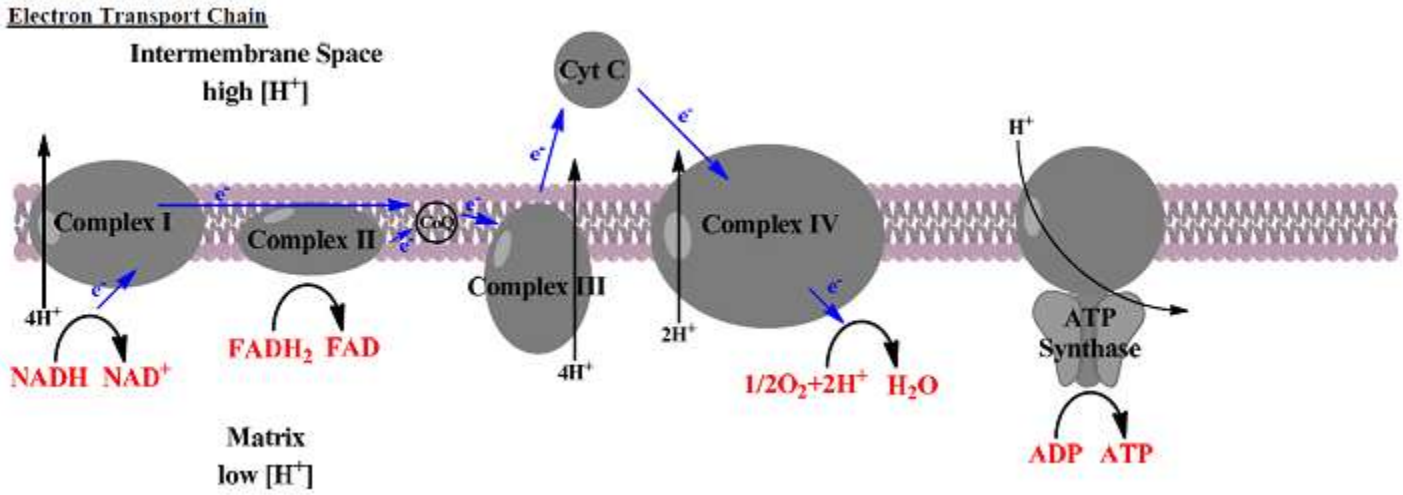
**Interlude: Biothermodynamics**

Recall Gibbs Free Energy, which tells us whether a given chemical rxn can occur spontaneously: $G = H - TS$ *(H is enthalpy, T is temperature, S is entropy).* If $\Delta G$ is negative, the reaction can occur spontaneously. Likewise, if $\Delta G$ is positive, the reaction is nonspontaneous. How does this apply to biology? Chemical reactions can be "coupled" together if they share intermediates. In this case, the overall Gibbs Free Energy change is the sum of the $\Delta G$ values for each reaction. Therefore, an unfavorable reaction (positive $\Delta G1$) can be driven by a second, highly favorable reaction (negative $\Delta G2$ where the magnitude of $\Delta G2$ > magnitude of $\Delta G1$). Example: the reaction of glucose with fructose to form sucrose has a $\Delta G$ value of +5.5 kcal/mole (will not occur spontaneously). The breakdown of ATP to form ADP and inorganic phosphate has a $\Delta G$ value of -7.3 kcal/mole. These two reactions can be coupled together, so that glucose binds with ATP to form glucose-1-phosphate and ADP. The glucose-1-phosphate is then able to bond with fructose yielding sucrose and inorganic phosphate. The $\Delta G$ value of the coupled reaction is -1.8 kcal/mole, indicating that the reaction will occur spontaneously. This principle of coupling reactions to alter the change in Gibbs Free Energy is the basic principle behind all enzymatic action in biological organisms.

**III. Cellular Respiration**: review page 46 in Cliffs.

CELLULAR RESPIRATION – overall an oxidative, exergonic process ($\Delta G$ = -686 kcal/mole)

- External respiration is entry of air into lungs and gas exchange between alveoli and blood; internal respiration is exchange of gas between blood and the cells + intracellular respiration processes
- During respiration, high energy H atoms removed from organic molecules (dehydrogenation)
- $C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O$ + energy
- Aerobic respiration = in the presence of $O_2$ (glycolysis, pyruvate decarb, krebs cycle, oxidative phosphorylation); water is the final product
- **Glycolysis** – decomposition of glucose into pyruvate in cytosol
    - 2ATP added, 2NADH produced, 4 ATP produced, 2 pyruvate formed
        - NET: 2 ATP + 2 NADH + 2 pyruvate (+2 $H_2O$ + 2 H+)
    - ATP produced here via substrate level phosphorylation
        - Direct enzymatic transfer of a phosphate to ADP, no extraneous carriers needed
    - Hexokinase phos's glucose, important because then it can't diffuse out + tricks the gradient
    - PFK (enzyme) adds 2nd phosphate, makes fructose 1,6-biphosphate – this is irreversible and commits to glycolysis, major regulatory point!
- **Pyruvate Decarboxylation**
    - At this point we are in the mitochondrial matrix
    - Pyruvate to Acetyl CoA, producing 1 NADH and 1 $CO_2$
        - NET: 2 NADH + 2 $CO_2$
    - Catalyzed by PDC enzyme (pyruvate dehydrogenase complex)
- **Krebs Cycle/Citric Acid Cycle/Tricarboxylic Acid Cycle** - fate of pyruvate that is produced in glycolysis
    - **In the Krebs cycle, Acetyl CoA merges with oxaloacetate to form citrate, cycle goes w/ 7 intermediates
    - 3 NADH, 1 FADH2, 1 ATP (via sub phos), and 2 $CO_2$ are produced per turn
    - x2 for glucose because 2 pyruvate are made from 1 glucose in glycolysis so two rounds of TCA cycle occur
        - Total 6 NADH, 2 $FADH_2$, 2 ATP (technically GTP), 4 $CO_2$
            - These ATP produced via substrate level phos
    - takes place in mitochondria matrix (likewise with pyruvate decarbox)
    - $CO_2$ produced here is the $CO_2$ animals exhale when they breathe
- **ETC (electron transport chain)**
    - Takes place at the inner membrane/cristae (folds which increase SA for more ETC action)




- Oxidative Phosphorylation – process of ADP → ATP from NADH and $FADH_2$ via passing of electrons through various carrier proteins; energy doesn't accompany the phosphate group but comes from the electrons in the ETC establishing an H+ gradient that supplies energy to ATP synthase
    - NADH makes more energy than $FADH_2$, more H+ is pumped across per NADH (both are coenzymes) (3:2 yield)
    - Final electron acceptor is oxygen – combines with native H+ to form water (H2O)
    - Random note: oxidizing agent causes something *else* to get oxidized; the oxidizing agent itself is reduced; vice versa for reducing agents

- Carriers extract energy from NADH and FADH2 while pumping protons into the intermembrane space – atp synthase uses this gradient (which is a pH and electrical gradient) to make atp as it shuttles H+ back into the inner matrix
- Coenzyme Q (CoQ)/Ubiquinone is a soluble carrier dissolved in the membrane that can be fully reduced/oxidized, it passes electrons as seen in diagram
- Cytochrome C is a protein carrier in the ETF, common in many living organisms, used for genetic relation
  - Cytochromes have nonprotein parts like iron (donate/accept electrons, for redox!)
- Couples exergonic flow of electrons with endergonic pumping of protons across cristae membrane

- TOTAL energy from 1 glucose is ~36 ATP, but in prokaryotes 38 ATP (not *actual* yield, mitochondrial efficacy varies)
  - **Difference because prokaryotes have no mitochondria so they (unlike eukaryotes) don't need to transfer pyruvate into the mitochondrial matrix (which is done via active transport thus costing ATP), they use cell membrane for respiration.**
- Mitochondria – outer membrane, intermembrane space (H+), inner membrane (ox phosp.), mitochondrial matrix (krebs)
- **Chemiosmosis** in mitochondria:
  - Mechanism of atp generation that occurs when energy is stored in the form of a proton concentration gradient across a membrane
  - Krebs produces $NADH/FADH_2$, they are oxidized (lose electrons), H+ transported from matrix to intermembrane space, pH and electric charge gradient is created, ATP synthase uses the energy in this gradient to create ATP by letting the protons flow through the channel
  - Common question topic is about pH changes from these processes; remember that H+ cxn up means pH down!

ATP (adenosine triphosphate) – an **RNA** nucleotide (due to its ribose sugar)

- Unstable molecule because the 3 phosphates in ATP are negatively charged and repel one another
  - When one phosphate group removed via hydrolysis, more stable molecule ADP results
  - **The change from less stable molecule to more stable always releases energy**
- Provides energy for all cells by transferring phosphate from ATP to another molecule

Anaerobic Respiration (cytosol) –

- Includes glycolysis + fermentation
- Aerobic respiration regenerates NAD+ via $O_2$, which is required for continuation of glycolysis, without $O_2$, there would be no replenishing – NADH accumulates, cell would die w/ no new ATP, so fermentation occurs…
- **Alcohol Fermentation
  - Occurs in plants, fungi (e.g. yeasts), and bacteria (e.g. botulinum)
  - Pyruvate → acetaldehyde + $CO_2$, then acetaldehyde →ethanol (and NADH → **NAD+**).
  - Acetaldehyde is the final electron acceptor! The final molecule isn't the final acceptor; acetaldehyde is the final acceptor of the electrons thus forming ethanol! Same with O2 being the final electron acceptor of cellular respiration; thus forming H2O!
- **Lactic Acid Fermentation
  - Occurs in human muscle cells, other microorganisms
  - Pyruvate → lactate (and NADH → **NAD+**)
  - Lactate is transported to liver for conversion back to glucose once surplus ATP available
- Facultative anaerobes can use oxygen when it's present (more efficient) but switch to fermentation/anaerobic respiration if it isn't; obligate anaerobes cannot live in presence of oxygen

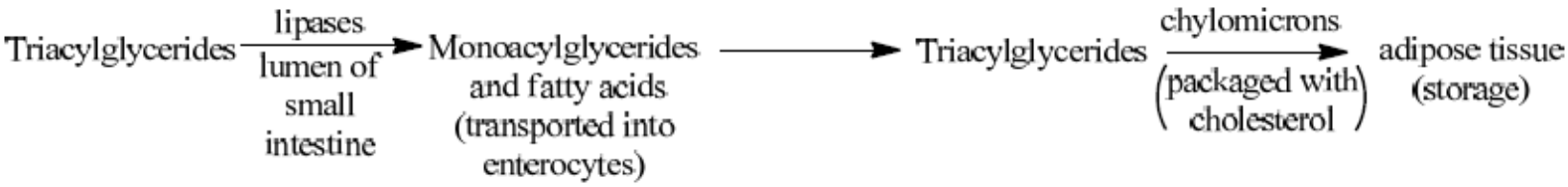
## Alternate energy sources:

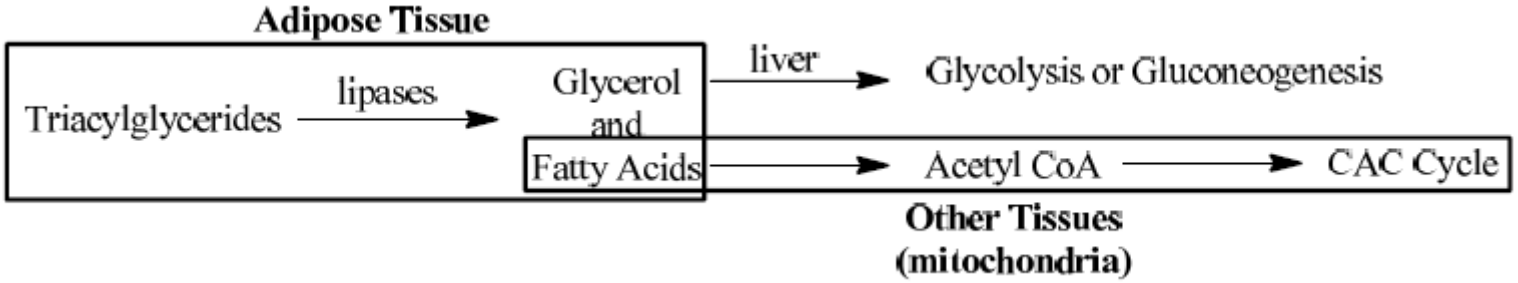
When glucose supply is low, body uses other energy sources, in the priority order of: other carbs, fats, and proteins. First converted to glucose or glucose intermediates, then degraded in glycolysis or CAC.

- Other carbohydrates
  - Unrelated: remember we don't just break down glucose, we can produce it (gluconeogenesis)
    - Occurs in liver and kidney (liver is responsible for maintaining glucose cxn in blood)
  - Also: glycogen is a glucose polymer, stored 2/3 in liver and 1/3 in muscles, storage of glucose
  - **Insulin after large meals stores glucose as glycogen, glucagon is the opposite effect and turns on glycogen degradation. **Insulin activates PFK enzyme, glucagon inhibits it (think about this: insulin means 'hey, we've got a lot of glucose around, so let's chew it up' whereas glucagon says 'uhoh, not enough glucose around, don't chew it up – we need it for the brain, other tissues can use other energy sources').**

- Disaccharides are hydrolyzed into monosaccharides, most of which can be converted to glucose or glycolytic intermediates
- **All cells capable of producing and storing glycogen but only muscle cells and especially liver cells have large amts

- Fats
  - Store more energy than carbohydrates per C, their carbons are in a more reduced state
    - Hence why fats are 10 cals/g, whereas carbs and protein are 4




**^What's going on above: triglycerides, in the lumen of the small intestine (the tube itself) are broken down via lipases into monoacylglycerides + fatty acids, which are then absorbed into the enterocytes (cell lining of the small intestine). There, they are reassembled into triglycerides, and then (along w/ cholesterol/proteins/phospholipids) packaged into chylomicrons which move on to the lymph capillary for transport to the rest of the body where they are stored as adipose tissue.

- Lipases in adipose tissue are hormone sensitive (e.g. to glucagon)
- Glycerol → PGAL, enters glycolysis
- When fatty acid → Acetyl CoA, every 2 carbon from fatty acid chain makes an Acetyl CoA
  - **Fatty acids in blood combine with **albumin** which carries them
- **Fatty acids are broken down for energy via beta oxidation (takes place in mitochondrial matrix)
  - 2 ATP spent activating the (entire) chain
  - Saturated fatty acids produce 1 NADH and 1 $FADH_2$ for **every cut** into 2 carbons
    - NOT the same as for every 2 carbons – e.g. 18C chain is 9 2C pieces but only cut 8 times, each cut is the beta oxidation step
  - Unsaturated fatty acids produce 1 less FADH2 for each double bond (can't use double bond forming step)
  - Results in BIG yield of ATP, yields more ATP per carbon than carbohydrates, more energy in fats than sugars

- Protein
  - Least desirable source of energy, only when carbs and fat unavailable
  - **Most amino acids are deaminated in liver, then converted to pyruvate or acetyl CoA or other CAC intermediates, enter cellular respiration at these various points (varies by AA)
    - Oxidative deamination removes ammonia molecule directly from AA. Ammonia is toxic to vertebrates: fish excrete, insects and birds convert to uric acid, mammals convert to urea for excretion.

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**IV. <u>Photosynthesis</u>**: overall $6CO_2 + 6H_2O \rightarrow C_6H_{12}O_6 + 6O_2$ (some say $6CO_2 + 12H_2O \rightarrow C_6H_{12}O_6 + 6O_2 + 6H_2O$)
- Photosynthesis begins with light-absorbing pigments in plant cells; able to absorb energy from light; chlorophyll a, b, and carotenoids (red, orange, yellow). Light is incorporated into electrons => excited electrons are unstable and re-emit absorbed energy; energy is then reabsorbed by electrons of nearby pigment molecule. The process ends when energy is

absorbed by one of two special chlorophyll a molecules ($P_{680}$ & $P_{700}$). $P_{700}$ forms pigment cluster (PSI) and $P_{680}$ forms pigment cluster (PSII). Antenna pigments (chlorophyll b, carotenoids, phycobilins [red algae pigment], xanthophylls) capture wavelegnths that chlorophyll a does not, passes energy to chlorophyll a where direct light rxn occurs. Chlorophyll a has porphyrin ring (alternating double and single bonds, double bonds critical for light rxns) complexed w/ Mg atom inside.

A. **Noncyclic Photophosphorylation** (ADP + $P_i$ + light -> ATP): **light-dependent reaction**.

1. Photosystem II: electrons trapped by $P_{680}$ in PSII are energized by light.
2. Primary $e^-$ acceptor: two excited $e^-$ passed to primary $e^-$ acceptor; primary because it is the first in chain of acceptor.
3. $E^-$ transport chain: consists of a plastoquinone complex (PSII) which contains proteins like **cytochrome** and cofactor $Fe^{2+}$; analogous to oxidative phosphorylation.
4. Phosphorylation: $2e^-$ move down chain => lose energy (energy used to phosphorylate about 1.5ATP).
5. Photosystem I: $e^-$ transport chain terminates with PSI ($P_{700}$); they are again energized by sunlight and passed on to another primary $e^-$ acceptor. From this point forward it can go to cyclic or noncyclic path. If noncyclic…
6. NADPH: 2e- then pass down a short electron transport chain (with proteins like **ferrodoxin**) to combine $NADP^+ + H^+ + 2e^-$ => NADPH (coenzyme) (only in noncyclic?).
7. Splitting of Water (photolysis): the loss of $2e^-$ from PSII (initially) is replaced when $H_2O$ splits into $2e^-$, $2H^+$, and $\frac{1}{2}O_2$.($H^+$ goes for NADPH formation and $\frac{1}{2}$ $O_2$ that contributes to release as oxygen gas). This occurs at PSII.

$$\{ H_2O + ADP + P_i + NADP^+ + light => ATP + NADPH + O_2 + H^+ \}$$

Note on photosystems: few hundred in each thylakoid, have a rxn center containing chlorophyll a surrounded by antenna pigments that funnel energy to it. Also note Cliff page 58 diagrams this well.

**B. Cyclic Photophosphorylation**: this replenishes ATP when Calvin cycle consumes it
- When excited $2e^-$ from PSI join with protein carriers in the first electron transport chain and generate 1ATP as they pass through; these $2e^-$ are recycled into PSI and can take either cyclic or noncyclic path.

**C. Calvin Cycle**: fixes $CO_2$, repeat 6 times, uses $6CO_2$ to produce $C_6H_{12}O_6$ (glucose). **$C_3$ photosynthesis (dark reaction)**

1. Carboxylation: $6CO_2$ + 6RuBP => 12PGA, **RuBisCo** (most common protein in the world, aka RuBP carboxylase) catalyzes this reaction. (so named because PGA is 3C).
2. Reduction: 12ATP + 12NADPH converts 12PGA => 12G3P or 12PGAL; energy is incorporated; by-products ($NADP^+$ and ADP) go into noncyclic photophosphorylation.
3. Regeneration: 6ATP convert 10G3P => 6RuBP (allows cycle to repeat).
4. Carbohydrate synthesis: 2 remaining **G3P** are used to build glucose.

$$6\mathbf{CO_2} + 18ATP + 12NADPH + H^+ => 18ADP + 18P_i + 12NADP^+ + \mathbf{1glucose\ (2G3P)}$$

5. This is the "dark reaction", but it cannot occur w/out light because it is dependent on the high energy molecules produced from the light rxn (ATP and NADPH)

**Note: Bootcamp says that the energy used to drive the light-independent rxns comes from light (photons). Light energy is what drives photosynthesis! And the energy in glucose traces back to light that gets stored in the form of glucose chemical bonds! Remember, plants do have mitochondria that make ATP, BUT: the ATP from photosynthesis comes from the chloroplast (not mitochondria) and is used to drive photosynthesis further (Calvin cycle). Photosynthesis primarily makes glucose for the plant's own mitochondria to use as energy! Still need mitochondria for plant tissues but they don't make the ATP for photosynthesis, and photosynthesis ATP isn't used for general cell fxn!**

**D. Chloroplast**: light-dependent and light-independent reactions occur. (double membrane like mito + nucleus)

1. Outer membrane: plasma membrane (phospholipid bilayer)
2. Intermembrane space
3. Inner membrane: also phospholipid bilayer.
4. Stroma: fluid material that fills area inside inner membrane; Calvin cycle occurs here (fixing $CO_2$ => G3P)
5. Thylakoids: suspended within stroma (stacks); individual membrane layers are thylakoids; entire stack is **granum** membrane of thylakoids contain (PSI + PSII), cytochromes, and other $e^-$ carriers. Also phospholipid bilayer.
6. Thylakoid lumen: interior of the thylakoid; $H^+$ accumulates here.

Note: Gradient uses ATP synthase to move the accumulated H+ from thylakoid lumen to stroma; H+ move from in to out to generate ATP via synthase, whereas in ox-phos we build up H+ outside and then shuttle it back in to mitochondria to generate ATP via synthase

Locations: noncyclic photophos takes place in thylakoid membranes. Cyclic phos takes place on stroma lamellae (pieces connecting the thylakoids). Photolysis takes place inside the thylakoid lumen (passes e- to the membrane for noncyclic photophos). Calvin Cycle takes place in the stroma. Chemiosmosis takes place across the

thylakoid membrane. All of these take place inside the chloroplast! **Remember that is the thylakoid membrane, not the outer/inner chloroplast membranes, that absorb light!**

**E. Chemiosmosis in Chloroplasts**: uses $H^+$ gradient to generate ATP. (*p. 61*)

1. H+ ions accumulate inside thylakoids: H+ are released into lumen when H2O is split by PSII. $H^+$ is also carried into lumen from stroma by cytochrome between PSII and PSI.
2. A pH and electrical gradient is created: about pH5.
3. ATP synthase generates ATP: phosphorylate ADP + $P_i$ => ATP. ($3H^+$ is required for 1ATP).
4. Calvin cycle produces 2G3P using NADPH & $CO_2$ & ATP: at the end of $e^-$ transport chain following PSI, $2e^-$ produces NADPH.

**F. Photorespiration**: *fixation of oxygen by rubisco* (can also fix $CO_2$) => produces no ATP or sugar. **Rubisco is not "efficient" or fast** because it will fix both $CO_2$ and oxygen at the same time if both are present. Probably arose because early earth atmosphere didn't have much $O_2$ so it didn't matter. **Peroxisomes breakdown the products of this process.**

G. **C4 Photosynthesis**: evolved from $C_3$, when $CO_2$ enters leaf; absorbed by mesophyll cells (then moved to bundle sheath cells); instead of being fixed by rubisco into PGA, $CO_2$ combines with PEP to form OAA by PEP carboxylase (in mesophyll)

- OAA has 4C => C4 photosynthesis.
- OAA => malate and then transported through plasmodesmata into bundle sheath cell.
- Malate => pyruvate + $CO_2$. ($CO_2$ can be used into Calvin cycle) (Pyruvate moved back to mesophyll then => PEP)

1 ATP → AMP required

- Overall purpose is to move $CO_2$ from mesophyll to bundle sheath cell (structure = Kranz anatomy, process = Hatch-Slack pathway (little $O_2$ presence reduces competition while rubisco is fixing). Minimize photorespiration and H2O loss from stomata (leaf pores); found in hot, dry climates (faster fixation speed and more efficient). Requires one additional ATP (which becomes AMP). $C_3$ typically occurs in mesophyll cells, but in $C_4$ it occurs in bundle-sheath cells. Corn, sugarcane

H. **CAM Photosynthesis**:

- Another add-on to C3, **crassulacean acid metabolism**; almost identical to $C_4$.

1. PEP carboxylase fixes $CO_2$ + PEP to OAA; OAA => malic acid.
2. Malic acid is shuttled into vacuole of cell.
3. At *night*, stomata are open (opposite of normal), PEP carboxylase is active, malic acid accumulates in vacuole.
4. During *day*, stomata are closed. Malic acid is out of vacuole and converted back to OAA (require 1ATP), releasing $CO_2$ (moved onto Calvin cycle with rubisco) and PEP.

- Overall advantages are can proceed during day while stomata are closed (reduce $H_2O$ loss). Cacti, crassulacea plants,

- As leaves age, chlorophyll breaks down to extract valuable components like $Mg^{2+}$, carotenoids are visible.
- Splitting of H2O provides 2e- for noncyclic photophosphorylation; incorporated into NADPH and Calvin cycle.
- Calvin cycle is light-independent, but it requires ATP and NADPH produced from light-dependent rxn.

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**V. Cell Division:** nuclear division (karyokinesis) followed by cytokinesis

- In diploid cells, there are two copies of every chromosome, forming a pair (homologous chromosome). Human have 46 chromosomes, 23 homologous pair, a total of 92 chromatids (depending on stage of division1).
- MTOCs: Microtubule organizing centers aka centrosomes. Pair of these lay outside nucleus. In animal cells, each MTOC contains a pair of centrioles. Recall that plants do have MTOC's called centrosomes, but they aren't composed of centrioles.

**A. Mitosis**:

1. Prophase: nucleus disassembles: nucleolus disappear, chromatin condenses into chromosomes, and nuclear envelope breaks down. Mitotic spindle is formed and microtubules (composed of tubulin) begin connecting to kinetochores.
2. Metaphase: chromosomes line up single file at center, each chromatid is complete with a centromere and a kinetochore, once separated, it is a chromosome (to keep track of total: count centromeres!). Centrosomes at opposite ends of cell. (note: once separated that's the end of metaphase, so to be precise the chromosome # doubles at anaphase). Karyotyping performed here.
3. Anaphase: microtubules shorten, each chromosome is pulled apart into two chromatids (once separated it is a chromosome; chromosome # doubles), pulls the chromosomes to opposite poles (disjunction); at the end of this phase, each pole has a complete set of chromosome, same as original cell before replication.
4. Telophase: nuclear division, nuclear envelop develops, chromosomes => chromatin, nucleoli reappear.

**Cytokinesis:** Actually begins during the later stages of mitosis (most sources indicate it begins towards the end of anaphase). Division of cytoplasm to form 2 cells.

- Cleavage furrow: actin and myosin microfilaments shorten, pull plasma membrane into center (animal)
Note: begins formation during anaphase?
- Cell plate: vesicles from Golgi bodies migrate and fuse to form cell plate, out growth and merge with plasma membrane separating the two new cells (plants). Cells don't actually separate from each other, middle lamella cements adjacent cells together.

**Interphase:** begins after mitosis and cytokinesis are complete, and consists G1, S, and G2 phase

- Cell cycle = M, G1, S, G2 phases
- During G1, cell increases in size, and the G1 checkpoint ensures everything is ready for DNA synthesis
- **During S phase, second molecule of DNA replicated from the first, provides sister chromatids – DNA synthesis**
- **During G2, rapid cell growth, preparation for of genetic material for cellular division**
- More time spent in interphase than mitosis (>90%). Growth occurs in all 3 interphases, not just G's.
- There are checkpoints in these cycles to make sure things are going as planned
  - Near the end of $G_1$ – cell growth assessed and favorable conditions checked. If fails, cell enters $G_0$
  - End of $G_2$ – checks for sufficient Mitosis Promoting Factor (MPF) levels to proceed
  - M checkpoint (metaphase checkpoint) during mitosis that triggers start of $G_1$

**B. Meiosis**: (note: meiosis 1 is reduction division)

* Meiosis I: homologous chromosomes pair at plate, migrate to opposite poles (no separation of sister chromatids).

1. Prophase I: nucleus disassembles: nucleolus disappears and nuclear envelop breaks down, chromatin condenses, spindle develops. MT's begin attaching to kinetochores. Crossing over means genetic recomb, NT seq. might change!
   - Synapsis: homologous chromosomes pair up. These pairs are referred to as **tetrads** (group of 4 chromatids) or bivalents.
   - Chiasmata: region where crossing over occur of non-sister chromatids.
   - Synaptonemal complex: protein structure that temporarily forms between homologous chromosomes: gives rise to the tetrad w/ chiasmata and crossing over

Prophase I has 5 steps: **leptotene** (chromosomes start condensing) → **zygotene** (synapsis begins; synaptonemal complex forming) → **pachytene** (synapsis complete, crossing over) → **diplotene** (synatopnemal complex disappears, chiasma still present) → **diakinesis** (nuclear envelope fragments, chomosomes complete condensing, tetrads ready for metaphase)

2. Metaphase I: homologous pairs are spread across metaphase plate. Microtubules attached to kinectochores of one member of each homologous pair. Microtubules from other site attach to 2nd member of pair.
3. Anaphase I: homologues within tetrads uncouple and pulled to opposite sides (disjunction)
4. Telophase I: nuclear membrane develops. Each pole forms a new nucleus that has half number of chromosomes (from homologous pair to each chromosome = 2 sister chromatids). Chromosomes reduction phase to haploid.

- Interphase may occur in between here, depending on the species.

* Meiosis II: chromosomes spread across metaphase plate and sister chromatids separate and migrate to opposite poles. It is similar to mitosis.

5. Prophase II: nuclear envelop disappears and spindle develops etc, no chiasmata and no crossing over.
6. Metaphase II: chromosomes align on plate like in mitosis but now with half number of chromosomes (no extra copy).
7. Anaphase II: each chromosome is pulled into 2 separate chromatids and migrate to opposite poles of cell
8. Telophase II: nuclear envelope reappears and cytokinesis occurs => 4 haploid cells (each chromosome = 1 chromatid).

- Mitosis in somatic cells and meiosis in gametes (egg, sperm, pollen)
  - Fusion of two haploid gametes = fertilization/syngamy = diploid zygote

- In plants, meiosis in **sporangia** produces **spores** (haploid); spores undergoes mitosis to become multicellular (**gametophyte**) which are haploid (n) since spores are already haploid. The gametes fuse and produce a diploid cell (zygote 2n) that grows by mitosis to become **sporophyte**. Cells in sporophyte (**sporangia**) undergoes meiosis to produce haploid spores which germinate and repeat life cycle. Illustrated here.
- **Alternation of generations: Alternation of diploid and haploid stages.**

Genetic Variation: Genetic recombination during meiosis and sexual reproduction originates from three events:

- Crossing over during prophase I
- Independent assortment of homologues during metaphase I (which chromosome goes into which cell)
- Random joining of gametes aka germ cells (which sperm fertilizes which egg – genetic composition of gamete affects this)

* Regulation of Cell Cycle: functional limitatioms

1. Surface-to-volume ratio (S/V): volume gets much larger when cells grow ($\frac{4}{3}\pi r^3$) vs. SA ($4\pi r^2$). When S/V is large, exchange becomes much easier. When S/V is small, exchange is hard, leads to cell death or cell division to increase SA.

2. Genome-to-volume ratio (G/V): genome size remains constant throughout life; as cell grows, only volume increases. G/V will be small and thus exceed the ability of its genome to produce sufficient amounts of regulator of activities. Some large cells (paramecium, human skeletal muscle) are multinucleated to deal with this.

A. Checkpoints: cell specific regulations

1. $G_1$ Checkpoint: aka restriction point, the most important one. At the end of $G_1$ phase, if cell is not ready to divide it may arrest here ($G_0$ phase – nerve and muscle cells remain here, rarely divide after maturing) and never proceed or wait until it is ready.
2. $G_2$ Checkpoint: end of $G_2$ phase, evaluates accuracy of DNA replication and signal whether to begin mitosis.
3. M Checkpoint: during metaphase, ensures microtubules are properly attached to all kinetochores. Prevents anaphase if not.

B. Cyclin-dependent kinases (Cdk's): Cdk enzyme activates proteins that regulate cell cycle by phosphorylation; Cdk's are activated by protein cyclin.
C. Growth Factor: plasma membrane has receptors for growth factors that stimulate cell for division (such as damaged cell)
D. Density-dependent inhibition: cells stop dividing when surrounding cells density reaches maximum.
F. Anchorage dependence: most cells only divide when attached to an external surface such as neighboring cells or side of culture dish.

- Cancer cells defied all of the 5 conditions above (such cells are called **transformed** cells).

Note: Cancer drugs that inhibit mitosis do so by disrupting the ability of microtubules to separate chromosomes during anaphase, stopping replication
- Keep in mind that if you are seeing chromosomes, that means the chromatin has condensed already so you're looking at mitosis occurring – so if asked the number of chromatids, assume they've already been doubled in this situation
- Joining of gametes is random, but some sperm cells contain genetic material that gives them a competitive advantage – so they aren't all "equally" competitive
- Chad's says that during meiosis, cytokinesis varies among species – can occur at end of Telophase I, end of meiosis, etc. (seems to occur during both in humans?)

* Questions:

1. At anaphase of mitosis, there would be a total of 92 chromosomes (92 chromatids) if a cell has 46 chromosomes at beginning. Even when pulled apart of sister chromatids, each one is now a complete chromosome (count centromere).
2. At anaphase I, there would be a total of 46 chromosomes if a cell has 46 chromosomes at beginning because 23 chromosomes are pulled to each pole by independent assortment and no chromatids are separated at anaphase I.
3. Plants do not have centrioles (formation of cell plate).
11. Mitosis = no genetic variations.

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**VI. Heredity**:

To determine the probability of two or more independent events occurring together multiply the probabilities of each separate event

- Gene: genetic material on a chromosome for a trait.
- Locus: location on chromosome where gene is located.
- Allele: variance of genes such as different color.
- Homologous chromosomes: a pair of chromosomes that contains same genetic material (gene for gene). Each parent contributed 1 of the chromosome in the pair and thus different alleles may exist for a gene (dominant and recessive or incomplete dominance (color blending) / co-dominant such as blood type).
- **Law of segregation: one member of each chromosome pair migrates to an opposite pole so that each gamete is haploid (aka each gamete has only one copy of each allele), occurs in anaphase I.**
- Law of independent assortment: migration of homologues within one pair of homologous chromosomes does not influence the migration of homologues of other homologous pairs (independent assortment of alleles) [both laws pertain to meiosis specifically] What's the difference between the above? They both refer to the separation of homologous chromosomes during meiosis. The difference is that law of segregation is basically "when we form gametes we separate our allele copies so gametes are haploid" and law of independent assortment says "the separation of each pair of chromosomes is completely independent from the separation of any other pair – they each separate at random, outcome of one doesn't affect others".
- Test crosses: Monohybrid crosses test one gene, Dihybrid test two (on different chromosomes). Crosses have P, F1, F2 etc generations. Unknown dominant genotype x homozygous recessive phenotype to determine if hetero or homo dominant. To determine probabilities in dihybrid, usually easier to calculate probability of each gene separately then multiply
- Incomplete Dominance: Blending of expressions of alleles (e.g. R red, R' white, RR' comes out pink) (unique hetero phenotype)
- Codominance: Both inherited alleles are completely expressed (e.g. blood types A and B or both can show up as AB if expressed)
- Multiple alleles: Blood groups have 3 possible alleles, the codominant A and B and the O, leading to 4 possible genotypes (phenotypes?): AO (A type), BO (B type), AB (codominant AB type), OO (O type)

- Epistasis: one gene affects phenotypic expression of 2nd gene. Pigmentation (one gene controls (turn on/off) the production of pigment, and 2nd gene controls color or amount). If 1st gene codes for no pigment => 2nd gene has no effect.

CCBx => black fur in mice ccxx => no pigment

- Pleiotropy: single gene has more than 1 phenotypic expression (gene in pea plants that expressed seed texture also influences phenotype of starch metabolism and water uptake; sickle cell anemia leads to different health conditions).
- Polygenic inheritance: the interaction of many genes to shape a single phenotype w/ continuous variation (height, skin color).
- Linked genes: two or more genes that reside on the same chromosomes and thus cannot separate independently because they are physically connected (inherited together). Linked genes exhibit recombination about 18% of the time.

In a cross of BbVv x bbvv (says that BV and bv are linked and each is in a homologues). We only get BV or bv and no Bv or bV. However, if there is recombination, we may get 18% of Bv and bV.

- Greater recombination frequencies (18% above) means farther distance of genes apart on the same chromosome.

- Linkage map: B-V is 18%, A-V is 12%, and B-A is 6% => B------A----------V '-' = 1 unit apart
- Sex-linked: refers to single gene resides on sex chromosome; when male (XY) receives an X from mother, whether it is dominant or recessive will be expressed because there is no copy on the Y chromosome.
- Sex-influenced: can be influenced by sex of individual carrying trait (e.g. Bb female not bald, Bb male is)
- Penetrance: probability an organism with a specific genotype will express a particular phenotype
- Expressivity: term describing the variation of phenotype for a specific genotype
- X-inactivation: during embryonic development in female mammals, one of two X chromosomes does not uncoil into chromatin => dark and coiled compact body chromosome (**Barr body**) => cannot be expressed. Thus, only the genes on the other X chromosome will be expressed. Either one can be inactivated => genes in the female will not be expressed similarly, so all cells in a female mammal not necessarily functionally identical (calico cats).

- Hemophilia: cannot form blood clot. $X^HX^h$ is a normal carrier. But if $X^H$ is inactivated => $X^h$ is expressed.

- Nondisjunction: failure of one/more chromosomes pairs or chromatids to separate during mitosis (failure of two chromatids of a single chromosome during anaphase) or meiosis (homologous chromosomes to separate during Meiosis I or sister chromatids to separate during Meiosis II; result in trisomy or monosomy; ex Down syndrome) – **note: specifically during anaphase!**

- Mosaicism in cells that undergo nondisjunction in mitosis during embryonic development; fraction of body cells have extra or missing chromosome

- Polyploidy: all chromosomes undergo meiotic nondisjunction and produce gametes with twice the number of chromosomes. Common in plants.

- Human genetic defects:

1. Point mutation: single nucleotide changes causing substitution, insertion, deletion (latter 2 could cause frameshift).
   - Transition mutation: Purine to purine or pyrimidine to pyrimidine
   - Transversion mutation: purine to pyrimidine or vice versa
2. Aneuploidy: genome with extra/missing chromosome <= often caused by nondisjunction (Down syndrome = trisomy 21).
   - Turner syndrome: nondisjunction in sex-chromosome. Gametes (single, from one parent) can be XX/XY or O (no chromosome) => XO sterile, physically abnormal; Klinefelter (XXY); Down Syndrome (Trisomy 21)
3. Chromosomal abberations: chromosome segments are changed.
   - Duplications: chromosome segment is repeated on same chromosome.
   - Inversions: chromosome segments are rearranged in reverse orientation.
   - Translocation: segment is moved to another chromosome. Can be reciprocal (two non-homologous chromosomes swap chunks) or Robertsonian (one chromosome from a pair becomes attached to another from a pair – e.g. an extra chromosome 21 attached to 14 can cause Downs as well, tripled 21 chunk)
4. Chromosomal Breakage – spontaneous or induced (mutagenic agents, Xrays). Deficiency = lost fragment
5. Mutagenic agents include cosmic rays, Xrays, UV rays, radioactivity, chemical compounds include colchicine (inhibits spindle formation causing polyploidy), mustard gas. Mutagenic agents are generally also carcinogenic.
   - Proto-oncogenes stimulate normal growth; if mutated become oncogenes → cancer.
6. **Genetic disorders** include: **AR:** PKU (inability to product proper enzyme for phenylalanine breakdown; degradation product phenylpyruvic acid accumulates), cystic fibrosis (fluid buildup in tracts), Tay-sachs (lysosome defect; can't breakdown lipids for normal brain fxn), sickle-cell (defective hemoglobin due to substitution mutation) **AD:** Huntingtons (degenerate nervous system disease), **SLR:** hemophilia (abnormal blood clotting), color blind, duchenne (muscular dystrophy), **chromosomal:** Downs, Turner (XO), Klinefelter (XXY), Cri Du Chat (deletion on chromosome 5)

**Note: Turner's doesn't typically cause mental retardation, but Downs, Kline, and Cri Du Chat (deletion on chromosome 5) do**

Forward mutation means already mutated organism mutates again even more, backward mutation is back to original

- Extranuclear inheritance: extranuclear genes are found in mitochondria and chloroplasts. Defects in mito DNA can reduce cell's ATP production. Mitochondria passed to zygote all come from mother, so all related diseases are mother inherited. Note that mitochondria have their own ~70S ribosomes that make mitochondrial proteins w/in mitochondrial matrix!

Homozygous: two copies of the same allele (AA or aa). Heterozygous: different alleles of the same gene (Aa). Hemizygous: one single copy of a gene instead of two. (male has XY sex chromosome → hemizygous).

Don't confuse this with homologous pairs (referring to same genes [not necessarily the same alleles] on same chromosome – XY aren't truly homologous).

If codominance will be represented you will know because both alleles will show as dominant – e.g. A and B are both capital, both dominant, together codominant. Incomplete dominance is represented as such: A and A', in this case A' is not completely recessive, causes incomplete dominance together as AA'. Otherwise, assume there is standard complete dominance/recessiveness.

- Lethal gene: cross between Aa and Aa, we get AA:2Aa:aa. If "aa" was lethal, we would have AA and Aa as 1:2 ratio.

- If the phenotype "skips" generations be suspicious of an autosomal recessive disorder. If no skip, most likely an autosomal dominant disorder. Be suspicious for X-linked recessive, if a father doesn't have the phenotype, none of his daughters display it.

* Random:

Mitochondrial DNA is an exception to the universality of genetic code

23. Two genes, A and B, are linked. An individual who is AaBb produces equal numbers of 4 gametes, AB, Ab, aB, ab. The two genes are separated by large distance on same chromosome that crossing over can be seemed as the genes are on different chromosomes.

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## VII. Molecular Genetics:

- DNA – A,T,G,C – hereditary information of the cell – double helix w/ major and minor grooves
- DNA backbone: 5' to 3' phosphodiester bonds form phosphate backbone
- RNA – A,U,G,C – functional usage – varies per type (mRNA linear, tRNA clover, rRNA globular)
- CUT the PYE – C, T, and U are pyrimidines, A and G purines
- DNA Replication begins at special sites (origins of replication) in middle of the DNA molecule (not the end); DNA strands separate to form replication bubbles that expand in both directions.. Thousands of these bubbles happen; speed up replication of 3 billion BP DNA molecule. Prokaryotes only have one origin of replication.

### A. DNA Replication:

- Second chromatid containing a copy of DNA is assembled during interphase
  - DNA is unzipped and each strand serves as a template for complementary replication
  - Semiconservative replication = one strand of the two is old, the other is new
- Helicase is the enzyme that unwinds DNA, forming a Y shaped replication fork
  - Single stranded binding proteins attach to each strand of uncoiled DNA to keep them separate
  - Topoisomerases break and rejoin the double helix, allowing the prevention of knots (if you unwind a twist, the ends will get extra tight and knot up)
- DNA polymerase moves from the 3'→5' direction only, synthesizes a new strand that is antiparallel (5'→3')
  - Leading Strand – works continuously as more dna unzips (synthesized 5' → 3')
  - Lagging Strand – for the 5→3 template strand the DNA polymerase has to go back to the replication fork and work away from it. It produces fragments at a time called okazaki fragments vs continuous replication
    - DNA Ligase connects okazaki fragments
- Primase is an enzyme that creates a small strip of rna primer off of which dna polymerase can work since it can only add to an existing strand
  - Dna replication requires an RNA primer
  - Every okazaki fragment has an RNA primer, these rna strips are later replaced with dna by DNA polymerase I
    - DNA Pol 1 replaces BPs from the primer and does DNA repair; DNA pol 3 is pure replication [eukaryotes have different polymerases: alpha gamma etc – not important])
    - Pol 1 and Pol 3 have 3' → 5' exonuclease: breaks phosphodiester backbone on a single strand of DNA and removes a nucleotide. Exonuclease can only remove from (in this case of 3' end) of the chain
    - Pol 3 can do some proofreading; if it makes a mistake it will go back and use this to replace it
    - Pol 1 also has a 5' → 3' exonuclease, to take off the primer; and can also proof with 3' to 5' when laying down new chain
    - So in summary: Pol 3 mainly replicates the DNA 5' to 3' but can also proofread via 3' to 5' exonuclease. Pol 1 primary breaks down RNA primer via 5' to 3' exonuclease and replaces it with DNA (laid down

between Okazaki fragments mainly) via 5' to 3' polymerase while proofreading as it goes, can proofread via 3' to 5' exonuclease as well.
    - In prokaryotes the "good" strand is methylated after replication so it doesn't accidentally repair wrong strand
    - In all cases of repair, ligase must come in to seal the backbone afterward
- Energy for elongation is provided by two additional phophates attached to each new nucleotide. Breaking the bonds holding the two extra phosphates provides chemical energy for the process (same w/ transcription!). Human rate 50n/s

**B. <u>Replication of Telomere</u>**: Two problems can occur.

1. Not enough template strand where primase can attach.
2. Last primase is removed => in order to change RNA to DNA, there must be another DNA strand in front of the RNA primer> DNA pol cannot build after removing RNA primer>ultimately that RNA is destroyed by enzymes that degrade RNA left on the DNA, section of the telomere subsequently lost w/ each replication cycle. Prokaryotic DNA is circular so no telomeres (or issue).

<u>Telomerase</u>: enzyme that attaches to the end of template strand and extends the template strand by adding short sequence of DNA over and over (not important code), allowing elongation of lagging strand to continue. However, at the end will still be not enough for primase to attach but this loss of unimportant segment will not cause any problem. Telomerase carries an RNA template: binds to flanking 3' end of telomere that compliments part of its RNA template, synthesizes to fill in over the rest of its template (better seen in image here)

**C. <u>Protein Synthesis</u>**: 3 steps

Note: one-gene-one-polypeptide hypothesis defines a gene as the DNA segment that codes for a particular polypeptide. Also, genetic code is universal for nearly all organisms and most AAs have more than one codon specifying them (**redundancy/degeneracy**)

RNA Types:

a. <u>mRNA</u>: Single stranded template. Since there are 64 possible ways (4x4x4) ways that four nucleotides can be arranged in triplet combinations, there are 64 possible codons. 3 of them are stop codons. Therefore, only 61 codes for amino acids.

b. <u>tRNA</u>: C-C-A-3' end of tRNA attaches to amino acid, and the other portion is the **anticodon** which bp with the codon in mRNA. **Wobbles**: exact bp of the 3rd nucleotide in the anticodon and the 3rd nucleotide in the codon is often not required, allowing 45 different tRNA's base-pair with 61 codons that code for amino acid. Transports AA to its mRNA codon.

c. <u>rRNA</u>: nucleolus is an assemblage of DNA actively being transcribed into rRNA. As ribosome, has three binding sites: one for mRNA, one for tRNA that carries a growing polypeptide chain (P site); one for 2nd tRNA that delivers the next aa (A site). Terminations sequences include UAA, UGA, UAG. Together w/ proteins, rRNA forms ribosomes. Ribosome is assembled in nucleolus but large and small subunits exported separately to cytoplasm.

**D. <u>Transcription</u>**: creation of RNA molecules from DNA template. Prokaryotes polycistronic, eukaryotes monocistronic

a. <u>Initiation</u>: RNA pol attaches to promoter region on DNA and unzip the DNA into two strands. A **promoter region** for mRNA transcription often contains the sequence TATA (TATA Box). Most common sequence of nucleotides at promoter region is called the consensus sequence; variations from it cause less tight RNA pol binding → lower transcription rate

b. <u>Elongation</u>: RNA pol unzips DNA and assembles RNA nucleotides using one strand of DNA as template; only one strand is transcribed **(from the template/(-) antisense DNA strand; other strand is coding/(+) sense strand for protection against degradation**).

c. <u>Termination</u>: when RNA pol reaches a special sequences often AAAAAAA in eukaryotes.

Note: transcription is occurring in the 3' to 5' direction of the DNA template strand (but synthesis of the RNA strand is, as always, 5' to 3')

**E. <u>mRNA Processing</u>**: Before leaving nucleus, pre-mRNA undergoes several modifications:

a. <u>5' cap (-P-P-P-G-5')</u>: the sequence is added to the 5' end of the mRNA; Guanine with 2 phosphate groups => GTP; providing stability for mRNA and point of attachment for ribosomes.

b. <u>A poly-A tail (-A-A-A..A-A-3')</u>: sequence is attached to the 3' end of the mRNA. Tail consists of 200A; provide stability and control movement of mRNA across the nuclear envelope. (in prokaryotes, polyA tail facilitates degradation!)

c. <u>RNA splicing</u>: removes nucleotide segments from mRNA; before mRNA moves into cytoplasm, **small nuclear ribonucleoproteins** (**snRNP's**) and the spliceosome delete the introns and splice the exons. (prokaryotes have no introns!)

d. <u>Alternative splicing</u>: allows different mRNA to be generated from same RNA transcript; by selectively removing differences of an RNA transcript into different combinations => each coding for a different protein product.

Note: prokaryotes generally have ready to go mRNA upon transcription. It is only in eukaryotes that you need the above processing. Because prokaryotes don't need to process their mRNA first, translation can begin immediately/simultaneously. In both prokaryotes and eukaryotes, multiple RNA polymerases can transcribe the same template simultaneously.

**F. <u>Translation</u>**: assembly of amino acids based on reading of new RNA; uses GTP as energy source

- <u>Aminoacyl-tRNA</u>: in cytoplasm, amino acid attaches to tRNA at 3' end, require 1 ATP → AMP per AA

a. Initiation: small ribosome unit attaches to 5' end of mRNA; tRNA-methionine attaches to start sequence of mRNA AUG, and large ribosomal unit attaches to form a complete complex. (requires 1 GTP)

b. Elongation: next tRNA binds to A site, peptide bond formation, tRNA without methionine is released, the tRNA currently in A site moves to P site (**translocation**) and the next tRNA comes into A site and repeat process. (req. 2 GTP per link)

c. Termination: encounters the stop codon UAG, UAA, UGA. Polypeptide and the two ribosomal subunits all release once release factor breaks down the bond between tRNA and final AA of the popypeptide. While polypeptide is being translated, AA sequences is determining folding conformation; folding process assisted by chaperone proteins (requires 1 GTP)

d. Post-translation: Translation begins on a free floating ribosome; signal peptide at the beginning of the translated polypeptide may direct the ribosome to attach to the ER, in which case the polypeptide is injected into the ER lumen. If injected, polypeptide may be secreted from the cell via Golgi. In general, post-translational modifications (addition of sugars, lipids, phosphate groups to the AAs) may occur. May be subsequently processed by Golgi before it is functional.

Amino acids are placed starting from the 5' end of the mRNA and move all the way down to the 3' end. tRNA codons for matching are 3' to 5'. Can occur simultaneously with transcription in prokaryotes, but not in eukaryotes. Multiple ribosomes may simultaneously translate 1 mRNA.

**Also note that in bacteria the start codon is n-formylmethionine rather than methionine.**

**G. Mutation**: (covered sub, del, insert, frameshift earlier)

- Silent mutation: new codon still codes for the same amino acid. **- Nonsense mutation: new codon codes for a stop codon.**
- Neutral mutation: no change in protein fxn
- Missense mutation: new codon codes for *new* amino acid => minor or fatal results as in sickle cell (val(new) for glu(old))

**X. Repair mechanisms**:

- Proofreading: DNA polymerase checks base pairs
- Mismatch repair: enzymes repair things DNA polymerase missed
- Excision repair: enzymes remove nucleotides damaged by mutagens

**H. DNA Organization**:

- **Nucleosome: DNA is coiled around bundles of 8/9 histones proteins (beads on a string).**
- Not during division, chromatin exists as either of two types:
  1. Euchromatin: loosely bound to nucleosomes, actively being transcribed.
  2. Heterochromatin: areas of tightly packed nucleosomes where DNA is inactive (condensed => darker). Contains a lot of satellite DNA (large tandem repeats of noncoding DNA)
- Transposons (jumping genes): DNA segments that can move to new location on same/different chromosome; 2 types: insertion sequences consist of only one gene that codes for enzyme that just transports it (transposase); complex transposons code for extra: replication, antibiotic resistance, etc. Insertion of transposons into another region could cause mutation (little to no effect).

**I. Molecular Genetics of Viruses**:

- Virus: a nucleic acid (RNA/DNA may be double/single stranded), capsid (protein coat that encloses the nucleic acid; **capsomeres** assembles to form the capsid), and envelope (surrounds capsid of some viruses; it incorporates phospholipid/protein obtained from cell membrane of host). (note: bacteriophage = virus that only attacks bacteria). Usually specific to a type of cell (bind to specific receptors) and species. Host range is range of organisms virus can attack.
- Replication:

1. Lytic Cycle: virus penetrates cell membrane of host and uses host machinery to produce nucleic acids and viral proteins that are then assembled to make new viruses – these viruses burst out of the cell and infect other cells
   - DNA virus: DNA is replicated and form new viral DNA => transcribed to produce viral proteins (DNA + viral proteins assemble to form new viruses).
   - RNA virus: RNA serves as mRNA => translated into protein (protein + RNA => new virus).
   - **Retroviruses**: e.g. HIV, **ssRNA** viruses that use **reverse transcriptase** to make DNA complement of their RNA => which can go to manufacture mRNA or go into lysogenic cycle (becoming incorporated into DNA host).
2. Lysogenic: viral DNA is incorporated into DNA of host cell; dormant state (**provirus**/**prophage** [if bacteria]); remain inactive until external stimuli. When triggered, begins lytic cycle.

**Teichoic Acids on cell wall of bacterium are used as recognition + binding sites by bacterial viruses that cause infxns; also provide cell wall rigidity: only found on gram-positive bacteria!**

**Prions**: - Not viruses or cells. Misfolded versions of proteins in brain that cause normal version to misfold too. Fatal.

**J. Molecular Genetics of Bacteria**:
- Bacteria are prokaryotes with no nucleus or organelles, single circular ds DNA molecule (tightly condensed and called a nucleoid), no histones or other assoc. proteins. Replicate DNA in both directions from single point of origin ("theta replc.")
- Reproduce by **binary fission** (chromosome replicates, cell divides into two cells: each cell bearing one chromosome); lacks nucleus => lack microtubules, spindle, centrioles.)
- Plasmids: short, circular DNA outside chromosome (carry genes that are beneficial but not essential for survival); replicate independently; **episomes** are plasmid that can incorporate into bacterial chromosome.
* Genetic variations:

**1. Conjugation: donor produces a bridge (pilus) and connect to recipient; send chromosome/plasmid to recipient and recombinant can occur; F plasmid allowing pilus to occur; once recipient receives, it is now $F^+$ and can donate as well. R plasmids provide bacteria with antibiotic resistance. Pili are also used for cell adhesion!**

**2. Transduction: DNA is introduced into genome by a virus. When virus is assembled during lytic cycle, some bacterial DNA is incorporated in place of viral DNA. When virus infects another host, the bacterial DNA part that it delivers can recombine with the resident DNA.**

**3. Transformation: bacteria absorb DNA from surrounds and incorporate into genome.**

**K. Regulation of Prokaryotic Gene Expression**:
* **Operon**: control gene transcription, consist of:
1. Promoter: sequence of DNA where RNA polymerase attaches to being transcription.
2. Operator: region that can block action of RNA polymerase if occupied by repressor protein.
3. Structural genes: DNA sequences that code for related enzymes.
4. Regulatory genes: located outside of operon region, produces **repressor proteins**. Others produce **activator proteins** that assist the attachment of RNA polymerase to promoter region.

**- Lac operon (*E. coli*): controls breakdown of lactose; regulatory gene produces active repressor (bind operator) and block RNA pol. When lactose is available, lactose binds repressor and inactivates it => RNA pol can now transcribe. Lactose induces the operon. The enzymes that the operon produces are said to be inducible enzymes.**

**Note: consists of three lac genes (Z, Y, A) which code for B-galactosidase (convert lactose into glucose/galactose, lactose permease (transport actose into cell), and thiogalactoside transacetylase. Also know that low glucose means high cAMP levels → cAMP binds to CAP binding site of promoter → RNA polymerase more efficiently transcribes → lactose can be broken down. If lactose AND glucose are high, operon is shut off (cAMP is low, doesn't bind to CAP, bacteria uses one sugar at a time and prefers glucose).**

**- trp operon (*E. coli*): produces enzyme for tryptophan synthesis; regulatory genes produce an inactive repressor => RNA pol produces enzymes. When tryptophan is available, no longer need to synthesize it internally: it binds to inactive repressor and activates repressor => able binds operator and block RNA pol. Tryptophan is corepressor.**

- **Repressible enzymes**: as above, when structural genes stop producing enzymes only in presence of an active repressor. Unlike repressible enzymes, some genes are **constitutive** (constantly expressed) either naturally or due to mutation

**K. Regulation of Eukaryotic Gene Expression**:
- Regulatory proteins: repressors and activators, influence RNA pol's attachment to promoter region
- Nucleosome packing: **methylation** of histones (tighter packing = preventing transcription); **acetylation** of histones (uncoiling and transcriptions proceeds). (side note: methylation also used in X-inactivation and on DNA bases to repress gene activity. Also, histone methylation *usually* prevents transcription, but sometimes it can activate it)
- RNA interference: **short interfering RNAs** (**siRNAs**) block mRNA transcriptions (fold back within itself = dsRNA), translation, or degrade existing mRNA. siRNAs: dsRNA gets chopped up, then made single stranded. The relevant strand will bind to DNA (prevent transcription) or mRNA (signals destruction)

**Human Genome:** 97% of human DNA does not code for protein product; noncoding DNA: regulatory sequences, introns, repetitive sequences never transcribed, etc. Tandem repeats abnormally long stretches of back to back repetitive sequences within an affected gene (e.g. Huntington's).

**L. Recombinant DNA/DNA tech**:
- Recombinant DNA contains DNA segments or genes from different sources. The transfer of these DNA segments can come from viral transduction, bacterial conjugation, transposons, or through artificial recombinant DNA technology. Crossing over during prophase of meiosis produces recombinant chromosomes.

- The technology uses restriction endonucleases to cut up specific segments of DNA and left it with **sticky end** (unpaired).

- These restriction enzymes (**e.g. EcoRI; BamHI**) normally used by bacteria to protect against viral DNA (protect their own DNA via methylation)
- Vector: such as plasmid because DNA molecule used as a vehicle to transfer foreign genetic material into another cell.
    - To introduce foreign DNA into plasmid, the plasmid is treated with the same restriction enzyme so the same sticky ends to bind. DNA ligase stabilizes the attachments; then the plasmid is introduced into bacterium by transformation. Bacterium must be "made competent" to take up the plasmid (electroporation or heat shock+CaCl2)
- After this process, bacteria can be grown to produce product, form clone library, etc. Use antibiotic resistance/screen method to filter out the ones that don't have the recombinant DNA.
- Gel Electrophoresis (after DNA cut up) – agarose gel under an electric field for the separation of proteins based on charge and size (e.g. negative DNA moves toward positive anode from negative cathode). Shorter DNA moves further than larger; distributes DNA by size.
    -After electrophoresis: DNA can then be sequenced, or probed to identify location of specific sequence of DNA
    -DNA probe is a radioactively labeled single strand of nucleic acid used to tag a specific DNA sequence
    **-You can do gel electrophoresis of proteins too. Add SDS (denatures+linearizes+adds negative charge). Same principle.**
- Restriction fragment length polymorphism (RFLPs): restriction fragments between individuals are compared, fragments differ in length are observed because of **polymorphism** (different length in DNA sequences). Inherited in Mendelian fashion so often used in paternity suits, RFLP analysis used at crime scenes to match suspects.
- DNA-Finger Printing: RFLPs at crime scene compared to RFLPs of suspects.
- Short tandem repeat (STR): repeat of 2-5 nucleotides and different between all individuals except identical twins.
- Reverse transcriptase: introns often prevent transcriptions; this enzyme makes DNA molecule directly from mRNA. DNA obtained from this manner is **complementary DNA** (**cDNA**) which lacks introns that suppress transcriptions.
- PCR uses synthetic primer (the primer may be RNA or DNA oligonucleotides) to clone DNA (rapidly amplify). Taq polymerase (heat stable) + nucleotides + primers + salts (buffer) necessary.
    1. Denaturation (>90C) 2. Primers + Anneal (~55C) 3. Elongation (Taq Polymerase ~70C)
- Southern Blotting: Technique to ID target fragments of known DNA sequence in a large population of DNA. Electrophoresis fragments first, separate DNA strands (usually with NaOH) then transfer the SS DNA fragments to nitrocellulose membrane, then add probe which will hybridize and mark it.
- Northern Blotting: Just like Southern blot, but for RNA fragments.
- Western Blot: similar method for proteins: electrophoresis, blot to membrane, primary antibody specific to protein added to bind to that protein, then secondary anti-body-enzyme conjugate will bind to primary and mark it w/ enzyme for visualization

**Note: easy way to distinguish these is SNOW DROP; match the letters up.**

- Genome of humans differs roughly one every 1000 nt's, these differences called single nucleotide polymorphisms (SNPs)
- Gene Cloning: Plasmids are circular dsDNA that have **restriction sites** (for restriction enzymes). Cut there → linear piece of DNA. Also has a promoter region + some gene product(s) (e.g. antibiotic resistance). We want to cut, add genes, close plasmid, add to something like bacteria to replicate it. Bacteria dislike plasmids → only fraction of them get taken up by some bacteria. Use antibiotic resistance gene to determine which bacteria were "transformed" that will survive on certain medium. Plasmid also has origin of replication. Plasmids will get reproduced during cell division or even not during cell division. If making a prokaryotic gene product in mammalian cell → need to add polyA tail for the mRNA to survive. If making eukaryotic gene product in prokaryotic cell → need to make sure no introns (use reverse transcriptase on the mRNA product to get the desired DNA fragment).
- Hybridization**:** complementary BP's annealing
- Want to test for specific gene sequence in someone's DNA? Method 1 (single test only): take drop of blood, cut up DNA, use PCR method w/ specific primer for that region. If that gene is there → lots of copies. Gene not there → no copies. Method 2 (test for many things at same time): take drop of blood, PCR it to amplify. We have a solid support w/ pieces of ssDNA w/ specific sequence covalently attached → will hybridize to anything complementary (e.g. disease genes). On that same solid support we can put sSDNA pieces specific for other genes, can do this hundreds of times at different spots on this **DNA microarray**. Take desired amplified DNA, heat it to denature, add to DNA microarray, any DNA that hybridizes is a match. The amplified DNA we added is already fluorescently tagged → hybridization wash to get rid of weakly bound sequences (e.g. not a complete match) →add a dye that will show heavily if something has bound to our microarray. Can also do this starting w/ mRNA → reverse transcriptase → PCR amplify → etc.

Note: supplement w/ Campbell's 19-21 notes

Note: endonucleases cleave the phosphodiester backbone internally to chunk out NT's (results in freed oligonucleotides unless it's a restriction endonuclease), whereas exonucleases cut out the NT's starting from the end of backbone (or an existing nick in the backbone), resulting in freed nucleosides

Note on Campbell's note set: it is **ubiquitin**, not ubiquinone, that marks proteins for degradation via proteasome. Totipotent/pluriplotent is wrong too: totipotent (**not** mature cells that dedifferentiate) can give rise to any and all human cells, and even an entire functional organism. Pluripotent can give rise to all tissue types, but not an entire organism. Multipotent can give rise to limited range of cells within a tissue type.

Note: ATP resembles RNA nucleotide with two extra phosphates (because adenine + ribose sugar = adenosine)

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**VIII. Evolution**

- Evolution: changes in populations, species or groups; changes in allele (traits) frequencies in populations over time.
- Microevolution: changes in allele frequencies that occur over time within a population (due to mutation, selection, gene flow & drift)
- Macroevolution: patterns of changes in groups of related species over broad periods of geologic time. Patterns determine **phylogeny** (evolutionary relationships among species and groups of species).

* **Lamarck theory**:

- Use and disuse: body parts can develop with increased usage, unused parts are weakened (correct in athletes).
- Inheritance of acquired characteristics: body features acquired during lifetime can be passed down to offsprings (incorrect, since only changes in genetic material of cells can be passed to offspring).
- Natural transformation of species: organisms produced offspring with changes, transforming each later generation slightly more complex (no extinction or splits into more species) => incorrect.
- Natural selection: survival of the fittest (Darwinism) => now called neo-Darwinism (synthetic theory of evolution).

**A. Evidence for Evolution**:

1. Paleontology: fossils reveal prehistoric existence of extinct species; often found in sediment layers (deepest fossils represent oldest specimens). (large, rapid changes produce new species)(fos types: actual remains, petrification, imprints, molds, casts)
2. Biogeography: geography to describe distribution of species; unrelated species in different regions of world look alike when found in similar environment. **continental drift** – supercontinent Pangea slowly broke apart to 7 continents
3. Embryology: similar stages of development (**ontogeny**) among related species => establish evolutionary relationships (**phylogeny**). Gill slits and tails are found in fish, chicken, pig, and human embryos. "ontogeny recapitulates phylogeny" – this specific recapitulation theory is considered defunt, basically said that embryological stages represent our past evolutionary ancestors .
4. Comparative anatomy: describes two kind of structures that contribute to identification of evolutionary relationship.
    a. Homologous structure: body parts that resemble one another in different species from common ancestor.
    b. Analogous structure: body parts that resemble one another in different species because they evolved independently as adaptation to their environments.
5. Molecular biology: examines nucleotide and amino acid sequences of DNA and proteins from different species. More than 98% of nucleotide sequences in humans and chimpanzees are identical. AA's in cytochrome c often compared.
6. Comparative biochemistry: Organisms w/ common ancestor = common biochemical pathways

**B. Natural Selection**: responsible for producing **adaptations** (superior inherited traits) that increase individual's **fitness** (ability to survive, leave offspring)

1. Populations possess an enormous reproductive potential: if all offspring produced and survived.
2. Population size remain stable: populations generally fluctuate around a constant size.
3. Resources are limited: resources do not increase as population grow larger.
4. Individuals compete for survival: growing pop will exceed available resources => compete.
5. There is variation among individuals in a population: such as skin color (very pale to very dark).
6. Much variation is heritable: DNA passed down.
7. Only the most fit individuals survive: survival of the fittest.
8. Evolution occurs as favorable traits accumulate in the population: best adapted individuals => best adapted offspring leave most offspring.

- Stabilizing selection: bell curve (average height in human is in middle), favors an intermediate (all selections shown)
- Directional selection: favors traits that are at one extreme of a range of traits. Traits at opposite extremes are selected against. After many generations => changes in allele frequencies (such as insecticide resistance).
    - Industrial melanism: selection of dark-colored (melanic) varieties in various species of moths (**peppered moth**) as a result of industrial pollution.
- Disruptive selection: occurs when environment favors extreme or unusual traits while selecting against common traits. Short and tall are favored while average is selected against.
- Sexual selection: differential mating of males (or females) in a population. Female chooses superior males => increase fitness of offspring; they invest greater energy so they maximize quality. Males increase fitness of offspring by maximizing quantity. Male competition: leads to fights; mating opportunities awarded to strongest male, favors traits like musculature,

horns, large stature, etc. Female choice: leads to traits/behaviors in males that are favorable to female, favors traits like colorful plumage or elaborate mating behavior. Result often leads to **sexual dimorphism** (differences in appearance of males and females) => becomes a form of disruptive selection.
- Artificial selection: a form of directional selection carried out by humans when they breed favorable traits (not natural selection).

**C. Sources of Variations**:
1. Mutation: introduce new allele.
2. Sexual Reproduction: genetic recombination (crossing over, independent, random joining of gametes).
3. Diploidy: presence of two copies of each chromosome. In heterozygous conditions, recessive allele is stored for later generations => more variations is maintained in gene pool.
4. Outbreeding: mating with unrelated partners => mixing different alleles => new allele combinations.
5. Balanced polymorphism: maintenance of different phenotypes in population (one is usually best and increased in allele frequency). However, polymorphisms (coexistence or two/more different phenotypes) can exist and be maintained:

a. Heterozygote advantage: heterozygous condition bears greater advantage than either homozygous conditions. Sickle cell (AA, AS, SS). AS is 14% in Africa because it has resistance against malaria.

b. Hybrid vigor (heterosis): superior quality of offspring resulting from crosses between two different inbred strains of plants => hybrid superior quality results from reduction of loci with deletion of recessive homozygous conditions and increase in heterozygous advantage.

c. Frequency-dependent selection (minority advantage): least common phenotypes have a selective advantage. Common phenotypes are selected against. Rare will increase in frequency and will be selected against and repeat. Predators (**search image** of common phenotypes) => rare escapes; rare eventually becomes common, cycle repeats.

Neutral variation – variation w/out selective value (e.g. fingerprints in humans)

Geographic variation – variation of a species dependent on climate or geographic conditions. A graded variation of a phenotype due to this is known as a **cline**; variation from north/south environments is a **north-south cline**

**D. Causes of Changes in Allele Frequencies**:
1. Natural selection: increase/decrease of allele frequencies due to environment.
2. Gene flow: introduction/removal of alleles from population when individuals leave (emigration) or enter population.
3. **Genetic drift**: *random* increase/decrease of allele by chance. Small population => larger effect.

- Founder effect: allele frequencies in group of migrating individuals are (by chance) not the same as that of their population origin.
- Bottleneck: occurs when population undergoes a dramatic decrease in size (natural catastrophe, etc) => vulnerable to genetic drift.

4. Nonrandom mating: individuals choose mates based upon their particular traits (mates choose nearby individuals).
- Inbreeding: individuals mate with relatives.
- Sexual selection: females choose males based on superior traits.

5. Mutations

**E. Genetic Equilibrium (Hardy-Weinberg eq.)**: allele frequencies remain constant from generation to generation => no evolution
- Require the following conditions: no mutation, all traits are neutral (no natural selection), population must be isolated (no gene flow), large population (no genetic drift), mating is random, no net migration.
- Allele frequencies for each allele ($p$, $q$)
- Frequency of homozygous ($p^2$, $q^2$)
- Heterozygous ($pq + pq = 2pq$)
- All alleles sum to 100%: $p + q = 1$
- All individuals sum to 100%: $p^2 + 2qp + q^2 = 1$. } both must be true for HW!

A plant population with 84% Red (R) and 16% White (r) => $q^2 = 0.16$ (rr) $p^2 + 2pq = 0.84$ (RR + Rr)

We can find q and p by taking square-root and plug in the two equations to find heterozygous frequency and homozygous dominant frequency.

**F. Speciation**: formation of new species
- Species: a group of individuals capable of interbreeding.

1. **Allopatric speciation**: population is divided by geographic barrier => interbreeding between two resulting populations is prevented => gene frequencies in two population can diverge due to natural selection, mutation, genetic drift. If gene pool is sufficiently diverge => will not interbreed when barrier is removed => new species formed. This form of speciation can

be through dispersal (group is isolated by being physically removed from the original location of the larger group) or vicariance (group is isolated by a geographic barrier but in the same overall location of the larger group).

2. **Sympatric speciation**: formation of new species without presence of geographic barrier.

- Balanced polymorphism: natural selection due to polymorphism. Example: different color in insects, one color can camouflage to different substrate, and the other that can't will be eaten. Only insects with same color can mate (isolated from other subpopulations).

- Polyploidy: possession of more than normal two sets of chromosomes (3n, 4n in plants <= nondisjunction => two viable diploid gametes and two sterile gametes with no chromosomes => tetraploid 4n zygote formed => repeat with diploid gametes male/female => reproductive isolation with normal gametes).

- Hybridization: two different forms of a species (closely related species) mate and produce along a geographic boundary called **hybrid zone** (more genetic variations => hybrid can live beyond range of either parents).

3. Adaptive radiation: rapid evolution of many species from a single ancestor; occurs when ancestral species is introduced to an area where diverse geographic/ecological conditions are available for colonization.

**G. Maintaining Reproductive Isolation**: prevent gene flow (no separation by geo barrier; may be random or result of NS)

* **Prezygotic Isolating mechanism**: prevent fertilization

1. Habitat isolation: species do not encounter. 2. Temporal isolation: species mate/flower during different seasons/time.
3. Behavioral isolation: does not perform correct courtship rituals.
4. Mechanical isolation: male/female genitalia are not compatible.
5. Gametic isolation: male gametes do not survive in environment of female gametes. (gametes do not recognize others).

*** Postzygotic Isolating mechanism**:

6. Hybrid inviability: zygote fails to develop properly and dies before reaching reproductive maturity.
7. Hybrid sterility: hybrids become functional adults but cannot reproduce.
8. Hybrid breakdown: hybrids produce *offspring* that have reduced viability/fertility (hybrid's children can't reproduce!)

**H. Patterns of Evolution**:

1. Divergent evolution: two/more species that originate from common ancestor and become increasingly different over time (result of speciation).
2. Convergent evolution: two unrelated species that share similar traits by environment (analogous traits).
3. Parallel evolution: two related species made similar evolutionary changes after their divergence from common ancestor.
4. Coevolution: evolution of one species in response to new adaptations that appear in another species (predator/prey)

**I. Macroevolution**:

1. Phyletic gradualism: evolution occurs by gradual accumulation of small changes; but unlikely to be valid because intermediate stages of evolution are missing (no fossils); fossils only reveals major changes in groups of organisms.
2. Punctuated equilibrium: evolutionary history consists of geologically long periods of stasis (stability) with little/no evolution followed by geologically short periods of rapid evolutions. Absence of fossils revealing intermediate stages of evolution is considered data that confirms rapid evolutionary events.

**J. Origin of Life**: (notes on age: Universe 12-15 billion yrs, solar system 4.6 billion, earth ~4.5, microfossils of prokaryotes 3.6 billion, Photosynthetic bacteria 2.3, eukaryotes 1.5)

**1. Earth and atmosphere form: through volcanoes ($CH_4$, $NH_3$, CO, $CO_2$, $H_2$, $N_2$, $H_2O$, S, HCl, HCN, little/no $O_2$).**

2. Primordial seas formation: as earth cooled => gases condense => sea with water and minerals.

3. Complex molecules were synthesized: formation of organic soup from inorganic, energy from UV, **lighting**, heat, radiation => acetic acid, formaldehyde, and amino acids.

- Oparin & Haldane: organic soup theory; if there was $O_2$ (very reactive), no organic molecules would have formed. **Operin's hypothesis was that origin Earth environment was reducing (providing chemical requirements to produce complex molecules from simple building blocks. In an oxidizing environment you'd break complex molecules apart).**

- Stanley Miller: tested theory of above and produced organic molecules. **Miller & Urey used ammonia, methane, water, and hydrogen sealed + simulated lightning → saw several organic molecules, AA's, starting materials, but no NAs!**

4. Polymers and self-replication: monomers => polymer (dehydration condensation). **Proteinoids** are abiotically produced polypeptides <= amino acids dehydration on hot, dry substrates confirms this

5. Organic molecules were concentrated/isolated into protobionts: **protobionts** (precursors of cells = like cells, metabolically active but unable to reproduce). **Microspheres/liposomes** and **coacervates** (spontaneously formed lipid or protein bilayer bubbles) are experimentally (abiotically) produced protobionts that have some selective permeable qualities.
Note: we can also produce microsomes in the lab: vesicle-like artifacts from reformed pieces of the ER if cell is broken up in a lab

6. Primitive heterotrophic prokaryotes: obtained materials by consuming other organic substances (pathogenic bacteria).

7. Primitive autotrophic prokaryotes: mutation, heterotroph gained ability to produce its own food => cyanobacteria.

8. Oxygen and ozone layer + abiotic chemical evolution ended: by production of photosynthetic activity of autotrophs.
- UV light + Oxygen => ozone layer (absorbed latter UV light => blocking energy for abiotic synthesis of organic materials => termination of primitive cells.

9. Eukaryotes formed: **endosymbiotic theory**, eukaryotic cells originated mutually among prokaryotes (mitochondria, chloroplast establish resident inside another prokaryotes). Evidence: **Thylakoid membranes of chloroplasts resemble photosynthetic membranes of cyanobacteria**, mitochondria and chloroplasts have their own circ. DNA not wrapped with histones (prokaryotic like), ribosomes of these organelles resemble those of bacteria, they reproduce independently via process similar to binary fission, two membranes.

**Note:** modern atmosphere is roughly 78% nitrogen, 21% oxygen, 1% argon, then a lot of other less important gases
**Vestigial Structures –** structures that appear to be useless but had ancestral function; ex humans (appendix and tail), horses (splints), python (legs reduced to bones)
**Mullerian mimicry** - two or more harmful species that are not closely related, and share one or more common predators, have come to mimic each other's warning signals
**Batesian mimicry –** deceptive; harmless species has evolved to imitate the warning signals of a harmful species directed at a common predator
**Gene Pool –** all the alleles for any given trait in the population
**Parapatric speciation** - Continuous population but it doesn't mate randomly: individuals more likely to mate with geographic neighbors, divergence may happen due to reduced gene flow since selection pressures vary across the population's range (different niches, adjacent but not isolated). Environmental gradients?
**Peripatric speciation** - Very similar to allopatric speciation in that a population is isolated and prevented from exchanging genes from the "main" one (geographically), but one of the populations is much smaller than the other, so it is subject to accelerated genetic drift – along w/ differing selection pressures
**Anagenesis/phyletic evolution –** one species replaces another, straight path evolution
**Cladogenesis/branching evolution –** New species branches out from parent species
**Clade –** a group of species that includes a common ancestor and all of its descendents (aka monophylum)
**Sere –** a particular stage of an ecosystem
**Mold –** an organic matter leaves an impression in rock or inorganic matter, later the organic matter decays and leaves a negative impression
**Cast –** a type of fossil formed when a mold is filled in
**Deme –** small local population (e.g. all the beavers along specific portion of a river)
**General Categories of living organisms: autotrophic anaerbones** (chemosynthetic bacteria), **autotropohic aerobes** (green plants, photoplankton), **heterotrophic anaerobes** (yeast), **heterotrophic aerobes** (amoebas, earthworms, humans)
**Symbiosis –** relationship between 2 species. Can be: **mutualism** (beneficial/beneficial), **commensalism** (beneficial/neutral), **parasitism** (beneficial/detrimental)
**Synapomorphies –** shared traits *derived from an evolutionary ancestor* common to all members of a group
**Analogous traits –** similar characteristics resulting from convergent evolution, therefore not derived from a common ancestor
**Law of parsimony –** Occam's Razor, simplest explanation is most likely correct (phylogenetic trees: fewest number of changes w/ respect to synapomorphies is likely most correct representation of reality)

* **Questions**: (Page 141): 2, 3, 4, 7, 14

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## IX. Biological Diversity (Review Questions Page 161)

- Taxonomy: organisms are classified into categories called **taxa**. A **species** name is given a name consisting of **genus** (closely related animal) name and **species** name. Domesticated dog is in genus *Canis* and name *Canis familiaris*; Wolf is *Canis lupis*.
- Family: genera that share related features; then Species <= Genus <= Family <= Orders <= Classes <= Phyla (division for fungi and plant) <= Kingdoms <= Domains. (**D**umb **K**ings **P**lay **C**hess **O**n **F**ine **G**reen **S**and)
- Systematics: study of evolutionary relationships among organisms (Phylogeny = evolutionary relationships).

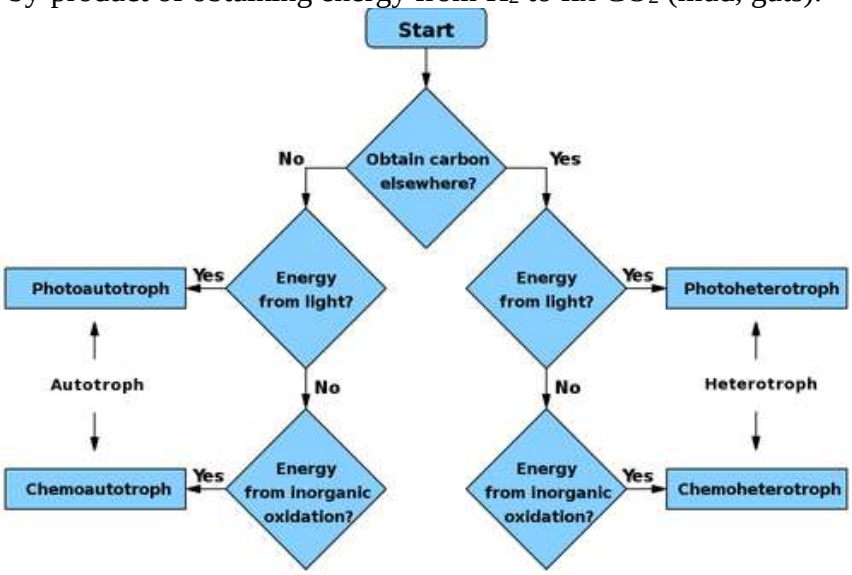
All living things have: one or more cells, plasma membrane, genetic material in DNA form, and a mechanism of using RNA and ribosomes to translate genetic material into proteins+enzymes. Two major divisions: eukaryotic vs prokaryotic
- Eukaryotic cells: chromosomes contain long, linear DNA with histone; enclosed in nucleus; specialized organelles to isolate metabolic activities; 9+2 microtubule array flagella and cilia.
- Prokaryotic cells: single chromosome is short, circular DNA **usually without** histone [but archaea have histones]; may contain **plasmids**; no nucleus; no organelles; flagella consist of chains of protein **flagellin** instead of "9 + 2" microtubules

**Note: flagella use proton motive force to spin and give locomotion in bacteria (electrical gradient!) – not ATP!**

Two major methods of energy acquisition (autotroph vs heterotroph):
- Autotrophs: manufacture their own organic materials; uses light or chemicals (photo- vs chemo-) such as $H_2S$, $NH_3$, $NO_2^-$, $NO_3^-$.
- Heterotrophs: obtain energy by consuming organic substances produced by autotrophs.
    - Parasites: obtain energy from living tissue of host
    - Saprobes (saprophytes): obtain energy from dead, decaying matter => contribute to organic decay = decomposers.
- Obligate aerobes: must have $O_2$ to live. - Obligate anaerobes: require absence of $O_2$ to live.
- Facultative anaerobe: grows in presence of $O_2$, but can switch to anaerobic metabolism when $O_2$ is absent.

**A. Domain Archaea**: are prokaryotes but differ from bacteria, the other major category of prokaryotes
- Archaeal cells wall contain various polysaccharide, **not** peptidoglycan (as in bacteria), cellulose (as in plant), or chitin (as in fungi). Phospholipid components: glycerol is different (uses an isomer of the one in bacteria/eukaryotes), and the hydrocarbon chain (fatty acid) is branched (rather than straight chain) w/ ether-linkages instead of ester-linkages.
- Similarity with eukaryotes:
  1. DNA of both archaea and eukaryotes are associated with histone; not bacterial DNA.
  2. Ribosome activity is not inhibited by antibiotics *streptomycin* and *chloramphenicol* unlike bacteria.
- Some groups of Archaea:
  1. Methanogens: obligate anaerobes that produce $CH_4$ as by-product of obtaining energy from $H_2$ to fix $CO_2$ (mud, guts).
  2. Extremophiles: live in extreme environment;

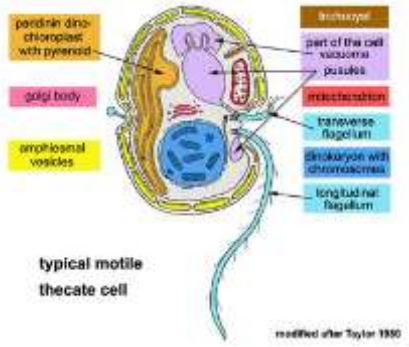
**Halophiles** (salt lover) high [salt] environment; most are aerobic and heterotrophic; others anaerobic and photosynthetic w/ pigment **bacteriorhodopsin**.
**Thermophiles** (heat lover) are sulfur-based chemoautotroph in very hot places
Others live in high acid/base/pressure environments




**B. Domain Bacteria**: five kingdoms
- Distinct from archaea and eukaryote by these features: cell wall (peptidoglycan = polymer of monosaccharide with amino acid); bacterial DNA is not associated with histone; ribosome activity is inhibited by above antibiotics.
- Classification of bacteria: difficult to classify
  1. Mode of nutrition/how they metabolize resources
  2. Ability to produce **endospore** (resistant bodies that contain DNA and small amount of cytoplasm surrounded by durable wall).
  3. Means of motility (flagella [apical, posterior, or engulf cell], corkscrew motion, or gliding through slime material).
  **4. Shapes: **cocci** (spherical), **bacilli** (rod-shaped), **spirilla/spirochetes** (spirals).
  5. Thick peptidoglycan wall cell (gram-positive); Thin peptidoglycan covered with lipopolysaccharides (gram-negative).
- Common groups of bacteria:
  1. Cyanobacteria: photosynthetic like plants (use chlorophyll a, split water, release $O_2$, etc.; contain accessory pigment **phycobilins**; some have specialized cells called **heterocysts** that produce nitrogen-fixing enzyme (converts fixed inorganic nitrogen gas into $NH_3$ that can be used to make AA's+NT's). Known as blue-green algae (not related to the other prokaryotic algae groups)
  2. Chemosynthetic: autotrophs; some are **nitrifying** bacteria $NO_2^- \rightarrow NO_3^-$.
  3. Nitrogen-fixing: heterotrophs that fix $N_2$, lives in nodules of plant (mutualism).
  4. Spirochetes: coiled bacteria that move with corkscrew motion, internal flagella between cell wall layers.

**C. Domain Eukarya**: four kingdoms
  1. **Kingdom Protista**: the subcategories are phylum. This is an artificial kingdom used mainly for convenience; poorly understood. Features shared by two or more groups may represent convergent evolution (arose independently). Most are unicellular.

- **Algaelike** (**plant-like**) members of protista all obtain energy by photosynthesis. All have chlorophyll a, some have others + accessory pigments. Mainly categorized via: form of carb used to store energy, # of flagella, makeup of cell wall




a. Euglenoids: one to three flagella at apical (leading) end; instead of cellulose cell wall: thin, protein strips called **pellicles** that wrap over cell membranes => heterotrophic in absence of light; some have **eyespot** that permits **phototaxis** (ability to move in response to light).

b. Dinoflagellates: have two flagella. One is posterior, 2nd flagellum is transverse and rests in encircling mid groove perpendicular to 1st flagellum. Some are bioluminescent. Others produce nerve toxin that concentrate in filter-feeding shellfish => cause illness to human when eaten. Responsible for the algal bloom known as red tide: high cxns of algae that can lead to toxin buildup, depletion of dissolved oxygen, and other harmful effects

c. Diatoms: have **tests** (shells) that fit together like a box with a lid; contain $SiO_2$ (silica)

d. Brown algae: multicellular and have flagellated sperm cells (giant seaweed)

e. Rhodophyta: red algae (red accessory pigments **phycobilins**); multicellular and gametes do not have flagella.

f. Chlorophyta: green algae, have both chlorophyll *a* and *b*, cellulose cell walls, store energy in starch. Some species have **isogamous** gamete (both sperm/egg equal in size and motile), others are **anisogamous** (sperm/egg differ in size); others can have **oogamous** (large egg cell remains with the parent and is fertilized by small/motile sperm). Trend from unicellular organisms (Chlamydomonas) towards multi-cellular colonies (Gonium, Pandorina, Volvox). A lineage of Chlorophytes, **charophytes** are believed to be the ancestor of plants.

- **Protozoa** (**animal-like**) protists are heterotrophs; consume living cells or dead organic matter; unicellular eukaryotes.

a. Rhizopoda: amoebas that move by extensions of their cell body called **pseudopodia**; encircle food, phagocytosis.

b. Foraminifera: aka forams, have tests (shells) usually made of calcium carbonate => sediments indicate oil deposit

c. Apicomplexans: parasites of animals; **apical complex** (complex of organelles located at an end (apex) of the cell); no physical motility; form spores which are dispersed by hosts that complete their life cycle (malaria caused by **sporozoan**).

d. Ciliates: use cilia for moving and other functions; have specialized structures: mouths, pores, contractile vacuoles [H2O balance], two kinds of nuclei (large macronucleus and several small nuclei); most complex of all cells. E.g. *paramecium*.

- Amoebas: genus of protozoa, shapeless and unicellular.

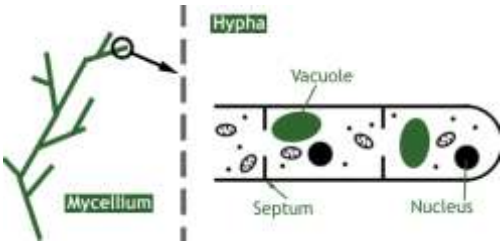
- **Fungus-like** protists resemble fungi (form filaments/spore-beating bodies like fungi do).

a. Cellular slime molds: funguslike and protozoalike characteristics; Spores germinate into **amoebas** which feed on bacteria; when no food, amoebas aggregates into single unit **slug** (individual cells of slug mobilize into stalk with capsule at top to release spores => germinate and repeat cycle); their stimulus for aggregation is cAMP secretion (secreted by the amoebas that first experience food deprivation).

b. Plasmodial slime molds: grow as single, spreading mass (**plasmodium**) feeding on decaying vegetation; when no food or desiccation=> stalks bearing spore capsules form => haploid spores released from capsule germinate into haploid amoeboid/flagellated cells, fuse to form diploid cells => grow into plasmodium; not mutualistic with others.

c. Oomycota: water molds, milders, white rusts; either parasites or **saprobes** (gets nutrition from nonliving/decaying organic matter); form filaments (**hyphae**) which secrete enzymes that digest surrounding substances like fungi do. **Hyphae** lacks **septa** (cross wall) which is in true fungi that partition filaments into compartments; so they are **coenocytic** (lack septa), containing many nuclei within a single cell; cell walls are made of cellulose rather than chitin of fungi.

2. **Kingdom Fungi**: fungi grow as filaments **(hyphae**), **Mycellium** is a mass of hyphae; some fungi have **septum** which divide filament into compartments containing single nucleus. Cell walls contain **chitin** (N-containing polysaccharide). Those w/out septa are coenocytic (multi-nucleate).




- Fungi are either parasites/saprobes (decomposer) absorbing food products due to digestive enzymes. Parasitic fungi have hyphae (**haustoria**) that penetrate host.

* **Stages of Sexual Reproduction**: - fungi are primarily haploid but form temporary diploid structures for sexual reprod.

a. Plasmogamy: fusing of cells from two different fungal strains to produce single cell w/ nuclei of both strains. A pair of haploid nuclei, one from each strain is called **dikaryon**. **Dikaryotic** hypha is hypha containing dikaryon.

b. Karyogamy: fusing of two haploid nuclei of a dikaryon to form single diploid nucleus.

c. Meiosis: of diploid nucleus restores haploid condition; daughter cells develop into haploid spores which germinate into haploid hyphae (has 1 fungal strain) => merge into dikaryon and repeat.

* Means of Asexual Reproduction: **fragmentation** (breaking up hyphae), **budding** (small hyphal outgrowth), and **asexual spores**, further described as two types:

- Sporangiospores: produced in sac-like capsules **(sporangia**) that are each borne on a stalk called **sporangiophore**.
- Conidia: formed at tips of specialized hyphae, not enclosed inside sac; hyphae bearing conidia called **conidiophores**

Note: the above two spore types are asexual. The below spore types described are sexual. A fungi sometimes will use both (e.g. ascomycete conidia).

- Six fungus groups: division/classes with suffix –mycota (division) or –mycete (classes) and used interchangeably.

a. Zygomycota: lack septa, except filaments bordering reproductive filaments; reproduce sexually by fusion of hyphae from different strains, followed by plasmogamy, karyogamy, meiosis; haploid **zygospores** are produced => germinate into new hyphae (e.g. bread molds). Life cycle here

b. Glomeromycota: lack septa, *do not produce zygospores*; mutualistic associations with roots of plants (**mycorrhizae**), plants provide carb, fungus increases ability of plant to absorb nutrient (especially phosphorus).

c. Ascomycota: have septa; reproduce sexually by producing haploid **ascospores**. After plasmogamy of hyphae from different strains, dikaryotic hypha produces more filaments by mitosis; karyogamy and meiosis occurs in terminal hyphal => 4 haploid cells => mitosis to produce 8 haploid ascospores in a sac called **ascus**; often grouped together into fruiting body **ascocarp** (yeast). The spores release and germinate into hyphae, cycle repeats. Life cycle here

d. Basidiomycota: septa, reproduce sexually by producing haploid **basidiospores**. Plasmogamy => mitosis =>fruiting body (**basidiocarp**) such as mushroom; Karyogamy occurs in terminal hyphal cells called **basidia**, followed by meiosis to produce 4 haploid basidiospores. Life cycle here

e. Deuteromycota: imperfect fungi, artificial group (no sexual reproductive cycle). *Penicillium* produces penicillin.

f. Lichens: mutualistic associations between fungi and algae (usually achlorophyta/cyanobacteria provide carbs from photosynthesis); also provide Nitrogen if algae is nitrogen-fixing; fungus (usually ascomycete) provides water and protection (pigments from UV light, or toxic chemicals against grazers) from environment.

3. **Kingdom Plantae**:

- Adaptations for survival on land:

a. Dominant generation is diploid sporophyte generation (except primitive bryophytes-mosses, liverworts, and hornworts); provide two copies against genetic damage that plants were more susceptible to once out of water.

b. Cuticle: waxy covering that reduces desiccation (drying up/water loss)

c. Vascular system reduces dependency on water (cells no longer need to be close to water) => formation of specialized tissues: true leaves (centers for photosynthesis, true stems (support leaves), true roots (acquire water/anchor plant. Two groups of vascular tissues evolved: **Xylem** (water transport), **phloem** (sugar transport).

d. In primitive plant divisions (flagellated sperm require water to swim to eggs). In advanced division (coniferophyta and anthophyta), sperm is packaged as pollen (wind).

e. Anthophyta: gametophytes are enclosed (protected) inside an ovary.

f. Adaptations (in coniferophyta + anthophyta) of seasonal variations in availability of water and light. Some are **deciduous** (shed leaves to prevent water loss through slow-growing seasons). Others like desert plants will germinate, grow, flower, and produce seeds rapidly in brief periods of rain.

- List of major plant divisions: note that each has increasingly greater adaptation to survive on land

a. Bryophytes: mosses, liverworts, and hornworts. Gametes are produced in **gametangia** (protective structures) on gametophytes, dominant haploid stage of life cycle of bryophytes. **Antheridium** (male gametangium) produces flagellated sperm that swim through water. **Archegonium** (female) produces egg. Zygote grows into diploid structure (still connected to gametophyte). They are anchored by rhizoids rather than roots.

- In mosses, this structure is a stalk bearing capsule which contains haploid spores produced by meiosis => spores dispersed by wind and germinate grow into haploid gametophytes which produces antheridium + archegonium.
- Lacks true root, true leaves, true stems (lack vascular tissues); so must remain in/near water.

* The following are vascular plants (**tracheophytes**): true root, leaves, and stems; germination of antheridium + archegonium (swim) produces diploid zygote into sporophyte (dominant generation).

b. Lycophyta: club mosses, spike mosses, and quillworts (herbaceous plants); club and spike mosses produce clusters of spore-bearing sporangia in conelike structure **strobili**. Resurrection plant (recover from dead-appearance after watered, is a spike moss).

c. Pterophyta: 3 groups. (note the life cycle here pictured is for ferns but they are very similar for lycophyta as well: primary difference is that the lycophyta use a prominent cone-like strobili, but ferns use the sori on undersurface of leaves.)

- Ferns: produce cluster of sporangia called **sori** that develop on undersurface of fern fronds (meiosis => spores).
- Horsetails: include extinct woody trees; hollow, ribbed stems that are jointed at **nodes**; strobili bear spores. Stems, branches, and leaves are green (photosynthetic) and have rough texture due to silica ($SiO_2$).
- Whisk ferns: branching stems without roots. Leaves reduced to small appendages or absent. Absence of roots/leaves is considered **secondary loss**; lost as whisk ferns diverged from ancestors.

These next two plant divisions produces seeds: male spores and female spores; **microsporangia** produces **microspores** (male spores) and **macrosporangia** produce the **macrospores** (female spores). Summary of seed plant reproduction:

- Microsporangium: produces numerous **microspore mother cell**, which divide by meiosis to produce 4 haploid cells (microspores-male) => mature into **pollen grains** (represent gametophyte generation) which divides into 3 cells (in flowering plants) or 4 cells (in conifers). One is **vegetative** (tube) cell that controls growth of pollen tube, others = sperms.
- Megasporangium: called **nucellus** produces **megaspore mother cell** → (meiosis) → 4 haploid cells, one survives to become **megaspore** (female gametophyte generation). **Megaspore** → (mitosis) → one egg (in flowering plants) or two eggs (in conifers). One/two tissue layers (**integuments**) surround megasporangium. **Ovule** (integument + nucellus + megaspore daughter cells); **Micropyle** is opening through integuments for pollen access to egg.
- **Once pollen grain contacts megasporangium**, tube cell (of sperm) directs growth of **pollen tube** through the micropyle and toward egg => fertilization (zygote) => embryo (beginning of sporophyte gen.); integuments => **seed coat**.

d. Coniferophyta: aka **gymnosperms** (naked-seeds): cone-bearing (pines, firs, spruces, junipers, redwoods, cedars); pollen-bearing male + ovule-bearing female cones; seeds produced in unprotected megaspores near surface of reproductive structure. Fertilization and seed development are lengthy (requires one to three years).

**e. Anthophyta (angiosperms)**: flowering plants, dominant land plant form. The major parts of flower:

1. Pistil: female reproductive structure (three-parts: **ovary (egg-bearing)**, **style**, and **stigma**).
2. Stamen: male reproductive structure (pollen-bearing **anther** and stalk, **filament**).
3. Petals: (and sometimes the **sepals** too) function to attract pollinators.

- Major evolutionary advancements: attracts pollinators (insects + birds); ovule protected inside **ovary** which develops into fruit => dispersal of seeds by wind or other animals.
- **Process of fertilization**:

1. Pollen lands on sticky stigma (female). Pollen tube (elongating cell) that contains **vegetative nucleus** grows down the style toward an ovule; **two sperm cells** inside pollen tube.
2. Ovule within ovary (consist of megaspore mother cell surrounded by nucellus + integuments). Megaspore mother cell => (meiosis) 4 haploid megaspores; one survives => (mitosis x 3) 8 nuclei => 6 nuclei undergoes cytokinesis and form plasma membranes (**embryo sac**). At the micropyle of embryo sac are 3 cells (**egg** + **2 synergids**). At the other end of micropyle are **3 antipodal cells**. In the middle are **polar nuclei** (2 haploid cells).
3. Pollen tube (2 sperm cells) enters embryo sac through micropyle; 1 sperm cell fertilizes egg (form diploid zygote); nucleus of 2nd sperm fuses with both polar nuclei => triploid (3N) nucleus → (mitosis) → **endosperm** (provide nutrient). **Double fertilization** is fertilization of the egg and polar nuclei each by a separate sperm.

| Phylum (Group) | Common Names | Dominant Gen. | Fluid Transport | Sperm Transport | Dispersal Unit |
|---|---|---|---|---|---|
| Bryophytes | Mosses, liverworts, hornworts | Gametophyte | Non-vascular | Flagellated sperm | spores |
| Lycophyta | Club mosses, spike mosses, quillworts | Sporophyte | Vascular | Flagellated sperm | Spores |
| Pterophyta | Ferns, horsetails, whisk ferns | Sporophyte | Vascular | Flagellated sperm | Spores |
| Coniferophyta | Conifers | Sporophyte | Vascular | Wind-dispersed | Seeds |
| Anthophyta | Flowering plants | Sporophyte | Vascular | Wind/animal | Seeds |

4. **Kingdom Animalia** (monophyletic: all can be traced back to one common ancestor)

- Variations in characteristics: (diverse kingdom, but its members share these characteristics: multicellular; heterotrophic; dominant diploid generation; *motile at some part of life cycle; *2-3 layers of tissues form during embryonic development.)

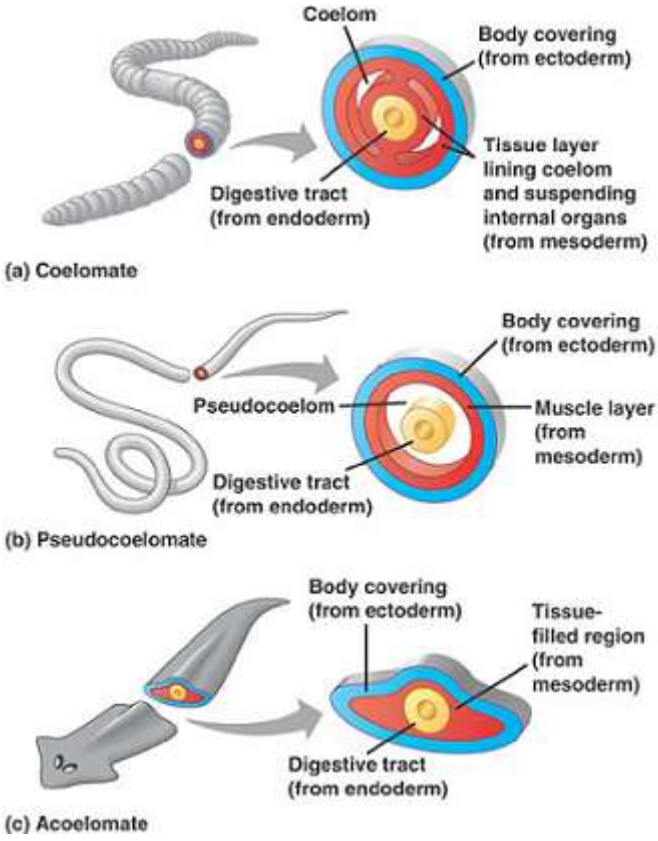
a. Tissue complexity: **eumetazoa** (functioning cells organized into tissues). **Diplobasltic/triploblastic** layers of tissue (ecto, meso, endoderm); another group is **parazoa** (cells not organized into true tissues => organs do not develop.)

b. body symmetry: **radial symmetry** (one orientation-front and back) w/ circular body pattern; **bilateral symmetry** (dorsal-top, ventral-bottom, head-anterior, tail-posterior).

c. Cephalization: in animals with bilateral symmetry (greater nerve tissue cxn at anterior end as organisms increase in complexity). E.g. brains have developed + sensory organs

d. Gastrovascular cavity: guts (digestion of food). One opening – sacline, limited processes. Two openings (**digestive tract**), specialized activities as food travels through

e. Coelom: more advanced animals develop this cavity derived from mesoderm; fluid-filled coelom cushions internal organs. **Acoelomate** animals lack coelom; **pseudocoelomate** animals have a cavity (but not completely lined by mesoderm-derived tissue).




f. Segmentation: sometimes repetitive and sometimes specialized (seen in: arthropods, annelids, chordates)

g. Protostomes and deuterostomes: **cleavages** (cell divisions in zygote's early development); **Archenteron** (The primitive gut that forms during gastrulation in the developing blastula. It develops into the digestive tract of an animal; its opening will either be mouth or anus). Coelom will either develop from splitting of mesodermal tissue at side of archenteron or directly from outpouching in archenteron wall. Know this img→

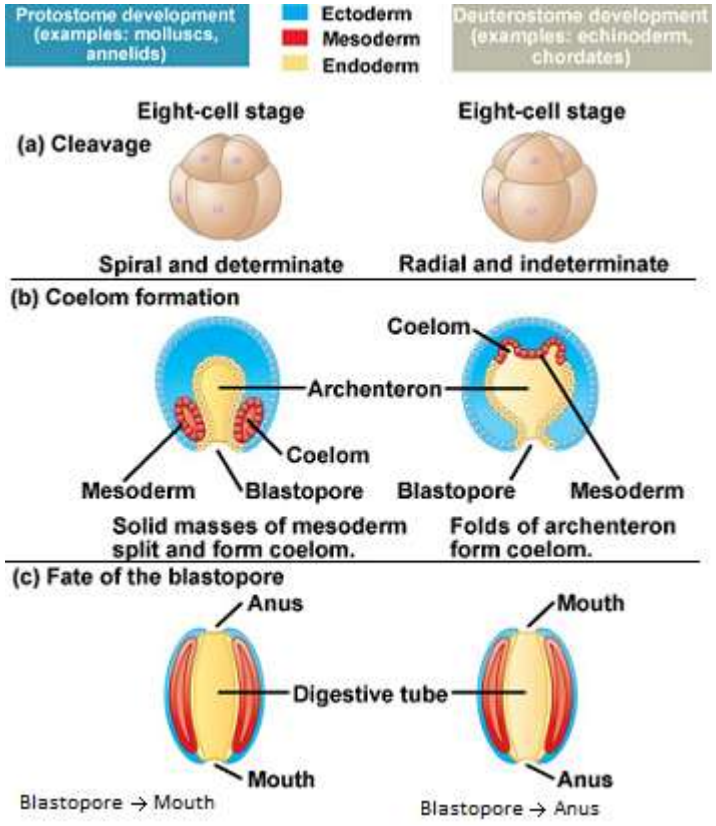
- List of Animal phyla:

- An **amebocyte** is a mobile cell in the body of invertebrates such as echinoderms, mollusks or sponges. They move by **pseudopodia** (a temporary protrusion of the cytoplasm-actin of an amoeba, serving for locomotion or the engulfment of food).

a. Porifera (parazoa): sponges; feed by filtering water through sponge wall of flagellated cells (**choanocytes**-flagella creates a flow of water for feed-filter). Water exits through **osculum** opening. Choanocytes pass food to **amoebocytes** (digesting + distribute nutrients); sponge wall contains **spicules** (skeletal needles made from $CaCO_3$ or $SiO_2$. Sessile (fixed). Used in development + research of antibiotics.

b. Cnidaria: hydrozoans, jellyfish, sea anemones, corals; two body forms (**medusa**-floating, umbrella-shaped body with tentacles; **polyp**-sessile cylinder-shaped with rising tentacles); some alternate between during medusa/polyp their life cycle.
**cnidoblasts –** specialized cells located in the tentacles and bodywalls of cnidaria; interior of cnidoblasts filled with stinging organelles (**nematocysts)**

c. Platyhelminthes: three types of **acoelomate flatworms**; **Free-living flatworms** (planarians-carnivores in marine or freshwater). **Flukes** are internal animal parasites/external parasites



that suck tissue fluids/blood. **Tapeworms** are internal parasites that often live in digestive tract of vertebrates; appear segmented (but these segments [proglottids] only develop secondarily for reproduction → not considered true segmented animal). Tapeworms do not have digestive tract, only need to absorb predigested food around them. Other Platyhelminthes have saclike gut.

d. Nematoda: roundworms: pseudocoelomate with complete digestive tract; free-living soil dwellers help decompose and recycle nutrients (causes trichinosis in human, when ingested via incompletely cooked meat).

e. Rotifera: multicellular with specialized organs enclosed in pseudocoelom, complete digestive tract; filter-feeder.

f. Mollusca: snail, octopus (highly developed NS w/ complex brain), squids (most have shells), bivalves (2 part shells e.g. clams and mussels); no shell in octopus, small and internal shell in squid. Mollusks have coelomate bodies, complete digestive tract, usually open circulatory system w/ internal cavity called **hemocoel**. Exoskeletons are **$CaCO_3$**

- **Class Gastropoda –** largest Molluscan class; ex. slugs & snails; characterized by *single shell*
- **Class Cephalopoda –** octopus and squid; have high O2 demand, giant nerve fibers, closed circulatory system
- **Class Bivalvia** - clams, mussels, scallops, oysters

g. Annelida: segmented worms (Leeches – have suckers at both ends for attachment and movement and are predators of small animals/blood parasites; earthworms; and polychaete worms – mostly marine, exhibit variety lifestyles). Septa divide the coelom into separate compartments.

h. Arthropoda: spiders, insects, crustaceans; jointed appendages, well-developed nervous system; specialized body segments, exoskeleton (chitin). Two kinds of life cycles: **Nymphs** (small version of adult, change shape as growth proceeds). **Larvae** are maggots specialized for eating; when they reach certain size => enclose themselves within **pupa** (cocoon) to undergo **metamorphosis** into adults (specialized to disperse and reproduce). Classes include:

- **Insects –** three pairs of legs, spiracles, tracheal tubes for breathing. More species than any other class on earth.
- **Arachnids –** four pair of legs and "book lungs" (spiders & scorpions)
- **Crustaceans (subphylum)–** segmented body with variable number of appendages and have gills. Crab, shrimp, lobster, crayfish, and barnacles

i. Echinodermata: sea stars, urchin, sand dollars; coelomate deuterostomes; complete digestive tract; adults have radial symmetry but are bilateral when young; some features are bilateral (ancestors are believed to have been bilateral).

j. Chordata: 4 main features (sometimes just temporary during embryonic development)

- **Notochord** provides dorsal, flexible rod that functions as support; replaced by bone during development in most vertebrates, it becomes nucleus pulposus of intervertebral disc; arrived from mesoderm. Defines primitive axis of embryo.
- **Dorsal hollow nerve cord** forms basis of nervous system. In some chordates, beomes brain and spinal cord.
- **Pharyngeal gill slits** provide channels across pharynx to outside body; slits become gills for $O_2$ or filter-feeding; slit disappear during embryonic development in others. In fish, gill pouch → fish gils. In mammals, gill pouch → Eustachian tubes in the ears
- **Muscular tail**: such tail is lost during embryonic development in humans and many other chordates
- Two groups of chordates: **invertebrate** chordates (lancelets, tunicates) and **vertebrate** (sharks, fish, amphibians, reptiles, birds, and mammals) have vertebrae that enclose the spinal cord.

Note: Reptiles have leathery eggs

**Review Classifications Excel sheet**

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## X. Plants

- Seed plants: include **gymnosperms** (conifers) and **angiosperms** (flowering plants). Angiosperms are divided into two groups: **dicotyledons** (dicots) and **monocotyledons** (monocots).

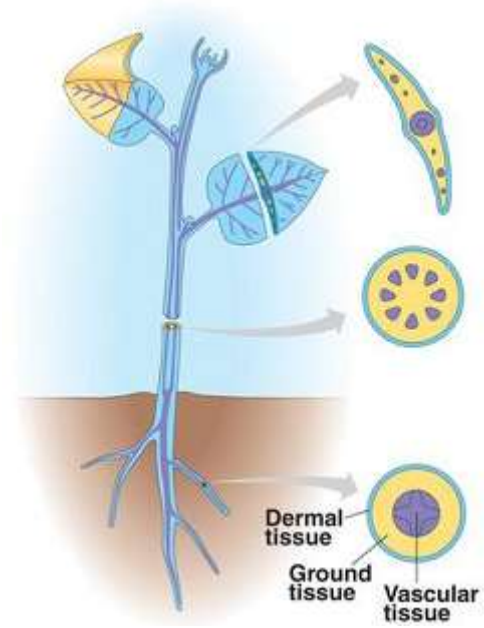
| Characteristics | Descriptions | Dicots | Monocots |
|---|---|---|---|
| Cotyledons | Storage tissue that provides nutrition to developing seedling | 2 cotyledons | 1 cotyledon |
| Leaf venation | Pattern of veins in leaves | Netted (branching pattern) | Parallel |
| Flower Parts | Numbers of petals, sepals, stamens, and other parts | In 4s, 5s, or multiples | In 3s or multiples |
| Vascular bundles | Arrangement of vascular tissue (xylem + phloem) in stems | Organized in a circle | Scattered |
| Root | Form of root | Taproot (large single root) | Fibrous system (many fine roots) |

**A. Plant Tissues** – 3 distinct major groups

1. Ground tissues: three kinds differ by nature of cell walls.
   a. Parenchyma: most common. Thin cell walls. Fxn: storage, photosynthesis, and secretion. (e.g. mesophyll cells in leaf)
   b. Collenchyma: thick but flexible cell walls, serve mechanical support functions.
   c. Sclerenchyma: thicker walls than collenchyma, also provide mechanical support.
2. Dermal tissue: epidermis cells that cover outside of plant parts: guard cells that surround stomata, hair cells, stinging cells, and glandular cells; in aerial portions of plants the epidermal cells secrete waxy protective substance: **cuticle**.

Note: roots do not have cuticle – would prevent them from absorbing water!

3. Vascular tissue: consists of xylem and phloem => form **vascular bundles**.
   a. Xylem: conduction of water and mineral and also fxns in mechanical support; have **2nd cell wall** for additional strength; some places in walls of xylem cells have **pits** (absence of 2nd cell wall). Cells are dead at maturity (no cellular component – just cell walls). Two kinds of xylem cells:
      - Tracheids: long and tapered where water passes from one to another through pits.
      - Vessel elements: shorter and wider, have less or no taper at ends. A column of vessel elements (members) is called a **vessel**. **Perforations** are where $H_2O$ passes through from one **vessel member** to the next (lack both 1st and 2nd cell wall). Perforations are an advantage vs. tracheids – $H_2O$ moves more efficiently
   b. Phloem: transport sugar. Made of cells called **sieve-tube members** (elements) that form fluid-conducting columns (**sieve tubes**); cells are living at maturity (but lack nuclei and ribosomes). **Pores** on end of member form **sieve plates** (areas where cytoplasm of one cell makes contact with next cell). Sieve tubes are associated with **companion cells** (living parenchyma cells that lie adjacent to each sieve-tube member) and connected by **plasmodesmata** to maintain physiological support due to lack of nuclei in the sieve-tube members.

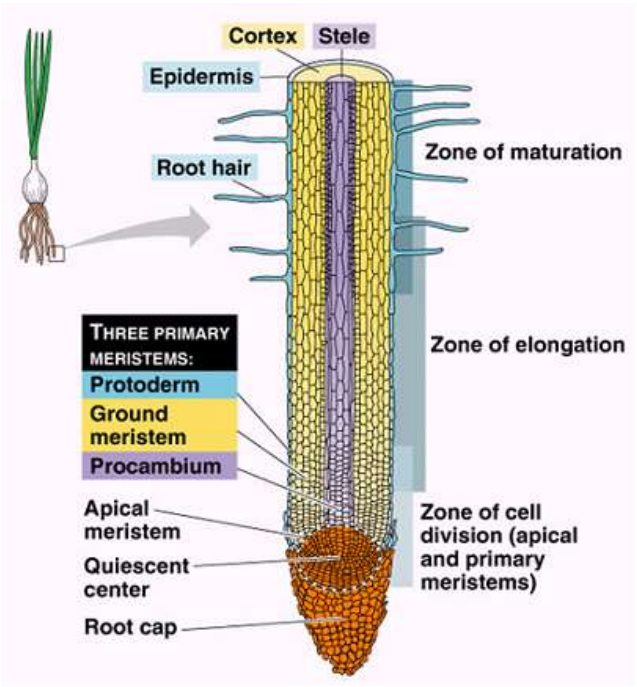



**B. The Seed** - development

- Consists of **embryo**, **seed coat**, and some kind of storage material (**endosperm** or **cotyledons**-formed by digesting material in endosperm). There are two cotyledons in **dicot** (pea), 1 cotyledon in **monocot** (corn). In many monocots the endosperm is the primary storage tissue, cotyledon fxns to transfer nutrients from endosperm → embryo.
- Embryo:
   1. **Epicotyl** (top portion of embryo) becomes shoot tip.
   2. **Plumule** are young leaves often attached to epicotyl; plumule can refer to both together.
   3. **Hypocotyl** becomes young shoot (below epicotyl and attached to cotyledons).
   4. **Radicles** develops from below hypocotyls into root.
   5. A sheath called **coleoptiles** (in monocots) surrounds and protects epicotyl. In developing young plants, coleoptiles appear 1st as leaf, but the 1st true leaves are from the plumule within the coleoptiles.

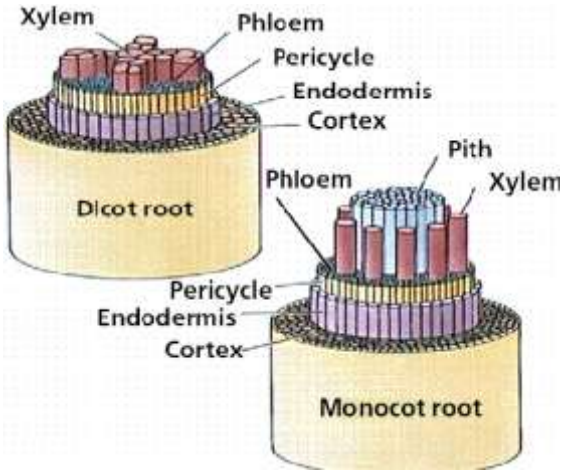
**C. Germination and Development**

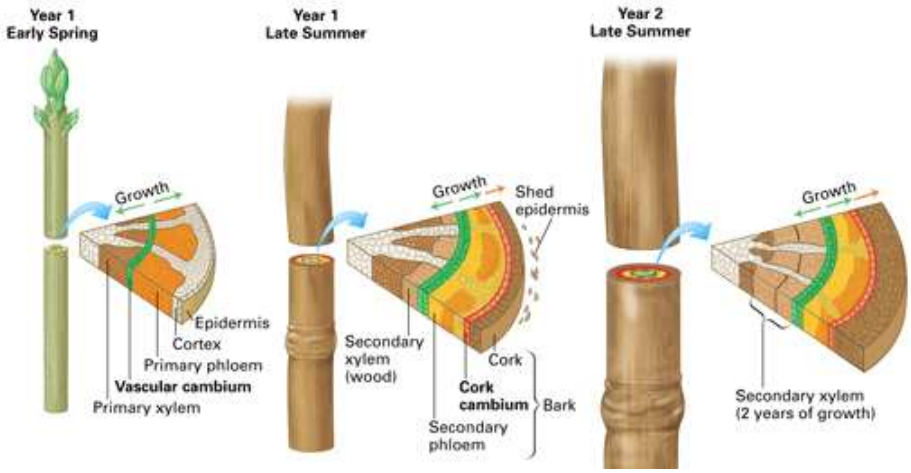
- Seed remain dormant at maturity until specific environment cues (water, temp, light, seed coat damage), others may have required dormancy period where germination won't happen regardless.
- Germination begins with inhibition (absorption) of water → enzymes activate → biochemical processes, respiration begin. Absorbed water causes seed to swell and seed coat to crack → growing tips of radicle produce roots that anchor seedling → elongation of hypocotyl → young shoot formed.
- In young seedling/plants, growth occurs at tips of roots and shoots (**apical meristerms**); areas of actively dividing (**meristematic**) cells. This kind of growth is called **primary growth** (produces **primary**



**tissues-primary xylem** and **primary phloem** → elongation). Most plants (incl. most monocots) just have this.
Root growth:
- Root cap: aka root tip, protects apical meristem behind it. Secretes polysaccharides that moisten soil, permitting root growth.
- Zone of cell division: formed from dividing cells of apical meristem.
- Zone of elongation: newly formed cells absorb water and elongate. Responsible for our perception of growth.
- Zone of maturation: differentiation; cells mature into xylem, phloem, parenchyma, or epidermal cells (root hairs may grow here). Note on root growth overall: the above is very similar for shoot tip growth, except there is no root cap present.
- **Meristems:** are areas in plants where active mitosis occurs, due to this cell division, it is also where growth occurs. Lateral meristems can be at tip of lateral growth in plant. Apical meristems are responsible for vertical growth and found at root and shoot (apex) tips.

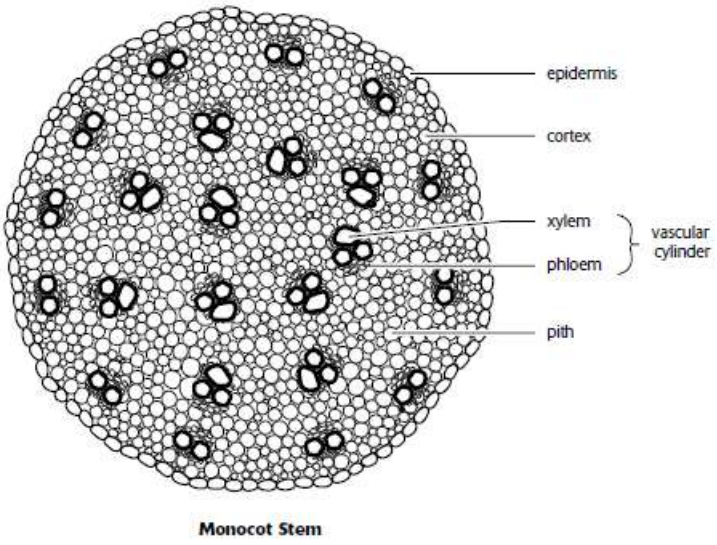
**D. Primary Growth Versus Secondary Growth**
- Conifers and woody dicots undergo **secondary growth** in addition to 1º growth (which extends length). 2º growth increase girth and is the origin of woody plant tissues; occurs at the **two lateral meristems:** the **vascular cambium (**2º xylem and 2º phloem) and the **cork cambium** (gives rise to periderm-protective material that lines outside of woody plant).



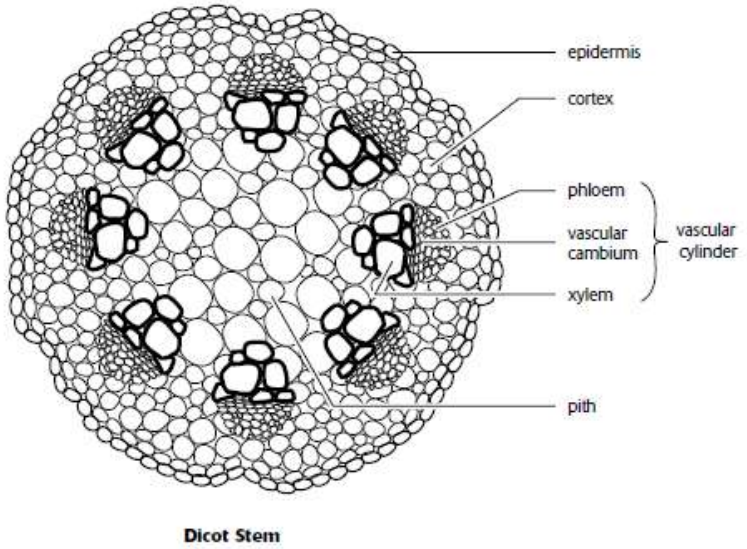




E. **Primary Structure of Roots**: from outside of root to center:
1. Epidermis: lines outside surface of root. In zone of maturation, epidermal cells produce **root hair**). When zone of maturation ages, root hair die. New epidermal cells from zone of elongation becomes cell of new zone of maturation, forms new root hairs to continue absorption of water. Old epidermis fxns to protect root.
2. Cortex: makes up bulk of root, storage of starch, contain intercellular spaces to provide aeration of cells for respiration.
3. Endodermis: ring of tightly packed cells at inner most portion of cortex. A band of fatty material (**suberin**) impregnates endodermal cell walls to form encircling band called **Casparian strip**: creates water-impenetrable barrier between cells → All water passing through endodermis must pass through endodermal cells, not between → controls movement of water into center of root and prevents water from moving back out to cortex
4. Vascular cylinder (stele): makes up tissues inside endodermis (phloem, xylem, pericycle). Outer part consists of one/several layers of cells (**pericycle**-from which lateral root arise). Inside pericycle are vascular tissue.
   - Dicot: **xylem** cells fill center of vascular cylinder (shape X with **phloem** (sieve-tube members and companion cells) in the spaces of X).

- Monocot: groups of xylem and phloem alternate in a ring with the **pith** in the middle.



Monocot Stem



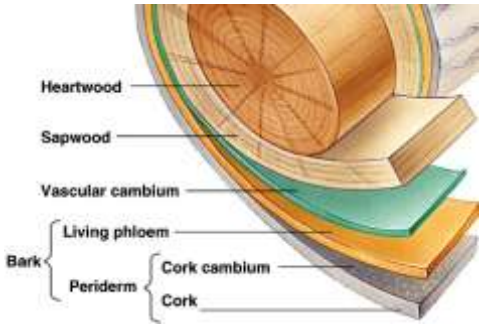
Dicot Stem

**E2. Primary Structure of Stems**

- Lack endodermis and Casparian strips (not needed, these tissues specialized for water absorption).

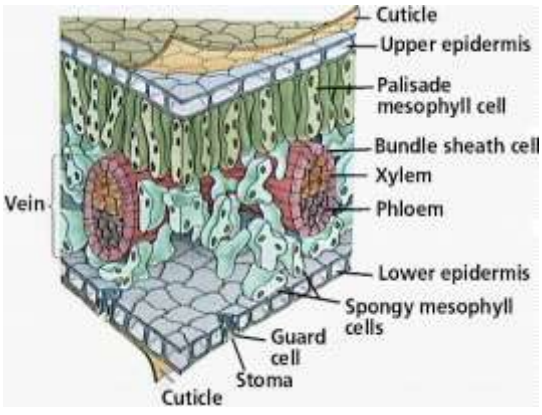
1. Epidermis: contain epidermal cells covered with waxy (fatty) **cutin** which forms protective layer called **cuticle**.
2. Cortex: ground tissue types that lies between epidermis and vascular cylinder (many contain chloroplasts).
3. Vascular cylinder: consists of **xylem, phloem,** and **pith**. In dicots + conifers, xylem and phloem are grouped in bundles (xylem inside, phloem outside) that ring a central pith area. A single layer of cells between the xylem and phloem may remain undifferentiated and later become the **vascular cambium**.

**F. Secondary Structure of Stems and Roots**




- Vascular cambium: becomes cylinder of tissue that extends the length of stem and root. Secondary growth in a stem illustrated above (cambium layer is meristematic, producing new cells on both inside and outside the cambium cylinder).
- Cells on the inside differentiate into **2º xylem**, and those on the outside into **2º phloem**. Over years, 2° xylem accumulate and increase girth of stem and root.
- Outside of cambium layer, new 2° phloem are added yearly. As a result, tisues beyond the 2° phloem are pushed outward as xylem increases its girth. These tissues include the primary tissue (epidermis and cortex) break apart and shed.
- In order to replace shed epidermis, **cork cambium** produces new cells on the outside (**cork cells**-impregnated with suberin). On the inside, **phelloderm** may be produced. Together, the cork/cork cambium/phelloderm are called **Periderm**. In stem of dicots/conifers, cork cambium originates from cortex just inside epidermis. In root, it originates from pericycle.
- Wood: formed from xylem tissues at maturity (dead), only the more recent 2º xylem produced from vascular cambium remain active to transport water (**sapwood**). Older xylem located at center (**heartwood**) functions only as support.
- Annual rings: alternation of growth (active vascular cambium divides) and dormancy due to season in secondary xylem tissue. Size of rings → rainfall history. Number of rings → age of tree.

**G. Structure of the Leaf**




1. Epidermis: protective layer(s), covered with **cuticle** (protective layer containing waxy **cutin**) which reduces **transpiration** (water loss through evaporation); may bear **trichomes** (hair, scales, glands, etc. outgrowths).
2. Palisade mesophyll: consists of parenchyma cells with chloroplasts and large surface area (specialized for photosynthesis). Oriented and packed in at upper surface, but for dry habitat → both surfaces. (leaf photosynthesis occurs here primarily)
3. Spongy mesophyll: parenchyma cells loosely arranged below palisade mesophyll. Numerous intercellular spaces provide air chambers $CO_2$ to photosynthesizing cells, $O_2$ to respiring cells.
4. Guard cells: specialized epidermal cells control opening and closing of **stomata** (allow gas exchange).

5. Vascular bundles: consist of xylem (water for photosynthesis) and phloem (transports sugar and by-products of photosynth to other parts of plants). **Bundle sheath cell** surrounds vascular bundle → no vascular tissue exposed to intercellular space → no air bubbles that can enter to impede movement of water; also provide anaerobic environment for $CO_2$ fixation in $C_4$ plant.

**H. Transport of Water**

- Enter root through root hairs by osmosis. There are two pathways for water → center of root:
  a. Water move through cell walls and intercellular spaces from one to another without ever enter cells. This pathway is called **apoplast** (nonliving portion of cells).
  b. Water move through cytoplasm of one cells to another (**symplast**-living portion) through **plasmodesmata** (small tubes that connect cytoplasm of adjacent cells).
- Once $H_2O$ reaches endodermis, it can only enter by symplast (due to Casparian strips blocking) into the stele (vascular cylinder) and is selective permeable ($K^+$ pass, $Na^+$ is blocked - common in soil but unused in plants). Once through endodermis, apoplast pathway takes over to reach xylem (which is the major conduction pathway via tracheids and vessels)

1. Osmosis: moves from soil through root and into xylem by gradient (continuous movement of water out of root by xylem, and high [mineral] inside stele). This osmotic force (**root pressure**) can be seen as **guttation**, formation of small droplets of sap (water and minerals) on ends of leaves in morning. But mostly, root pressure too small to have major effect on $H_2O$ transport
2. Capillary action: rise of liquids in narrow tubes, contribute to movement of $H_2O$ up xylem; results from forces of **adhesion** (molecular attraction between unlike substances) between $H_2O$ and tube → **meniscus** is formed at top of water column. No meniscus in active xylem since water forms a continuous column; capillary effect minimal.
3. Cohesion-tension theory: most water movement is explained by this; major contributor (above two minimal). Consists of:
   a. Transpiration: evaporation of water from plants, removes water from leaves => causing **negative pressure** (tension) to develop within leaves and xylem.
   b. Cohesion: attraction between like substances (water); so $H_2O$ within xylem cells behaves as a single, polymerlike column from roots to leaves
   c. Bulk flow: when a water molecule is lost from a leaf by transpiration, it pulls up behind an entire column of water molecules (generated by transpiration, which is itself caused by heat action of the sun, so technically sun drives sap ascent).

**I. Control of Stomata** – open vs closed – affects gas exchange, transpiration, sap ascent, photosynthesis

- When stomata are closed → $CO_2$ not available → cannot photosynthesize.
- When stomata are open → $CO_2$ can enter leaf → photosynthesize but plant risks desiccation from transpiration.
- Guard cells: two surrounds the stomata. Cell walls of guard cells do not have the same thickness (thicker when border the stomata). Guard cell expand when water diffuses in. Due to the irregular thickness and radial shape, the sides with thinner cell walls expand more → creates opening (**stoma**). When water diffuses out → kidney shape collapses and stoma closes.
- Factors involved in mechanism of opening and closing:
  1. High Temp -> Close.
  2. Low [$CO_2$] inside → Open → photosynthesis.
  3. Close at night, Open during day. $CO_2$ is low during daylight because used by photosynthesis. Could be response to $CO_2$ levels: high at night because of respiration, low during day because used for photosynthesis.
  4. Stomata opening accompanied by diffusion of $K^+$ into guard cell → create gradient → more water moves in).
  5. $K^+$ enter → unbalanced charge state. $Cl^-$ can come in or $H^+$ (from ionization of cell's organic substances) gets pumped out.

QVault: guard cells also have a blue light receptor on plasma membrane, blue light → H2O in → stomata opens

**J. Transport of Sugars**

- Translocation: movement of carbohydrate through phloem from a **source** (e.g. leaves) to **sink** (site of carb utilization). Described by **pressure-flow** hypothesis:

1. Sugars enter sieve-tube members: soluble carbs move from site of production (palisade mesophyll) to phloem sieve-tube members by active transport => higher [solute] at source than at sink [root].
2. Water enters sieve-tube members: water diffuses into source by osmosis to balance the lower water cxn from step 1.
3. Pressure in sieve-tube members at source moves water and sugars to sieve-tube members at sink through sieve tubes: when water enters the sieve-tube members, pressure build up since rigid cell walls do not expand. Result: water and sugar move by bulk flow through sieve tubes (through plates between sieve-tube members).

4. Pressure is reduced in sieve-tube members at sink as sugar are removed for utilization by nearby cells: pressure begins to build up at sink (from bulk flow source → sink). However, sink is where sugar are used →sugars removed from sieve-tube members by active transport → increases [water] at sink → water diffuses out of cell → relieves pressure.

- Cells store energy as insoluble starch – benefit of this = any cell can act as a SINK and get the sugar and water transported there
    - Likewise, by breaking down starch, any cell can act as a source (e.g. plant roots at night break down starch when photosynthesis activity is low, they act as a sugar source)

**K. Plant Hormones**

- Auxin (IAA-indoleacetic acid): promotes plant growth (elongation of cells) by increasing [$H^+$] in primary cell walls → activates enzymes that loosen cellulose fiber (increase cell wall plasticity) thus turgor pressure expands cells to grow. Produced at tips of shoots and roots (apical meristem). In concert w/ other hormones, influeces plant response to light (phototropism) and gravity (geotropism). It is a modified tryptophan AA. After synthesis it is actively transported (ATP) from cell to cell in a specific direction (polar transport) by means of chemiosmotic process. It inhibits lateral buds when it is produced at terminal bud of growing tip. Moves unidirectional from shoot to root.
- Gibberellins (GA): group of hormones that promote cell growth (flower and stem elongation),synth'd in young leaves/roots/seeds then transported to other parts of plant. Can act together w/ auxin to stim growth.Involved in inhibition of aging in leaves, promote fruit development and seed germination (gibberellin is released from embryo, moves through endosperm to aleurone layer. Aleurone then secretes digestive enzymes (amylase) to break down endosperm starch into sugars → nourishment → germination commences. High cxn of gibberellins causes bolting (rapid elongation of stems).
- Cytokinins: stimulate cytokinesis [cell division], stimulate (and influence direction of) organogenesis; stimulate growth of lateral buds (which weakens **apical dominance**-dominance growth of apical meristem); delay **senescence** (aging) of leaves. Effects depend on target organ and presence/cxn of auxin. Structurally: variations of the nitrogen base adenine; include naturally occurring zeratin and artificially produced kinetin.
- Ethylene ($H_2C=CH_2$): gas that promotes ripening of fruit; production of flowers; influences **leaf abscission** (aging [**senescence**] and dropping of leaves); apoptosis. Together w/ auxin, can inhibit elongation of roots, stems, and leaves. Stimulates ripening by enzymatic breakdown of cell walls. Ethylene is why ripe fruit in proximity to a spoiled one will als cause it to spoil – remember, it is gaseous.
- Abscisic acid (ABA): growth inhibitor. In buds it delays growth and forms scales, maintains dormancy in seeds. Dormancy can be broken by increase in gibberellins or mechanistic response to environmental cues (temp, light).

**L. Plant Responses to Stimuli** – anchored by roots → can't move to respond to environmental stimuli. Instead, change growth pattern.

- Tropism: growth pattern in response to an environmental stimulus
- Phototropism: response to light (achieved by hormone auxin). Auxin is produced in apical meristem → moves downward by active transport into zone of elongation → generate growth by stimming elongation.
    - Stem grows straight when all sides of apical meristem are equally illuminated. But growth can be differential if…
    - When not equally illuminated, auxin moves more toward shady side (grow more) → stem bends toward light.
- Gravitropism (geotropism): response to gravity by stems and roots (auxin and gibberellins involved).
    - If stem is horizontal, auxin concentrates on lower side => stem bends upward.
    - If root is horizontal, auxin is produced at apical meristem moves up in root and concentrates on lower side.

However, auxin *inhibits* growth in roots due to higher [auxin] at root than stems → lower side grows less, root curls down

Note: Dissolved ions, auxins, gibberellins, and other hormones do not directly respond to gravity (evenly distributed in solution regardless). BUT starch is insoluble in water and does respond to gravity. It's believed that specialized starch-storing plastids called **statoliths,** which settle at the lower ends of cells, somehow influence the direction of auxin movement.

- Thigmotropism: response to touch (e.g. vines wrap around object they contact)

**M. Photoperiodism**

- Photoperiodism: response of plants to changes in **photoperiod** (relative length of daylight and night); plants maintain **circadian rhythm** (a clock that measures length of daylight and night); **endogenous** mechanism (internal clock that continues to keep time even if external cues are absent). External cues (dawn, dusk) reset clock for accuracy.
- Phytochrome: protein modified with light-absorbing chromophore. Two forms: $P_r$ ($P_{660}$-red) and $P_{fr}$ ($P_{730}$-far red). They are reversible. When exposed to red light, $P_r$ → $P_{fr}$ and vice versa.

1. $P_{fr}$ appears to reset circadian-rhythm clock: $P_{fr}$ is active form of phytochrome; maintains accuracy by resetting clock

2. $P_r$ is the form of phytochrome synthesized in plant cells: $P_r$ is synthesized in leaves.
3. $P_r$ and $P_{fr}$ are in equilibrium during daylight: red light is present as sunlight $P_r \rightarrow P_{fr}$ and far-red is also present ($P_{fr} \rightarrow P_r$)
4. $P_r$ accumulates at night: cells keep making $P_r$ at night, but no sunlight to convert $P_r \rightarrow P_{fr}$; $P_{fr}$ breaks down faster than $P_r$ and is also converted back to $P_r$ metabolically → $P_r$ accumulates
5. At daybreak, light rapidly converts accumulated $P_r$ to $P_{fr}$: equilibrium is maintained.
6. Night length is responsible for resetting clock: Interrupt daylight with brief dark period → no effect. But flashes of red and far-red during night period can reset the clock. Only the last flash effects the night length. Red → shorter night length. Far Red → Restores night length.
    - Flash of red during night: $P_r \rightarrow P_{fr}$ → shorter night period measured → circadian rhythm reset
    - Flash of far-red after red flash → effect of red light reversed → night length restored to before
    - In series of alternating flashes, only last one affects perception of night length: red shortens, far-red restores

* Flowering Plants: initiate flowering in response to changes in photoperiod
  1. Long-day plants: flower in spring and early summer when daylight is increasing.
  2. Short-day plants: flower late summer and early fall when daylight is decreasing (need daylight < a critical length)
  3. Day-neutral plants: do not flower in response to daylight changes but temp or water.

- Florigen: when flowering is initiated, this flowering hormone is produced in leaves and travels to shoot tips

Phytochrome involved in other light-related fxns:

- Many seeds require minimum light exposure before germinating. Phytochrome system detects changes in light amt → if critical exposure is exceeded (or other facts like water present) → giberellins produced (or ABA destroyed) → germination
- Red to far red ratio is measured by phytochrome to sense quality of light (i.e. if it is being shaded by other plants). If shaded it can stim growth if the plant is shade-intolerant.
- In C3 plants, $CO_2$ levels are relatively low in leaves when photosynthesis is active during the DAY, when stomata are OPEN. At night stomata close and $CO_2$ levels in leaves increase due to respiration.
- In CAM plants, stomata closed during day but photosynthesis proceeds because $CO_2$ supplied by metabolic conversion of malic acid

Note: Rhizomes are underground stems that can sprout to produce new shoots and roots for the plant.

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## XI. Animal Forms and Functions

- Tissues: 4 types (epithelial [skin, internal covering]; connective [bone, cartilage, blood], nervous, muscle).
- Negative feedback: original condition is canceled so that conditions are returned to normal.
- Positive feedback: an action intensifies a condition so that it is driven further beyond normal limits (labor contraction, lactation, and sexual orgasm).
- Respiration: movement of gases in and out; also means cellular respiration producing ATP within mitochondria.

Thermoregulation –

- Ectotherms – obtain body heat from environment (aka poikilotherms/cold-blooded)
    - Invertebrates, amphibians, reptiles, fish
- Endotherms – generate their own body heat (aka homeotherms/warm-blooded)
- Regulatory mechanisms
    - Evaporation – body heat is removed as liquid evaporates (endergonic)
    - Metabolism – muscle contraction and other metabolic activities generate heat
    - Surface Area – Vasodilation or vasoconstriction of extremity vessels results in heat retention or removal (blood flow to ears reduce body temp, countercurrent exchange keeps central parts of body warm)

### B. The Respiratory System – gas exchange mechanisms:

**Invertebrate Respiration:**

- Cnidaria: Protozoa and Hydra
    - **Direct with environment:** large surface areas and every cell is either exposed to environment or close to it → simple diffusion of gases directly with outside environment (e.g. flatworms). Small animals only.
- Annelids:
    - Mucus secreted by earthworm provides moist surface for gaseous exchange by diffusion
    - Circulatory system bring $O_2$ to cells and waste products ($CO_2$) back to skin for excretion
- Arthropods (80% of all living species – insects, spiders, crustaceans (crabs), etc…
    - Grasshopper
        - Series of chitin-lined respiratory tubules called **trachae** open to surface in openings called **spiracles** through with O2 enters, CO2 exits. No oxygen carrier is needed due to direct distribution and removal of respiratory gases between air and body cells; diffusion across moistened tracheal endings.

- Spider
  - Book lungs: stacks of flattened membranes enclosed in internal chamber
- Fish
  - Water enters mouth, passes over **gills** (evaginated structures, create large SA, take $O_2$ and deposit CO; can be external/unprotected or internal/protected), exits through **operculum** (gill cover). **Countercurrent exchange** between opposing movements of water and underlying blood maximizes diffusion of $O_2$ into blood and $CO_2$ into water

**Plant Respiration**

- Photosynthesis only takes place during the day.
  - Photosynthesis produces glucose and gives off oxygen
  - While respiration requires oxygen to degrade glucose
- Plants undergo aerobic respiration similar to animals
  - Glucose → 2ATP + 2 pyruvic acid
  - Gases diffuse into air space by entering and leaving through **stomata** of leaves or **lenticels** in woody stems
  - Anaerobic respiration takes place in simple plants when molecular oxygen is lacking

4. Lungs: invaginated structures

- Gas exchange in human: $CO_2$ is transported as $HCO_3^-$ in the plasma (liquid portion of blood), catalyzed by **carbonic anhydrase** (**$CO_2 + H_2O \leftrightarrow H_2CO_3 \leftrightarrow H^+ + HCO_3^-$**) located in the RBC. Some $CO_2$ mixes direct w/ plasma as gas, or binds with hemoglobin in RBCs

- **Alveoli –** where gas exchange between the circulatory system and the lungs occurs; **surfactant** reduces the surface tension (prevents H2O from collapsing alveoli). There are two types of epithelial cells in human alveoli: type 1 (structural support) and type 2 (produce surfactant)
  - Nose (filter, moisten, warms incoming air – mucus secreted by goblet cells traps large dust particles here), pharynx (throat – passageway for food and air; dust/mucus swept back here by cilia for disposal via spitting or swallowing), larynx (voice box- if non-gas enters, cough reflex activates)
  - Trachea (**epiglottis** covers the trachea during swallowing) – ringed cartilage (**C-shaped**) covered by ciliated mucus cells
  - Bronchi, Bronchioles: Two bronchi, which enter the lungs and branch into narrower bronchioles
  - Alveoli: Each bronchiole branches ends in these small sacs, which are surrounded by blood-carrying capillaries
  - Diffusion between alveolar chambers and blood: Gas exchange across moist, sac membranes of alveoli. $O_2$ diffuses through alveolar wall, through pulmonary capillary wall, into blood, and into red blood cells. ($CO_2$ is opposite)
  - Bulk flow of $O_2$: $O_2$ transported through body within hemoglobin containing red blood cells (RBCs)
  - Diffusion between blood and cells: Oxygen diffuses out of RBCs, across blood capillary walls, into interstitial fluids, and across cell membranes ($CO_2$ opposite)
  - Bulk flow of $CO_2$: $CO_2$ mainly transported as $HCO_3^-$ ions in plasma, liquid portion of blood. Produced by carbonic anhydrase in RBCs. $CO_2$ can also directly mix with plasma (as $CO_2$ gas), or bind hemoglobin inside RBCs
  - Bulk flow of air into and out of the lungs:
    a. **Inhalation –** diaphragm (under lungs) and intercostal muscles (between ribs) contract/ flattens; increase in volume / decrease in pressure in lungs → bulk flow of air into lungs.
    b. **Exhalation –** passive process; decrease in lung volume/ increase in air pressure→air rushes out; diaphragm relaxes and expands

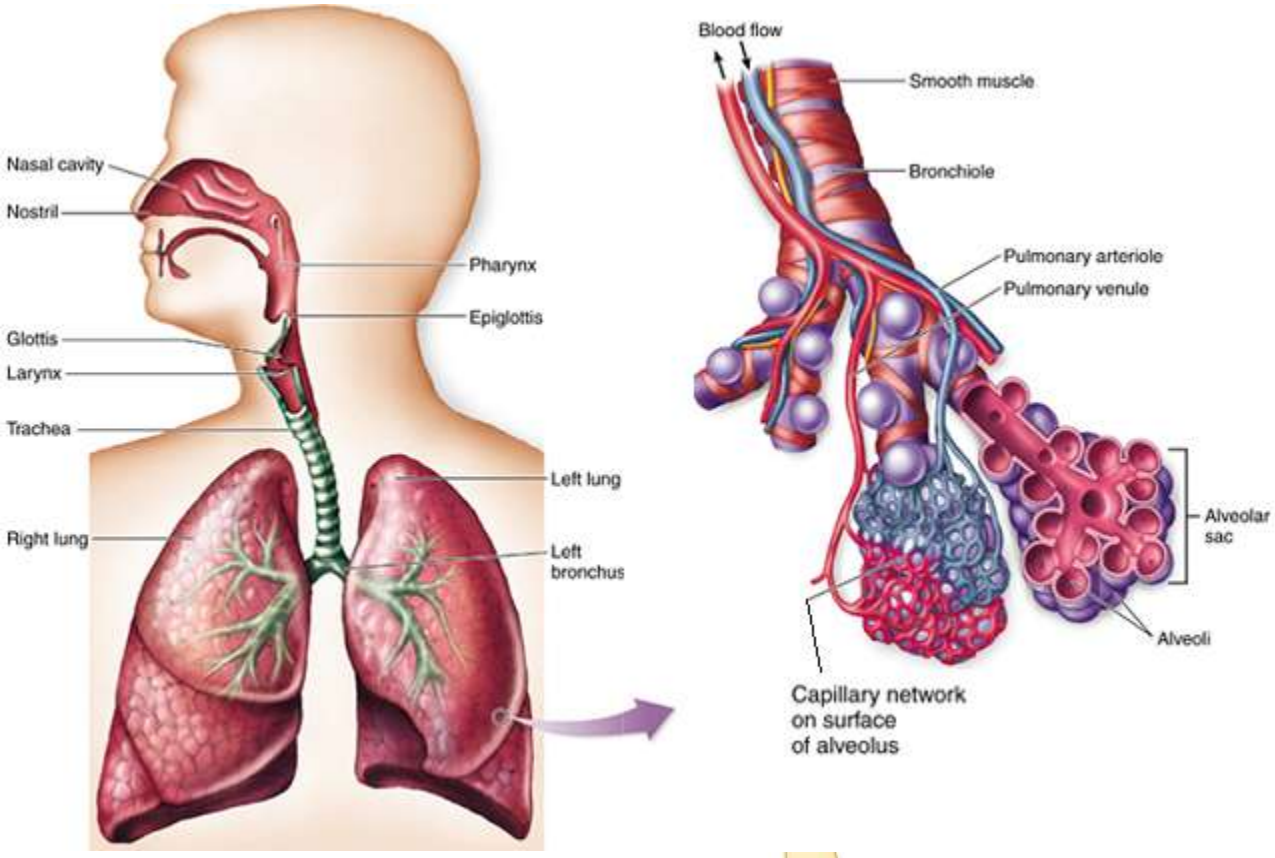
  **Bohr effect** – hemoglobin $O_2$ binding affinity decreases under conditions of low pH (high $CO_2$ & [H+]) → oxygen loads released by hemoglobin
  - Decrease in $CO_2$ or increase in pH will result in hemoglobin binding more $O_2$
  - Result of: $CO_2 + H_2O \rightleftharpoons H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$

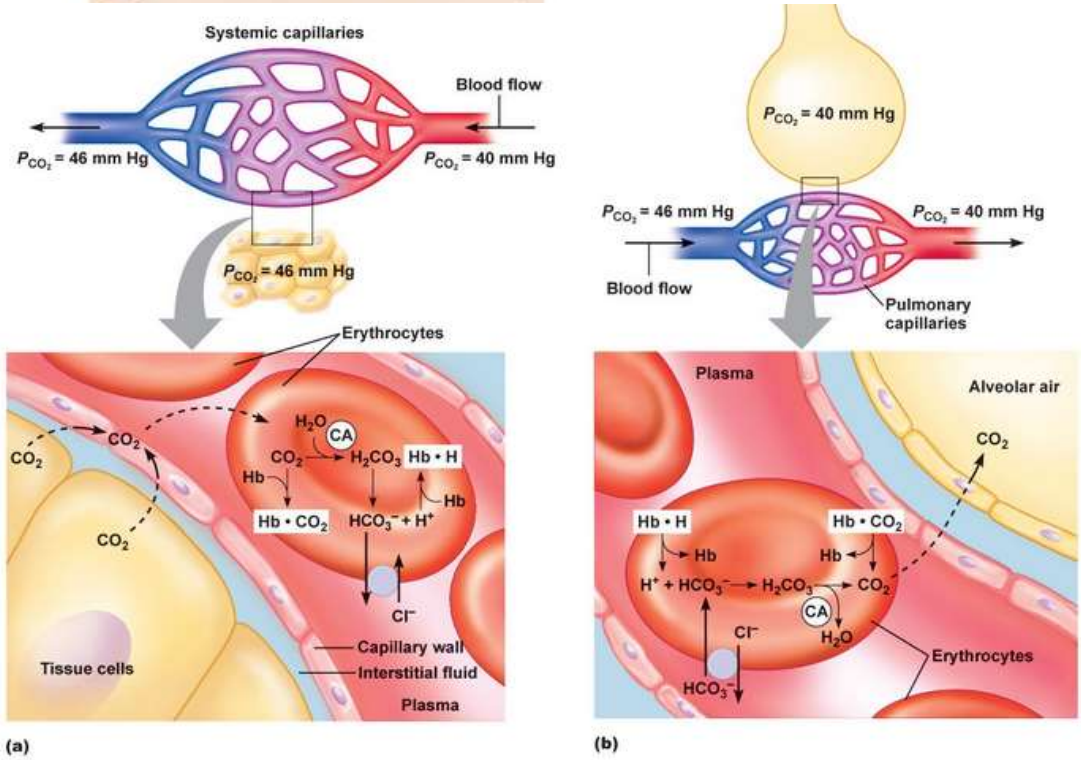
  **Haldane effect** - Basically explains $CO_2$'s dissociation curve. ↑ $CO_2$ pressure = ↑ $CO_2$ content in blood. But when hemoglobin is saturated by oxygen, its capacity to hold $CO_2$ is reduced. Essentially: we pick up $CO_2$ in the tissues where it's been generated, and get rid of it at the lungs and grab oxygen instead. Hemoglobin w/out oxygen acts as blood buffer by accepting H+ → this reduced hemoglobin has higher capacity to form carbamino hemoglobin rather than the oxygen carrying kind, explaining how the Haldane effect occurs.

*Oxygen diffuses from alveolar air into blood, $CO_2$ diffuses from blood into lungs

- Human respiration controlled by **medulla oblongata – signals the diaphragm to contract**
  - When $pp_{CO2}$ increases, medulla stimulates increase in rate of ventilation
  - The diaphragm is a skeletal muscle innervated by the phrenic nerve. It is also the only organ which only and all mammals have, and without which no mammals can live.

**Critical note: the majority of CO2 in the blood is transported in the form of the bicarbonate ion ($HCO_3^-$). To a lesser extent, it can be transported bound to haemoglobin/plasma proteins, and to an even lesser extent simply dissolved in the plasma ($CO_2$ is significantly more soluble in blood than $O_2$)**




Above: use this to clear up confusion on carbonic anhydrase's role. (a) At the tissues, we have a high cxn of $CO_2$ – it diffuses into the blood, into the cell, where carbonic anhydrase turns it into $H_2CO_3$, which then becomes bicarbonate and H+. The bicarbonate then travels out to the plasma, where it travels through the blood. This also explains why high [CO2] = low pH: the formation of bicarbonate (done in the presence of high [CO2]) results in H+ creaton as well. In (b) we have reached the lungs – $CO_2$ wants out and $O_2$ wants in. The $CO_2$ is in bicarbonate form though, so it has to re-enter the RBC where CA enzyme will now catalyze the reverse rxn to turn it back into $CO_2$. It will then diffuse out to the lungs. There is also hemoglobgin to consider: hemoglobin also interacts with the H+ to form a more reduced version of hemoglobin that does not bind oxygen as well (and binds CO2 more) – so in the presence of high [CO2] and [H+], the hemoglobin structure is altered to the reduced form that will release its oxygen. Bigger picture: tissues are high CO2 and high H+, and they're not getting a lot of oxygen, we want to oxygenate them. So Hb (Hemoglobin) once near the tissues is exposed to the higher CO2/H+, and changes structure to reduced form: this reduced form now releases its O2 to the tissues, and will also more preferably bind CO2. At the lungs, the CO2 wants out and is released. The H+ cxn is also lower due to bicarbonate being converted back into CO2 form for release. Now hemoglobin will change to its non-reduced state that preferably binds oxygen, which it holds more tightly under these conditions. The Bohr effect relates to how [H+] affects hemglobin's affinity for O2. The Haldane effect relates to higher PO2 means hemoglobin binds CO2 less and vice versa. Also: higher temperature → O2 unloads more easily. Also: 2,3 -DPG is produced from an

intermediate compound in glycolysis and decreases the affinity of hemoglobin for oxygen. At low oxygen levels an enzyme catalyzes the synthesis of 2,3-DPG. Hence, 2,3-DPG concentration increases, the affinity of Hb for oxygen decreases. This is helpful for unloading oxygen during anemia and at high altitudes. At high oxygen levels, oxyhemoglobin inhibits the enzyme that synthesizes 2,3-DPG and 2,3-DPG levels decrease. Note the chloride shift that occurs to balance bicarbonate ion leaving/entering the cell Visual

- Control of respiration: central chemoreceptors in the medulla monitors [H+] in the cerebrospinal fluid (though not directly) and peripheral chemoreceptors in the carotid arties and aorta monitor aterial [$CO_2$], [$O_2$], and [H+]. In an active body, there is increased $CO_2$ production; it enters plasma is converted to $HCO_3^-$ and $H^+$, the blood pH drops → respiratory rate increases. Oxygen and pH mainly monitored by the peripheral chemoreceptors.

**Chemistry of Gas Exchange**

- 98% of blood oxygen binds rapidly and reversibly with protein hemoglobin inside RBCs, forming oxyhemoglobin
  - Hemoglobin structure is 4 polypeptide subunits, each has a heme cofactor (organic molecule w/ iron atom center)
    - Each iron atom can bind with one $O_2$ molecule
    - Via cooperativity: one $O_2$ binds → the rest bind easier (this is why hemoglobin has a sigmoidal shape). Likewise: one $O_2$ released → the rest release easier.
  - As $O_2$ pressure increases, $O_2$ saturation of hemoglobin increases
    - This is ideal – in the lungs we are O2 rich and want to hang on to it, but in the tissues we are O2 poor (lower O2 pressure) so the hemoglobin will release the O2 to the tissues
  - $O_2$ saturation of hemoglobin also depends on $CO_2$ pressure, pH, temp of blood
    - Oxygen dissociation curve shows the percentage of hemoglobin bound w/ $O_2$ at various partial pressures of $O_2$
    - Curve is shifted right (i.e. oxygen is released easier, low O2 affinity) by an increase of $CO_2$ pressure, H+ cxn, or temp (and vice versa) (CADET face Right! – **C**O2, **A**cid, 2,3-**D**PG, **E**xercise, and **T**emperature)
    - **Bohr effect** – hemoglobin $O_2$ binding affinity decreases under conditions of low pH (high $CO_2$ & [H+]) → oxygen loads released by hemoglobin because both $O_2$ and H+ compete for binding at hemoglobin molecule
    - 2,3-DPG cxn increase also shifts right: it's produced in presence of diminished peripheral tissue O2 capacity
  - Metabolic vs respiratory acidosis/alkalosis: distinguishable by the cause of the imbalance (respiratory from breathing issues, metabolic from anything else). Respiratory acidosis comes from inadequate ventilation: we don't clear enough $CO_2$ and it builds up, so via rxn above more H+ ends up getting formed → pH drops in tissues. Respiratory alkalosis comes from breathing too rapidly: we are losing $CO_2$ too quickly, via rxn above, H+ and $HCO_3^-$ start combining to form more $CO_2$, pH rises. Metabolic acidosis and alkalosis are not due to breathing issues – you may alter breathing to compensate, but the cause is not breathing related.
  - Chloride shift: carbonic anhydrase is in RBC's so at the tissues to balance bicarbonate ions diffusing out of cells (because CO2 enters RBC, carbonic anhydrase converts, bicarbonate diffuses out to plasma) (vice versa at lungs), Cl- enters
    - CO2 carried in blood in three forms: in physical solution, as bicarbonate ion, and in carbamino compounds (combined w/ hemoglobin and other proteins). Majority carried as bicarbonate ion form.
  - Myoglobin of muscle has hyperbolic curve (structure doesn't do allosteric cooperative binding, single subunit) saturates quickly and releases in very low oxygen "emergency muscle" situations
  - Fetal hemoglobin curve is shifted left of adult – has higher binding affinity to grab O2 from maternal blood

Hemoglobin, myoglobin, fetal hemoglobin curve illustrated here. Hemoglobin affected by various factors here.
Note: **CADET**, face Right!" for **C**O2, **A**cid, 2,3-**D**PG, **E**xercise and **T**emperature. Factors that move the oxygen dissociation curve to the right are those physiological states where tissues need more oxygen. For example during exercise, muscles have a higher metabolic rate, and consequently need more oxygen, produce more carbon dioxide and lactic acid, and their temperature rises. So right shift means we are releasing $O_2$ easier.
Note: carbon monoxide has a 200x greater affinity for hemoglobin than oxygen does! Have to administer pure O2 to displace it once bound.
Avian respiration is drastically different than human respiration. Due to the unique anatomy of birds, respiration is both continuous and unidirectional. Air sacs allow birds to exchange gas during both inhalation and exhalation – oxygen rich incoming air is first stored in air sacs before entering lungs for exhalation, so it is not mixed with the deoxygenated exhalated air.
In mammalian respiration there is tidal breathing - we breathe in and out through the same tubing, inhibiting gas exchange during exhalation. Deoxygenated air is mixed with some fresh air during inhalation, some of it is re-breathed. Much less efficient than birds.

## C. Circulatory System

**Circulation in Invertebrates**

- Protozoans (unicellular animal-like [due to movement] protists)- movement of gas through simple diffusion within cell
- Cnidarians – body walls 2 cells thick, therefore all cells in direct contact with either internal or external environment. Ex- hydra
- Arthropods- most insects and molluscs
  - **Open circulatory system**- pump blood into internal cavity called **hemocoel** (cavities called **sinuses**), which bathe tissues in oxygen and nutrient containing fluid (**hemolymph**). This fluid returns to pumping mechanism (**heart**) through holes called **ostia**.
- Annelids- earthworm
  - **Closed circulatory system**- blood is confined to vessels.
    - Also seen in certain mollusks (octopus and squid) and vertebrates
    - Away from heart: aorta →arteries → arterioles → capillaries
    - Back to heart: capillaries → venules → veins

Note: human and bird hearts have 4 chambers, reptiles+amphibians 3, fish 2 (but crocs+gators have 4 chambers)

- Human heart – (note: the atrium are the upper chambers of the heart) (animation of circuit flow)

- Right atrium – deoxygenated blood enters via superior and inferior vena cava
- Right ventricle – blood is squeezed through right AV/tricuspid valve into right ventricle which contracts and pumps blood into pulmonary artery through the pulmonary semilunar valve.
  - When the ventricle contracts, AV valve closes to prevent backflow
  - When ventricle relaxes, semilunar valve prevents backflow from pulmonary artery back into ventricles
- Pulmonary circuit: blood pathway from right side of heart to lungs to left side of heart
  - Blood flows from pulmonary artery → arterioles → capillaries of the lungs → collects in venules → veins → pulmonary veins → left atrium
- Systemic circuit is the circulation pathway through the body between left and right sides of heart
- Left atrium – after lungs the oxygenated blood enters left atrium via pulmonary veins
- Left ventricle – after going through left AV(aka mitral or bicuspid) valve, blood from left ventricle goes to aorta through the aortic semilunar valve into rest of body:
  - Aorta → arteries → arterioles → capillaries → tissues get what they want → venules → veins → superior and inferior vena cava → cycle repeats
  - As above: left AV valve prevents backlow into atrium, aortic semilunar valve prevents it into ventricle
- So: right/left AV valves and pulmonary/aortic SL valves

- Cardiac Cycle – regulated (in terms of rate)by autorhythmic cells of the autonomic NS, but contractions are intiated independently of the autonomic NS. Instead the heart contracts automatically:
  - **SA (sinoatrial) node,** or **pacemaker** (located in upper wall of right atrium) is a group of specialized cariac muscle cells that initiates by contracting both atria and sending delayed impulse to stimulate **AV (atrioventricular) node**.
    - Spreads contraction to surrounding cardiac muscles via electrical synapses made from gap junctions
    - Pace of SA node is faster than normal heartbeat but parasympathetic **vagus nerve** innervates SA node (also increases digestive activity of intestines); slows contractions
  - AV node – located in lower wall of the right atrium/interatrial septa; sends impulse through bundle of His → passes between both ventricles → branches into ventricles via the purkinje fibers which results in contraction
  - When the ventricles contract (**systole** phase), blood is forced through pulmonary arteries and aorta – When they relax (**diastole** phase), backflow into ventricles causes semilunar valves to close.
    - Cardiac output: Heart Rate * Stroke Volume. The volume of blood pumped by the ventricle (per min)
    - Heart rate: number of beats per minute
    - Stroke volume = EDV - ESV. Volume of blood pumped out of the heart with each beat. Formula subtracts the End-systolic Volume (blood in the ventricle at the end of the contraction/systole) from the End-diastolic Volume (volume of blood in the ventricle just before contraction)

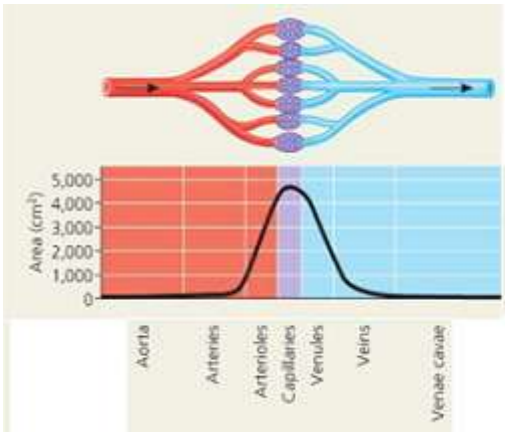
Heart contraction: heart is a large muscle, but unlike skeletal, not anchored to bone. Its fibers form a net and the net contracts upon itself, which squeezes blood into arteries.

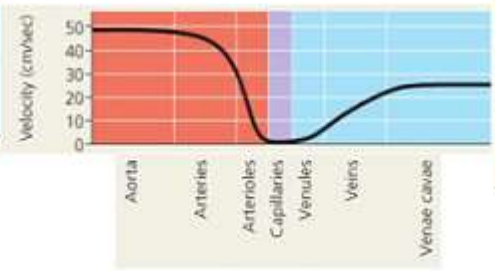
Systole: occurs when ventricles contract. Diastole: occurs during relaxation of the entire heart and then contraction of the atria.

Hydrostatic pressure from heart contracting causes blood to move through arteries. Blood pressure drops as it reaches the capillaries, and reaches near zero in the venules. Blood continues to move through veins because of pumping of the heart assisted by movements of adjacent skeletal muscles, expansion of atria each time heart beats, and falling pressure in chest when a person breathes. Valves in the veins prevent backflow.

- **Blood Vessels:** (arteries, veins, and capillaries)
  - **Arteries**: thick-walled, muscular, elastic, pump oxygenated away (except for pulmonary arteries that transport deoxygenated blood from heart to lungs). Wrapped in smooth muscle typically innervated by sympathetic NS
  - **Arterioles**: Very small, wrapped in smooth muscle, constrict/dilate to regulate BP and reroute blood – major determinant of pressure
  - **Capillaries**: have smallest diameter- single layer of endothelial cells across which gases, nutrients, enzymes, hormones, and waste diffuse
    - 4 methods for material to cross capillary wall: pinocytosis, diffusion through capillary cell membrane, movement through pores in the cells (fenestrations), movement through space between the cells
  - **Venules**: Small blood vessels that lead back to veins; very thin and porous; drain blood from capillary bed → venules combine → veins
  - **Veins**: Larger veins often have valves to aid in transport of deoxygenated blood back to heart due to fighting gravity (except for pulmonary veins and umbilical vein that carry *oxygenated* blood)

**Blood flow:** (see below). Cross sectional area of veins is about 4x higher than that of arteries. *Total* cross-sectional area of capillaries far greater than that of arteries or veins (capillaries are the narrowest vessels, BUT there are far more capillaries → total cross-sectional area of all of them put together is higher than any other cross sectional area). Since blood volume flow rate is approx. constant, **blood velocity is inversely proportional to total cross-sectional area**. Bernoulli's principle tells us pressure is inversely proportional to cross-sectional area, so why is pressure highest from aorta and then continues downward? Blood is not an ideal flow: pumping force of heart is the major contributor to pressure (p=F/A). Aside: arterioles have the greatest resistance to flow (high ability to constrict)*. At any given time, most blood is in the veins/venules/venus sinuses.




In the squiggly lines on the left in the image below, the high peak is the systolic pressure and the low peak is the diastolic pressure.


- **Lymph Vessels**
  - Lymphatic system is an open secondary circulatory system- transports excess **interstitial fluids (lymph)** through the contraction of adjacent muscles & some walls of larger lymph vessels have smooth muscle
  - Proteins & large particles that can't be taken up by capillaries removed to lymph; also monitors blood for infxn
  - Valves prevent backflow- fluid returns to blood circulatory system through two ducts located in shoulder region (thoracic&right lymphatic duct)
  - **Lymph nodes** contain phagocytic cells (leukocytes) that filter the lymph and serve as immune response centers
- **Blood** – 4-6 liters in the human body; is a connective tissue
  - 55% liquid (**plasma**) and 45% cellular components – plasma is an aqueous mixture of nutrients, salts, gases, wastes, hormones, and blood proteins (immunoglobulins, albumin, fibrinogen, clotting factors)
  - Cellular components
    - **Erythrocytes** (RBCs) – transport $O_2$ (up to 4) on hemoglobin, catalyze conversion of $CO_2$ and $H_2O$ to $H_2CO_3$ – lack nucleus/organelles to maximize hemoglobin content
    - **Leukocytes** (WBCs) – larger and phagocytize foreign matter and organisms
      - **Diapedesis** – the process by which WBCs become part of the interstitial fluid (slip through the endothelial lining)
    - **Platelets/thrombocytes-** cell fragments involved in blood clotting – lack nuclei; stick to damaged epithelium; attract more
      - Convert **fibrinogen (**inactive) to **fibrin** (active)
      - Derived from **megakaryocytes**

**Process of blood clotting**

1. Platelets contact exposed collagen of damaged vessel and cause neighboring platelets to form **platelet plug**
2. Both the platelets and damaged tissue release clotting factor, **thromboplastin**
3. Thromboplastin converts inactive plasma protein **prothombrin** to **thrombin** (active)
4. Thrombin converts **fibrinogen** into **fibrin**
5. Fibrin threads coat damaged area and trap blood cells to form a clot

**Hemoglobin** – binds CO w/ much greater affinity than myoglobin (it also has 4 subunits vs 1)
**Myoglobin** = single chain/protein subunit, stores $O_2$ in muscle
Myoglobin curve = hyperbolic, Hemoglobin curve = sigmoidal. Myoglobin has higher affinity for $O_2$ than hemoglobin. Myoglobin has no change in $O_2$ binding over a pH range.
**Fetal circulation:** oxygenated, nutrient-rich blood from placenta carried to fetus via umbilical vein → half enters **Ductus venosus** (allows blood to bypass the liver) →carried to inferior vena cava → RA → RV → **Ductus arteriosus** (conducts some blood from the pulmonary artery to the aorta [bypassing the lungs/fetal pulmonary circulation]) → aorta. Other half enters liver/portal vein → RA → **Foramen ovale** (allows blood to bypass pulmonary circulation by entering the left atria directly from the right atria since there is no gas exchange in fetal lung) → LA → LV → aorta. Illustrated here.
**Cardiac Output (CO) =** SV (stroke volume) X HR (heart rate)

- *Stroke volume* = volume of blood discharged from the ventricles with each contraction.
- *Cardiac output* = volume discharged from ventricle each minute.
- **Stroke volume = end systolic volume – end diastolic volume.**

**Blood is a connective tissue!**
**Rh factor** =another blood antigen; mother might attack Rh+ in 2nd fetus (**erythroblastosis fetalis**) (first child is fine but during 1st childbirth blood exposure → antibodies to Rh attack 2nd)
Double capillary beds (portal system) occur in glomerulus, capillaries that surround loop of Henle, small intestine, liver, and hypothalamus and anterior pituitary gland. Capillary bed pools into another capillary bed (capillary bed 1 → drains into portal vein → capillary bed 2 → drains into vein that returns blood to heart) w/out first going to heart (transport products in high cxn without spreading to rest of body)
**Phosphate buffer system** – maintains pH of *internal fluids* of all cells; $H_2PO_4^-$ and $HPO_4^{2-}$ act as acid & base (**amphoteric**)

## D. Excretory System - don't confuse excretion (getting rid of) with digestion (breaking down for absorption)

1. Osmoregulation:

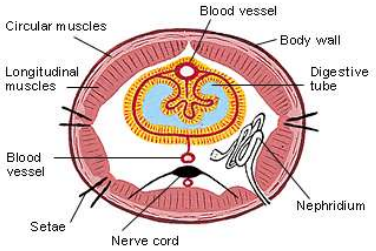
a. Marine fish: body is hypotonic to environment → water is constantly lost by osmosis, constant drinking, rarely urinate, and secrete accumulated salts through gills.

b. Fresh water fish: body is hypertonic to environment; water moves in => rarely drink, constantly urinate, and absorb salts through gills.

**Protozoans and Cnidarians –** all cells in contact with external, aqueous environment
- Water soluble wastes (ammonia, $CO_2$) exit by simple diffusion
- **Protists such as Paramecium** and aoebas – possesses **contractile vacuole** for XS $H_2O$ excretion by active transport

**Annelids** – $CO_2$ excretion directly through moist skin

- **Nephridia (metanephridia)** occur in pairs within each segment of annelids (earthworms). Interstitial fluids enter a nephridium through ciliated opening **nephrostome** and concentrate through **collecting tubule** due to selective secretion into surrounding coelomic fluid. Blood that surrounds tubule reabsorb. Water, salts, urea are excreted through **excretory pore**.




**Platyhelminthes – flame cells** (**protonephridia**) – distributed along branched tube system that permeates the flatworm

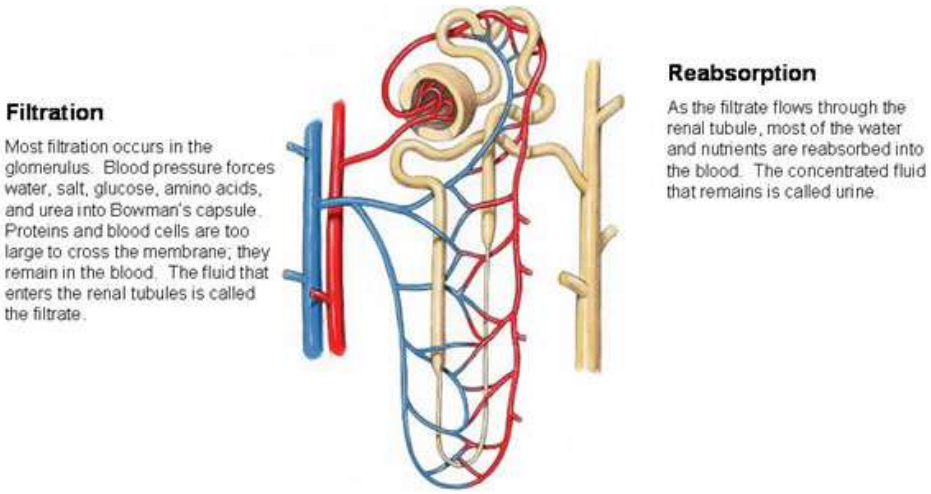
- Body fluids filtered across flame cells, whose cilia move fluids through tube system; wastes exit through pores of tube

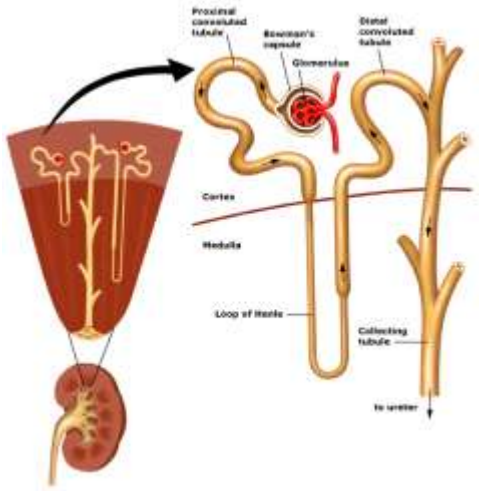
**Arthropods** – $CO_2$ released from tissues → **tracheae** (which are continue with ext. air thru **spiracles**)

- **Malphigian tubules**: occurs in arthropods (terrestrial insects). Tubes attached to mid digestive tract (midgut) collect body fluids from hemolymph that bath the cells; fluids are deposited into midgut. Fluids include nitrogen wastes (in form of **uric** acid crystals; $H_2O$, salt retained. As fluid passes through hindgut, retained materials pass out of walls and wastes continue down the tract for excretion through anus.

**Excretion in Humans –** lungs, liver, skin, and kidney

- **Lungs** – $CO_2$ and $H_2O_{(g)}$ diffuse from blood and are continually exhaled
- **Liver** – processes nitrogenous wastes, blood pigment wastes, other chemicals, UREA prod.
- **Skin –** sweat glands in skin excrete water and dissolved salts/regulate body temp (sweat gland fxn decreases as we age)
- **Kidney –** Three regions: 1) outer cortex, 2) inner medulla, and 3) renal pelvis which drains to ureter. Each has many nephrons. Kidneys → ureter → bladder → urethra. Functions to excrete waste, maintain homeostasis of body fluid volume and solute composition, and help control plasma pH




**Nephrons –** composed of renal corpuscle and renal tubule; reabsorbs nutrients, salts, and water (image summary here)

- *Renal corpuscle* – glomerulus (sieve) surrounded by Bowman's capsule; afferent arteriole=into glomerulus; efferent arteriole=out of glomerulus
  - After efferent arteriole passes back out of the glomerulus is just webs around the entire nephron structure (see above) as the peritubular capillaries (surround PCT and DCT; reabsorb stuff) and vena cava (surround LOH in medulla, maintain cxn gradient) before dumping back in to the renal branch of renal vein. Meanwhile, Bowman's capsule leads to…
- *Renal tubule* –
  - **Proximal convoluted tubule** – *active reabsorption* of glucose, ions, amino acids begins (water follows → cortex not salty)
    - Drugs, toxins, etc secreted into filtrate; H+ ions secreted in as well via antiport with Na+
  - **Loop of Henle** (majority of nephron)
    - DESCENDING – only permeable to water (but this water is picked up by vasa recta → medulla stays salty)
    - ASCENDING makes renal medulla *salty*–actively pumps out Na+,K+,$Cl^-$ ; impermeable to water!
    - This process allows reabsorption of 99% of filtrate → conc. urine
  - **Distal convoluted tubule** – more reabsorption of glucose, ions, water, etc (cortex not salty).Filtrate: Na+ and Ca2+ get resorbed into body, K+/H+/$HCO_3$- secreted out via tubule. Distal tubule empties to…
  - **Collecting duct** – collects remaining filtrate. Is ordinarily impermeable to water unless ADH acts on it
    - Descends to medulla (salty part), where *antidiuretic* hormones (**ADH / vasopressin)** can make MORE water leave from urine by increasing permeability of collecting duct → urine even more concentrated. 1 CD shared by many nephrons
    - Also, aldosterone acts on DCT and CD: increase Na+ resorbtion, K+ secretion → water passively follows Na+

**Urine Formation –** filtration, secretion, and reabsorption

- **Filtration** – The fluid that goes through glomerulus (afferent arteriole => glomerulus => efferent) to the rest of the nephron is called filtrate; particles that are too large to filter through (blood and albumin) remain in circulatory system; passive process; driven by hydrostatic pressure of blood. So Glomerulus → filtrate pushed into Bowman's.
- **Secretion** – substances such as acids, bases, and ions (K+) are secreted by both passive / active transport; secreted from *peritubular capillaries*
- **Reabsorption** – glucose, salts, AA, and water are reabsorbed from filtrate & return to blood; takes place namely in PROXIMAL convoluted tubule (active)
- **Concentration** – when dehydrated volume of fluid in bloodstream is low so you need to make small amounts of concentrated urine => ADH prevents water loss by making distal tubule permeable to water /// when Blood Pressure is low => aldosterone increases reabsorption of Na+ by distal nephron which increases water retention (serum [Na+] increases BP)

**Recap**: filtration occurs in renal corpuscle → reabsorption/secretion mostly in proximal tubule → filtrate becomes more cxn as it moves down loop of Henle (water passive out of tube) → more dilute as it moves up loop (passive and active transport of salts out, but not water) →DCT dumps into collecting dict → filtrate more cxn again as it descends collecting duct (because surrounding medulla is salty, water leaves) → CD leads to renal calyx → empties into renal pelvis → drains to ureter. Keep in mind reabsorb means *back into the body*

**Juxtaglomerular Apparatus**: monitors filtrate pressure in DT via granular cells → secrete renin → angiotensin cascade → tells A.C. to make aldost

** Selective permeability of the tubules establishes an osmolarity gradient in the surrounding interstitial fluid

*** Urine is *hypertonic* to the blood and contains a high urea and solute concentration.

**Osmolarity Gradient –** created by exiting / entering of solutes; increases from cortex to medulla

**Counter Current Multiplier -** descending loop permeable to water & ascending is permeable to salts / ions; this makes the medulla very salty and facilitates water reabsorption

Nitrogen as a waste product: Aquatic animals excrete NH3 or NH4 directly into water, mammals convert NH3 to urea, Birds/insects/reptiles convert urea to uric acid (insoluble in water, water conservation, excreted as solid)

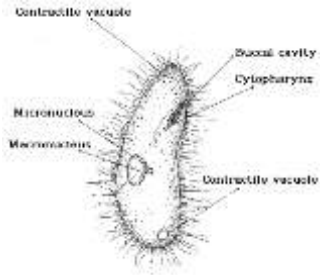
- Allantois = special sac in bird egg that keeps N waste away from embryo

**Excretion in Plants** – excess $CO_2$, waste $O_2$, and $H_2O_{(g)}$, leave by diffusion through stomata and lenticels

- This process is called *transpiration*

## E. Digestive system

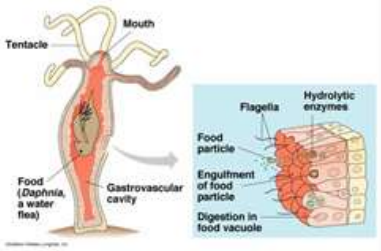
### Unicellular

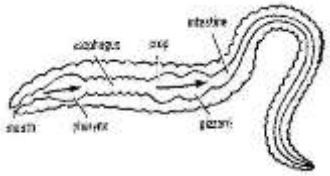


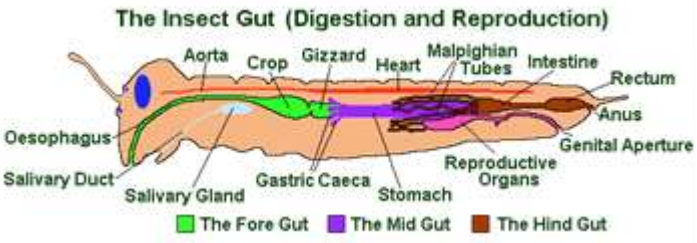

- **Amoeba**
  - Food capture: phagocytosis→food vacuoles
  - Food vacuoles fuse with lysosomes
- **Paramecium**
  - Cilia sweep food into cytopharynx
  - Food vacuole forms and moves toward anterior end of cell

### Invertebrates

- *Physical breakdown* – cutting and grinding in mouth; churning in digestive tract
- *Chemical breakdown* – enzymatic hydrolysis → smaller nutrients → pass through semi-permeable membrane of gut cells to be further metabolized
- **Cnidarians**
  - Hydra- intracellular and extracellular digestion
- **Annelids**
  - Earthworms – one-way digestive tract
    - Crop – food storage
    - Gizzard – grind food
    - Intestine – contains **typholosole** to increase surface area for absorption
- **Arthropods**
  - Also have jaws for chewing and **salivary glands**






**Digestion in Humans**

**Four groups of molecules encountered**

1. Starches → glucose
2. Proteins → amino acids
3. Fats → fatty acids

4. Nucleic acids → nucleotides

**Digestion follows a specific series of events** ***Note – All digestive enzymes cleave SPECIFIC bonds

1. **Mouth - salivary a-amylase** breaks down (starch→maltose), chewing creates **bolus** which is swallowed
2. **Pharynx** (throat) – this is where food and air passages cross; the **epiglottis,** flap of tissue, blocks trachea so only solid and liquid enter…
3. **Esophagus** – tube leading to stomach, food travels by contractions (**peristalsis**),
4. **Stomach** – secretes **gastric juice** (digestive enzymes and HCl) – food enters stomach through lower esophageal/cardiac sphincter. The stomach contains **exocrine glands** (local secretion by way of duct) within gastric pits (indentations in stomach that denote entrance to the gastric glands, which contain secreting chief cells, parietal cells, and mucous cells (secrete mucus to prevent backwash)
    a. Storage – accordion-like folds allow 2-4 liters of storage
    b. Mixing – mixes food w/ $H_2O$ and gastric juice → **chyme** (creamy medium)
    c. Physical breakdown – muscles break food; HCl denatures proteins & kills bacteria
    **d.** Chemical breakdown – **pepsin (**secreted by **Chief cells**) digests proteins; (pepsinogen activated by HCl, which is secreted by **parietal cells**)
        i. **Peptic ulcers** – caused by failure of mucosal lining to protect stomach
            – Ulcers can be caused by excess stomach acid or H.pylori as well
    e. Controlled release – chyme → small intestine; controlled by **pyloric sphincter**
    f. **Stomach cells**
        i. **Mucous Cells** – secrete mucus that lubricates & protects stomach's epithelial lining from acid environment
        ii. **Chief Cells** – ex.gl. secrete pepsinogen (zymoegn precursor to pepsin).
            – **Pepsinogen** activated to **pepsin** by low pH in stomach; once active begins protein digestion
        iii. **Parietal Cells** – Secrete HCl; intrinsic factor (B-12 absorption)
        iv. **G cells** – secrete **gastrin**, a large peptide hormone which is absorbed into blood → stims parietal cell to secrete HCl
        v. Affected by: A-chol increases secretion of all cell types, gastrin and histamine increase HCl secretion
5. **Small intestine** – food goes from stomach to small intestine through the **pyloric sphincter** - first 25cm (**duodenum)**, continues breakdown of starches and proteins as well as remaining food types (fats and nucleotides); ileocecal valve between it and large intestine. Structure is duodenum (most digestion), jejunum, then ileum (jej and il mostly absorption). 90% of digestion and absorption occurs in SI; completes.
    **a. Structure** – Wall has finger-like projections called villi that increase the surface area for greater digestion/absorption. Each villi has a **lacteal** (lymph vessel surrounded by capillary network; both fxn for nutrient absorption). Villi have microvilli, more SA.
        **i. Goblet cells** secrete mucus to lubricate and protect from mech/chem damage
        **ii.** Duodenum has a ph ~6 mainly due to bicarbonate ions secreted by pancreas
    **b. Enzyme origin**
        **i. Small intestine** – proteolytic enzymes: proteases, maltase and *lactase*, phosphatases/nucleosidases (nucleotides); lipase
    c. **<u>Pancreas –</u>** secretes bicarbonate; also acts as exocrine gland releasing major enzymes from acinar cells via pancreatic duct → duodenum
    - Trypsin & chymotrypsin (proteases), lipase, pancreatic amylase, deoxy&ribonucleases
    - All exist as **zymogens/proenzymes (inactive)** first. Trypsin gets activated, then activates the other enzymes
    - These enzymes in alkaline solution (**pancreatic duct → duodenum)**
    d. **Liver –** produces bile (no enzymes, emulsifies fats) stored in **gall bladder**, flows thru bile duct which merges with pancreatic duct
    e. Remainder of small intestine (6m) absorbs breakdown products (**villi** and **microvilli)**
        i. Amino acids and sugars→capillaries ; fatty acids and glycerol → lymph. System
    f. Chyme moves through intestines via peristalsis as well. Segmentation (2nd type of intestinal motion) mixes chime w/ dig. juices
6. **Large intestine (colon) –** reabsorption of water and salts to form **feces**; 1.5m long
    a. Feces stored at end of L.I. in the **rectum** → excreted through **anus**
    b. At beginning is **appendix**, which in herbivores is large **cecum** (cellulose digestion) with the help of bacteria
    c. Bacteria (e.g. E.Coli) a **symbiont** in large intestine = main source of **vitamin K** (also Vitamin B)

**ECL cells** are neuroendocrine cells in the digestive tract; gastrin stimulates them to release histamine which in turn stimulates parietal cells to produce gastric acid

**Hormones involved in the digestive process**

1. **Gastrin** – produced by stomach lining when food reaches or upon sensing of food; more above
2. **Secretin –** produced by cells lining **duodenum** when food enters; stimulates pancreas to produce bicarbonate (neutralizes the chime)
3. **Cholecystokinin –** produced by S.I. in response to **fats**; stimulates gallbladder to release bile and pancreas to release its enzymes
4. **Gastric Inhibitory Peptide** – produced in response to fat/protein digestates in duodenum; mild decrease of stomach motor activity

**<u>Digestion in plants and fungi</u>**

***Plants have no digestive system, but intracellular processes similar to animals do occur***

**Intracellular digestion** – store primarily **starch** in seeds, stems, and roots; when nutrients are required, polymers are broken down (into glucose, fatty acid, glycerol, and amino acids) by enzymatic **hydrolysis**

**Extracellular digestion** – several plants must obtain nutrient from environment

- **Fungi – rhizoids** of bread mold, secrete enzymes into bread, producing simple digestive products which are then absorbed by diffusion into rhizoid
- **Venus flytrap** – enzymes digest trapped fly (serves as **nitrate** source); ***still autotrophic**

## Liver Functions

- **Blood Storage**
- **Blood Filtration** – Kupfer cells phagocytize bacteria picked up in intestines
- **Carbohydrate Metabolism** – Liver maintains normal blood glucose levels via **gluconeogenesis** (production of glycogen and glucose from noncarb precursors), **glycogenesis**, and storage of glycogen
  - All carbs absorbed into blood are carried by **portal vein** to the liver. Absorbed gal and fru converted to glu, then stored as glycog.
- **Protein metabolism** – Liver deaminates AA's, forms urea from ammonia in blood, synths plasma proteins, synths nonessential AAs
- **Detoxification** – Detox'd chemicals, excreted by liver as part of bile (or polarized to be excreted by kidneys)
- **Erythrocyte destruction** – Kupfer cells destroy irregular erythrocytes (but most are destroyed by spleen)
- **Vitamin Storage** – Stores vit A, D, $B_{12}$. Also stores iron by combining it with apoferritin → ferritin
- All carbs absorbed into blood are carried by **portal vein** to the liver
- **Glycogenesis** (formation of glycogen) and **glycogenolysis** (if blood glucose levels decrease → glycogen broken down to glu for release)
- When liver mobilizes fat or protein for energy, blood acidity increases (ketone bodies are produced → ketosis/acidosis results)
- Blood supply: hepatic portal vein supplies blood as does hepatic artery (oxygenates liver); blood leaves via hepatic vein → vena cava
- **Digestive** (produces bile); **Transport** (synthesizes blood plasma proteins important in clotting)

## F. Nervous System

Nervous system vs endocrine: neuronal communication is rapid/direct/specific. Hormonal is slower/spread through body/affects many cells/tissues in different ways/longer lasting

**Neuron** – consists of several dendrites, single (branched) axon, and cell body

**Dendrites** – receive information and transfer it TO CELL body

**Axon** – transfers impulses AWAY from cell body

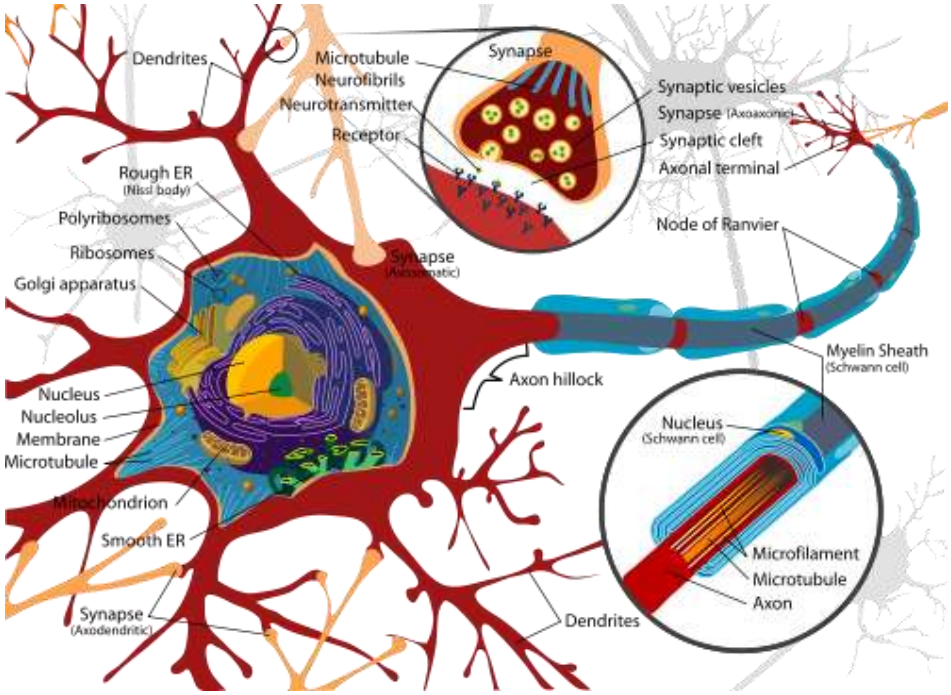
**Glial Cells** – nervous tissue support cells; capable of cellular division

• **Oligodendrocytes** – produce myelin in CNS; wrap many times around axons

• **Schwann cells** – produce myelin in PNS. Myelin sheaths act as insulators and are separated by **nodes of Ranvier**. Instead of traveling continuously down axon, action potential jumps from node to node (**salutatory conduction**), speeding up impulse

- Only vertebrates have myelinated axons. Myelinated axons appear white (white matter); neuronal cell bodies gray (gray matter).

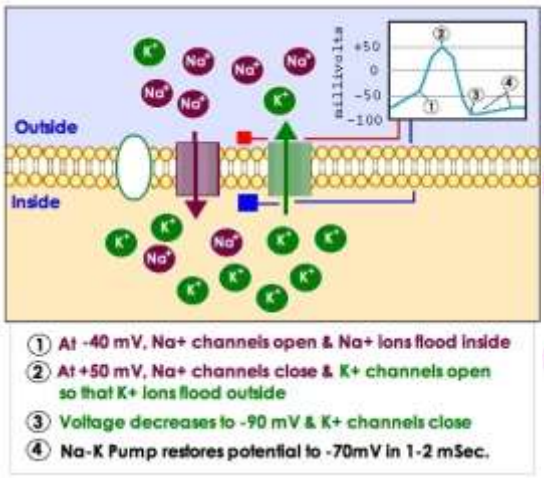
- Other glial cells include: microglia (phagocytes of the CNS), ependymal (use cilia to circulate CSF), satellite cells (support ganglia – groups of cell bodies in PNS), and astrocytes (physical support to neurons of CNS; maintain mineral and nutrient balance

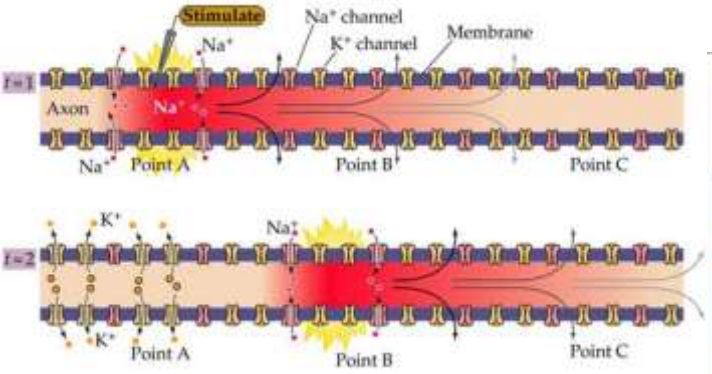


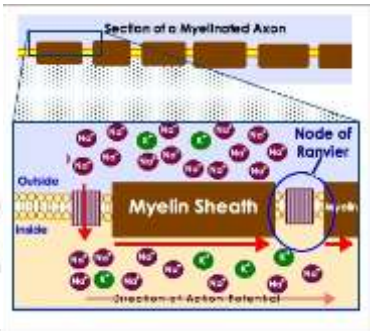

**Three types of neurons:**

1. ***Sensory (Afferent)***- receive initial stimulus (Ex: neurons in retina of eye) A→BRAIN
2. ***Motor (Efferent)***- stimulate **effectors**, target cells that elicit some response (Ex: neurons may stimulate the muscles, sweat glands, or cells in the stomach to secrete gastrin. BRAIN → M
3. ***Association (Interneuron)***- located in spinal cord & brain- receive impulses from sensory and send impulses to motor neurons. They are **integrators**, as they evaluate impulses for appropriate response. ~99% of nerves are interneurons.

**Transmission of a nerve impulse**:




***The membrane of an unstimulated neuron is **polarized,** although a high concentration of $Na^+$ is present outside the cell and a high concentration of $K^+$ is present inside the cell (the inside is actually negative due to the negatively charged proteins and nucleic acids residing in the cell). Additionally, neuron membranes are selectively permeable to $K^+$ as opposed to $Na^+$, which helps to maintain the polarization.***

1. **Resting potential.** Normal polarized state of neuron, -70 mV.
2. **Action potential.** Stimulus → **gated ion channels** let $Na^+$ into the cell, *depolarizing* it. If the threshold level is reached (~ -50mV), it will cause an action potential that will result in opening of (voltage gated) $Na^+$ channels down the entire length of the neuron. **All or nothing event!**
3. **Repolarization.** In response to $Na^+$ flow in, more gated ion channels let $K^+$ out of the cell, restoring polarization- but the $Na^+$ are IN and the $K^+$ are OUT
4. **Hyperpolarization.** By the time the channels close, too much $K^+$ is released (-80 millivolts)
5. **Refractory period.** Neuron will NOT respond to new stimulus until $Na^+/K^+$ pumps return the ions to their resting potential locations (outside/in, respectively) if absolute. If relative, abnormally large stimuli can create an AP. Note that refractory period is what prevents an AP from moving backwards, even though ions are theoretically rushing in and diffusing in both directions.

**Note** that from -70 up to threshold (or -70 downward) is the **graded potential** that cannot travel, but it can potentially (if it surpasses threshold) open the voltage gated channels and this part is the action potential, that travels by opening other voltage gated. The other gated types cannot spread unless they trigger this AP. Also note that AP is all or nothing, so strength of a neural signal is based on other factors (frequency of AP firing or how many nervous cells contribute AP's, etc).
**Note** in case you encounter it, the K-ATP sensitive channel will close in the presence of ATP → K+ can't escape → depolarization occurs. In beta cells, this depolarization leads to the voltage dependent calcium channel (VDCC) opening, which itself causes the exocytosis of insulin.

**<u>Transmission across synapse</u>**- presynaptic cell → postsynaptic cell

*I.* *Electrical*- action potential travels along membranes of gap junctions (less common); fast; cardiac and visceral smooth muscle.

**II.** *Chemical*- most typical in animal cells; unidirectional (unlike electrical) [Isn't electrical conduction unidirectional too?]

1. **$Ca^{2+}$ gates open**- depolarization allows $Ca^{2+}$ to enter the cell via VDCC's (also found in beta cells!)
2. **Synaptic vessels release neurotransmitter**- influx causes release into cleft
3. **Neurotransmitter binds with postsynaptic receptors**. Diffusion (via Brownian motion) and binding
4. **Postsynaptic membrane is excited or inhibited**. Two possible outcomes:
   i. $Na^+$ gates open, membrane is depolarized→**excitatory postsynaptic potential (EPSP)**, if threshold potential is succeeded, action potential is generated
   **ii.** $K^+$ gates open, membrane becomes hyperpolarized →**inhibitory postsynaptic potential** (**IPSP**)… it becomes more difficult to generate action potential
5. **Neurotransmitter is degraded and recycled**. Broken down by enzymes in cleft and recycled

**<u>Some common neurotransmitters</u>**

1. **Acetylcholine**- secreted at *neuromuscular junctions* → muscle contraction/relaxation. Inhibitory everywhere else.
   a. parasympathetic nervous system
2. **Epinephrine, norepinephrine, dopamine,** and **serotonin (5HT)**- AA derived, secreted between neurons of CNS
   a. sympathetic nervous system
3. **Gamma aminobutyric acid (GABA)**- inhibitory neurotransmitter among brain neurons

**Greater diameter & more heavily myelinated axons will propagate faster impulses (greater diameter because less resistance to "flow" of ions – think water through a large pipe vs a small one, and myelinated because of saltatory conduction; the Na doesn't gradually defuse outward [charge leakage?] at every successive AP requiring new Na to rush in to keep the impulse going; it can't leak out of myelin wrapped sections so it drives straight from node to node, see image above)
** Synaptic vesicles fuse w/ presynaptic membrane => neurotransmitter => postsynaptic

** Neurotransmitter may be taken back into nerve terminal (active transport), degraded synaptic cleft enzymes (recycle back to presyn), or diffuse out of the synapse

**Central Nervous System (CNS) –** consists of the brain and spinal cord

**Brain –** outer grey matter (cell bodies) and inner white matter (axons); forebrain, midbrain, hindbrain

- **Forebrain –** largest & most important brain region. contains **cerebral cortex** (processes sensory input / important for memory and creative thought), **olfactory bulb** (smell), **thalamus** (relay for spinal cord and cerebral cortex), **hypothalamus**- visceral function (water balance, blood pressure, and temp regulation, hunger, thirst, sex)
- **Midbrain –** relay center for visual/ auditory impulses; motor control
- **Hindbrain –** posterior part of brain; **cerebellum** (maintenance of balance, hand-eye coord, timing of rapid movements), **pons** (relay center to allow communication b/w cortex and cerebellum), **medulla oblongata** (breathing, heart rate, gastrointestinal activity) -
    - The **brainstem** consists of midbrain + medulla oblongata + pons. Connects the cerebrum with the spinal cord.

**Spinal cord-** out white/inner gray(cell bodies). Sensory info enters through **dorsal horn**. All motor info exits through the **ventral horn**.

Cerebrum is largest part of brain w/ two hemispheres connected by corpus callosum (thick nerve bundle). Divided by lobes: frontal (conscious thought; voluntary skeletal muscle movement), partietal (sensory areas – temperature, touch, pressure, pain), temporal (sensory – hearing and smelling), occipital (sensory – vision). Cerebrum has outer portion (cerebral cortex – gray matter) +inner portion (medulla – white matter) see ↑. Cerebrum contains sensory, motor, association areas.

**Peripheral Nervous System (PNS) –** consists of sensory branch and motor branch. Motor consists of somatic and autonomic nervous systems

- Somatic – responsible for VOLUNTARY movement of skeletal muscles
- Autonomic – involuntary movement; innervates cardiac and smooth muscle
    - Sympathetic – fight or flight (higher BP and HR)
    - Parasympathetic – rest and digest; non-emergency (lower HR, digestion, relaxation, sexual arousal)

***A **reflex arc** is a rapid, involuntary response to a stimulus involving two or three neurons, but brain DOES NOT integrate the sensory and motor activities… instead *synapse in spinal cord****

Ex: Knee-jerk (patellar) reflex

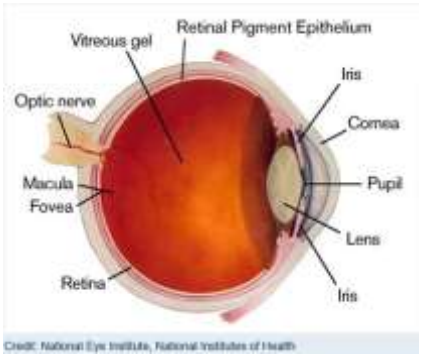
5 types of **sensory receptors**: mechanoreceptors (touch), thermoreceptors (temperature), nociceptors (pain), electromagnetic receptors (light), chemoreceptors (taste, smell, blood chemistry). Respond strongly to own stimuli, weakly to others; neural pathways separate + terminate in CNS

Note: all nerves not *directly* inside the brain or spinal cord are all part of the PNS. Cranial and spinal nerves come OUT of those structures; & are part of PNS

## Eye

**Eye – cornea** (focuses light) => **pupil** (diameter controlled by iris {pigmented}) => **lens** (controlled by cilliary muscles; focuses img) => **retina**(light sensitive cells)

- **Cones:** high-intensity illumination; sensitive to color
- **Rods:** low intensity; important in night vision; no color
    - Rod pigment **rhodopsin** is struck by photons from light, causing hyperpolarization transduced into neural AP sent to brain
        - Photoreceptor cells synapse to bipolar cells → ganglion cells → axions of ganglion cells bundle to optic nerve
            - Point at which optic nerve exits is **blind spot** (no photoreceptors there)
- **Fovea:** densely packed with cones; important for high acuity vision



Credit: National Eye Institute, National Institutes of Health

Eye has **vitrous humor** (jelly like, maintains eye shape and optical properties) and **aqueous humor** (anterior chamber, eye produces it)

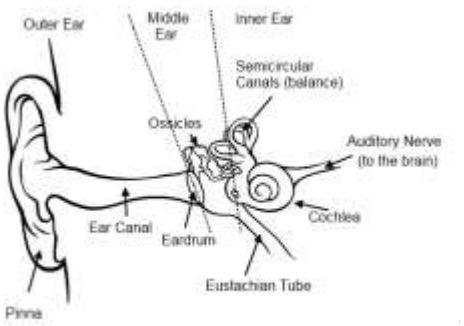
**Eye disorders**

- Myopia – nearsightedness
- Hyperopia – farsightedness
- Astigmatism – irregularly shaped cornea
- Cataracts – lens becomes opaque→light cannot enter
- Glaucoma – increase in pressure of eye due to blocking of outflow of aqueous humor

## Ear

**Ear –** Structure is three main parts: outer, middle and inner ear; transduces sound energy into impulses

- Outer ear – auricle/pinna (what we think of as the ear) and auditory canal; direct sound into external auditory canal →



- Middle ear – amplifies sound; tympanic membrane (eardrum) begins the middle ear and vibrates at same frequency as incoming sound => ossicles (malleus, incus, and stapes) →
- Inner Ear – wave moves through the **cochlea** (vibration of ossicles exert pressure on fluid). As wave moves through pressure alternates, moving the vestibular membrane in and out; this movement is detected by **hair cells** (not actual hair but specialized stereocilia) of the **organ of Corti** => transduced t neural signal →action potential
- The inner ear also has **semicircular canals** responsible for balance (fluid + hair cells sense orientation + motion)

## G. Muscular System

Muscle contraction can result in movement, stabilization of position, movement of substances throughout body, generation of body heat

**Organization of Vertebrate Skeleton**

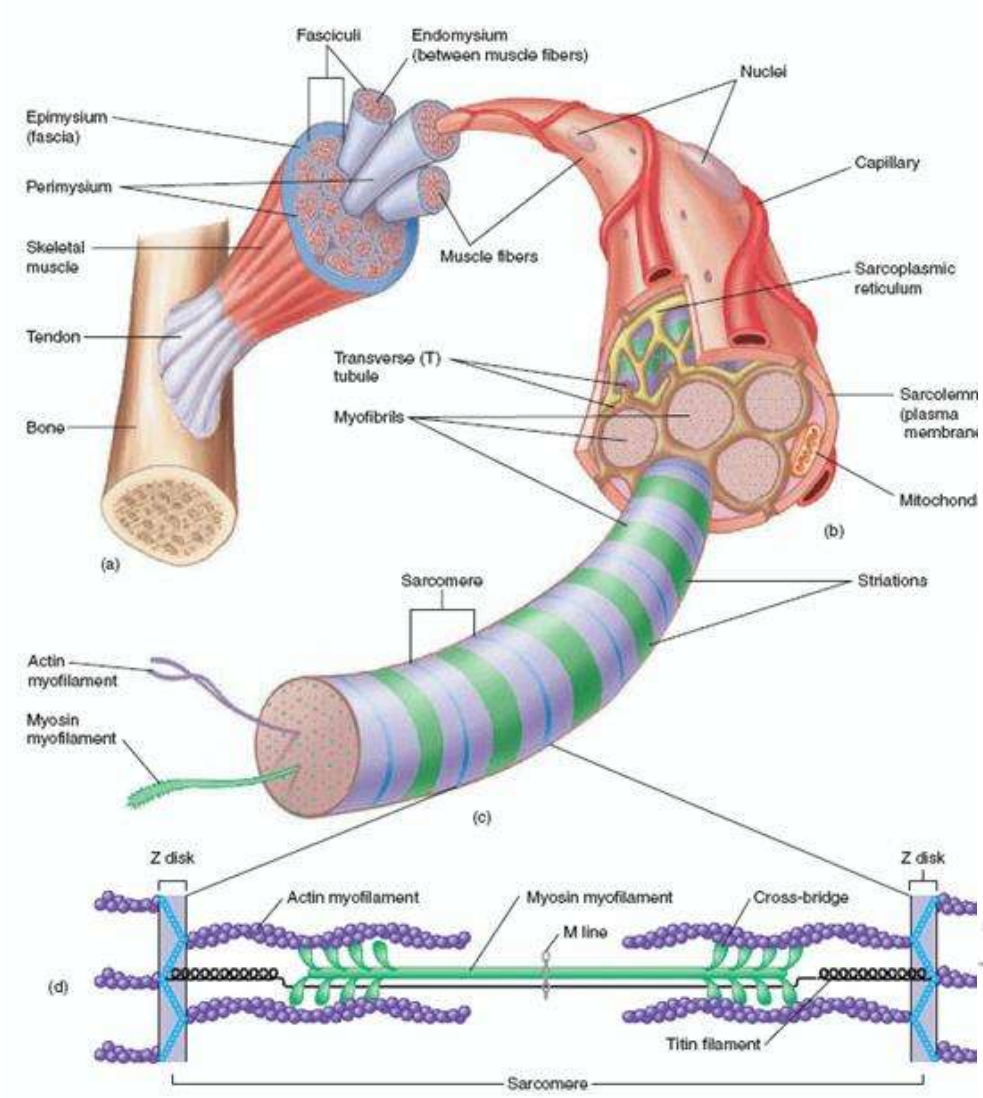
- **Axial skeleton –** basic framework (skull, vertebral column, rib cage)
- **Appendicular skeleton –** bones of appendages, pectoral and pelvic girdles
- **Bone organization**
    - **Sutures –** immovable joints (holds together bones of skull)
    - **Moveable joints –** bones that move relative to each other
        - **Ligaments –** bone-to-bone connectors; strengthen joints
        - **Tendons**- muscle-to-bone; bend skeleton at moveable joints
    - **Origin –** point of attachment of muscle to *stationary* bone
    - **Insertion –** point of attachment of muscle to bone that *moves*
    - **Extension =** straightening of joint
    - **Flexion** = bending of joint

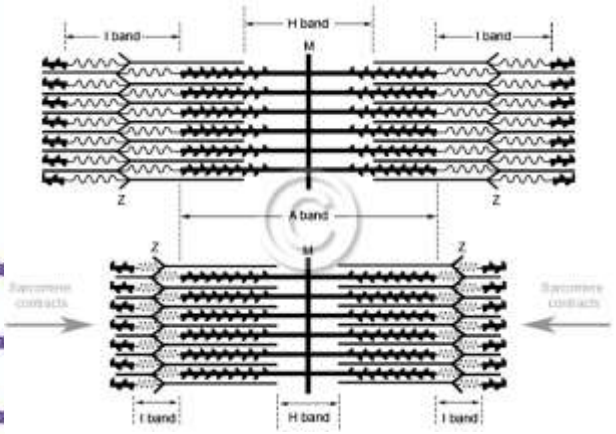
**Joint types** –

1. Fibrous – connect bones without allowing any movement (Ex: skull, pelvis, spinous process and vertebrae)
2. Cartilaginous – bones attached by cartilage, allow little movement (Ex: spine and ribs)
3. Synovial – allow for much more movement; most common; filled with synovial fluid which acts as a lubricant (Ex: carpals, wrist, elbow, humerus & ulna, shoulder and hip joints, knee joint)

**Muscular system**- consists of **contractile fibers** held together by **connective tissue**

1. **Skeletal muscle** (striated muscle) – voluntary movement, fibers are **multinucleated** cells
    a. **Myofibrils** – filaments divided into **sarcomeres**
    b. **Sarcomeres** – individual contractile units separated by a border (Z-line)
    c. **Sarcoplasmic reticulum** – stores $Ca^{2+}$; surrounds myofibrils
    d. **Sarcoplasm** – cytoplasm
    e. **Sarcolemma** – plasma membrane of muscle cells; can propagate **action potential**
        i. Invaginated by **T-tubules**- channels for ion flow
        ii. Wraps several myofibrils together to form a muscle cell/muscle fiber
    f. **Mitochondria –** present in large amounts in myofibrils



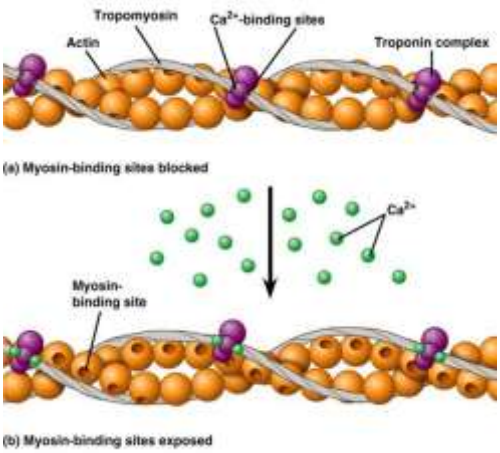

**Sarcomere –** is composed of thin filaments (**actin**) and thick filaments (**myosin**)

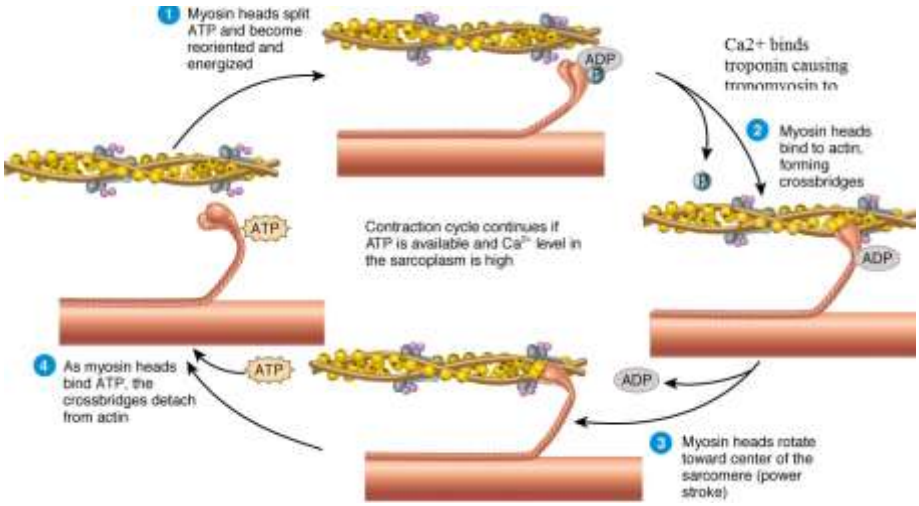
- **Z line –** boundary of a single sarcomere; anchor thin filaments
- **M line –** center of sarcomere
- **I band –** region containing thin filaments (**actin)** only (on ends, only purple above)
- **H zone –** region containing thick filaments (**myosin**) only (in middle, only green above)
- **A band –** actin and myosin overlapping (one end of overlap to the other end of overlap)
    - **H** and **I** reduce during contraction, while **A** does NOT

**<u>Contraction –</u>**

**Stimulation Process of Sliding Filament Model –** "all-or-nothing" response

1. **Action potential of neuron releases acetylcholine** when meets neuromuscular jxn
2. **Action potential then generated on sarcolemma and throughout T-tubules**
3. **Sarcoplasmic reticulum releases $Ca^{2+}$**
4. **Myosin cross bridges form** – result of $Ca^{2+}$ binding to troponin on actin helix



**Sliding Filament Model**

1. **ATP binds to myosin head** – converted to ADP + Pi, which remain attached to head
2. **$Ca^{2+}$ exposes binding sites on actin** – binds troponin→tropomyosin exposes attachment sites
3. **Cross bridges between myosin heads and actin filaments form**
4. **ADP + Pi are released** → sliding motion of actin bring **Z lines** together (contraction, power stroke)
5. **New ATP attaches to myosin head, causes cross bridges to unbind** – new phosphorylation breaks cross bridge

*****Without new ATP, the cross bridges remain attached to myosin head… this is why corpses are stiff*****
******Strength of contraction of single muscle fiber cannot be increase, but strength of overall contraction can be increased by recruiting more muscle fibers******

**Types of Muscle Response**

A) **Simple Twitch –** response of a single muscle fiber to brief stimulus; latent, contraction, relax
   1. Latent period – time btw stimulation and onset of contraction; lag
      - Action potential spreads on sarcolemma and $Ca^{2+}$ ions released
   2. Contraction
   3. Relaxation (absolute refractory period) – **unresponsive** to stimulus

**B) Summation and Tetanus –**
   **a. Summation –** contractions combine and become stronger and more prolonged (repeated APs summate)
   **b. Tetanus** – continuous sustained contraction; muscle cannot relax; will release if maintained (in tetanus, rate of muscle stimulation so fast that twitches blur into one smooth constant)

**C) Tonus** – state of partial contraction; muscle never completely relaxed

**Smooth Muscle –** mainly involuntary, ONE central nucleus; LACK striation; stimulated by **autonomic** nervous system (EX: lining of bladder, uterus, digestive tract, blood vessel walls, etc). No sarcomere organization: intermediate filaments attached to dense bodies spread throughout cell. Thick & thin filaments attached to IFs, contract → IF's pull dense bodies together →smooth muscle length shrinks. Two types of smooth muscle:

- Single-unit: aka visceral, connected by gap jxns, contract as single unit (stomach uterus, urinary bladder)
- Multiunit: each fiber directly attached to neuron; can contract independently (iris, bronchioles, etc)

In addition to neuronal response, can respond to: hormones, change in pH, $O_2$, $CO_2$ levels, temperature, [ion]

**Cardiac Muscle –** striated appearance (sarcomeres); one or TWO central nuclei; cells separated by intercalated discs that have gap jxn to allow AP's to chain flow via electrical synapse; involuntary; lots of mitochondria

Both smooth and cardiac muscle are **myogenic** – capable of contracting without stimuli from nerve cells

- Muscle fibers of single muscle don't all contract at once. Single neuron innervates multiple muscle fibers (collectively called **motor unit**). Usually: smaller motor units activated first, then larger ones as needed → smooth increase in force. Fine movement uses smaller motor units.
- Skeletal muscle types: Type I (slow-twitch), lots of myoglobin, lots of mitochondria, aerobic endurance. Type IIA: fast-twitch, endurance by not as much as type 1 (anaerobic endurance). Type IIB: fast-twitch, low myoglobin, lots of glycogen, power. Know this table – showed up on DAT.
- Skeletal muscle generally doesn't undergo mitosis to create new muscle cells (**hyperplasia**), but will increase in size (**hypertrophy**)

Movement in lower forms:

**Unicellular locomotion-**

- Protozoans & primitive algae – cilia or flagella by means of **power stroke** and **recovery stroke**
- Amoeba – extend **pseudopodia**; advancing cell membrane extends forward

**Invertebrate locomotion**

- **Hydrostatic skeletons**
  - Flatworms – bi-layered muscles, **longitudinal** and **circular**, contract against **hydrostatic skeleton**
    - Contraction causes hydrostatic skeleton to flow longitudinally, lengthening animal
  - Segmented worms (Annelids) – advance by action of muscles on hydrostatic skeleton
    - Bristles in lower part of each segment, **setae**, anchor worm in earth while muscles push ahead

## Skeletal System

- **Exoskeleton**
  - Arthropods – insect exoskeletons composed of hard **chitin**, necessitates **molting** for growth

**Vertebrate Skeleton**- comprised of an **endoskeleton**. Two major components are **cartilage** and **bone**

1. **Cartilage** – avascular connective tissue; softer and more flexible; (ex: ear, nose, larynx, trachea, joints)
   - **3 types**: hyaline (most common – reduced friction/absorbs shock in joints), fibrocartilage, and elastic.
   - from mesenchyme tissue → chondrocytes → produce collagen (present in tissue as **triple helix** with hydroxyproline and hydroxylysine, ground substance, & elastin fibers ??. Composed primarily of collagen, receive nutrients via diffusion.
2. **Bone** – connective tissue; hard and strong, while elastic and lightweight
   - **Functions*:*** support of soft tissue, protection of internal organs, assistance in body movement, mineral storage, blood cell production, and energy storage in form of adipose cells in marrow

**Bone** has four types of cells surrounded by extensive matrix:

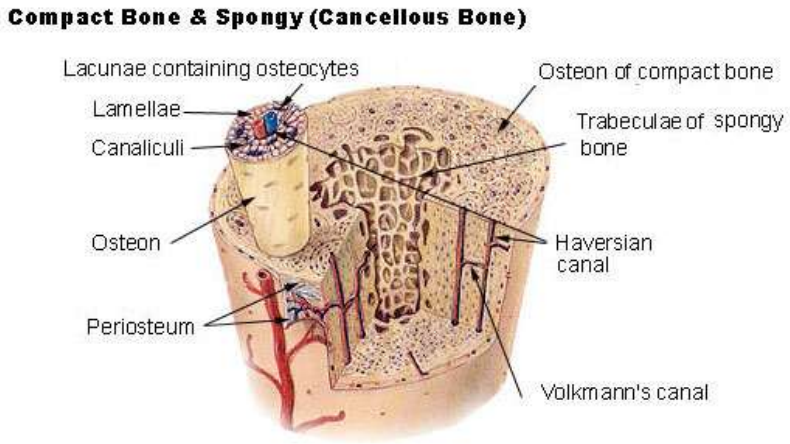
1. Osteoprogenitor/Osteogenic: differentiate into osteoblasts
2. **Osteoblasts**: secrete collagen and organic compounds upon which bone is formed. Incapable of mitosis. As matrix released around them → enveloped by matrix → differentiate into osteocytes (remember, **B**last means **B**uild)
3. **Osteocytes**: incapable of mitosis; exchange nutrients and waste material w/ blood
4. **Osteoclasts**: resorb (destroy) bone matrix, releasing minerals back to blood. Develop from monocytes.

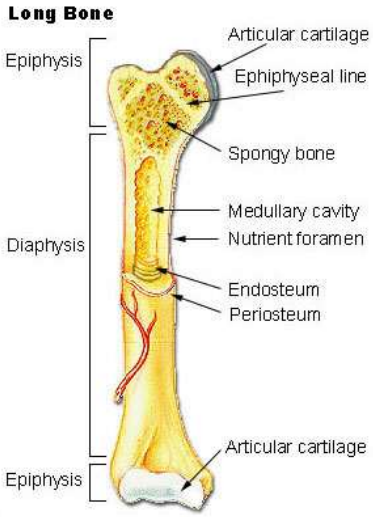
**Structure:**

- ***Compact bone***- highly organized, dense bone that doesn't appear to have cavities from outside: osteoclasts burrow tunnels (**Haversian canals**) throughout. Osteoclasts are followed by osteoblasts, which lay down new matrix onto tunnel walls forming concentric rings (**lamellae**). Osteocytes trapped between the lamella (**lacunae**) exchange nutrients via **canaliculi**. The Haversian canals also contain blood+lymph vessels and are connected by **Volkmann's canals**. Entire system of lamellae+Haversian canals is called an **osteon** (Haversian system). Compact bone is filled with yellow bone marrow that contains adipose cells for fat storage.
- ***Spongy (Cancellous) bone***- less dense and consists of an interconnecting lattice of bony spicules (trabeculae); filled with red bone marrow (site of RBC development)
- ***Bone growth occurs at cartilaginous **epiphyseal plates** that are replaced by bone in adulthood. Bone increases in length but also in diameter along the diaphysis as well. See here for illustration
- Most of the Ca2+ in body is stored in bone matrix as **hydroxyapatite**
- Bones can be made from a combination of compact and spongy

3. **Osteocytes** – covered above
4. **Bone Formation –** during FETAL stage of development
   - Endochondral ossification- cartilage → bone (EX: long bones; limbs, fingers, toes)
   - Intramembranous ossification- undifferentiated connective tissue replaced by bone
     - (EX: flat bones; skull, sternum, mandible, clavicles)

**Haversian canal** contains bone nerves and blood supply



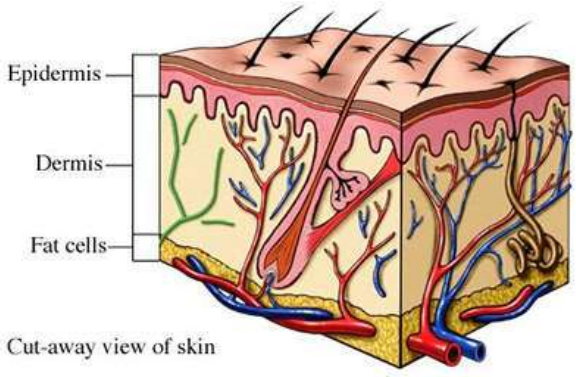




## Integumentary (Skin) System

**Functions of skin**:

- **Thermoregulation**: helps regulate body temp
- **Protection**: skin is a physical barrier to abrasion, bacteria, dehydration, many chemicals, UV radiation
- **Environmental sensory input**: skin gathers info about environment by sensing temp, pressure, pain, touch
- **Excretion**: water and salts excreted through skin
- **Immunity**: specialized cells of the epidermis are components of immune system
- **Blood reservoir**: Vessels in the dermis hold up to 10% of the blood in resting adult
- **Vit D synthesis**: UV radiation activates skin molecule that is a precursor to Vit D

**Structure of skin**




1. **Epidermis** – superficial; avascular epithelial tissue (depends on dermis for oxygen and nutrients). Layers from top down:
   a. **Stratum corneum –** 25-30 dead layers; filled w/ keratin and surrounded by lipids
      i. *Lamellar granules* make it water repellent
   b. **Stratum lucidum** – only in palms and soles of feet, and finger tips; 3-5 layers, clear/dead
   c. **Stratum granulosum**–3-5 layer of *dying* cells; lamellar bodies release hydrophobic lipids
   d. **Stratum spinosum –** strength and flexibility; 8-10 layers held together by (desmosomes-keratin involving adhesion proteins)

e. **Stratum basale (germinativum)** – contains Merkel cells and stem cells that divide to produce keratinocytes; attached by basement membrane.
   i. The keratinocytes are pushed to the top layer. Rise→ accumulate keratin and die → lose cytoplasm/nucleus/other organelles → at outermost layer of skin, slough off body

-**Cells of the epidermis:**
**1. Keratinocytes**: produce the protein keratin that helps waterproof the skin
**2. Melanocytes**: transfer skin pigment melanin to keratinocytes
**3. Langerhans cells**: interact with helper T-cells of immune system
**4. Merkel cells**: attach to sensory neurons and fxn in touch sensation

2. **Dermis –** primarily connective tissue; collagen and elastic fibers; contains hair follicles, glands, nerves, and blood vessels
   a. *Papillary region* – top 20%
   **b.** *Reticular region* – dense connective tissue, collagen and elastic fibers; packed with oil glands, sweat gland ducts, fat, and hair follicles; provides strength, and elasticity (stretch marks are dermal tears)
3. **Hypodermis (subcutaneous) –** not part of skin; areolar and adipose tissue; fat storage; pressure sensing nerve endings; passage for blood vessels

**Glands of the Skin**
1. **Sebaceous (oil) glands** – connected to hair follicles; absent in palms and soles
2. **Sudoriferous (sweat) glands**
   **a. Eccrine** (most of the body)- regulate temperature through perspiration; eliminate urea
   **b. Apocrine –** armpits, pubic region, and nipples; secretions are more viscous
3. **Ceruminous (wax) glands** – found in ear canal; produce wax-like material as barrier to entrance
4. **Mammary (milk) glands**

## H. Immune System

* *Nonspecific 1st line of defense*: **innate immunity** – generalized protection
- Skin: physical and hostile barrier covered with oily and acidic (pH 3-5) secretions from sweat glands.
- Antimicrobial proteins: lysozyme (saliva, tear) which breaks down cell wall of bacteria.
- Cilia: line the lungs serve to sweep invaders out. - Gastric juice: stomach kills most microbes.
- Symbiotic bacteria: digestive tract and vagina outcompetes many other organisms.

* *Nonspecific 2nd line of defense* – also innate
**Types of WBCs (leukocytes)** – see image here – all WBC's originate from bone marrow but some multiply + become non-naive in the lymph node (lymph drainage acts as a sewer system of antigens; cell recognizes antigen, goes from naïve → activated; multiplies).

- Phagocytes – engulf foreign particles/bacteria/dead or dying cells
  - Neutrophils – fxn in destruction of pathogens in infected tissues; drawn to infected or injured areas by chemicals in process called **chemotaxis**; slip between endothelial cells of capillary (*into* tissue) via diapedesis
  - Monocytes – move into tissues (diapedesis) where they develop into **macrophages** (which phagocytize cell debris + pathogens, are a professional antigen-presenting cell)
  - Eosinophils – work collectively to surround and destroy multicellular parasites
  - Dendritic Cells – responsible for the ingestion of pathogens and stimulate acquired immunity ("main function as APCs that activates T-lymphocytes")
  - Mast Cells – fxn in allergic response, inflammatory response (histamine release), anaphylaxis
- Lymphocytes – covered below
- Basophils – release histamines for inflammatory response

- Phagocytes: leukocytes (WBC's) engulf pathogens by phagocytosis (**neutrophils** and **monocytes** [enlarge into **macrophages**]). Other WBCs called **natural killer cells (NK cells)** attack abnormal body cells-tumors or pathogen-infected.
- Complements: 20 complement proteins; help attract phagocytes to foreign cells and help destroy by promoting cell lysis.
- Interferons: secreted by cells invaded by viruses/pathogens that stimulate neighboring cells to produce proteins defend against virus.
- Inflammatory: series of non-specific events that occur in response to pathogens. EX: when skin is damaged and bacteria enter the body

1. Histamine is secreted by basophils (white blood cells found in CT) → causes vasodilation.
2. Vasodilation- stimulated by histamine, increases blood supply to area- increase in temperature that stimulates WBCs and can kill pathogens
3. Phagocytes attracted to injury by chemical gradients of complement, engulf pathogens and damaged cells.
4. Complement helps phagocytes engulf foreign cells, stimulate basophils to release histamine, and help lyse foreign cells

* *Specific 3rd line of defense* (Immune response-targets specific antigen) (**acquired immunity** – develops after body has been attacked)
- Major histocompatibility complex: mechanism by which immune system is able to differentiate between self and nonself. MHC is a collection of glycoprotein that exists on membranes of all body cells. The proteins of single individual are unique (20 genes, each w/ 50+ alleles, unlikely to have same cells w/ same MHC set as someone else). Antigen presentation.
- Lymphocytes: primary agents of immune response, leukocytes that originate in bone marrow but concentrate in lymphatic tissues such as lymph nodes, thymus gland, and spleen.

1. **B cells (antibodies**): originates and mature (?) in bone marrow (B cell for bone); response to antigens. Plasma membrane of B cells contains **antigen receptor-antibodies (immunoglobulins)**.

- are proteins; specific to each antigen, five classes (IgA, IgD, IgE, IgG, IgM-variation in Y-shaped protein-constant region and variable regions). **Insert antibody structure picture for IgG; note that disulfide bonds connect the heavy chains to each other and to light chains. Include fxn of each Ig?**

- Antibodies inactivate antigens upon binding → mark for macrophage or natural killer cell phagocytosis, lysis by complement proteins, agglutination of antigenic substance, or chemical inactivation (if a toxin)

- When antigen bound to B cell → proliferation (2 copies) into daughter B cells (assisted by helper T) →

a. Plasma cells: B cells that release specific antibodies that circulate in blood

b. Memory cells: long-lived B cells that do not release antibodies in response to immediate antigen invasion; instead, they circulate the body, proliferate, and response quickly (via antibody synthesis) to eliminate **subsequent** invasion by same antigen. (2ndary response – takes less time, ~5 days)

2. **T cells** (**foreign**): originates in bone marrow but mature in *thymus* gland (T for thymus). T cells have antigen receptors but *do not make antibodies*; they check *molecules displayed by nonself cells*. In the thymus, if a T cell binds to a self-antigen, it is destroyed. If not, released for work in lymphoid tissue. Discrimination of self and nonself are as follow:

- MHC markers on plasma membrane of cells distinguish between self and nonself cells.
- When body cell is invaded by pathogen (nonself), it displays a combination of self and nonself markers. T cells interpret this as nonself.
- Cancer cells or tissues transplant cells are often recognized as nonself by T cells due to the combination.

+ When T cells encounter nonself cells: they divide and produce four kinds of cells:

a. Cytotoxic T cells: **killer T cells** recognize and destroy by releasing perforin protein to puncture them (lysis).

b. Helper T cells: stimulate activation of B cells, cytotoxic T cells, and suppressor T cells

c. Suppressor T cells: play negative feedback role in immune system

d. Memory T cells: similar fxn to memory B cells

3. **Natural killer cells**: attack virus-infected cells or abnormal body cells (tumors)

* **Clonal Selection**: when antigen bind to B cell or when nonself binds to T cell → divide into daughter cells, only B or T cells that bears effective antigen receptor is "selected" and reproduces to make clones.

* Responses of immune system are categorized into two kinds of reactions:

1. Cell-mediated response: Effective against infected cells. Uses mostly T *cells* and responds to *any nonself cell*, including cells invaded by pathogens. Nonself cell binds T cell → clonal selection → chain of events:

a. Produce **cytotoxic T cells (destroy) and helper T cells**.

b. **Helper T cells** bind **macrophages** (macrophages engulf pathogens = whole is nonself).

c. **Helper T cells then produce interleukins to stimulate proliferation of T cells and B cells** and macrophages

2. Humoral response (antibody-mediated response): responds to *antigens* or *pathogens* that circulate in lymph or blood (bacteria, fungi, parasites, viruses, blood toxins). Basically the B-cell stuff. *Humor* is body fluid and the following events:

a. **B cells produce plasma cells**. b. **B cells produce memory cells.**

c. **Macrophage and helper T cells** (in cell-mediated of macrophages engulf-nonself) **stimulate B cell production**.

d. General progression: Naïve → Mature → Plasma → antibody

Note that antibodies are released from plasma cells, are specific for an antigen, and a single B lymphocyte produces only one antibody type.

Humans supplement natural body defenses by:
- Antibiotics: are chemicals derived from bacteria/fungi that are harmful to other microorganisms.
- Vaccines: stimulate production of memory cells from inactivated viruses or weakened bacteria (artificially active immun)

- Passive immunity: transferred antibodies from another individual- EX: newborns from mother
    a. Acquired immediately, but short-lived and non-specific
    b. Gamma globulin (blood containing antibodies) – can confer temporary protection against hepatitis and other diseases

First time immune system is exposed to an antigen → **primary response**, requires 20 days to reach full potential

Recap of humoral response: imagine a bacterial infxn. 1st, inflammation. Macrophages + neutrophils engulf the bacteria. Interstitial fluid flushed into lymphatic system where lymphocytes are waiting in lymph nodes. Macrophages process+present bacterial antigen to B-lymphocytes. W/ help of helper-T, B differentiate into plasma and memory cells. Memory cells prepare for event of same bacteria ever attacking again (2ndary response); plasma cells produce antibodies released to blood to attack the bacteria.

## I. Endocrine System

**Endocrine –** synthesize and secretes hormones into bloodstream

**Exocrine –** secrete substances into ducts (ex. gall bladder) (Pancreas is both exo and endo)

- Sudoriferous (sweat), sebaceous (oil), mucous, digestive, mammary glands are examples

**Paracrine** – cell signalling where target is nearby; **Autocrine** is cell signaling via hormone/chemical messenger that binds to receptors on same cell

**Prostaglandins** – locally acting autocrine/paracrine lipid messenger molecules that have physiological effect (e.g. contract/relax smooth muscle)

- General characteristics of hormone: are transported throughout body in blood; small amount = large impact; slower effect

- **Hormone Types**
    - **Peptide** – synth'd in rough ER and modified in Golgi (requires vesicle to cross membrane), acts on surface receptors typically via secondary messengers (ex. Cyclic AMP)
        - Manufactured in rough ER as larger preprohormone → cleaved in ER lumen to prohormone → cleaved again (possibly modified w/ carbs) in Golgi to final form
        - Receptor-mediated endocytosis: protein stimulates production of 2nd messengers (G-protein → cAMP-produced from ATP; IP3-produced from membrane phospholipids which triggers Ca release from ER).
        - Include (AP) FSH, LH, ACTH, hGH, TSH, prolactin; (PP) ADH & oxytocin; (PT) PTH; (PANCR) glucagon & insulin
    - **Steroid** – synth'd from cholesterol in smooth ER; hydrophobic = freely diffuse but require protein transport molecule to dissolve in blood; intracellular receptors
        - Direct stimulation: "steroid" diffuses past plasma membrane and binds receptor in cytoplasm → hormone+receptor transported to nucleus → binds activate portion of DNA.
        - Incudes glucocorticoids and mineralicorticoids of the Adrenal Cortex: cortisol & aldosterone; the gonadal hormones: estrogen, progesterone, and testosterone (estrogen & progesterone are also produced by placenta)
    - **Tyrosine Derivatives** – formed by enzymes in cytosol or on rough ER
        - Thyroid hormones: lipid soluble; require protein carrier in blood; bind to receptors in nucleus
        - Catecholamines: (epi and norepi) water soluble; dissolve in blood; bind to receptors on target tissue and mainly act via 2nd messenger
        - Includes thyroid hormones ($T_3$ and $T_4$ aka thyroxine) and catecholamines formed in adrenal medulla: epi and norepi

All hormones bind to receptors highly specific to them. Some hormones have receptors on almost all cells, some have receptors only on specific tissues. Hormone regulation can occur by increasing/decreasing # of these receptors in response to hormone amount.

**Hypothalamus**- monitors external environment and internal conditions of the body; Contains **neurosecretory** cells that link the hypothalamus to the **pituitary gland**. Regulation of the pituitary = negative feedback mechanisms and by secretion of **releasing** and **inhibiting hormones**; secretes **ADH** (vasopressin) and **oxytocin** to be stored in posterior pituitary; also secretes **GnRH** (gonadotropin releasing hormone) from neurons, which stimulates anterior pituitary to secrete **FSH and LH**

**Anterior Pituitary**- mainly regulates hormone production by other glands – itself regulated by hypothalamus

1. *Direct hormones:* directly stimulate target organs
    - **Growth hormone (HGH)**- aka somatotropin; stimulates bone and muscle growth
    - **Prolactin**- stimulates milk production in females
    - Endorphins- inhibit perception of pain (technically a neurohormone)
2. *Tropic hormones:* stimulate *other endocrine glands*
    - Adrenocorticotrophic hormone (**ACTH**)- stimulates adrenal cortex → release glucocorticoids- involved in regulation of metabolism of glucose
    - **Thyroid-stimulating hormone (TSH)**- stimulates thyroid gland (↑ size, cell #) to release thyroid hormone ($T_4$ and $T_3$)
    - **Luteinizing hormone (LH):** females-stimulates formation of **corpus luteum** / males- stimulates interstitial cells of testes to produce testosterone
    - **Follicle-stimulating hormone (FSH):** females- stimulates maturation of ovarian follicles to secrete estrogen / males- stimulates maturation of seminiferous tubules and sperm prod

**Posterior Pituitary**- does not synthesize hormones, **stores** ADH and oxytocin produced by hypothalamus

- **Antidiuretic hormone (ADH/vasopressin)**- increases reabsorption of water by increasing permeability of nephron's **collecting duct** → water reabsorption and increased blood volume and pressure. Coffee blocks ADH.
- **Oxytocin**- secreted during childbirth- increases strength of uterine contractions and stimulates milk *ejection*

**Pineal gland-** secretes melatonin- plays role in circadian rhythm

**Thyroid**- located on ventral surface of trachea

- **Thyroxine ($T_4$) and Triiodothyronine ($T_3$)**
  - Derived from tyrosine and necessary for growth and neurological development in children and increase basal metabolic rate in body (negative feedback on TSH)
  - Hypothyroidism- undersecretion→low heart rate and respiratory rate
  - Hyperthyroidism- oversecretion → increased metabolic rate and sweating
    - Both lead to GOITERS
- **Calcitonin** ("tones down" $Ca^{2+}$) in blood
  - *Decreases plasma* $Ca^{2+}$ by inhibiting its release from bone
  - *Decreases* osteoclast activity and number

Disorders of the thyroid include **anchondroplasia** (AD; dwarfism) and **progeria** (AR; premature aging)

**Parathyroid**- four pea-shaped structures attached to back of thyroid

- **Parathyroid hormone (PTH)-** antagonistic to calcitonin
  - *Raises* $Ca^{2+}$ concentrations in blood by stimulating release from bone
    - Increases osteocyte absorption of Ca + P from bone; stimulates osteoclast proliferation
  - Increases renal Ca reabsorption

**Thymus-** involved in immune response

- Secretes **thymosins** that stimulate lymphocytes (WBCs) to become **T-cells (**identification and destroying of infected body cells)

**Adrenal gland**- on top of kidneys and consist of:

- ***Adrenal cortex* –** secretes only steroid hormones
  - Glucocorticoids (**cortisol** and **cortisone**)- raise blood glucose levels (stimulates gluconeogenesis in the liver); affect fat and protein metabolism; stress hormones
  - Mineralcorticoids (**aldosterone**)- increases reabsorption of $Na^+$ and excretion of $K^+$
    - Causes passive reabsorption of water in nephron→ rise in blood volume/pressure
  - Cortical sex hormones (**androgens**=male sex hormones)- effect is small due to testis
- ***Adrenal medulla***
  - Epinephrine and Norepinephrine (adrenaline and noradrenaline)- "fight or flight" – the **catecholamines**
    - "fight or flight"(*sympathetic* N.S.); considered stress hormones
    - glycogen→glucose, vasoconstrictor to internal organs+skin but vasodilator to skeletal muscle, increased heartbeat

**Pancreas**- both exocrine and endocrine; has bundles of cells called **islet of Landerhans** which contains two cell types:

- Alpha cells secrete **glucagon (**α "active"): catabolic, released when energy charge low; raises blood glucose levels
  - Stimulates liver to glycogen → glucose
- Beta cells secrete **insulin (**β "bumming"): anabolic, released when energy charge is high; lower blood glucose levels
  - Stimulates liver (and most other body cells) to absorb glucose
  - Liver +muscle cells: glucose → glycogen; fat cells: glucose → fat
- **Somatostatin** is released by delta cells of pancreas; inhibits both insulin and glucagon; possibly increases nutrient absorption time

**Testis**- testosterone- spermatogenesis, secondary sex characteristics

**Ovaries**-

- Estrogen- menstrual cycle, secondary sex characteristics
- Progesterone- menstrual cycle, pregnancy

**Gastrointestinal hormones**

- Gastrin- food in stomach, stimulates secretion of HCl
- Secretin- small intestine- when acidic food enters from stomach → neutralize acidity of chime by secretion of alkaline bicarbonate
- Cholecystokinin- small intestine- presence of fats → causes contraction of gall-bladder and release of **bile**(involved in digestion of fats)

| Source | Hormone | Target | Action |
|---|---|---|---|
| Posterior Pituitary | ADH (antidiuretic hormone) | Kidney | Increases reabsorption of water |

| | | | |
|---|---|---|---|
| | Oxytoxin | Mammary glands | Milk letdown |
| Anterior Pituitary (tropic hormones) | TSH (thyroid stimulating hormones)<br>ACTH (adrenocorticotropic hormones)<br>FSH (follicle stimulating hormones)<br>LH (luteinizing hormones) | Thyroid<br>Adrenal cortex<br>Ovaries, testes<br>Ovaries, testes | Secretion of $T_4$ and $T_3$<br>Secretion of glucocorticoids<br>Regulates oogenesis and spermatogenesis (both) |
| Anterior Pituitary (hormones) | PRL (prolactin)<br>GH (Growth hormones) | Mammary glands<br>Bone, muscle | Production of milk<br>Stimulates growth |
| Pancreas (α cells) | Glucagon | Liver | Increases blood glucose |
| Pancreas (β cells) | Insulin | Liver, muscles, fat | Decreases blood glucose |
| Adrenal gland (medulla) | Epinephrine (adrenalin) and norepinephrine (noradrenalin) | Blood vessels, liver and heart | Increases blood glucose, vasoconstriction (sympathytic) |
| Adrenal gland (cortex) | Glucocorticoids (cortisol)<br>Mineralocorticoids (aldosterone) | General<br>Kidney | Increases blood glucose<br>Increases reabsorption of $Na^+$ and excretion of $K^+$ |
| Thyroid | $T_4$ (thyroxin) and $T_3$ (triiodothyronine)<br>Calcitonin | General<br>Bone | Increases cellular metabolism<br>Lower blood $Ca^{2+}$ |
| Parathyroid | PTH (parathyroid) | Bone | Increases blood $Ca^{2+}$ |
| Testis | Testosterone | Testes, general | Spermatogenesis, $2^{nd}$ sex char |
| Ovary | Estrogen<br>Progesteron | Uterus, general<br>Uterus | Menstrual cycle, $2^{nd}$ sex char<br>Menstrual cycle, pregnancy |
| Pineal | melatonin | body | Circadian rhythms |

*** Questions**

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## XII. Animal Reproduction and Development

Non-animal: Asexual reproduction: benefits from stable environment since offspring are clones; sexual reproduction's advantage is **variation**

**Fission:** separation of organism into two new cells (amoeba)

**Budding:** new individual splits off from existing one (hydra)

**Fragmentation + Regeneration:** single parent breaks into parts that regenerate into new individuals (sponge/planaria/starfish)

**Parthenogenesis:** development of egg w/out fertilization; resulting adult is haploid (honeybees, some lizards)

### A. Human Reproductive Anatomy (9 month gestation)

**Gonads** – reproductive structure responsible for production of gametes. Male = testis, female = ovaries (primary sex characteristics)

- Secondary sex characteristics: indication of sexual maturity but not specifically involved in reproduction (e.g. breasts)

1. Female reproduction System:

a. Ovary: **ova**, or eggs, are produced. Each female has two ovaries.

b. Oviduct: eggs move from ovary to uterus through oviduct (Fallopian/uterine tube); one for each ovary; swept by fimbrae

c. Uterus: fertilized ovum implants (attaches) on the inside wall, **endometrium**, of uterus. Development of embryo occurs here until birth.

d. Vagina: at birth, fetus passes through **cervix** (opening in the uterus), through and out of body.

2. Male Reproduction System – path of sperm is SEVEnUP

a. Testis: each consists of **seminiferous tubules** for production of sperm and **interstitial cells** (Leydig cells) produces male sex hormones (testosterone = androgen) secreted in the presence of LH; **sertoli cells** stimulated by FSH surround and nurture sperm (also secrete peptide hormone *inhibin*, acts on PitGl to inhibit FSH release); testis contained in **scrotum**-about $2^oC$ lower than body temp for sperm production.

b. Epididymis: coiled tube, one attached to each testis; site for final maturation and storage of sperm.

c. Vas deferens: transfer sperms from one epididymis to urethra.

d. Seminal vesicles: Two glands, during ejaculation secrete into vas deferens: provide mucus (liquid for sperm), fructose as ATP, and prostaglandins (stimulate uterine contractions that help sperm move into uterus).

e. Prostate gland: secretes milky alkaline fluid into urethra; neutralizes acidity of urine that may still be in urethra, also vagina acidity. Also neutralizes seminal fluid (too acidic from metabolic waste of sperm)

f. Bulbourethral glands (aka Cowper's): secrete small amount of fluid of unknown function into urethra.

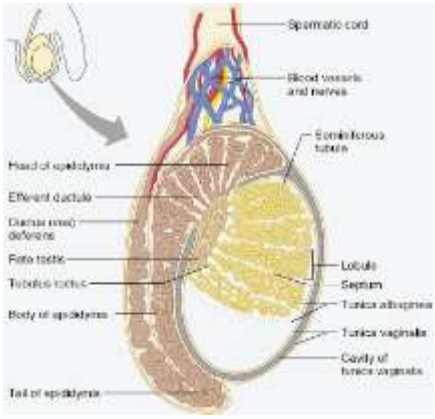
g. Penis: transport semen (fluid containing sperm and secretions) into vagina.

3. Sperm: compact packages of DNA specialized for effective male genome delivery.

a. Sperm head: haploid (23 chromosomes); at tip is **acrosome** (a lysosome containing enzymes [hyaluronidase] which are used to penetrate egg-originates from Golgi body vesicles that fused together). Only nuclear portion of sperm enters the egg.

b. Midpiece: flagellum (9 + 2 microtubule array), lots of mitochondria.

c. Tail: remainder of flagellum; sperm is propelled by whiplike motion of tail and midpiece.




**SEVEnUP: seminiferous tubules → epidydmis → vas deferens → ejaculatory duct → urethra → penis**

## B. Gametogenesis in Humans

- It is the meiotic cell divisions that produce eggs (oogenesis) and sperm (spermatogenesis). Egg contains most of the cytoplasm, RNA, organelles, and nutrients needed by developing embryo.

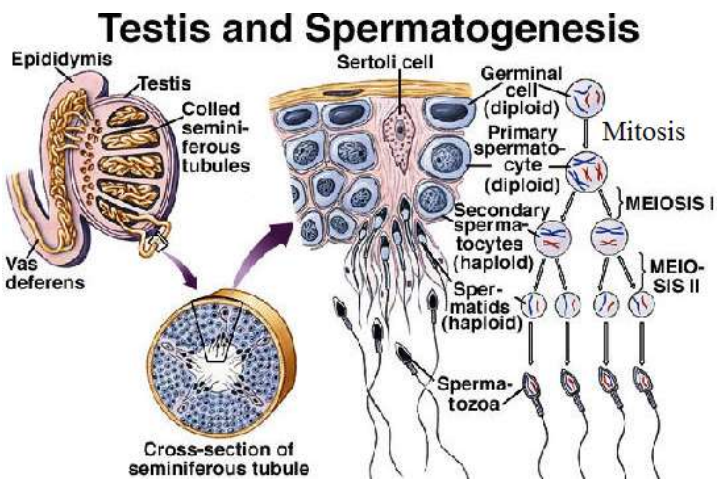
1. Oogenesis: being during embryonic development; **oogonia** (fetal cells) → (mitosis) **primary oocytes** → (meiosis) and remain at Prophase I until puberty (one primary oocyte during each menstrual cycle-28days, stim'd by FSH) continue its development through remainder of meiosis I within **follicle** (protects and nourishes oocyte) → (completion of Meiosis I) **secondary oocyte** (most of cytoplasm) + **polar body** (small cytoplasm; may or may not divide but products disintegrate) formed; now arrested at metaphase of meiosis II until → ovulation

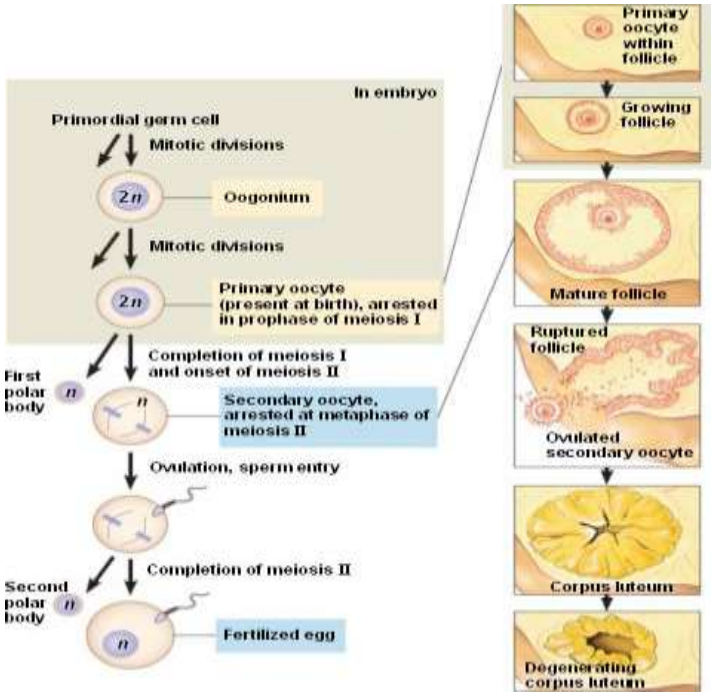
2. Ovulation: releases **secondary oocyte** from **vesicular follicle** (caused by LH surge). If fertilized by sperm → (finishes meiosis II) **ovum/egg (diploid once completely fertilized)** + **polar body** (degenerate)

3. Spermatogenesis: begins at *puberty* within seminiferous tubules of testes. **Spermatogonia** cells → (mitosis) **primary spermatocytes** → (meiosis) **2 secondary spermatocytes** → (meiosis II) **4 spermatids**.

- Sertoli cells: in seminiferous tubules provide nourishment to spermatids as they differentiate into mature **spermatozoa (sperm).** They complete maturation (gain motility and are stored) in the epididymis.

**Capacitation** – penultimate step in maturation of the spermatozoa while in the vagina, allows for egg penetration




## C. Hormonal Control of Human Reproduction

1. Female Reproductive Cycle: **ovarian cycle** (ovary) + **menstrual cycle** (uterus).

a. Menstrual Cycle – divided into follicular, ovulation, luteal, menstruation (proliferative/secretory/menstruation)

**Hypothalamus and anterior pituitary initiate**: monitor estrogen and progesterone in blood;

Low level → hypothalamus → GnRH → FSH and LH (via anterior pituitary-*negative feedback*) →

**Follicle develops** → FSH stimulate follicle to secrete estrogen → lots of estrogen (*positive feedback on AP*) →

**LH Surge → Ovulation** (follicle is now **corpus luteum**-maintained by LH [which along w/ estrogen begins to decrease after ovulation], secretes → estrogen + progesterone) →

**Development of endometrium** (thickens in prep$^{n}$ for implantation of fertilized egg) →

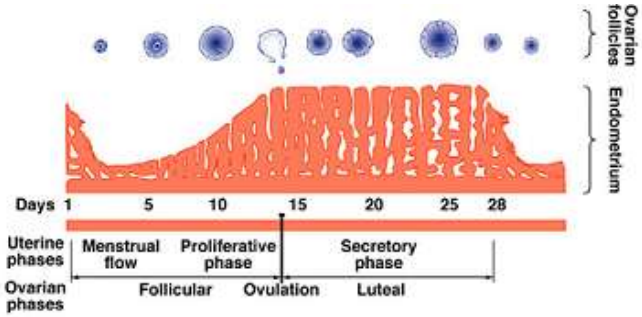
NO IMPLANTATION:

(*negative-feedback on AP* from ↑e+p) **terminates production of FSH + LH** (due to ↓GnRH from hypothalamus) →

**Corpus luteum** (no longer maintained by LH) **disintegrates** → corpus albicans, no estrogen + progesterone → endometrium shed during menstruation's flow phase.

IMPLANTATION:

**If implantation occurs** → embryo (placenta) secretes chorionic gonadotropin (**HCG**) → maintain **corpus luteum** → **Production of e + p** remain high → endometrium stays → HCG is later replaced by progesterone from placenta.




b. Ovarian Cycle

1. Follicular phase: development of egg and secretion of estrogen from follicle.
2. Ovulation: midcycle release of egg.
3. Luteal phase: secretion of **estrogen** and **progesterone** from **corpus luteum** after ovulation.

**Estrogen –** thicken endometrium

**Progesterone –** development and maintenance of endometrial wall

2. Male Reproductive Cycle:

- GnRH → FSH + LH (also called **ICSH**, interstitial cell stimulating hormone → testosterone and androgens from testis).
- FSH and testosterone → influence **Sertoli** cells to promote development of sperms (nourish sperm during development-spermatogenesis). Hormone and gamete production are constant unlike female.

## D. Embryonic Development

- Four stages in growth and development of animal: gametogenesis (sperm/egg formation), embryonic development (fertilization of egg until birth), reproductive maturity (puberty), aging process to death.
- In mammals, development is two stages—embryonic followed by fetal development. **Fetus** is an embryo that resembles the infant form.

1. Stages of Embryonic Development (sea urchin-echinoderm):

a. **Fertilization**: sperm penetrate plasma membrane of 2$^{nd}$ oocyte.

1. Recognition: before penetration, sperm secretes proteins that bind with receptor that reside on glycoprotein layer (**vitelline layer-zone pellucida** in human) surrounding plasma membrane of oocyte ensures same species fertilization

**Zona Pellucida** – !! Glycoprotein membrane surrounding plasma membrane of an oocyte. External but essential to the oocyte. First appears in unilaminar oocytes; secreted by both the oocyte and follicular cells (at puberty FSH stimulates growth of granulosa cells around primary oocyte that secrete the viscous zona pellucoda). It binds sperm, and is required to initiate the **acrosome reaction** (sperm releases contents of acrosome as it approaches egg; contributes to charge based *fast block* of polyspermy). 5 days after fertilization, blastocyst performs **zone hatching** (zona pellucida degenerates + replaced by underlying layer of trophoblastic cells so it can implant in the uterus).

Note: the above restated for emphasis in humans: Fertilization cannot occur until capacitation and the acrosomal rxn have taken place. In capacitation, secretions from uterus wall and uterine tube destabilize the plasma membrane surrounding the head of the sperm (acrosome), making the head more fluid which helps prepare it for fertilization, and makes the sperm hyperactive (faster and wiggle more). The capacitated sperm moves through the corona radiata (dense layer of granulosa cell surrounding the oocyte) and comes into contact with the zona pellucida. The zona pellucida expresses specific receptor proteins called ZP3 which bind to proteins expressed in the head of the sperm. The binding of ZP3 triggers the acrosome reaction during which the enzymatic contents of the acrosome are released. These enzymes help digest a path through the zona pellucida, allowing the sperm to enter the perivitelline space (space between the plasma membrane of the secondary oocyte and the zona pellucida), which then fuses with with oocyte's plasma membrane. To ensure only one sperm penetrates the zona pellucida and fuses with the oocyte membrane, this fusion activates a fast block and a slow block to polyspermy. First, during the fast block (takes place after fusion), the oocyte membrane depolarizes preventing other sperm from fusing with it. Slow block to polyspermy is then stimulated by this depolarization – during slow block to polyspermy, a wave of intracellular calcium is released, causing small cortical granules beneath the oocyte membrane to release their contents outward, rendering ZP3 in the zona pellucida inactive and making it impermeable.

Note: Fertilization can be external in water (lots of eggs laid since change of fertilization is lower; e.g. frogs, amphibians) or internal (terrestrial vertebrates; # of eggs affected by: internal vs. external (more eggs), early development, amount of parental care (less care = more eggs).

Note: In non-mammals the zona pellucida pelucida plays an important role in preventing cross-breeding of different species (especially in species that fertilize outside the body)

Note: The zona pellucida is commonly used to control wildlife population problems by immunocontraception. When the zona pellucida of one animal species is injected into the bloodstream of another, it results in sterility of the second species due to immune response – fertilization can't occur because antibodies have already bound the zona pellucida, preventing sperm from binding

2. Penetration: plasma membranes of sperm and oocyte fuse, sperm nucleus enter oocyte.

3. Formation of fertilization membrane: vitelline layer forms fertilization membrane blocks additional sperm (due to **cortical reaction**: exocytosis of enzymes produced by cortical granules in egg cytoplasm during fertilization – *slow block* when seen in mammals)

4. Completion of meiosis II in 2nd oocyte: sperm penetration triggers meiosis 2; ovum + polar body (discharged through plasma membrane) produced.

5. Fusion of nuclei and replication of DNA: sperm and ovum nuclei fuse → zygote (diploid-23 pairs in human).

b. **Cleavage**: rapid cell divisions without cell growth; each cell = **blastomere** (less cytoplasm than original zygote)

1. Embryo polarity: egg has upper, **animal pole** and lower, **vegetal pole** (contain more yolk material which is denser than cytoplasm, settles at bottom; differentiates into extraembryonic membranes that protect+nourish embryo). **Animal cell can divide through mitosis at a faster rate. (?)**

2. Polar and equatorial cleavages: early cleavages are polar, dividing egg into segments that stretch from pole to pole (segments of orange); others are parallel with equator.

3. Radial and spiral cleavages: radial in deuterostomes forming (indeterminate) cells at animal and vegetal poles that are aligned together, top cells directly above bottom cells. In protostomes (spiral-determinate), cells formed on top are shifted relative to those below.

4. Indeterminate and determinate cleavages: indeterminate (blastomeres can individually complete normal development if separated). Determinate cannot develop into complete embryo if separated; each is differentiated into part of the embryo.

Note: fertilization takes place in the oviduct; cleavage while swept; embryo at blastula stage by the time it reaches the uterus for implantation (img)

c. **Morula**: successive cleavage results in solid ball of cells (~8+ cells stage) (first 8 cells are totipotent)

d. **Blastula**: cell division continues; liquid fills morula and pushes cells out to form circular cavity surrounded by single layer of cells. **Blastocoel** is the cavity. (~128 cells stage). (get a good picture for this and make sure it distinguishes how the mammalian blastocyst has an inner cell mass)

-In humans the blastula is called the **blastocyst** and implants into the endometrium (development here)

e. **Gastrula(tion)**: invagination into blastula, forming two-layered embryo with an opening from outside into center cavity.

1. Three germ layers: ectoderm, mesoderm, and endoderm (3rd layer is formed between outer and inner layer of invaginated embryo). Give rise to all subsequent tissues.

a. **Endo**derm – epithelial lining of digestive & respiratory, parts of liver, pancreas, thyroid, and urinary bladder lining
b. **Meso**derm – musculoskeletal, circulatory system, excretory system, gonads, connective tissue, portions of digestive & respiratory, notochord
c. **Ecto**derm – Nervous system (brain and spinal cord), integument (epidermis & hair / epithelium of nose, mouth, anal canal), sense structures (lens of eye, retina), teeth, neural tube

Note: some primitive animals (e.g. sponges, cnidarian) will develop **mesoglea**, a noncellular layer, instead of mesoderm

2. Archenteron: center cavity formed by gastrulation.

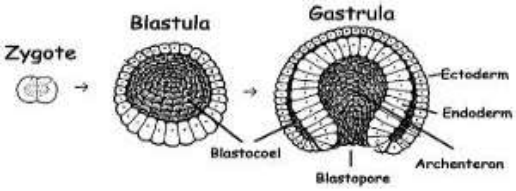
3. Blastopore: opening into archenteron, becomes mouth (protostomes) or the anus (deuterostomes).

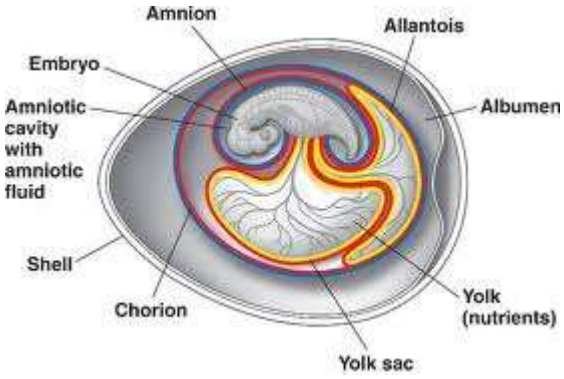
f. **Extraembryonic membrane development** – In birds, reptiles, and humans (called **amniotes**), this develops as follows:

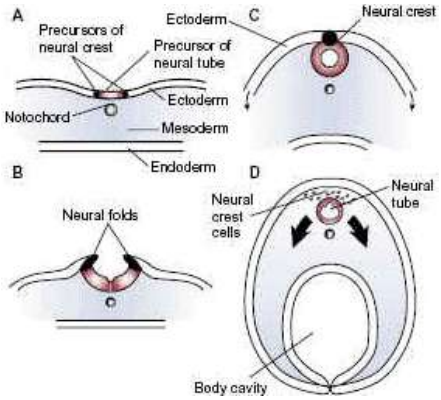
1. Chorion: outer membrane. Birds and reptiles: membrane for gas exchange. Mammals: chorion implants into endometrium, and later, the chorion and maternal tissue form the **placenta** (a blend of maternal and embryonic tissues across which gases, nutrients, and wastes are exchanged)

2. Allantois: Sac that buds off from archenteron (cavity of gastrula forming primitive gut) that eventually encircles the embryo, forming layer below chorion. Birds + reptiles: initially stores waste products as uric acid. Later fuses w/ chorion → membrane for gas exchange w/ blood vessels below. Mammals: allantois transports waste products to placenta; eventually forms umbilical cord between embryo and placenta: transporting gases, nutrients, and wastes. Becomes urinary bladder in adults.

3. Amnion: encloses **amniotic cavity**, a fluid-filled cavity that cushions the developing embryo, much like the coelom cushions internal organs in coelomates




4. Yolk sac: In birds and reptiles, yolk sac membrane digests enclosed yolk. Blood vessels transfer nutrients to embryo. In placental mammals, yolk sac is empty, as umbilical cord/placenta delivers nutrients.

**Differences in development**

- **External development**: fish & amphibians have external fertilization in water; reptiles, birds, and some mammals (e.g. monotremes) have internal fertilization then lay eggs. No placenta.
- **Non-placental internal development**: certain animals (e.g. marsupials, tropical fish) w/ no placenta either, limited exchange of food+$O_2$ between mother/young.
- **Placental internal development**: (e.g. humans). Major components are umbilical cord & placenta system: $O_2$ received direct from mother (fetal lungs not fxnal until birth) + nutrients; $CO_2$ and metabolic wastes removed. P & UC form from outgrowths of amnion, chorion, allantois, and yolk sac. Amnion contains amniotic fluid as shock absorber; placenta formation begins with chorion; blood vessels of allantois wall enlarge and become umbilical vessels (connect fetus → developing placenta); yolk sac (site of early development of blood vessels) becomes associated w/ umbilical vessels. Aka **viviparous** in mammals, results in live birth.

g. **Organogenesis**: cells continue to divide after gastrulation → differentiate → develop into specific tissues and organs. In chordates:

1. Notochord: cells along dorsal surface of mesoderm layer form notochord, a stiff rod that provides support in lower chordates. Vertebrae of higher chordates are formed from nearby cells in mesoderm.

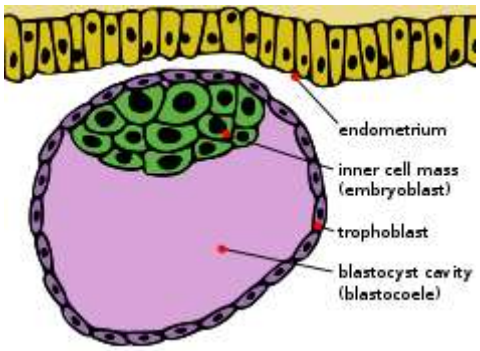
2. Neural tube: In ectoderm layer directly above notochord, layer of cells forms neural plate. Plate indents, forming **neural groove**, then rolls up into a cylinder, the **neural tube**. This develops into the CNS. Additional cells roll off top of neural tube and form **neural crest** (which form teeth, bones, muscles of skull, pigment cells in skin, and nerve tissue)

**Notable exceptions to the general embryonic development patterns**

1. Frog: amphibian

a. Gray crescent: sperm penetrates frog egg → reorganization of cytoplasm → pigmented cap of animal pole rotates towards point of penetration while gray, crescent-shaped region forms opposite the point of penetration. Spemann found in early cleavage, each individual cell could develop into a frog only if it had a small portion of gray crescent.

b. Gastrulation: blastopore forms at border between gray crescent and vegetal pole. During gastrulation, cells migrate over top edge (**dorsal lip**-formed from same region previously occupied by gray crescent) of and into blastopore in process called involution; blastocoel disappears and replaced by a different cavity (the archenteron). (this is confusing, see here for in depth explanation). Bottom edge of blastopore → **ventral lip**, side → **lateral lip**.




c. Yolk: more extensive than sea urchin; cells from vegetal pole rich in yolk material form **yolk plug** near dorsal lip.

2. Bird

a. Blastodisc: yolk of bird egg is very large, not involved in cleavages; cleavages only occur in blastula that consists of *flattened*, disk-shaped region that sits on top of yolk (**blastodisc**).

b. Primitive streak: when gastrulation begins, invagination occurs along line called primitive streak (rather than a circle). As cells migrate into here, results in an elongated blastopore rather than circular as in sea urchins and frogs.

3. Humans and most other mammals:

a. Blastocyst: blastula stage consisting of two parts—outer ring of cells (**trophoblast**) and inner mass of cells (**embryonic disc**).

-Inner cell mass goes on to form the epiblast and hypoblast; epiblast is what gives rise to the endo/epi/mesoderm.

b. Trophoblast: accomplishes implantation by embedding into endometrium; produces **human chorionic gonadotropin (HCG)** to maintain e+p production from **corpus luteum** (which in turn maintains endometrium); it later forms the **chorion** (later forms **placenta**).

c. Embryonic disc: within cavity created by trophoblast, **inner cell mass** clusters at one pole and flatten into embryonic disc (analogous to blastodisc of birds and reptiles). Primitive streak develops → gastrulation → development of embryo + extraembryonic membranes (except chorion)

**E. Factors that Influence Development**

1. Influence of egg cytoplasm: cytoplasmic material distributed unequally in egg, non-uniform distribution of cytoplasm (think gray crescent in frogs and yolk in bird eggs) results in embryonic axes, such as animal and vegetal poles. When cleavages divide egg → daughter cells have different quality of cytoplasmic substances (**cytoplasmic determinants)**. → Unique substances influence subsequent development of each daughter cell. Sea urchin: slice 8-ball embryo into two halves. Longitudinal → embryo has cells from animal & vegetal pole → normal development results. Horizontal → embryo only has cells from animal OR vegetal → abnormal development results. Confirms the cytoplasmic determinants affecting development. Spemann confirmed with gray crescent vs none cuts.
2. Embryonic induction: influence of one cell/group of cells over neighboring cells; **organizers** (controller cells) secrete chemicals that diffuse among neighboring cells, influence their development (Dorsal lip [fxning as a primary organizer] of blastopore induces notochord development in nearby cells); 2nd dorsal lip grafted to embryo → two notochords developed.
3. Homeotic genes: control of development by turning on and off other genes that code for substances that directly affect development. *Mutant* homeotic genes in fruit flies → wrong body parts in wrong places. **Homeobox** (unique DNA segment-180 nts) identifies a particular class of genes that control development (encodes homeodomain of protein that can bind DNA)
4. Apoptosis: Programmed cell death that is a part of normal cell development. Essential for development of nervous system, operation of immune system, and destroy tissue (webbing) between fingers/toes. Damaged cells also undergo apoptosis; if not cancer may develop. Regulated by protein activity (rather than at transcriptional/translational level); apoptosis proteins are present but inactive in normal cell. Mammals: mitochondria play important role in apoptosis. Characteristics of apoptosis: changes include blebbing, cell shrinkage, nuclear fragmentation, chromatin condensation, and chromosomal DNA fragmentation. There is no cellular rupturing, no inflammatory response. The dead cells are engulfed. Typically affects single cells.

Cell is said to be **determined** if its final form cannot be changed; cytoplasmic influences narrowed by successive cell division; determination likely later than earlier. Trace cells during development to build **lineage map**.

**Labor (three stages) –** a series of strong uterine contractions

1. Cervix thins out and dilates, amniotic sac ruptures and releases fluids
2. Rapid contractions followed by birth
3. Uterus contracts and expels umbilical cord and placenta

**Fraternal twins** result from more than one egg being fertilized; **identical twins** result from indeterminate cleavage

*** Questions**

- Amniotes: group of tetrapods (four-limbed animals with backbones or spinal columns) that have a terrestrially adapted egg; supported by several extraembryonic membranes.

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**XIII. Animal Behavior**

**A. Genetic Basis of Behavior**: can be inherited through genes (innate-molded by natural selection-increase fitness) or learned. **Behavioral ecology** is the study of behavior that seeks to explain how specific behaviors increase fitness.

**B. Kinds of Animal Behavior**

1. **Simple and Complex Reflexes**
    a. Simple- automatic 2 nerve (afferent/efferent) response to stimulus controlled @ spinal cord (lower animals)
    b. Complex- automatic response to significant stimulus (controlled @ brains stem or even cerebrum)
        **i.** Ex: **Startle response-** controlled by the **reticular activating system**
2. **Instinct**- behavior that is innate, or inherited
    a. Ex: In mammals, care for offspring by female parents
3. **Fixed action patterns (FAP) -** innate behaviors following a regular, unvarying pattern. Initiated by a specific stimulus called **sign stimuli** (**releaser** when between members of same species**)**, and completed even if original intent of behavior cannot be fulfilled
    a. Ex: Goose methodically rolling egg back to nest even if it slips away or is removed
    b. Ex: Male stickleback fish defending territory against any object with red underside
    c. Ex: Swimming actions of fish/flying actions of locusts
4. **Imprinting-** innate program for acquiring specific behavior only if appropriate stimulus is experienced during **critical period**. Once acquired, trait is irreversible

a. Ex: Gay goslings accepting any moving object as mother during first day of life
b. Ex: salmon hatch in freshwater, migrate to ocean to feed, return to birthplace to breed based on imprinted odors associated w/ birthplace

5. **Associative learning**- occurs when an animal recognizes (learns) that events are connected. A form called **classical conditioning** occurs when animal performs behavior in response to substitute stimulus rather than normal stimulus
    - **i.** Ex: Dogs salivate when presented with food. PAVLOV bell ringing prior to food, could stimulate salivation with bell alone
    - **ii.** Established innate reflex is **unconditioned stimulus** (food causing salivation), natural response to that is the **unconditioned response** (salivation)
    - **iii.** Association of bell with food leads to it becoming **conditioned stimulus** that will elicit response even in absence of the unconditioned stimulus. Product of this conditioning experience is called the **conditioned reflex** (salivation)

b. **Trial-and-error learning (operant conditioning)-** another form of associative learning that occurs when animal connects its own behavior with environmental response, **reward**. If response is desirable (positive reinforcement), animal will repeat behavior. If negative/undesirable (painful, e.g. punishment), animal avoids behavior (positive reinforcement = add something good to increase a behavior; negative reinforcement = take away something bad to increase a behavior vs positive punishment = add something bad to decrease behavior; negative punishment = take away something good to decrease behavior)
    - **i.** Learned behavior can be reversed in absence of reinforcement; behavior no longer elicits the response (**extinction)**
    - ii. Recovery of conditioned response to conditioned stimulus after delay following extinction = **spontaneous recovery**

**c. Spatial learning**- Another form of associative learning. Animal associates attributes of landmark with reward of identifying and returning to that location
    - i. **Ex**: Wasps able to associate pinecones with location of nest (lost upon removal)

6. **Habituation-** learned behavior that allows animal to disregard meaningless stimuli
    a. Sea anemones disregarding repeated "feeding" stimulation with a stick
    b. If stimulus no longer regularly applies, response will recover over time – **spontaneous recovery**

7. **Observational learning**- animal copies behavior of another without having experienced any feedback themselves
    a. **Ex:** All monkeys followed lead of first by washing off potato in water

8. **Insight**- When animal exposed to new situation w/out prior exp., performs a behavior that generates (+) outcome
    a. Chimpanzee stacks boxes to reach bananas previously out of reach

Some behaviors appear learned but are actually innate behaviors that require **maturation** (ex: bird appears to learn to fly by trial+error or observational learning, but if raised in isolation will fly on first try if physically capable → flight ability is innate but requires physical maturation).

- Inherited behaviors: evolved because they increase fitness. Innate behaviors (e.g. FAP) provide successful/dependable mechanism to an expected event; challenge need not be resolved repeatedly by every new generation. In contrast imprinting provides flexibility → if mother killed, imprint → new mother chosen (likely same species)

- Associative learning: allows individuals to benefit from exposure to *unexpected* repeated events. Habituation allows individuals to ignore repetitive events known to be inconsequential from exp. → can remain focused on other, more meaningful events. Observational and Insight provide mechanism to learn new behaviors in response to *unexpected events* w/out receiving reinforcement → reduces time for new behavior to be acquired

- Daily cycles of behavior are **circadian rhythms**

- Learning involves **adaptive responses** to the environment; in higher animals capacity of learning closely associated with degree of neurological development

-**Stimulus generalization:** conditioned organism responds to stimuli similar but not identical to original conditioned stimulus. **Stimulus discrimination** involves the ability of the learning organism to differentially respond to slightly different stimuli (e.g. only respond to 990 to 1010 Hz range). **Stimulus generalization gradient** = further from original conditioned stimulus, lesser the magnitude of response

## C. Animal Movement

1. Kinesis: an *undirected* (without direction) change in *speed* of an animal's movement in response to a stimulus; slow down in favorable environment and speed up in unfavorable environment. Ex: animals scurrying when rock is lifted up

2. Taxis: *directed* movement in response to stimulus. Movement is either *toward/away* from stimulus. **Phototaxis** is the movement toward light. Ex: moths moving toward light, sharks moving toward food odors

3. Migration: long-distance, seasonal movement of animals. Usually in response to availability of food/degradation of environmental conditions. Ex: migration by whales, birds, elk, insects, and bats to warmer climates.

**D. Communication in Animals**

1. **Chemical**- chemicals used for communication are **pheromones**. Chemicals that trigger reversible behavioral changes are called **releaser pheromones**; those that cause long term physiological (and behavioral) changes are called **primer pheromones**. Pheromones may be smelled or eaten.
    a. Ex: Doe in heat – releaser pheromones
    **b.** Ex: Queen bees and aunts secrete primer pheromones to prevent development of reproductive capability
2. **Visual-** during displays of aggression (agonistic behavior) or during courtship
    a. Ex: aggression- wolves baring teeth/ submission- laying on back
    **b.** Ex: Male sage grouse assemble into groups (**leks**) to perform courtship dance
3. **Auditory**
    **a.** Ex: whale sound, elephant infrasound, frog calls, and songs of male birds
4. **Tactile**
    a. Common in social bonding, infant care, grooming, and mating

**E. Foraging Behavior**: optimize feeding (minimize energy spent and risk)

1. Herds, flocks, schools: several advantages, uses cooperation (carry out a behavior more successfully as a group_
    a. Concealment: most individuals in flock are hidden from view.
    b. Vigilance: in a group, individuals can trade off foraging and watching for predators.
    c. Defense: a group of individuals can shield their young or mob their predator.
2. Packs: enable members to corner and successfully attack large prey.
3. Search images: help animals find favored or plentiful food based on specific and/or abbreviated target 'image'; ex spotting a police car (black and white search image), book on shelf (color and shape w/out reading title)

**F. Social Behavior**

1. **Herds, flocks, and schools**
    a. Provide benefit of *concealment, vigilance, and defense*
2. **Packs**
    a. Allow members to corner and attack large prey
3. **Search images**
    a. Help animals find favored or plentiful food
        i. Ex: Black and white search image = police car for humans

**Social Behavior**

1. **Agonistic behavior** - (aggression and submission)- Ex: dog wagging tail
    a. Originates from competition from food, mates, or territory
    b. Agnostic behavior is ritualized, so injuries and time spent in contests are minimized
2. **Dominance hierarchies –** indicate power and status relationship in a group; minimize fighting for food/mates
    a. **Pecking order**- linear order of status used to describe dominance hierarchy in chickens
3. **Territoriality**- active possession and defense of territory- ensures adequate food/place to mate
4. **Altruistic behavior**- seemingly unselfish behavior that appears to reduce fitness of individual- when an animal risks its safety in defense of another/in order to help another individual rear its young
    a. Actually increases **inclusive fitness** (fitness of individual *plus* relatives [who share some identical genes])
    b. **Kin selection**- natural selection that increases inclusive fitness
    c. Ex: Squirrels alarm when predator comes → risky to self but save daughters, mothers, sisters, and aunts → kin selection.
    d. Ex: **haplodiploid** reproductive system of bees- males are haploid (unfertilized egg of queen) and female workers and queen are diploid (fertilized eggs). Females are highly related to each other (same father whose genes all come from a queen mother + same queen). Inclusive fitness of female workers is greater if she promotes production of sisters

*** Questions**

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**XIV. Ecology** – study of distribution+abundance of organisms and their interactions w/ other organisms + their physical environment

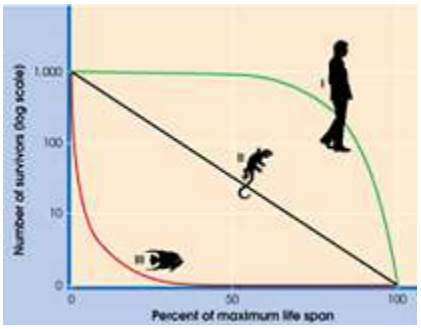
- **Abiotic –** nonliving (temp, climate, light and water availability, topology)
    - *Sunlight* –
        - **Photic zone** in water = light penetrates; all aquatic photosynthesis
        - **Aphotic zone** – only animal and other heterotrophs
    - *Oxygen* – air is ~ 80% nitrogen, 20% oxygen

- **Biotic** – all living things that directly or indirectly influence the life of the organism

- Population: group of individuals of same species living in the same area.
- Community: group of populations living in the same area.
- Ecosystem: describes interrelationships between organisms in a community and their physical environment.
- Biosphere: composed of all regions of earth that contain living things. (ex. Atmosphere, hydrosphere, lithosphere, etc)
- Habitat: type of place where organism usually lives; including other organisms as well as physical, chemical environment.
- Niche: describes all biotic and abiotic resources in the environment used by an organism. When an organism is said to occupy a niche, certain resources are consumed or certain qualities of environment are changed in some way by presence.

**A. Population Ecology**: study of growth, abundance, and distribution of populations.

1. Size: *N*, total number of individuals in population.
2. Density: total number of individuals per area or volume occupied.
3. Dispersion: describes how individuals in a population are distributed; may be clumped, uniform, or random.
4. Age structure: description of the abundance of individuals of each age. 3 2 1 (% male) 0 (% female) 1 2 3 with horizontal bars for each age group.
5. Survivorship curves: how mortality of individuals in a species varies during their lifetimes.




a. Type I: most individuals survive to middle age and dies quicker after this age (human).

b. Type II: length of survivorship is random (invertebrates-hydra).

c. Type III: most individuals die young, with few surviving to reproductive age and beyond (oysters).

6. Population Growth

a. Biotic potential: maximum growth rate under ideal conditions (unlimited resources and no restrictions). The following factors contribute to biotic potential of a species: age at reproductive maturity, clutch size (# offspring produced at each reproduction), frequency of reproduction, reproductive lifetime, survivorship of offspring to reproductive maturity.

b. Carrying capacity (K): maximum number of individuals of a population that can be sustained by habitat.

c. Limiting factors: **density-dependent** (limiting effect becomes more intense as population density increases- competition, spread of disease, parasites, predation) and **density-independent** (occur independently of density of population such as natural disasters or big temp changes).

- Growth rate of population: r = (births – death)/N  Change: $\Delta N/\Delta t = rN$ = births - deaths
- Intrinsic rate: of growth is when the reproductive rate (r) is maximum (biotic potential).

d. Exponential growth: occurs whenever reproductive rate (*r*) is greater than zero (J-shaped).

e. Logistic growth: occurs when limiting factors restrict size of population to the carrying capacity of habitat.

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

- K is carrying capacity. When population size increase → growth rate decreases and reach 0 when population size reach carrying capacity → S-shaped.

- Population cycle: fluctuations in population size in response to varying effects of limiting factors. when population grows over carrying capacity, it may be limited (lower) than the initial K due to the damage caused to the habitat → lower new carrying capacity K or it may crash to extinction.

Two growths above are associated with two kinds of life-history:

**K-selected population** – members have low reproductive rates and are roughly constant (at K) in size (ex. human population). Have a carrying capacity that population levels out at. Carrying capacity is a density dependent factor.

**R – selected population** – rapid exponential population growth, numerous offspring, fast maturation, little postnatal care (ex. bacteria). Generally found in rapidly changing environments affected by density independent factors. Characterized by **opportunistic species** (e.g. grasses, insects that quickly invade a habitat, reproduce, then die)

Human Population Growth – enabled by: increase in food supply, reduction in disease (medicine), reduction in human wastes, habitat expansion (advancements now allow inhabitance of previously uninhabitable places)

**Ecological footprint:** amount of raw land necessary to sustain an individual's lifestyle habits (consider eating, traveling, housing habits)

**species richness** reflects the diversity of a community in regards to the total number of different species present

**B. Community Ecology**: concerned with interaction of populations; such as **Interspecific competition** (different species).

1. Competitive exclusion principle (Gause's principle): two species compete for exactly the same resources (or occupy the same niche), one is likely to be more successful (*no two species can sustain coexistence if they occupy the same niche*).

2. Resource partitioning: two species occupy same niche but pursue slightly different resources or securing their resources in different ways, individuals minimize competition and maximize success (*multiple species-slightly different niches*).

3. Character displacement (niche shift): as a result of resource partitioning, certain traits allow for more success in obtaining resources in their partitions → reduces competition → divergence of features (character displacement) such as different beak of birds on the same island. The mating calls of 2 species of frogs are different when they occupy the same island. On separate islands, the mating calls are the same.

4. Realized niche: niche that an organism occupies in absence of competing species is its **fundamental niche**. When competitors are present, one/both species may be able to coexist by occupying their **realized niches**, that part of their existence where **niche overlap** is absent (occupy areas of niche that don't overlap so no competition for resources)

Example: One barnacle species can live on rocks that are exposed to full range of tides (fundamental). In natural environment, 2nd species of barnacle outcompetes the 1st, but only at lower tide levels where desiccation is minimal. The 1st species then only survive in its realized niche, the higher tide levels.

5. Predation: another form of community interaction.

a. True predator: kills and eats another animal.

b. Parasite: spends most of its life living on host, host usually doesn't die until parasite complete one life cycle.

c. Parasitoid: an insect that lays its eggs on host (insect or spider). After eggs hatch, larvae obtain nourishment by consuming host's tissues. Host eventually dies, but not until larvae complete development and begin pupation.

d. Herbivore: animal that eats plants. **Granivores** are seeds eater (act like predators totally consume organism). **Grazers** (animals that eat grasses) and **browsers** (eat leaves) and eat only part → weaken it in process.

6. **Symbiosis –** intimate, often permanent association b/w two organisms; may or may not be beneficial; some may be **obligatory** (one or both organisms cannot survive w/o the other)

a. **Commensalism (+/o) –** one benefits, the other is unaffected
   - Remora and shark – remora gets food shark discards
   - Barnacle and Whale – barnacle gets wider feeding opportunities

b. **Mutualism (+/+) –** both organisms benefit
   - Tick bird and Rhinoceros – bird gets food (ticks) and rhino loses ticks
   - Lichen (fungus + algae) – algae produces food for itself and fungus via photosynth; fungus provided $CO_2$ and nitrogenous wastes
   - Nitrogen Fixing Bacteria and Legumes – legumes provides nutrients for bacteria and bacteria fixes nitrogen
   - Protozoa and Termites – protozoa digests cellulose for termites, termites protect and provide food
   - Intestinal Bacteria and Humans – bacteria utilized food and provide vitamin K

c. **Parasitism (+/-) –** benefits at the expense of the host; bacteria and fungi; live with minimum expenditure of energy
   - Parasites can be **ectoparasites** (cling to exterior of host) or **endoparasites** (live within the host)
   - Virus and Host cell – all viruses are parasites
   - Disease Bacteria and Animals – diphtheria is parasitic upon man; anthrax on sheep; tuberculosis on cow or man
   - Disease Fungi and Animals – ringworm is parasitic on man
   - Worms and Animals – tapeworm and man (less dangerous = more survival; better for parasite not to kill its host)

**Saprophytism –** protists and fungi that decompose dead organic matter *externally* and absorb nutrients

**Scavengers** consume dead animals directly (ex. Vulture, hyena, bacteria of decay)

*Intraspecific interactions between members of the same species are influenced by disruptive (competition) and cohesive (reproduction and protection from predators and weather) forces*

**Interactions between organisms and their Environment**

1. **Osmoregulation**
   a. **Freshwater fish –** live in hypoosmotic environment which causes excess intake of water; thus the fish seldom drink and excrete dilute urine
   b. **Saltwater fish –** live in hyperosmotic environment; constantly drinking and excreting salt across their gills
   c. **Arthropods** – secrete solid uric acid crystals to conserve water
   d. **Plants** – possess waxy cuticles on leaf surface and stomata and have stomata on the lower leaf surfaces only; leaves shed in winter; desert plants have extensive root systems, fleshy stems, spiny leaves, extra thick cuticles, and few stomata
2. **Thermoregulation**
   a. **Cold-blooded (poikilothermic) –**vast majority of plants and animals; body temp. is close to that of surroundings, so metabolism is radically affected by environmental temp.
   b. **Warm-blooded (homeothermic) –** make use of heat produced by respiration; physical adaptations like fat, hair, and feathers retard heat loss (Ex: mammals and birds)

**C. Coevolution**: evolution of one species in response to new adaptation that appear in another species.

1. Secondary compounds: toxic chemicals produced in plants that discourage would-be herbivores (tannins in oaks/nicotine/ tobacco are toxic)

2. Camouflage (cryptic coloration): is any color, pattern, shape, or behavior that enables an animal to blend in with its surroundings. Both prey and predator benefit from camouflage.

3. Aposematic coloration (warning coloration): conspicuous pattern or coloration of animals that warns predators that they sting, bite, taste bad, poisonous, or are other wise to be avoided.

4. Mimicry: occurs when two or more species resemble one another in appearance. There are two kinds:

a. Mullerian mimicry: occurs when several animals, *all with some special defense mechanism*, share the same coloration → effective with single pattern such [predator only has to learn one pattern is bad instead of lots of variants] as yellow and black body markings (dangerous) from bees, yellow jackets, and wasps.

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

Coloration, camouflage, mimicry etc are passive defenses. Active defenses are hiding, fleeing, defending but can be costly in energy.

5. Pollination: of many kinds of flowers occur as result of Coevolution of finely-tuned traits between flowers + pollinators

-red tubular flower coevolves with hummingbird attracted to red → provides nectar to hummingbird in exchange for pollen transfer

**D. Ecological Succession**: change in composition of species over time.

- It describes how one community is replaced by another gradually consisting of different species. As it progresses, diversity (# of species in community) and total biomass increase. A final successional stage of constant species composition (**climax community**), is attained (usually never-random occurs) → unchanged until destroyed by catastrophic event (**blowout**). Succession has a factor of randomness that makes it hard to predict; resident species can also change a habitat:
- Substrate texture: may change from solid rock, to fertile soil, to sand/others (because rock erodes, plants+animals decomp)
- Soil pH: may decrease due to decomposition of organic matter such as acidic leaves.
- Soil water potential: ability of soil to retain water, changes as soil texture changes.
- Light availability: may change from full sunlight to shady to darkness as trees become established
- Crowding: increases with population growth, may be unsuitable to certain species.
- Pioneer species: plants and animals that are first to colonize a newly exposed habitat (usually opportunistic, r-selected species); can tolerate harsh conditions. (ex. Lichens and mosses)

- As soil, water, light change, r-selected will be replaced by stable K-selected species (live longer, slow succession) and reach climax where it remains for hundreds of years.

1. Primary succession: occurs on substrates that never previously supported living things (volcanic islands, lava flows). Essential and dominant characteristic of primary succession is soil building.

2. Secondary succession: begins in habitats where communities were entirely/partially destroyed by damaging event; begins on substrate that already bear soil (may contain native seed bank).

- A community stage is identified by a **dominant species**; Ex: grass in grassland community
- **Ecological succession in a Pond**
  1. *Pond*: Plants such as algae, pondweed. Animals such as protozoa, insects, fish
  2. *Shallow water-pond fills in*: Reeds, cattails, water lilies
  3. *Moist land:* grass, herbs, shrubs, willow trees. Frogs, snakes
  4. *Woodland:* climax tree – perhaps pine or oak

**E. Ecosystems** – have trophic levels that categorize plants/animals based on their main energy source

1. Primary producers: autotrophs that convert sun energy into chemical energy; plants, photosynthetic protists, cyanobacteria, and chemosynthetic bacteria.

2. Primary consumers: herbivores (long digestive tract w/ greater surface area and time for more digestion; symbiotic bacteria in digestive tract break down the cellulose which the herbivore itself cannot), eat primary producers.

3. Secondary consumers: primary carnivores, eat primary producers.

4. Tertiary consumers: 2nd carnivores, eat 2nd consumers. (example of primary producer → tertiary consumer chain here)

5. Detritivores: consumers that obtain energy by consuming dead plants/animals (**detritus**). smallest ones are **decomposers** (fungi and bacteria). Also includes nematodes, earthworms, insects, + **scavengers** (vultures, jackals, crab), saprophytes

- Ecological pyramids: show relationships between trophic levels.

- Ecological efficiency: describes the proportion of energy represented at one trophic level that is transferred to the next. On average, an efficiency of about 10% is transferred to the next. 90% is for metabolism and to detritivores when they die.

- Food chain: linear flow chart of who's eaten by whom (grass → zebra → lion → vulture).

- Food web: is an expanded, more complete version of food chain (greater number of pathways in a community food web, the more stable the community is)

Energy/biomass/quantity is greatest at primary producer level, lowest at tertiary consumer level. Tertiary is least stable + most sensitive to population fluctuations of lower levels

**F. Biogeochemical Cycles** – flow of essential elements: environment → living things → environment

1. Hydrologic cycle (water cycle) a. Reservoir: oceans, air, groundwater, glaciers.
   b. Assimilation: plants absorb water from soil; animals drink and eat other organisms.
   c. Release: plants transpire; animals and plants decompose.
2. Carbon cycle: required for building organic materials. Basis for this is photosynthesis + respiration
   a. Reservoirs: atmosphere ($CO_2$), fossil fuels (coal, oil), peat, cellulose.
   b. Assimilation: plant uses $CO_2$ in photosynthesis, animals consume plants (this is carbon fixing – reduced from its inorganic form of $CO_2$ to organic compounds) (just like in N-fixing: $N_2$ is relatively inert, N-fixing frees it up for use)
   c. Release: release $CO_2$ through respiration and decomposition + when organic material is burned
3. Nitrogen cycle: required for amino acid and nucleic acids. (this cycle is important, memorize this)
   a. Reservoirs: atmosphere ($N_2$), soil ($NH_4^+$, $NH_3$, $NO_2$, $NO_3$)
   b. Assimilation: Plants absorb nitrogen as either $NO_3^-$ or $NH_4^+$., animals obtain nitrogen by eating plants/animals
      1. Nitrogen fixation: **nitrogen-fixing bacteria in soil** ($N_2$ → $NH_4^+$); **Lighting + UV** ($N_2$ → $NO_3^-$)
      2. Nitrification: $NH_4^+$ → $NO_2^-$ and $NO_2^-$ → $NO_3^-$ by **nitrifying bacteria**.
   c. Release: denitrifying bacteria (convert $NO_3$ → $N_2$; **denitrification**), detrivorous bacteria convert organic compounds back to $NH_4^+$ (**ammonification**), animals excrete $NH_4$, urea, or uric acid, decay (nitrogen in the form of $NH_3$ is released from dead tissues)
4. Phosphorus cycle: required for manufacturing of ATP and all nucleic acids. Cycles for other minerals (Ca, Mg) are similar to phos cycle.
   a. Reservoirs: rocks and ocean sediments (erosion transfers P to water and soil)
   b. Assimilation: plants absorb inorganic $PO_4^{3-}$ (phosphate) from soil; animals obtain organic phosphorus when they eat.
   c. Release: plants and animals release phosphorous when they decompose, and animals excrete in waste products

**G. Biomes** - regions with common environmental characteristics (Know this info)

1. Tropical rain forest: high (but stable) temperature and humidity, heavy rainfall, (tall trees with branch at tops → little light to enter). Most diverse biome.
   - Epiphytes are plants that grow commensally on other plants (like vines)
2. Savannas: grasslands with scattered trees. similar to tropics in that they have high temperature, but they get very little rainfall
3. Temperate grasslands: receive less water (+ uneven seasonal occurrence of rainfaill) and are subject to lower temperatures than savannas (e.g. north American prairie)
4. Temperate deciduous forests: warm summers, cold winters, and moderate precipitation. Deciduous trees shed leaves during winter. Soil is rich due to leaf shed. **Vertical stratification**: plants+animals live on ground, low branches, and treetops. Principal mammals hibernate through cold winter.

Temperate coniferous: cold dry forests; vegetation has evolved adaptations to conserve water (needle leaves)

5. Deserts: hot and dry; most extreme temp fluctuations (hot day, cold night); growth of annual plants is limited to short period following rare rain, plants and animals adapt to conserve as much water as possible (urinate infrequently, cacti spines, etc)
6. Taigas: coniferous forests (and trees with needles for leaves). Very long cold winters and precipitation in form of heavy snow. Largest terrestrial biome.
7. Tundras: cold winters (ground freezes), top layer thaws during summer → support minimal vegetation (grasses). but deeper soil (**permafrost**) remains permanently frozen. Very little rainfall that can't penetrate frozen ground.

Chaparral: terrestrial biome along California coastline characterized by wet winters, dry summers, scattered vegetation

Polar region: frozen w/ no vegetation or terrestrial animals

Aquatic Biomes:

8. Fresh water biomes: ponds, lakes, streams, and rivers. Hypotonic to organisms, affected by climate/weather variations.
9. Marine biomes: the largest biome covering ¾ of world surface. Provides most of earth's food + oxygen. Includes **estuaries** (where oceans and river meet), intertidal zones (where ocean meet land), continental shelves/littoral zone (shallow oceans bordering continents), coral reefs, and pelagic ocean (deep). Have a relatively constant temperature (water's high

heat capacity + volume), amount of nutrient materials and dissolved salts. Divided into regions classified by amount of sunlight received, distance from shore, depth, open water vs ocean bottom.
Two major divisions to the marine biome: benthic zone is lowest layer of a body of water, including sediment surface and sub-surface layers. In ocean water (deep) light doesn't penetrate; most organisms are scavengers and detritivores.
Second major zone is the pelagic, the water that is neither close to shore nor the very bottom. It is broken down from top to bottom in layers. Epiplagic (surface layer of water, only photic zone since enough light for penetration, nearly all primary production of ocean occurs here) → (all zones from here on out are aphotic) mesoplagic (not enough light for photosynthesis, minimal oxygen) → bathypelagic (pitch black, no plant life, most organisms here consume detritus) → abyssopelagic (cold, high temp, most species have no eyes due to lack of light) → hadopelagic (most life here exists in hydrothermal vents). Illustrated here

**H. Human Impact on Biosphere**

1. Global climate change: burning of fossil fuels and forests increase $CO_2$ in atmosphere → more heat trapped (**greenhouse effect**; normally a good thing for maintaining heat on Earth but this is overkill) → global temp rises → raise sea level by melting ice and decrease agriculture output (affecting weather patterns).
2. Ozone depletion: $O_2$ + UV in atmosphere→ $O_3$ is ozone which absorbs UV radiation, preventing it from reaching surface of earth (UV damages DNA). CFCs (chlorofluorocarbons) enter upper atmosphere and break down $O_3$.
3. Acid rain: burning of fossil fuels (e.g. coal) releases into air $SO_2$ and $NO_2$. When they react with water vapor → sulfuric acid and nitric acid ($HNO_3$) → kills plants and animals when they rain to earth.
4. Desertification: overgrazing of grasslands that border deserts transform the grasslands into deserts → agricultural output decreases, or habitat available to native species are lost.
5. Deforestation: clear-cutting of forests causes erosion, flooding, and changes in weather patterns.
6. Pollution: air, water, and land pollution contaminate materials essential to life; many remain in environment for decades. **Eutrophication** is the process of nutrient enrichment in lakes and subsequent increase in biomass (lakes polluted with fertilizer runoff →abundant nutrients (especially phosphates) stim **algal blooms** (massive algae/phytoplankton growth) which respire and deplete oxygen + breakdown and detrivous bacteria deplete even more oxygen → many animals die of oxygen starvation → lakes fills with carcasses of dead animals/plants). Note: phytoplankton does photosynthesis, but at night they reduce oxygen when they respire + the detrivores continue to multiply as stuff dies

- **Biological magnification**: as one organism eats another, toxin (e.g. pesticide) becomes more concentrated at higher trophic level.
  - Toxins: antibiotics, hormones, carcinogens, tetratogens (cause birth defects) which get into food chain cause biomag

7. Reduction in species diversity: result of human activities.
8. Introduction of new species: killer honeybee introduced; stung + killed people. Zebra mussel outcompeted residents.

Pesticides vs biological control: pesticides effective but dangerous to humans; biological control alternatives safer: crop rotation, natural enemies, natural plat toxins, insect birth control.

**rain shadows** – areas of dry land that form on the leeward side (downwind) of a high mountain. Rain cloud approaches mountain range → rise in elevation → surrounding air becomes cooler → due point eventually reached → precipitation occurs as cloud gains precipitation, continues to rain towards peak → cloud begins to descend leeway side of mountain → decrease in elevation → air temperature increases → precipitation decreases → rain shadow is dry (desert biome)

*** Questions**

## ADDITIONAL NOTES

- **Glycine** is the only optically **inactive** amino acid, since it has no chiral carbons.
- **Enterogastrone** is any hormone secreted by duodenum when fatty food present → slow down stomach muscular movement (probably close pyloric sphincter) (slow peristalsis).
- pKa = half-equivalence pH. Amino acid deprotonates @ higher pH & becomes protonated @ lower pH.
- **Sporazoans** = division of Protozoan; diverse group of parasites (ex. plasmodium), cause malaria in humans
- In a typical antibody, the heavy and light chains are linked by *disulfide bonds*.
- *Streptococci* – can be virulent, form chains; *staphylococci* form clusters
- *Purple/green bacteria,* in the anaerobic sediments of lakes/ponds, carry out photosynthesis with $H_2$, $H_2S$, or D as the electron donor, oxygen is not a byproduct.
- pH of lysosome is 5, pH of cytosol is 7
- Starch and glucose are polymers of *alpha glucose*. Polysaccharides are branched/linear. Peptides can only be linear. Polysaccharides can have alpha or beta linkages.
- **Nerve gas** – inhibitors of acetylcholinesterase, and cause death respiratory paralysis

- Cells of PCT & DCT are very rich in mitochondria because of active transport.
- **Dynein** = motor protein; used for movement in 9+2 flagella & cilia; may also be used in chromosomal movement
- Parasite & host population densities mimic each other
- **Necrosis** = traumatic cell death
- **ruminants –** animals w/ stomachs of alkaline pH; usually 4 chambers capable of digesting cellulose
- **Albumin** - carry bilirubin (can be made from heme of old-red-blood cell) to the liver from spleen (removes dead RBC). Bilirubin is converted by liver to soluble form that become part of bile. Both Liver and Spleen are involved.
- **Diapause** - resting condition in life of an insect such as hibernation in vertebrates.
- **Isoelectric focusing -** technique for separating different molecules by differences in their isoelectric point (pI). A type of zone electrophoresis, usually performed on proteins in a gel, utilizes the fact that overall charge on the molecule of interest is a function of the pH of its surroundings. Uses a pH gradient, loses H's as it moves through, eventually remains static at its isoelectric point where its net charge is 0. (more on this in orgo notes)
- C. elegans (nematode: fully sequenced genome, good analysis of genetic control of development) and D. melagaster (fly: easy to raise, rapid generations, easy to mutate, easy to observe mutations) are model organisms
- **B-cells**: develop in fetal liver and spleen and produce antibodies. T-cells are involved in immune system and develop in thymus.
- **Autophagy**: lysosomes recycle old or degraded cell material
- **Somatic hypermutation**: genes responsible for antibody synthesis are intentionally mutated → lots of variety!
- **Note to self**: incorporate material from ABQ

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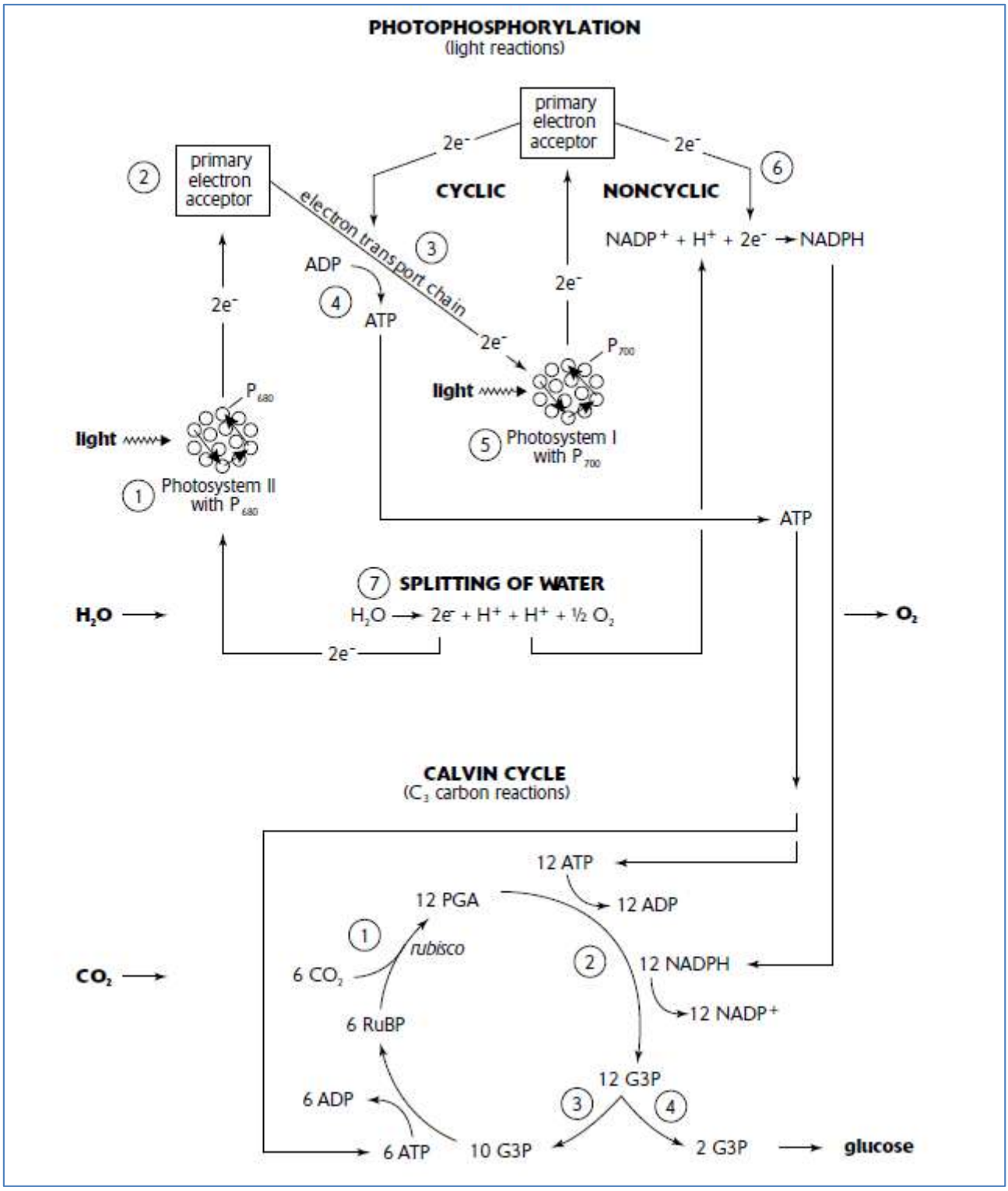
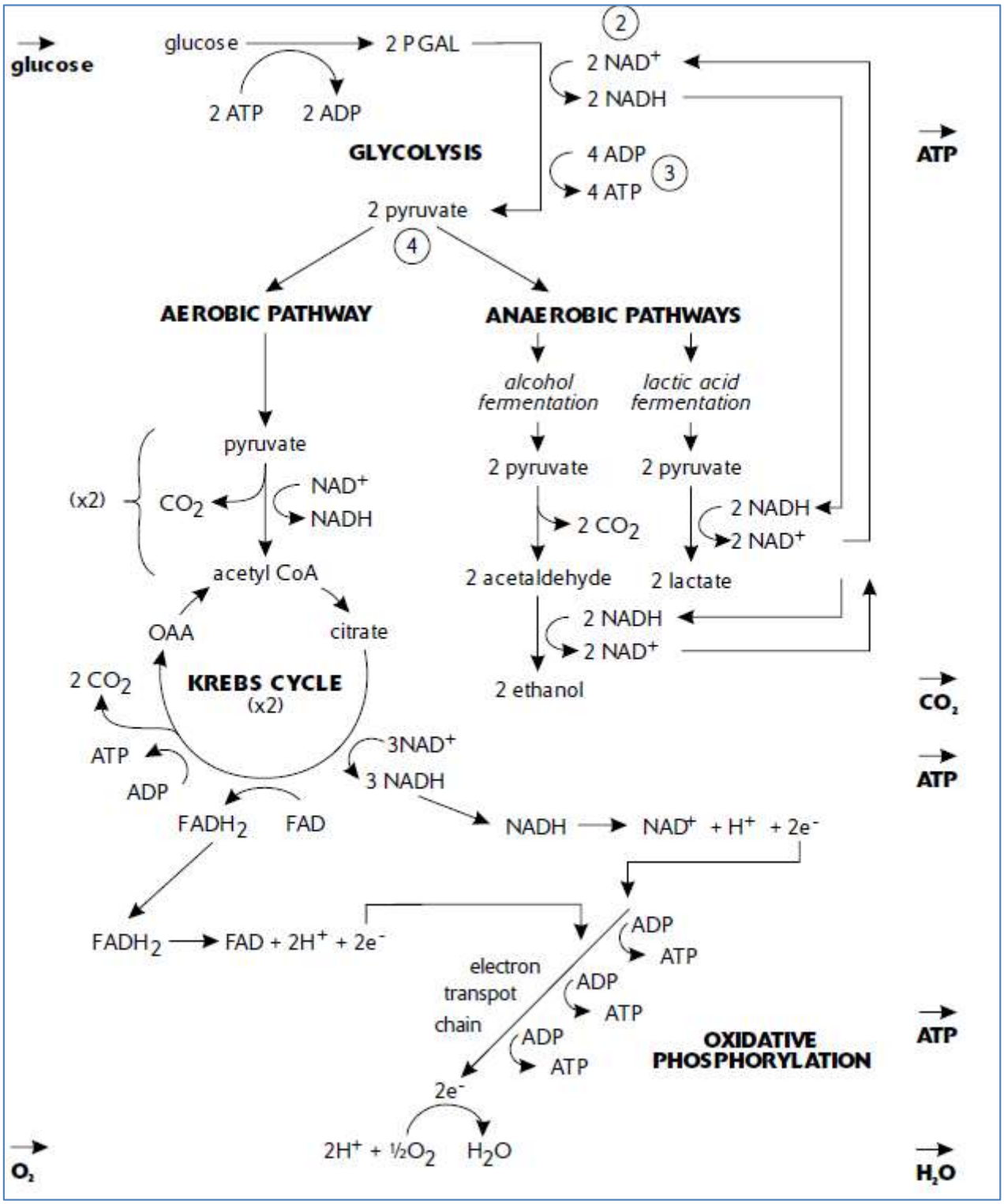
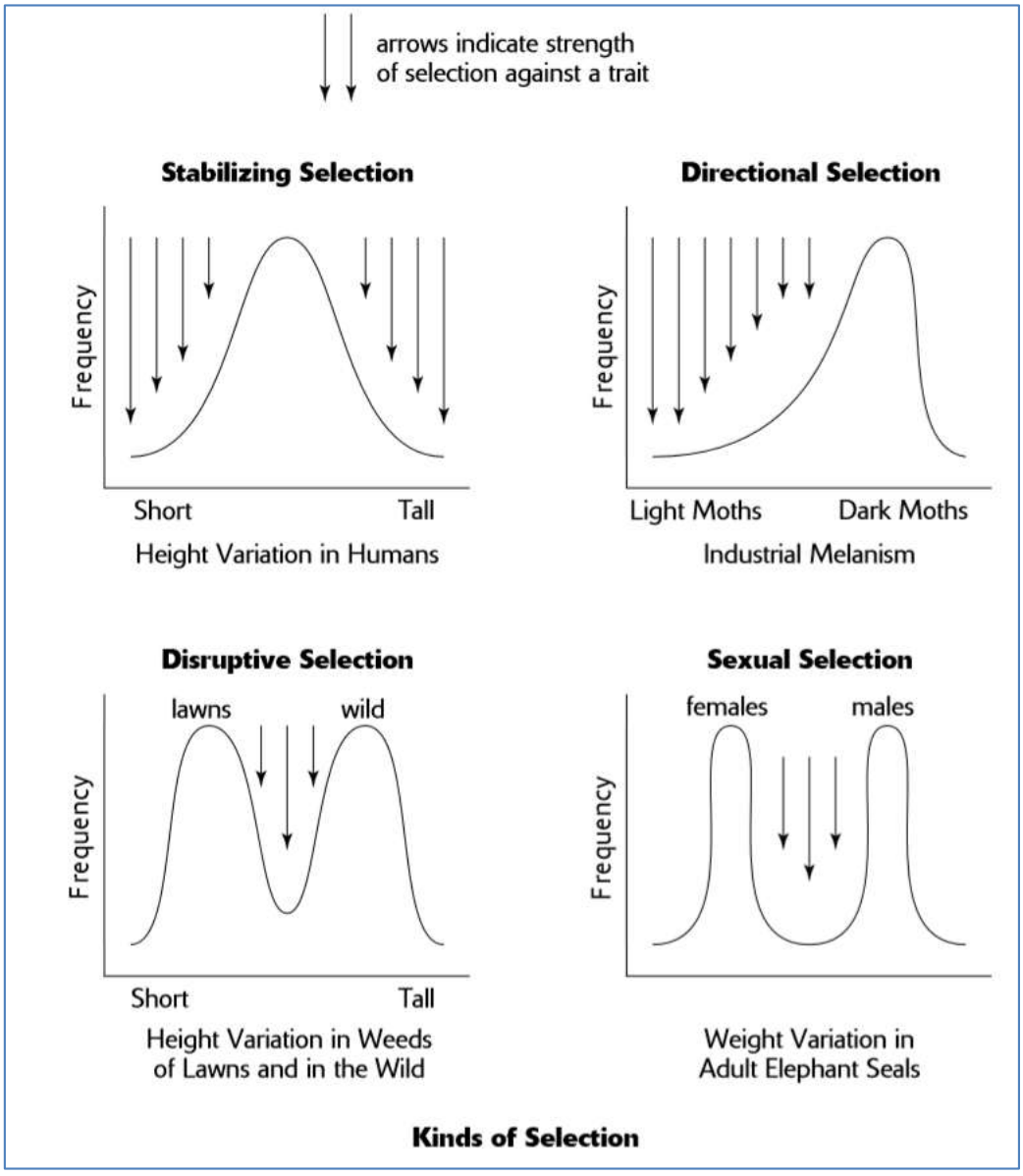
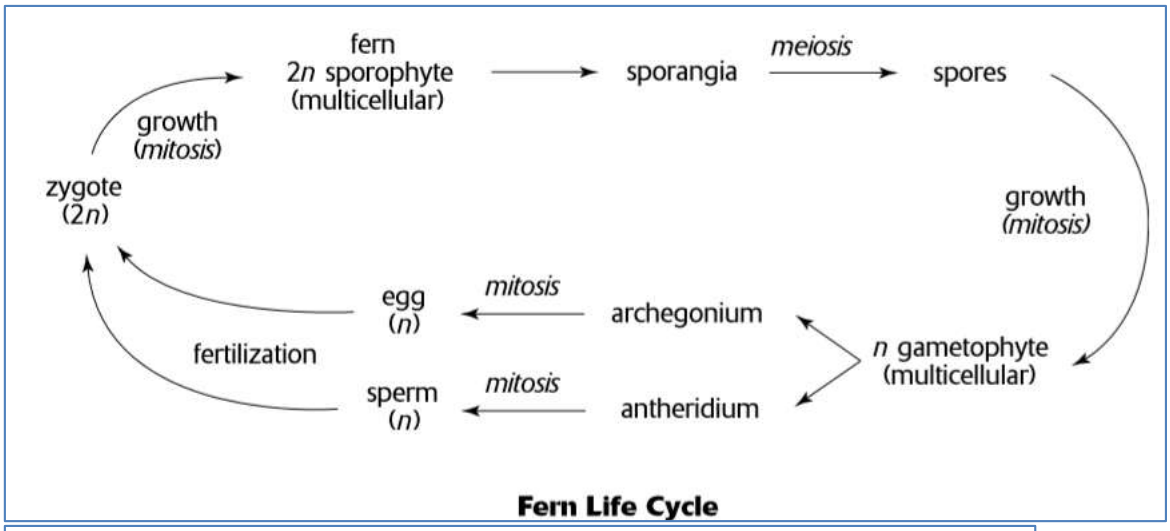
Images:

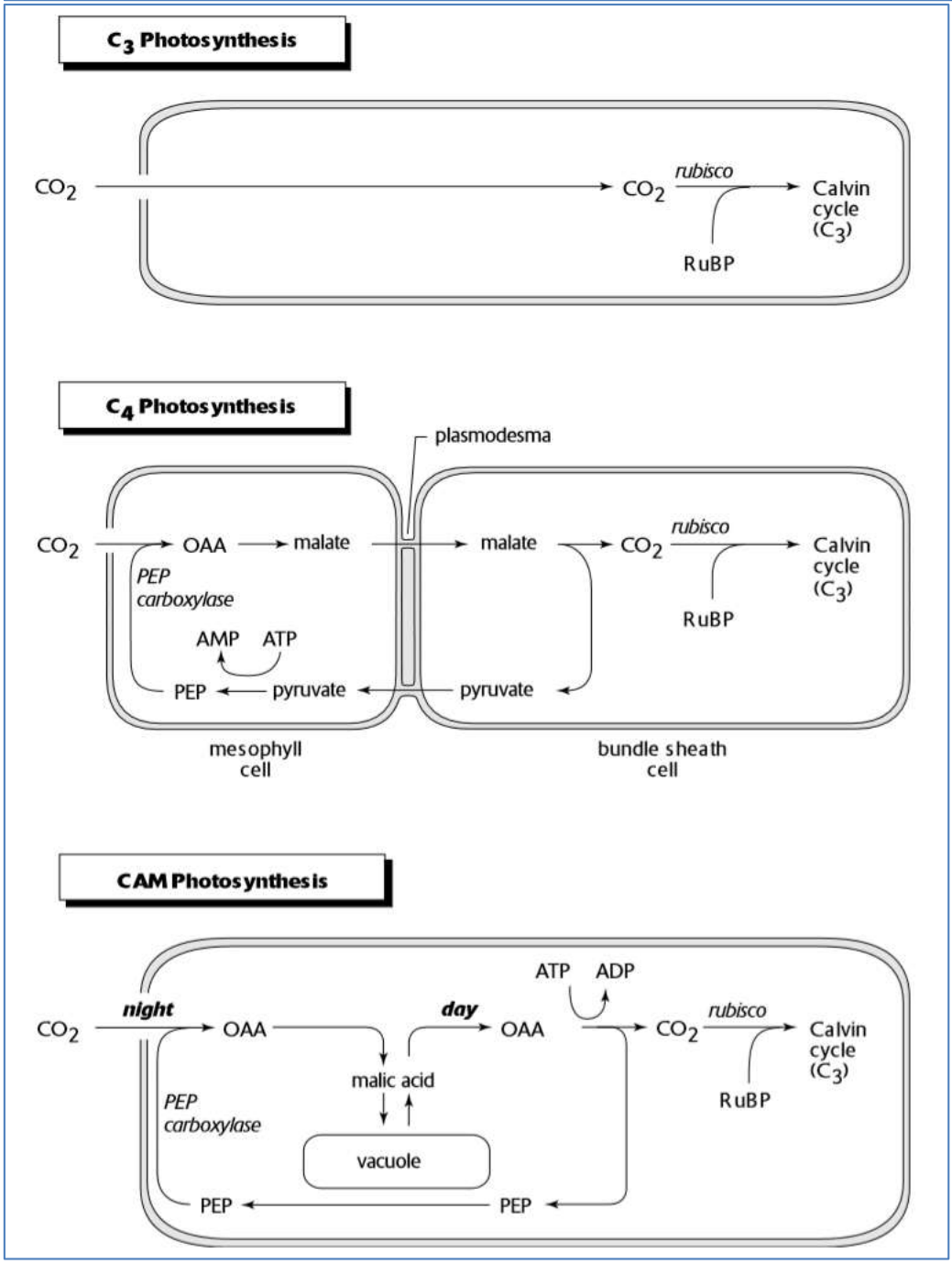

PHOTOPHOSPHORYLATION
(light reactions)
primary electron acceptor
2e⁻
2e⁻
CYCLIC
NONCYCLIC
6
2
primary electron acceptor
electron transport chain
NADP⁺ + H⁺ + 2e⁻ → NADPH
3
ADP
4
ATP
2e⁻
2e⁻
2e⁻
P700
light
P680
light
5
Photosystem I with P700
1
Photosystem II with P680
ATP
7
SPLITTING OF WATER
H2O
H2O → 2e⁻ + H⁺ + H⁺ + ½ O2
O2
2e⁻
CALVIN CYCLE
(C3 carbon reactions)
12 ATP
12 ADP
12 PGA
1
rubisco
2
12 NADPH
12 NADP⁺
CO2
6 CO2
6 RuBP
12 G3P
6 ADP
3
4
6 ATP
10 G3P
2 G3P
glucose

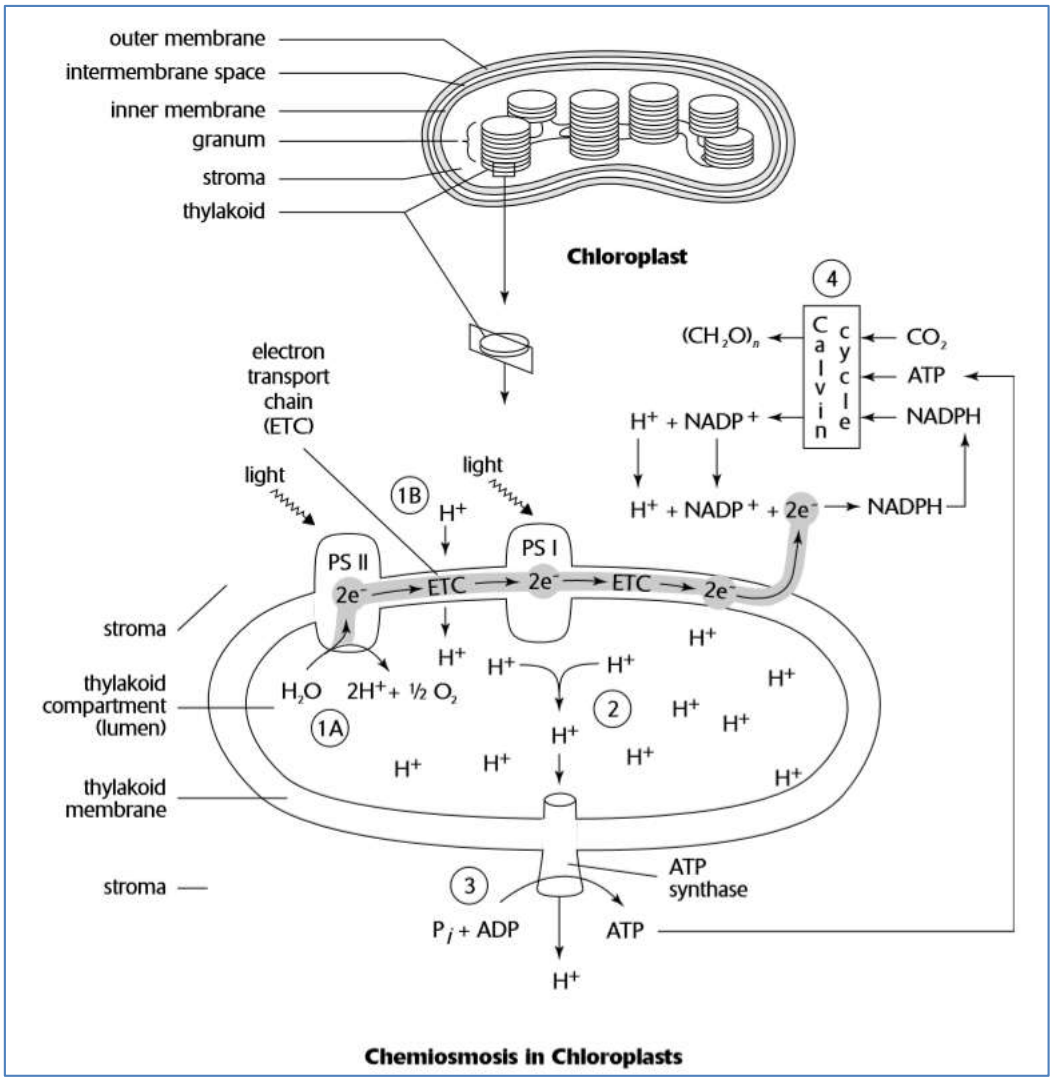

glucose
glucose
2 PGAL
2 ATP
2 ADP
GLYCOLYSIS
2
2 NAD+
2 NADH
4 ADP
4 ATP
3
ATP
2 pyruvate
4
AEROBIC PATHWAY
ANAEROBIC PATHWAYS
alcohol fermentation
lactic acid fermentation
pyruvate
2 pyruvate
2 pyruvate
(x2)
CO2
NAD+
NADH
2 CO2
2 NADH
2 NAD+
acetyl CoA
2 acetaldehyde
2 lactate
OAA
citrate
2 NADH
2 NAD+
2 CO2
KREBS CYCLE
(x2)
2 ethanol
CO2
ATP
3NAD+
ATP
ADP
3 NADH
FADH2
FAD
NADH
NAD+ + H+ + 2e-
FADH2
FAD + 2H+ + 2e-
ADP
ATP
electron
transpot
chain
ADP
ATP
ADP
ATP
OXIDATIVE
PHOSPHORYLATION
ATP
2e-
2H+ + ½O2
H2O
O2
H2O


arrows indicate strength
of selection against a trait
Stabilizing Selection
Frequency
Short
Tall
Height Variation in Humans
Directional Selection
Frequency
Light Moths
Dark Moths
Industrial Melanism
Disruptive Selection
lawns
wild
Frequency
Short
Tall
Height Variation in Weeds
of Lawns and in the Wild
Sexual Selection
females
males
Frequency
Weight Variation in
Adult Elephant Seals
Kinds of Selection

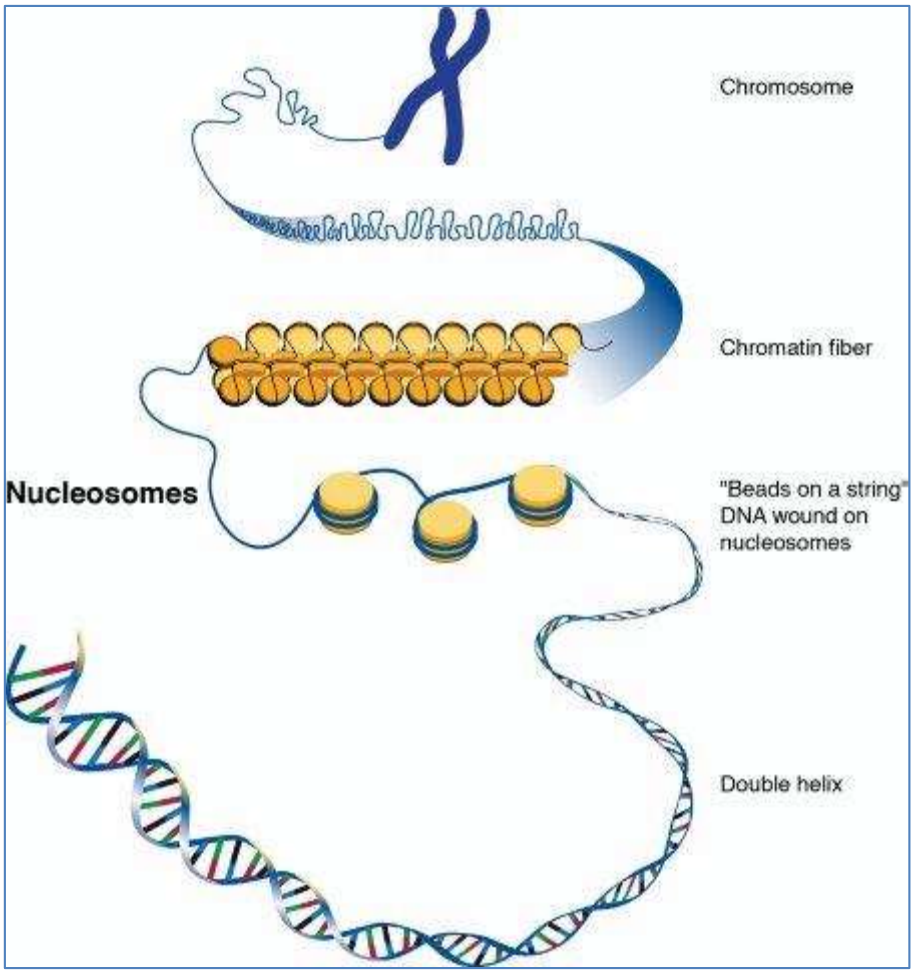



**Fern Life Cycle**

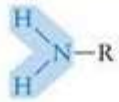
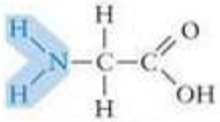
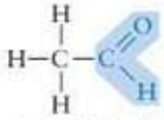
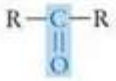
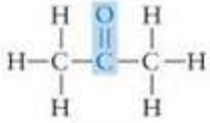
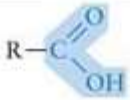
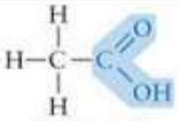
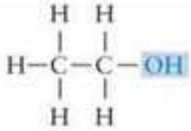
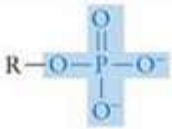
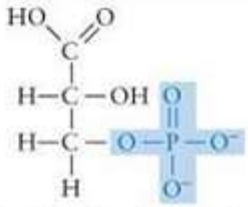
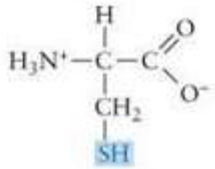




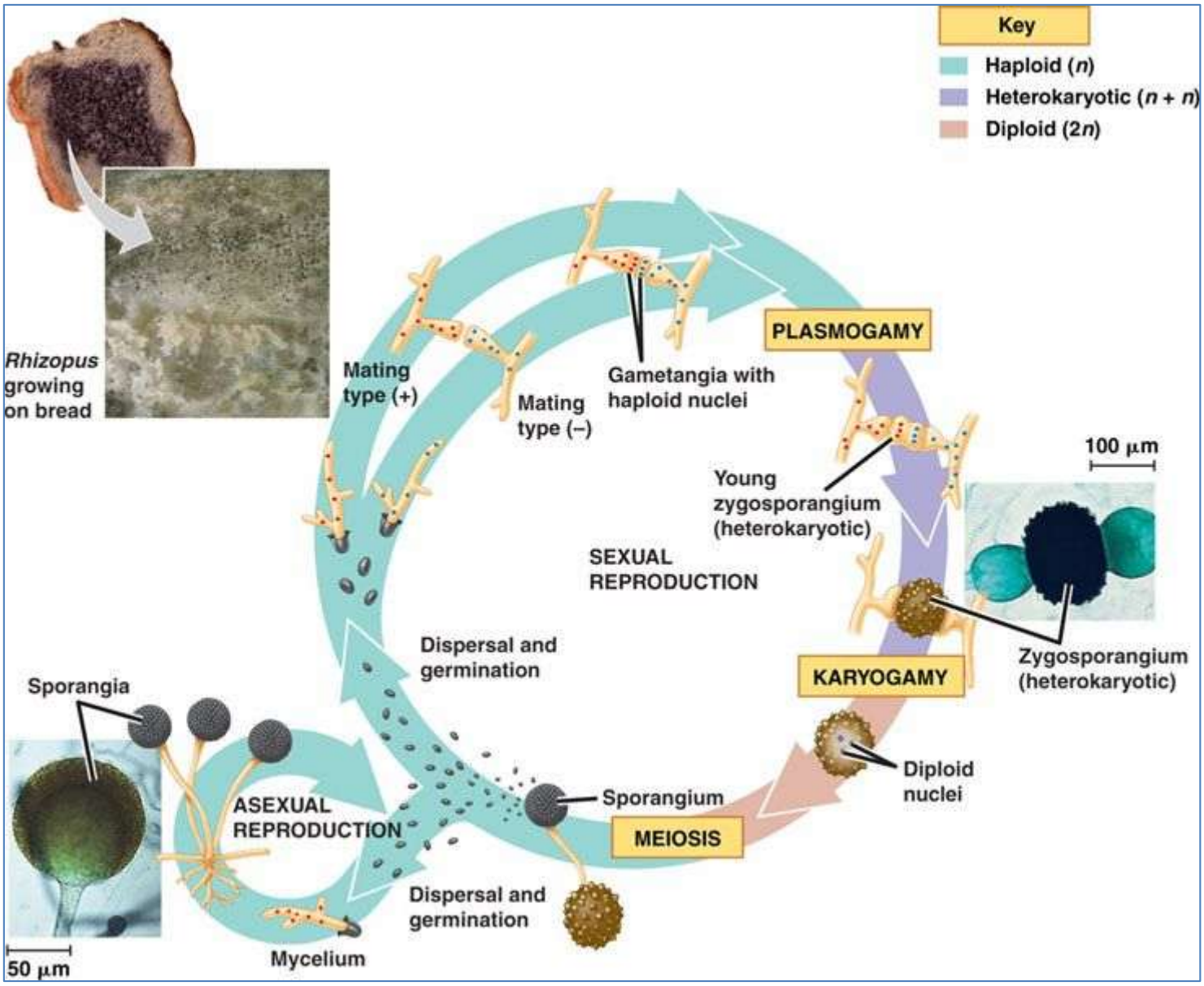

**Chemiosmosis in Chloroplasts**

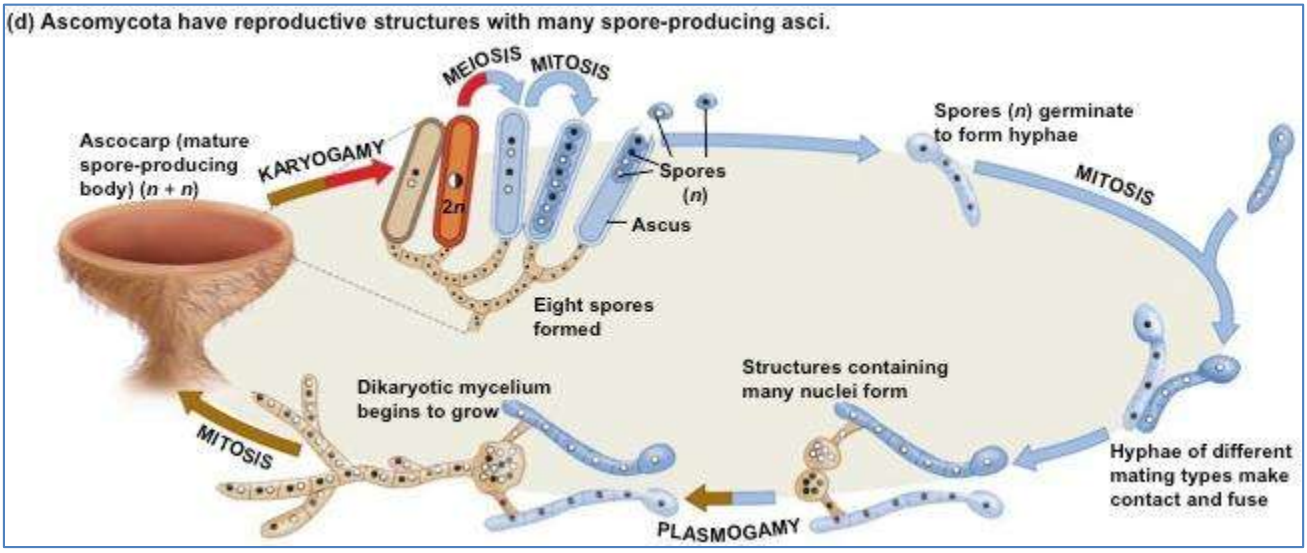

Chromosome
Chromatin fiber
Nucleosomes
"Beads on a string"
DNA wound on
nucleosomes
Double helix

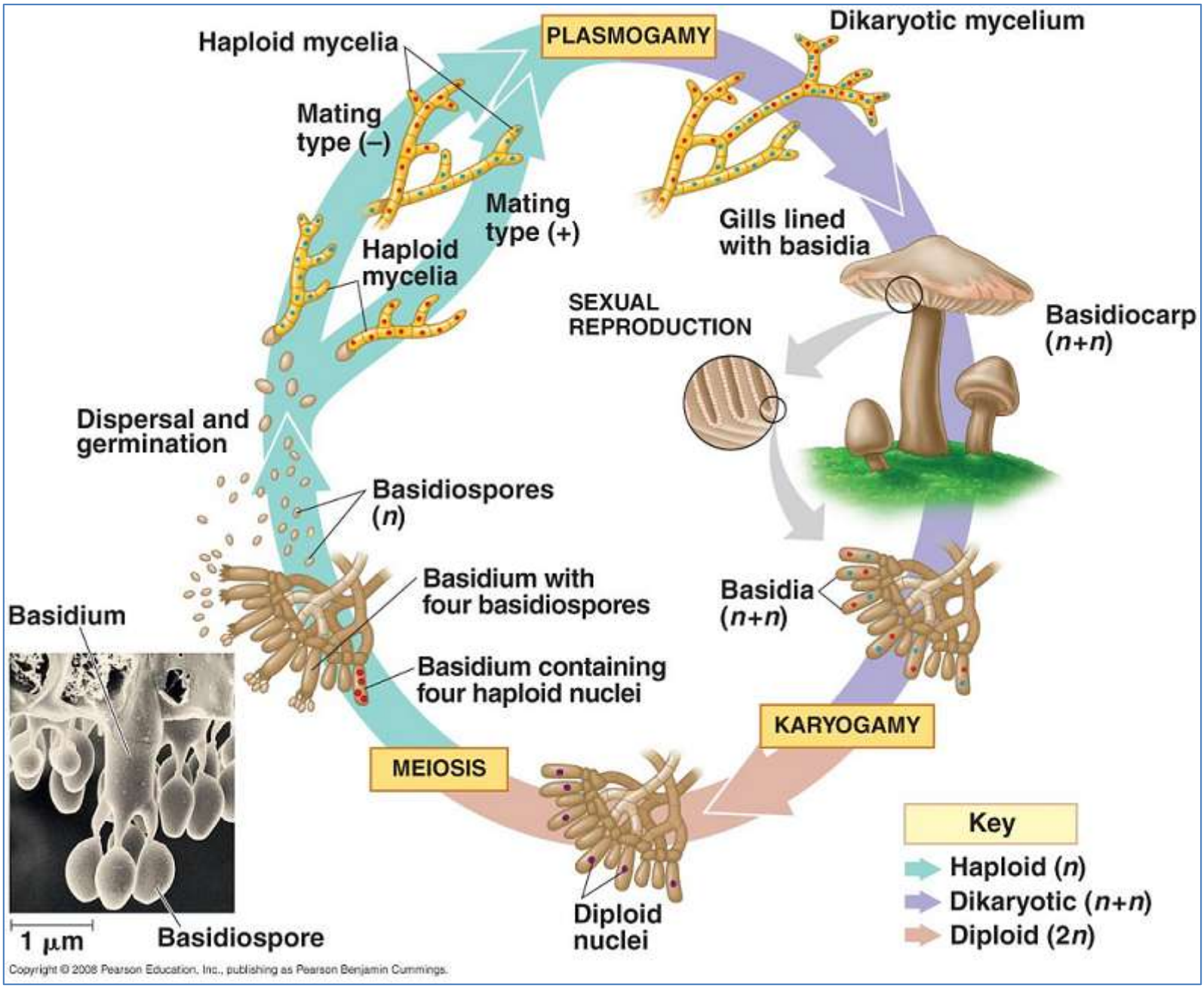
SUMMARY TABLE 2.3 **Six Functional Groups Commonly Attached to Carbon Atoms**

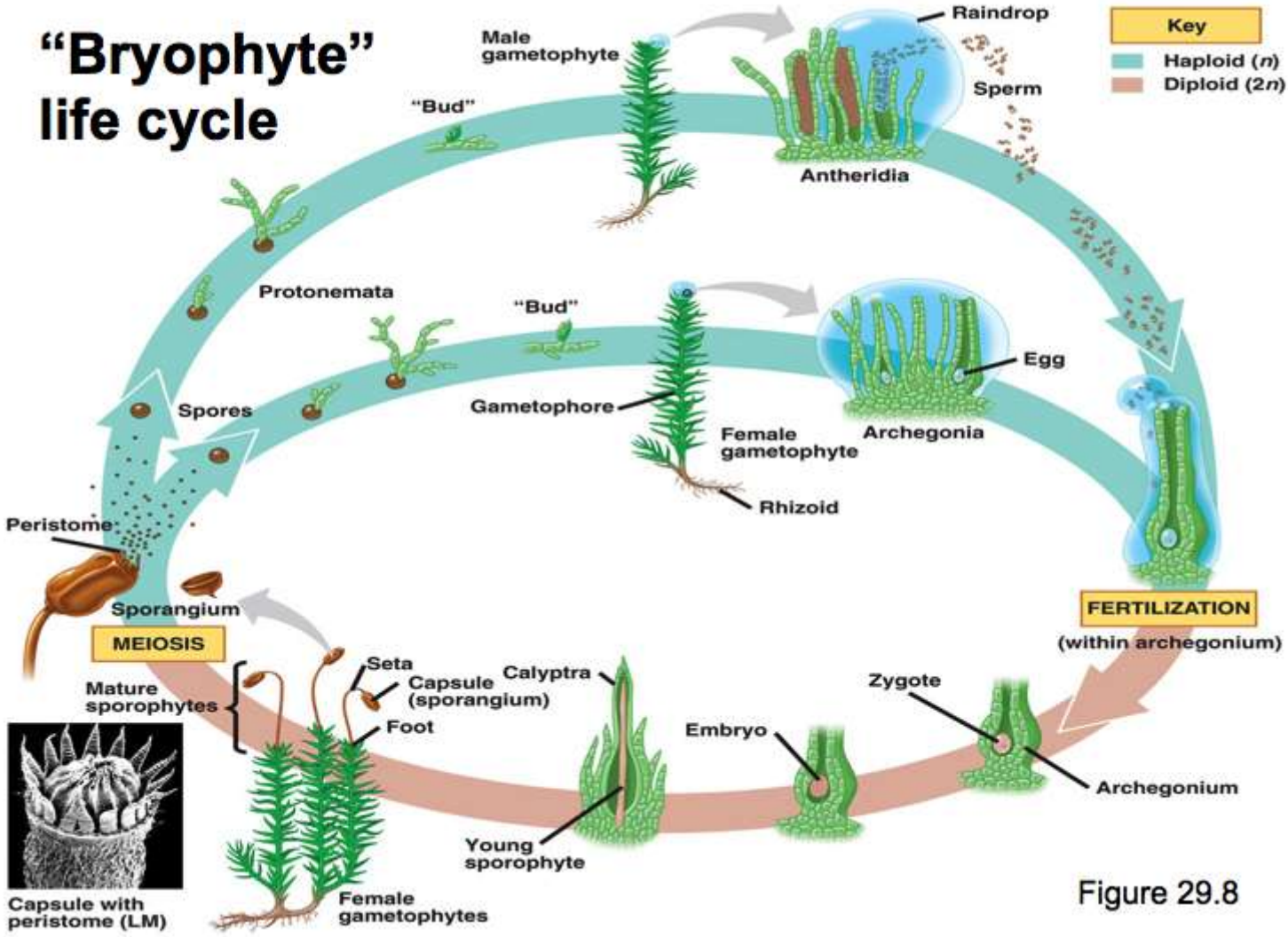
| Functional Group | *Formula | Family of Molecules | Example |
|---|---|---|---|
| Amino |  | Amines |  Glycine (an amino acid) |
| Carbonyl |  | Aldehydes |  Acetaldehyde |
| |  | Ketones |  Acetone |
| Carboxyl |  | Carboxylic acids |  Acetic acid |
| Hydroxyl |  | Alcohols |  Ethanol |
| Phosphate |  | Organic phosphates |  3–Phosphoglyceric acid |
| Sulfhydryl |  | Thiols |  Cysteine |

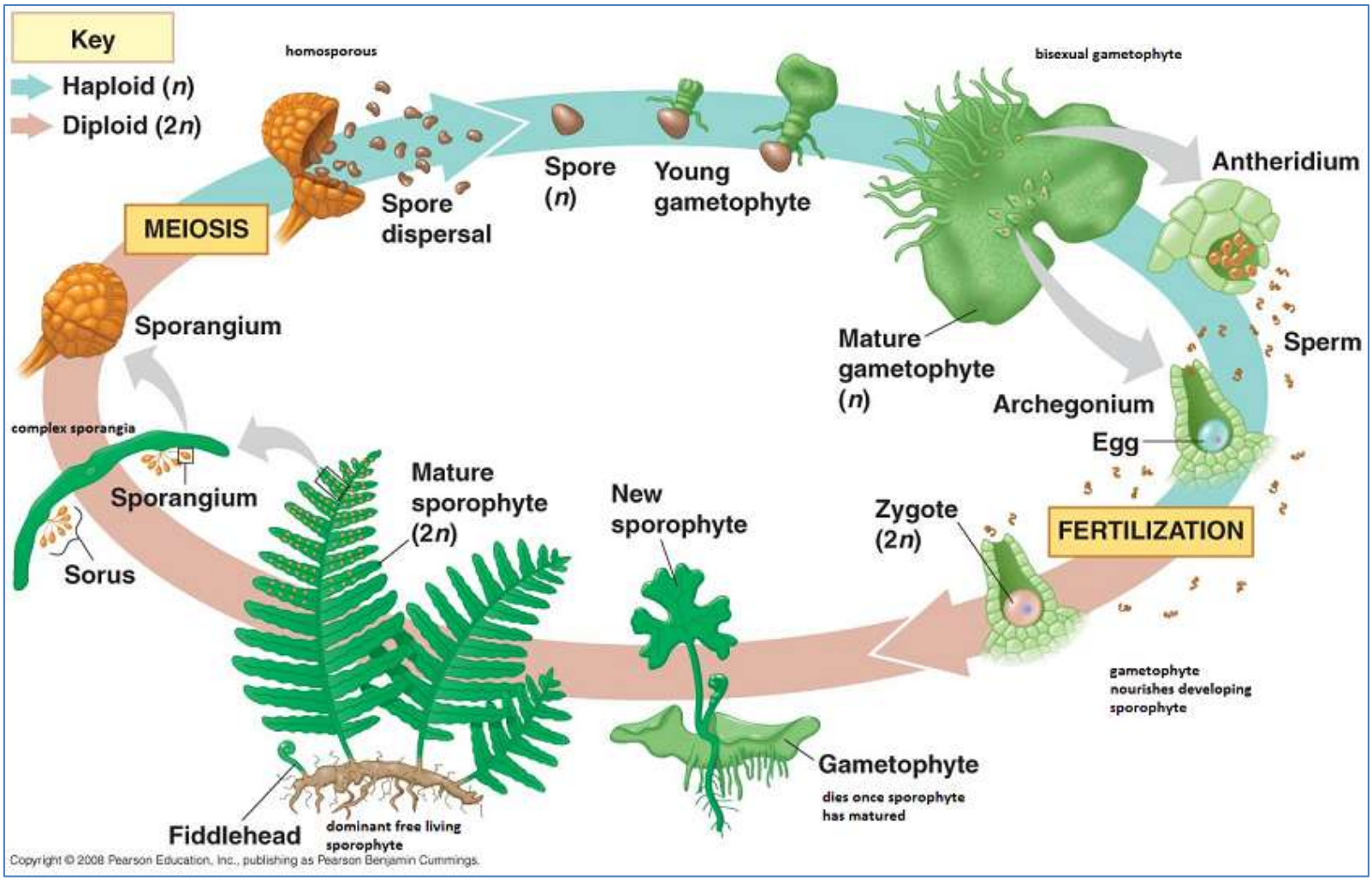
*In these structural formulas, "R" stands for the rest of the molecule.

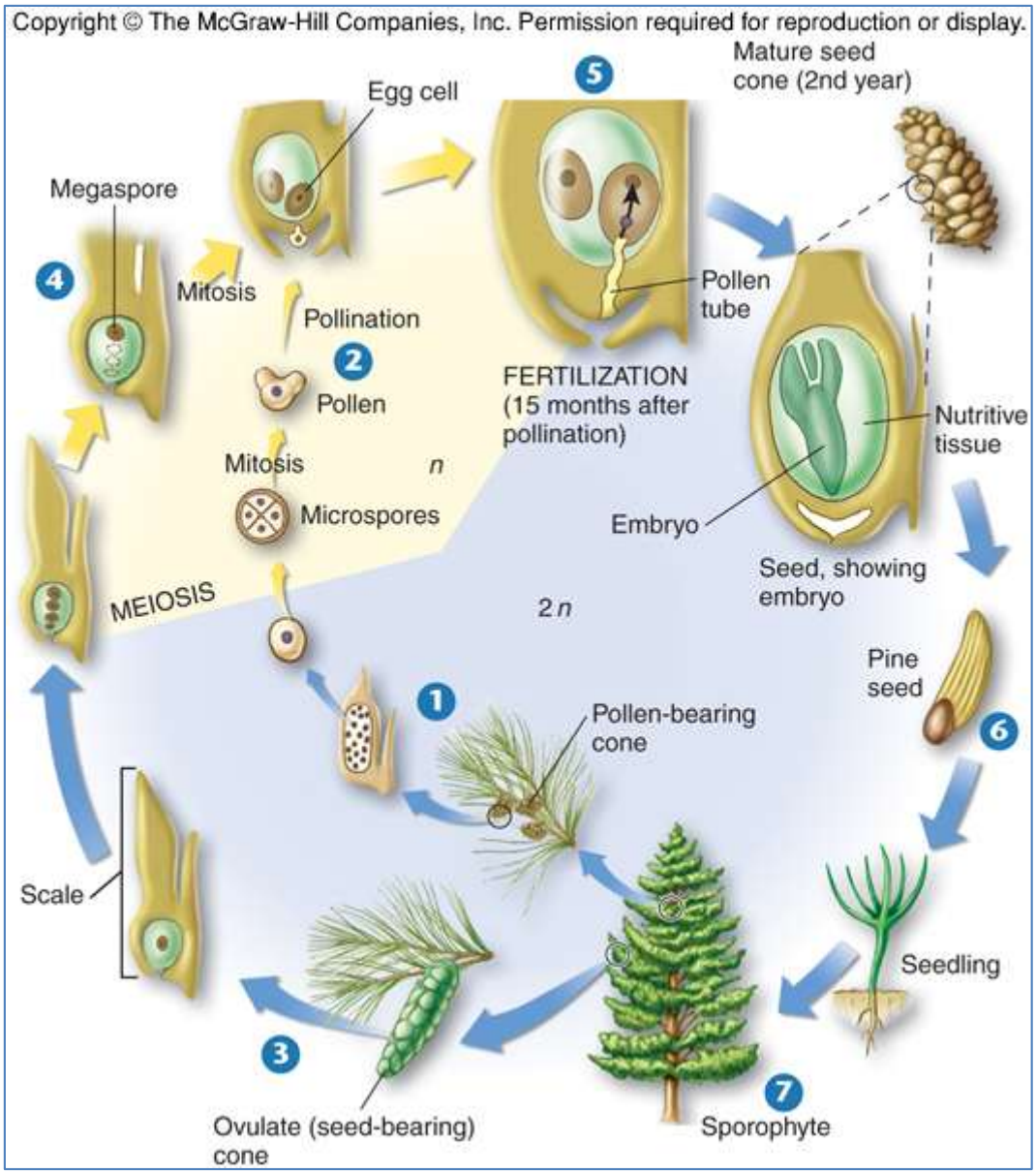

Key
Haploid (n)
Heterokaryotic (n + n)
Diploid (2n)
Rhizopus growing on bread
Mating type (+)
Mating type (–)
Gametangia with haploid nuclei
PLASMOGAMY
Young zygosporangium (heterokaryotic)
100 µm
SEXUAL REPRODUCTION
Zygosporangium (heterokaryotic)
KARYOGAMY
Dispersal and germination
Sporangia
Diploid nuclei
ASEXUAL REPRODUCTION
Sporangium
MEIOSIS
Dispersal and germination
Mycelium
50 µm

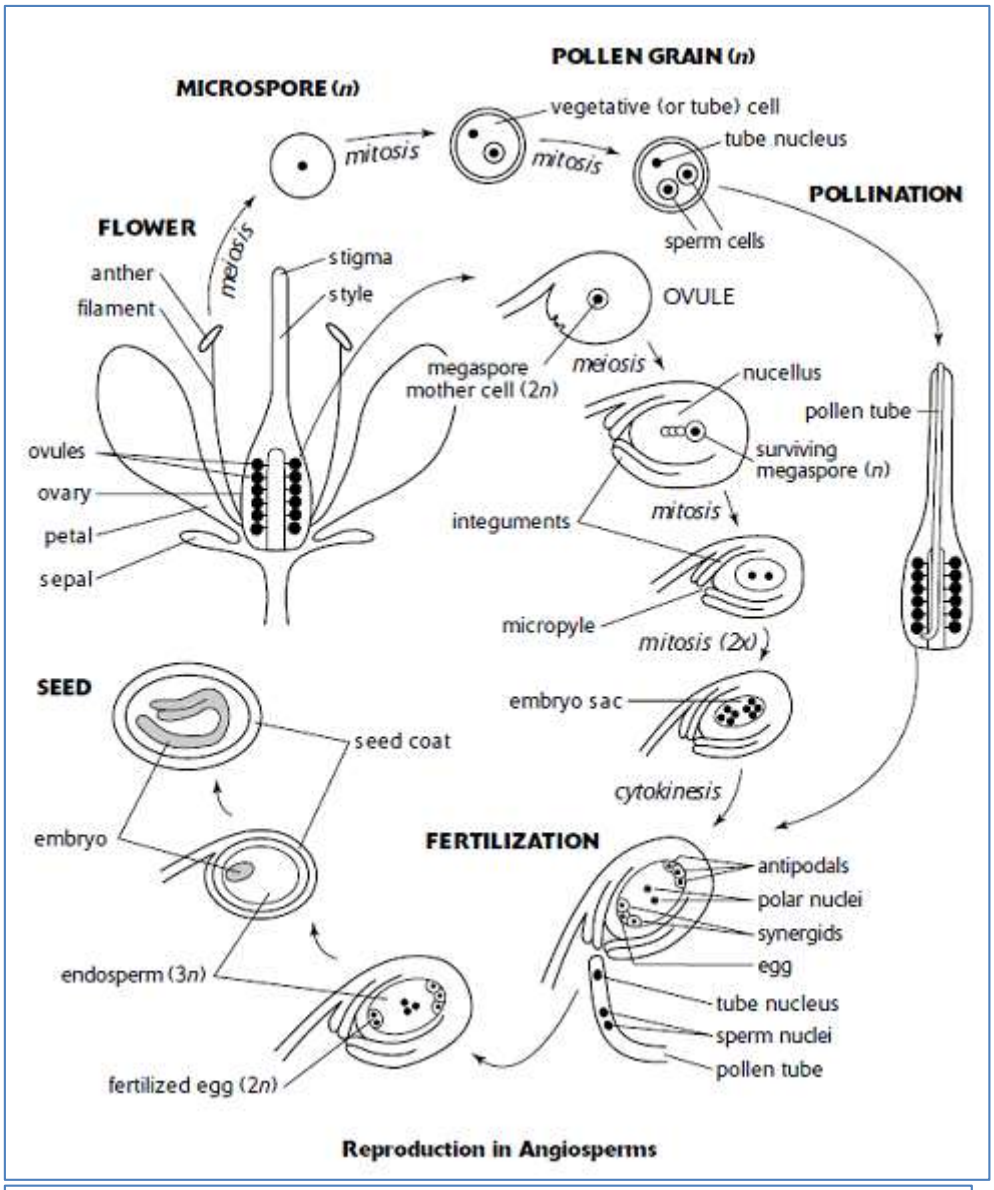

(d) Ascomycota have reproductive structures with many spore-producing asci.
MEIOSIS
MITOSIS
Ascocarp (mature spore-producing body) (n + n)
KARYOGAMY
2n
Spores (n)
Ascus
Eight spores formed
Spores (n) germinate to form hyphae
MITOSIS
Structures containing many nuclei form
Dikaryotic mycelium begins to grow
MITOSIS
Hyphae of different mating types make contact and fuse
PLASMOGAMY



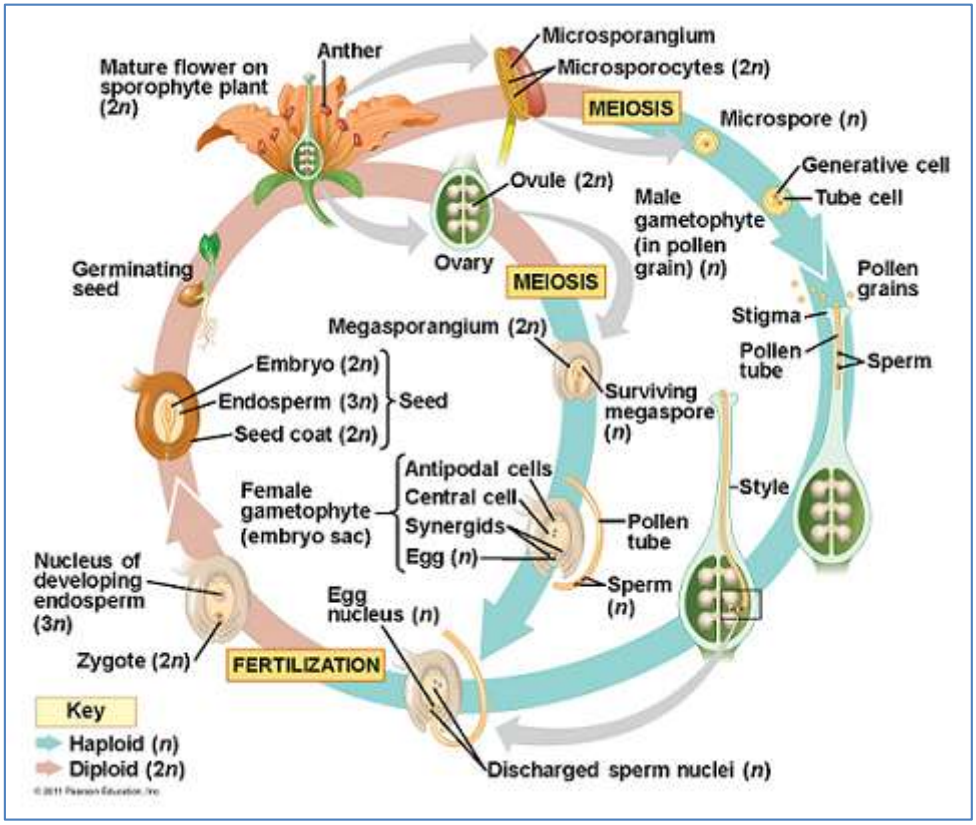

"Bryophyte" life cycle
Male gametophyte
"Bud"
Raindrop
Sperm
Antheridia
Key
Haploid (n)
Diploid (2n)
Protonemata
"Bud"
Egg
Spores
Gametophore
Female gametophyte
Archegonia
Rhizoid
Peristome
Sporangium
MEIOSIS
FERTILIZATION
(within archegonium)
Seta
Calyptra
Capsule (sporangium)
Zygote
Mature sporophytes
Foot
Embryo
Archegonium
Young sporophyte
Capsule with peristome (LM)
Female gametophytes
Figure 29.8


Key
Haploid (n)
Diploid (2n)
homosporous
Spore dispersal
MEIOSIS
Spore (n)
Young gametophyte
bisexual gametophyte
Antheridium
Sperm
Archegonium
Egg
Mature gametophyte (n)
Sporangium
complex sporangia
Sporangium
Sorus
Mature sporophyte (2n)
Fiddlehead
dominant free living sporophyte
New sporophyte
Zygote (2n)
FERTILIZATION
gametophyte nourishes developing sporophyte
Gametophyte
dies once sporophyte has matured
Copyright © 2008 Pearson Education, Inc., publishing as Pearson Benjamin Cummings.

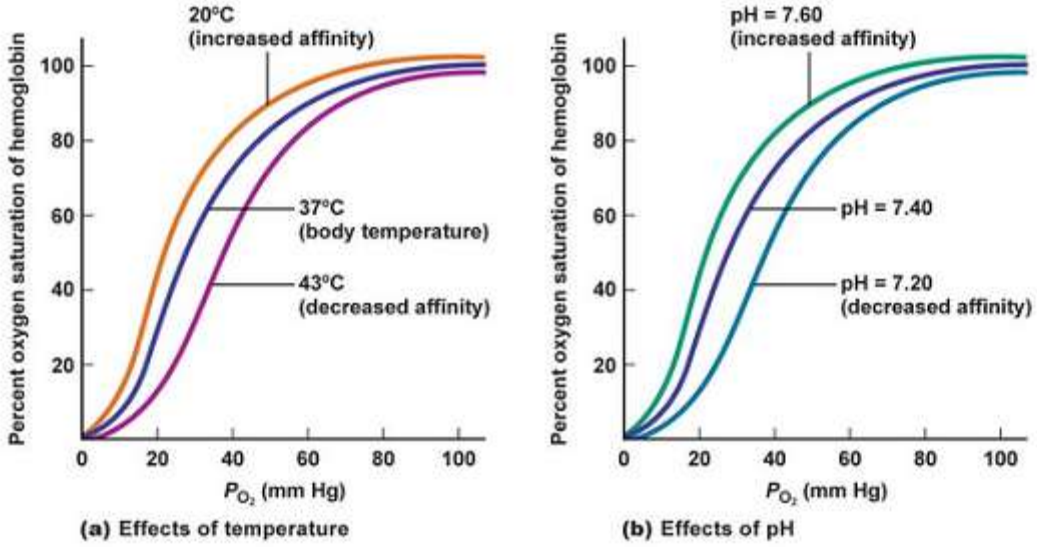

Copyright © The McGraw-Hill Companies, Inc. Permission required for reproduction or display.
Mature seed cone (2nd year)
5
Egg cell
Megaspore
4
Mitosis
Pollination
2
Pollen
Mitosis
n
Microspores
MEIOSIS
Pollen tube
FERTILIZATION (15 months after pollination)
Nutritive tissue
Embryo
Seed, showing embryo
2n
Pine seed
6
1
Pollen-bearing cone
Scale
Seedling
3
7
Ovulate (seed-bearing) cone
Sporophyte

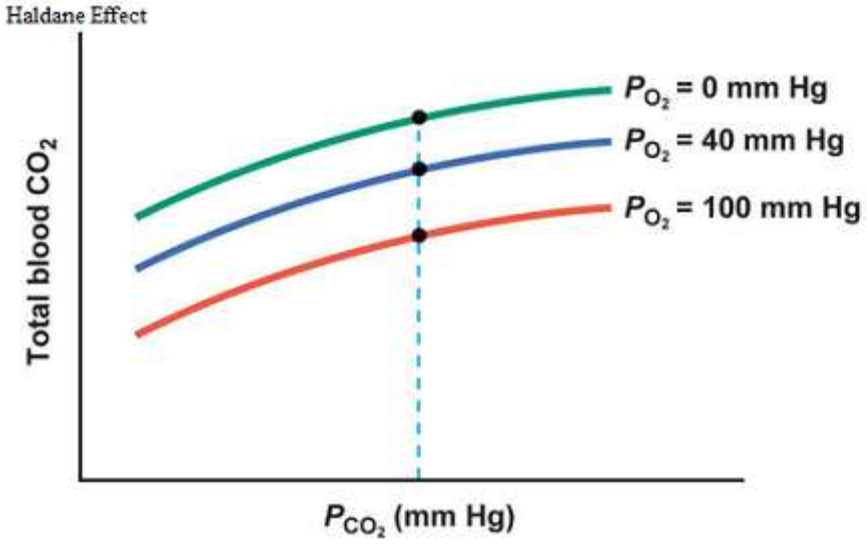


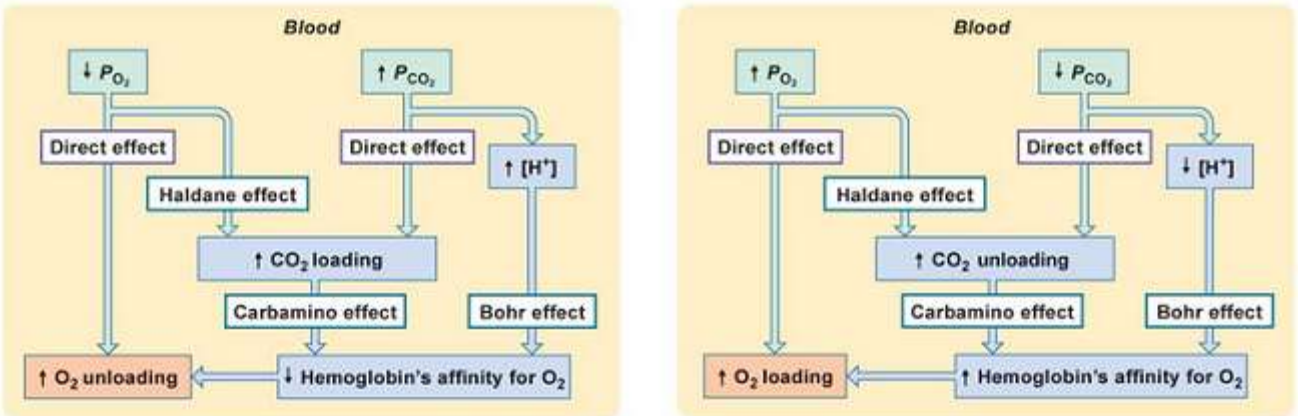

**Reproduction in Angiosperms**

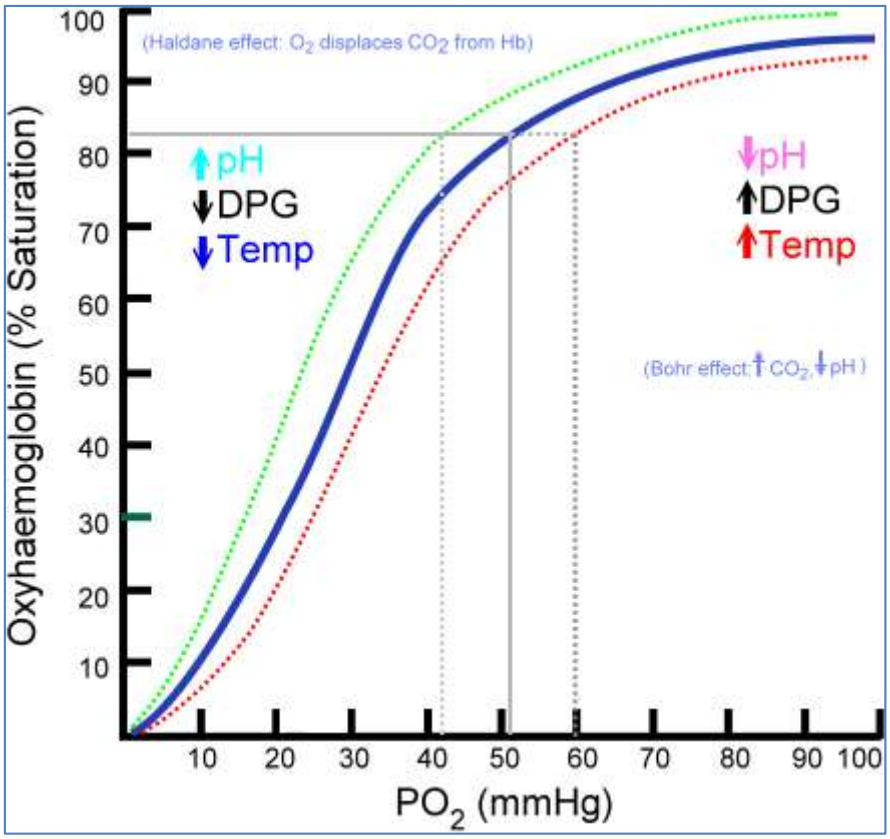


In more active tissue pH **decreases** and $O_2$ is more easily **unloaded**.




(Haldane effect: $O_2$ displaces $CO_2$ from Hb)
↑pH
↓DPG
↓Temp
↓pH
↑DPG
↑Temp
(Bohr effect: ↑ $CO_2$, ↓pH )
Oxyhaemoglobin (% Saturation)
100
90
80
70
60
50
40
30
20
10
10 20 30 40 50 60 70 80 90 100
$PO_2$ (mmHg)