Biology
Campbell and Reese
The “Varun” outline

- Chapter 1: Ten Themes in the Study of Life
  - Exploring Life on its Many Levels
    - Each level of biological organization has emergent properties
      - Emergent properties - when you put things together, you get new properties not in either part
      - Atom, molecule, organelle, cell, tissue, organ, organism
      - Reductionism - break things down to make them easier to understand
    - Cells are an organism’s basic units of structure of function
      - Properties of life: order, reproduction, growth and development, energy utilization, response to environment, homeostasis, evolutionary adaption
      - All living things consist of cells
      - Eukaryotic cells:
        - Subdivided by membranes, organelles
        - DNA is organized into chromosomes in a nucleus
        - Some, like plant cells, have cell walls. Others, like animal cells, don’t
      - Prokaryotic cells:
        - No organelles
        - DNA is not separated into the nucleus
        - Generally smaller than Eukaryotic cells
    - Continuity of life based on DNA
      - DNA is double helix, has 4 different nucleotides, split between daughter cells
    - Structure and Function
      - From molecules to organisms, form often fits function
      - Ex: bird wings have airfoil shape and honeycombed bones
    - Organisms interact continuously with environment
      - Sunlight goes in, heat comes out (increasing entropy)
      - Nutrients cycle through ecosystem
    - Regulatory stuff
      - Positive feedback - products stimulate reaction
      - Negative feedback - products inhibit reaction
      - Homeostasis - keeping things steady with negative feedback
  - Evolution, Unity, and Diversity
    - Diversity/Unity
      - Taxonomy groups species in an increasingly specific manner
      - 3 domains: Bacteria, Archaea, and Eukarya
      - Eukarya has plants, fungi, animals, and protists
      - Lots of unity - universal genetic language of DNA, details of cell structure (eukaryotes)
    - Evolution is the core theme
      - Darwin observed individual variation among organisms of the same species and struggle for existence due to over reproduction
      - He inferred differential reproductive success (natural selection) where organisms with favorable traits had more offspring survive
      - Explains diversity with being able to let different populations differentiate into different species, yet share unity because of common roots
  - The Process of Science
    - Science is a process of inquiry with observations and hypotheses
      - Discovery science and induction - describing things
      - Hypothetico-deductive science - if... then
    - Science and tech are part of society
      - Medicine, standard of living, conservation

- Chapter 2: The Chemical Context of Life
    - Chemical Elements and Compounds
        - Matter consists of chemical elements...
            - Matter - takes up space and has mass
            - Element - substance that cannot be broken down to other substances by chemical reactions
            - Compound - a substance consisting of two or more elements combined in a fixed ratio
        - Life requires about 25 elements
            - C, H, O, and N make up 96% of living matter
            - P, S, Ca, K, and a few others account for most of the remaining 4%
            - Trace elements are required in minute quantities (Ex: iron)
    - Atoms and Molecules
        - Atomic structure determines element behavior
            - Atom - smallest unit of matter that still retains properties of an element
            - Atomic nucleus made of neutral neutrons and positive protons with negative electrons orbiting
            - Neutron and proton are nearly identical in mass, proton and electron are equal and opposite in charge
            - Dalton = amu = mass of proton or neutron = $1.7*10^{(-24)}$ grams
            - Atomic number - # of protons
            - Mass number - sum of protons and neutrons
            - Atomic weight - mass number of daltons
            - Isotope - screw with # of neutrons
                - Radioactive isotopes - nucleus decays spontaneously, giving off particles and energy
                - If decay leads to change in number of protons, it transforms the former isotope to a new element
                - Can be used in fossil dating and tracers for research
            - Nuclei are tiny compared to atom size, so atoms interact through electrons
            - Energy - ability to do work
                - Potential energy - energy matter stores because of position or location
            - Electrons have differing potential energies because of different distances from the nucleus (farther, faster, more energy)
            - Energy levels (electron shells) - discrete levels of energy an electron can have
                - absorbing or losing energy just moves the electrons between shells
                - first shell can hold 2 electrons, subsequent shells hold up to 8, filling up inner shells first
                - Valence electrons - electrons in valence (outermost) shell
                - Atoms with the same # of valence electrons behave similarly
            - Orbital - 3-d space where an electron is 90% of the time because exact location cannot be determined
        - Atoms combine by chemical bonding to form molecules
            - Chemical bonds - atoms complete each other's valence shells with their own electrons
            - Covalent bond - sharing of a pair of valence electrons
            - Molecule - two or more atoms held together by covalent bonds
            - Structural formula - H-O-H
            - Molecular formula - $H2O$
            - Valence - # of bonds, usually same as # of unpaired electrons, but not always
            - $H2$ and $O2$ are pure elements, not compounds (2 or more different elements)
            - Electronegativity - how much the atom pulls the electron
                - Nonpolar covalent bond - equal pull
                - Polar covalent bond - a little pull

        - Ionic bonds - completely steals the electron (talked about next)
      - Ionic bond - 1 atom is so much more electronegative, it completely strips away the partner's electron
        - Creates ions - charged atoms from change in # of electrons
        - + = cation, - = anion
      - Ionic compound (salts) - compounds formed by ionic bonds
      - Individual bonds weaker than covalent bonds, but atoms are arranged in 3-d crystal lattice, making each atom in contact with many of the other type and making attraction VERY strong
    - Weak chemical bonds
      - Bonds much weaker than covalent or ionic
      - Ex: neurotransmitter binds to receptor just long enough to send signal, then detaches
      - Hydrogen bond - positive hydrogen in polar covalent bond is drawn to negative atom in a polar covalent bond in a different molecule
      - Van der Waals interactions
        - Because electrons are constantly moving around, changing regions of molecules are positive and negative
        - Apply either to very close molecules or regions of the same, big molecule
        - Although the bonds are weak, cumulative effect helps reinforce 3-d shape of large molecules
    - Function related to shape
      - 4 electron pairs of an atom spread into the four vertices of a tetrahedron
      - Each vertex can either remain as an electron pair or be the location of a bonded atom
      - Ex: The water molecule's bent shape is caused by the H atoms taking up to of the vertices of a tetrahedron around the O atom with the other two vertices taken up by the extra electron pairs around the O atom.
      - Molecular shape determines how molecules recognize and react with each other
    - Chemical reactions make and break chemical bonds
      - Chemical reactions - making and breaking of chemical bonds leading to changes in the composition of matter
      - Reactants → products
      - Matter (and so all of the atoms) from the reactants preserved in products
      - Some reactions go to completion (symbol: →) while others are reversible and have an equilibrium with reactants and products (symbol: ↔)
      - Chemical equilibrium - point at which reaction turning reactants into products perfectly offsets reaction turning products back into reactants

- Chapter 3: Water and the Fitness of the Environment
  - The Effects of Water's Polarity
    - The polarity of water molecules results in hydrogen bonding
      - Polar molecule - opposite ends have opposite charges (Ex: water)
      - Many properties arise from the hydrogen bonds between water molecules
      - Each water molecule can H bond to a maximum of 4 others (each H to an outside O and two outside H's to the O)
      - The H bonds or continuously breaking and re-forming
    - Organisms depend on the cohesion of water molecules
      - Although H bonds are only about 1/20 times the strength of covalent bonds, the bonds break and re-form billions of times a second, so most molecules are bonded to neighbors at a given instant
      - Cohesion - a phenomenon where tons of H bonds hold a substance together
      - Adhesion - clinging of one substance to another
      - Surface tension - a measure of how difficult it is to stretch or break the surface of a liquid
        - Water molecules want to party together, none want to be stuck on the "edge"

    - between water and air
    - This minimizes the number at the edge, minimizing the surface area
    - Minimal surface area per volume achieved with sphere, explaining shape of water drops
- Water moderates temperatures on Earth
  - Kinetic energy - energy of motion
  - Heat - total quantity of kinetic energy due to molecular motion in some matter
  - Temperature - intensity of heat from average KE of molecules
  - Heat always moves from higher temp to lower temp
  - Calorie(cal) - unit of heat needed to raise the temp of 1 g of water by 1 C
  - Kilocalorie(kcal) - is the "calorie" on a food package
  - Joule (J) - 1 cal = 4.184 J
  - Specific heat - amount of heat that must be absorbed or lost for 1 g of the substance to change its temperature by 1 C
    - Because of definition of calorie, specific heat of water is already known as 4.184 J/g/C
    - Most substances have specific heats far below that of water
  - Water's extremely high specific heat can be traced to H bonds
    - A ton of heat must be added to break all of the H bonds
    - If the temp drops slightly, many H bonds will form, releasing a large amount of heat
  - During the day, bodies of water can absorb very much heat from the son while only becoming a few degrees warmer. At night, the gradually cooling water can warm the air
  - Moderates coastal temperatures and stabilizes ocean temperatures
  - Heat of vaporization - quantity of heat a liquid must absorb for 1 g of it to be converted from the liquid to the gaseous state.
    - Like specific heat, especially high in water
    - Moderates temp when considerable solar radiation can be absorbed and transferred by evaporation of surface water
  - Evaporative cooling - as a liquid evaporates, the surface of the liquid that remains behind cools down because the "hottest" molecules are the most likely to leave as gas, lowering the average
    - Represented by transpiration in plants and sweat in some mammals, preventing overheating
    - Also prevents overheating in bodies of water
- Oceans and lakes don't freeze solid because ice floats
  - Water is one of the few substances that becomes less as it solidifies
  - This happens when the temperature reaches 0 C, the water molecules become locked into a crystal lattice with each molecule bonded to 4 (max) others.
    - Imagine them holding each other at an "arm's length"
    - Causes ice to be about 10% less dense than water where molecules can slip closer together because the H bonds are temporary
  - If ice didn't float, eventually all ponds, lakes, and oceans would completely freeze solid
- Water is the solvent of life
  - Solution - a liquid that is a completely homogeneous mixture of two or more substances
  - Solute - what is dissolved
  - Solvent - what the solute is dissolved in
  - Aqueous solution - water is the solvent
  - Although water is an extremely versatile solvent, it is not universal because then it would not be able to be stored in any container, including our cells
  - Water is a good solvent because of its polarity
    - Ex: When a cube of NaCl is placed in water, the negative portions of water molecules will surround the Na^+ ions and the positive parts will surround the Cl^- ions
    - Hydration shell - the sphere of water molecules around each dissolved ion shielding

            - and separating it from other ions
            - Result is solution of two solutes, Na+ and Cl-
        - Even molecules as large as proteins can be soluble if they have enough ionic and polar regions for water to adhere to
        - Hydrophilic - affinity for water even if it cannot dissolve
            - Ex: Cotton absorbs water, but the cellulose molecules are too big to dissolve
            - Polar or contains sufficient polar regions
        - Hydrophobic - no affinity for water
            - non ionic and nonpolar
        - Mole (mol) - the number of a molecule required to have the mass of the amount be equal in grams to the mass number
            - Mol is a constant, like a dozen (equal to 6.022*10^23)
            - There is a mol daltons in a gram
        - Molecular weight - sum of the weights of all the atoms in molecule
        - Molarity - number of moles of solute per liter of solution (most commonly used unit of concentration)
- The Dissociation of Water Molecules
        - Water dissociates into hydrogen ions and hydroxide ions
        - Hydrogen ion - a single proton with a charge of +1
            - Usually binds to another H2O to make H3O+ (hydronium) in water
        - Hydroxide ion - (OH-)
        - In equilibrium, water is nearly all H20 with the concentrations of hydroxide and hydronium equal
    - Organisms are sensitive to changes in pH
        - Acid - increases hydrogen ion concentration of a solution
        - Base - reduces hydrogen ion concentration of a solution
        - Strong acid/base dissociates completely
        - Weak acid/base has reversible reaction, though at equilibrium there will be a fixed ratio of the reactants to the products of the dissociation
        - In any aqueous solution, product of H+ and OH- concentrations is 10^(-14)
        - Neutral solution, each is 10^(-7). Increasing one will decrease other to keep product constant
        - pH = -log [H+]
            - 0-7 is acidic, 7 is neutral, 7-14 is basic
        - Buffers - substances that minimize changes in the concentrations of H+ and OH- in a solution
            - Common in body fluids
            - Can accept or give protons (Ex: carbonic acid)
    - Acid precipitation threatens the fitness of the environment
        - Normal rain has pH of about 5.6 because of formation of carbonic acid from CO2 and H2O
        - Acid precipitation - precipitation more acidic than pH = 5.6
            - Caused by presence of sulfur oxides and nitrogen oxides in the atmosphere that react with the water to form strong acids
        - Effect of acids in lakes and streams is worst in spring as snow melts
            - When snow melts, acid that has accumulated over the winter flows into the water causing meltwater to have a pH as low as 3
            - This can hurt fish and other aquatic life that are just producing eggs and young
        - Acid precipitation on land washes away many important mineral ions
        - It also increases solubility of some toxic minerals like Aluminum, allowing them to reach dangerous concentrations

- Chapter 4: Carbon and the Molecular Diversity of Life
    - The Importance of Carbon
        - Organic chemistry is the study of carbon compounds

        - Organic compounds range from small molecules like CO_2 to huge molecules like proteins
        - Most contain H
        - Overall percentages of major elements of life, C, H, O, N, S, and P, are relatively uniform from one organism to another
            - Because of C's versatility, even atoms stuck in roughly fixed proportions can make an inexhaustible variety of molecules.
        - Vitalism - the belief in a life force outside the jurisdiction of physical and chemical laws (false)
            - Organic compounds are those that arise from living organisms
            - A series of experiments creating more and more complex organic molecules in labs chipped away at vitalism until it crumbled out of the mind of the scientific community
        - Mechanism - the belief that all natural phenomena, including the processes of life, are governed by physical and chemical laws
    - Carbon atoms are the most versatile building blocks of life
        - 4 valence electrons lets carbon make 4 covalent bonds
    - Variation in carbon skeletons contributes to the diversity of organic molecules
        - Vary in length, double bonds, branching, and presence of rings
        - Hydrocarbons - organic molecules consisting only of C and H
            - Our bodies don't have many pure hydrocarbons, rather molecules with hydrocarbon regions, like fats (head molecule with hydrocarbon tails)
            - These molecules are hydrophobic because the C-H bond is nonpolar
            - Store TONS of energy (Ex: gasoline, fat tissue)
        - Isomers - compounds that have the same molecular formula, but different structures
        - Structural isomers - differ in how the carbon skeleton branches
        - Geometric isomers - differ in arrangement around a double bond in carbon skeleton
        - Enantiomers - differ in arrangement around an asymmetric carbon, resulting in molecules that are mirror images (like right and left hands)
- Functional groups
    - Functional groups contribute to the molecular diversity of life
        - Functional groups - the components of organic molecules that are most commonly involved in chemical reactions
        - Functional groups behave consistently between molecules, but the types and arrangement of them give each molecule its unique properties
        - Hydroxyl group: -OH
            - Alcohol - compound containing hydroxyl group
            - Polar, helps substances dissolve in water
        - Carbonyl group: -C=O
            - Aldehyde - substance with carbonyl group on end carbon
            - Ketone - substance with carbonyl group on any other carbon
        - Carboxyl group: -COOH
            - Carboxylic acid (organic acid) - substance containing carboxyl group
            - H^+ can break away from -COOH, making it acidic
        - Amino group: $-NH_2$
            - Amine - substance containing amino group
            - Acts as a base by being able to pick up H^+ and become NH_3^+
            - Component of amino acids along with carboxyl group
        - Sulfhydryl group: -SH
            - Thiol - substance with sulfhydryl group
            - Similar to -OH because S and O have the same number of valence electrons
        - Phosphate group: $-OPO_3^{2-}$ (written -OPO3(-2))
            - Formed by dissociation of phosphoric acid (H_3PO_4)
            - Functions in energy transfer between organic molecules

- Chapter 5: The Structure and Function of Macromolecules
    - Polymer Principles
        - Most macromolecules are polymers
            - Polymer - a long molecule consisting of many similar or identical building blocks linked by covalent bonds
                - Monomer - one block of a polymer
            - Dehydration reaction - puts monomers together by taking out a water
            - Hydrolysis - puts in a water to split monomers
        - An immense variety of polymers can be built from a small set of monomers
            - Many polymers are built from only 40-50 different common monomers, but these can be arranged in countless different ways
    - Carbs - Fuel and Building Material
            - Carbohydrates - sugars and their polymers
        - Sugars, the smallest carbs, serve as fuel and carbon sources
            - Monosaccharides - single sugar unit
                - Molecular formula is multiple of $CH2O$
                - Glucose is most important ($C6H12O6$)
                - Carbonyl group and multiple hydroxyl groups
                - Can be aldose (aldehyde sugar) or ketose (ketone sugar)
                - Size of carbon skeleton (3 to 7 carbons) classifies sugars
                - Spatial arrangement of parts around asymmetric carbons
                - Major nutrients for energy and providing carbon as a raw material for synthesizing other molecules
                - Glucose, fructose, galactose
            - Disaccharide - two sugar units joined by glycosidic linkage
                - glycosidic linkage - a covalent bond formed between two monosaccharides by dehydration reaction
                - Sucrose, maltose, lactose
        - Polysaccharides, the polymers of sugars have storage and structural roles
            - Polysaccharides - macromolecules, polymers with a few hundred to a few thousand monosaccharides joined by glycosidic linkages
            - Can be used as storage to later by hydrolyzed as needed to provide sugar
                - Starch - polymer made completely of glucose (1-4 linkages)
                    - Amylose is unbranched
                    - Amylopectin is branched with 1-6 linkages at branch points
                    - Stored as granules within cellular structures called plastids within plants
                    - Can be digested by animals, though not made by animals
                - Glycogen - a polymer of glucose like amylopectin, but more branched
                    - Used by animals and stored in liver and muscle cells
                    - In humans, glycogen bank is depleted in a day if not replenished
            - Can be used as a building material to protect cells or entire organism
                - Cellulose - major component of plant cell walls made of a chain of glucose
                    - Formed by beta glucose configuration which makes every other monomer flip “upside down”
                    - In starch, glucose isi alpha configuration so they are all facing the same way
                    - This makes cellulose into straight, unbranched chains that allow it to H bond with other celluloses around it
                    - Cannot be digested by humans or most other animals, many have bacteria in digestive tract to break it down for them
                        - Even for us, aids in smooth passing of other food, though
                - Chitin - major component of fungi cell walls and arthropod exoskeletons
                    - Made with glucose monomers having N containing appendages

- Lipids - Diverse Hydrophobic Molecules
    - The one class of large biological molecules that does not include polymers
    - Little or no affinity for water
  - Fats store large amounts of energy
    - Fat - molecule constructed with glycerol (alcohol with 3 carbons) and fatty acids
    - Fatty acid - a long hydrocarbon with a carboxyl group at the end
    - Triacylglycerol - another name for fat, comes from having 1 glycerol and 3 fatty acids
    - Saturated fatty acid - no double bonds in carbon skeleton, so "saturated" with hydrogens
      - Most animal fats
      - Solid at room temperature
      - Contributes to cardiovascular disease
    - Unsaturated fatty acid - one or more double bonds, causing a "kink" in the tail
      - From fish and plants
      - Liquid at room temperature
      - Healthier in diet
    - Fats store twice as much energy per gram as starch
  - Phospholipids are major components of cell membranes
    - Phospholipids - Glycerol binds to only 2 fatty acids and fills third place with a phosphate
      - Tails are hydrophobic, heads are hydrophilic
      - When added to water, they either form a tiny bubble with tails in and heads out, or a bilayer with tails on inside and heads on both outsides (this is how they are in cell membranes)
  - Steroids include cholesterol and certain hormones
    - Steroids - lipids characterized by a carbon skeleton consisting of 4 fused rings
      - Cholesterol - a steroid that is a common component of animal cell membranes
        - Precursor from which other steroids are synthesized
- Proteins - Many Structures, Many Functions
    - Account for over 50% of dry weight of food
    - Polypeptide - polymer of amino acids
    - Protein - one or more polypeptides folded and coiled into specific conformations
  - A polypeptide is a polymer of amino acids connected in a specific sequence
    - Types: structural proteins, storage proteins, transport proteins, hormonal proteins, receptor proteins, contractile proteins, defensive proteins, and enzymatic proteins
    - Amino acids - organic molecules possessing both carboxyl and amino groups
    - Has those, an H, and a variable R group all connected to the alpha carbon
      - R group is called side chain and determines chemical and physical properties of an amino acid
      - Amino acids with carboxyl groups in the side chains are more hydrophilic and acidic
      - Amino acids that have amino groups in the side chains are basic
      - Amino acids with nonpolar side chains are hydrophobic
    - Peptide bond - carboxyl group of one amino acid binds to amino group of another with dehydration reaction
  - A protein's function depends on its specific conformation
    - Primary structure - unique sequence of amino acids
      - Huge variety with 20 different amino acids available for each position
      - A change in one amino acid can cause a disease (Ex: sickle cell) or be harmless
    - Secondary structure - coils and folds
      - Alpha helix - a delicate coil held together by H bonding between every fourth amino acid
      - Beta pleated sheet - two or more regions of the polypeptide chain lie parallel to each other
    - Tertiary structure - irregular contortions from interactions between side chains of the various

amino acids
- Hydrophobic interaction - amino acids with hydrophobic side chains end up in clusters at center of polypeptide, away from water
- Disulfide bridges - two cysteine monomers (amino acids with sulfhydryl groups) are brought close together by folding
  - They form a -S-S- and rivet parts of the protein together

- Quaternary structure - overall structure that results from the aggregation of the polypeptide subunits
- Protein shape also relies on physical and chemical conditions of environment
- Denaturation - unraveling of protein due to change in aspects in environment
  - Usually occurs from pH, salinity, or temperature
  - Often, if the denaturing agent is removed, the protein will return to its original state (in a test tube, cell is more crowded and difficult)
- Chaperonins - proteins that assist in proper folding of other proteins by taking the protein into a hollow cylinder and providing an appropriate environment for the right shape to form
- X-ray crystallography - diffraction of x-rays through crystal of protein makes it possible to analytically determine shape of protein

- Nucleic Acids - Informational Polymers
  - Nucleic acids store and transmit hereditary information
    - DNA - genetic material that organisms inherit from their parents
      - Molecule is long and usually consists of hundreds or thousands of genes
      - Holds info that programs all of the cell's activities
    - RNA - the other type of nucleic acid
      - Each gene along the DNA molecule directs synthesis of mRNA, which reacts with protein making machinery to make polypeptides
      - DNA → RNA → protein
      - Polypeptides are synthesized in ribosomes in the cytoplasm and nuclear envelope
  - A nucleic acid strand is a polymer of nucleotides
    - Nucleotide - monomer of nucleic acid
      - Pyrimidine - 6 C ring with N atoms (C, T, U)
      - Purine - 6 carbon ring fused to 5 carbon ring (A, G)
      - A, G, and C are in DNA and RNA. T is only in DNA and U is only in RNA
      - Deoxyribose - pentose sugar attached to nitrogenous bases in DNA
      - Ribose - equivalent for RNA
      - To complete nucleotide, add a phosphate to C 5 on sugar
    - Polynucleotide - nucleotides joined by covalent bonds called phosphodiester linkages
  - Inheritance is based on replication of the DNA double helix
    - Double helix - structure of DNA, a twisted ladder
    - A pairs with T, C pairs with G
      - This is what allows for precise replication
  - We can use DNA and proteins as tape measures of evolution
    - Bigger differences in DNA/proteins = less closely related

- Chapter 6: An Introduction to Metabolism
  - Metabolism, Energy, and Life
    - Metabolism - totality of an organism's chemical reactions
    - The chemistry of life is organized into metabolic pathways
      - Catabolic pathways - break down molecules, exothermic
      - Anabolic pathways - build up molecules, endothermic
      - Catabolic pathways can be coupled to anabolic pathways so the energy gain from the catabolic fuels the anabolic
      - Bioenergetics - study of how organisms manage their energy resources

- Organisms transform energy
  - Chemical energy - a form of potential energy stored in molecules as a result of atom arrangement
    - Can be used in reactions where breaking down of the molecule gives atoms KE
- The energy transformations of life are subject to two laws of thermodynamics
  - Thermodynamics - the study of the energy transformations that occur in a collection of matter
    - System - matter under study
    - Surroundings - Everything outside system, rest of universe
    - Closed system - system is isolated from surroundings
    - Open system - energy can flow between system and surroundings
  - First law of thermodynamics - Total energy of the universe is constant
    - Energy can be transformed or transferred, not created or destroyed
  - Second law of thermodynamics - every energy transfer or transformation increases entropy
    - Entropy - a measure of disorder, or randomness
    - Although order can increase locally, universal entropy is constantly increasing
    - In a car, 25% of the gas's energy is transformed into motion, rest is released as heat
  - Quantity of energy is same, but quality is not
    - Heat is "lowest grade" of energy
    - Most disordered
  - Organisms are islands of low entropy in an increasingly random universe
- Organisms live at the expense of free energy
  - Spontaneous process - occurs without outside help, can be harnessed to perform work
    - Makes unstable systems more stable
  - Free energy - the portion of a system's energy that can perform work when temperature is uniform throughout the system
    - Energy that is available to do work
    - $\Delta G = \Delta H - T\Delta S$, H is enthalpy, T is temperature, S is entropy
      - Enthalpy - total energy in a system
      - Positive ΔG is endergonic reaction. Negative ΔG is exergonic/spontaneous
      - At equilibrium, ΔG is zero
  - Metabolic disequilibrium - defining feature of life because when $\Delta G = 0$ in a cell, no work can be done and the cell is dead.
    - Constant flow of materials in and out of cell keeps from reaching equilibrium
    - Sunlight continues to add free energy to system as it flows out as heat
  - Energy coupling - the use of an exergonic process to drive an endergonic one.
- ATP powers cellular work by coupling exergonic reactions to endergonic reactions
  - Cell does 3 types of work:
    - Mechanical work - cilia, contraction, movement of chromosomes
    - Transport work - pumping of substances against electrochemical gradient
    - Chemical work - pushing of endergonic reactions that would not normally occur, like synthesizing of polymers from monomers
  - ATP (adenosine triphosphate) - just like RNA adenine, but 3 phosphates
    - Removal of terminal phosphate group is exergonic ($\Delta G = -31$ kJ/mol)
    - Works by phosphorylation of a molecule, letting the molecule bind to another in an exergonic reaction.
      - Phosphorylation - ATP gives another molecule a phosphate, making the other molecule able to bind to something exergonically when it would have been endergonically
  - ATP can be regenerated from free energy generated by catabolism reactions in the cell
    - 10 million molecules of ATP are regenerated per second per cell
    - If not for regeneration, humans would go through nearly their body weight in ATP every day

- Enzymes
    - Enzymes speed up metabolic reactions by lowering energy barriers
        - Catalyst - a chemical agent that changes the rate of a reaction without being consumed by the reaction
        - Enzyme - catalytic protein
        - To form bonds in a reaction, some must be broken first with activation energy
            - Activation energy - the initial investment of energy for starting a reaction
            - Even required in most exergonic reactions
            - (Ex: energy of a match required to burn paper, which releases way more energy)
            - Often, much heat is needed to get the molecules moving enough to break their initial bonds
        - Enzymes/catalysts speed up reactions by providing an alternate pathway with a lower activation energy
            - Does not change ΔG, just makes the first step less endergonic and the second less exergonic
    - Enzymes are substrate specific
        - Substrate - the reactant an enzyme acts on
        - Enzyme binds to substrates and uses catalytic action to create products
        - Enzymes are super specific to their substrates, caused by precise active site
            - Active site - a pocket or groove on the protein where the substrate attaches
            - Formed by only a few amino acids, while others reinforce shape of active site
        - Induced fit - when substrate binds to enzyme, it induces the enzyme to conform to the substrate even more snugly
    - The active site is the enzyme's catalytic center
        - Often, the enzyme is held in place by ionic and H bonds
        - Side groups in the active site catalyze the change from substrate to product and remove product
        - Entire cycle can happen on about 1000 substrate molecules per second
        - Most metabolic reactions are reversible and the enzyme can catalyze both the forward and reverse
        - Enzymes work by putting molecules in proper orientations, deforming them, and/or creating a microenvironment conducive to the reaction
        - Sometimes, there is even brief covalent bonds between the substrate and the R groups
        - Rate can be increased by increasing concentration of enzyme or reactant
    - A cell's physical and chemical environment affects enzyme activity
        - Like other proteins, enzymes have optimal conditions in temperature and pH
        - Up to a point, enzyme activity increases with increasing temperature because of increased movement, then the enzyme starts to denature and activity plummets
        - Different enzymes work best in different pH's (Ex: stomach pepsin is adapted to pH 2)
        - Cofactors - nonprotein helpers for catalytic activity
        - Coenzyme - organic molecule cofactor
        - Competitive inhibitor - blocks substrates
            - Can be overcome by increasing concentration of substrate molecules so they fill the spots instead of the inhibitors
        - Noncompetitive inhibitors - impede enzymatic reactions by binding to another part of the enzyme, changing shape of enzyme and rendering active site useless
        - Some poisons work as enzyme inhibitors (Ex: DDT)
- The Control of Metabolism
    - Metabolic control often depends on allosteric regulation
        - Allosteric site - a specific receptor site on part on an enzyme that can cause either inhibition or stimulation
        - Most allosterically regulated enzymes are made from 2 or more polypeptides

            - Each has its own active site and allosteric sites are where subunits join
            - Usually enzyme is unstable so activators stabilizes active form and inhibitors stabilize inactive form
            - The subunits are arranged in a way so a change in one changes all so a single activator or inhibitor will affect all of the subunits.
            - Often products are inhibitors and reactants can be activators
        - Feedback inhibition - the switching off of a metabolic pathway by its end product
        - Cooperativity - induced fit of one substrate makes rest of enzyme more conducive to binding
    - The localization of enzymes within a cell helps order metabolism
        - Teams of enzymes in multistep pathways are usually arranged together rather than just floating around for increased efficiency
            - Enzyme complexes can be in solution, enclosed in organelles, or have fixed locations as structural components of particular membranes

- Chapter 7: A Tour of the Cell
    - How We Study Cells
        - Microscopes provide windows to the world of the cell
            - Resolving power - a measure of clarity; the minimum distance two points can be separated and still be distinguished as separate
            - Light Microscope - works by visible light being bent and refracted
                - Resolving power is 0.2 micrometer, can magnify up to 1000x
                - Cannot make out organelles - subcellular structures
                - Allows specimen to remain alive
            - Electron Microscope - uses a focused beam of electrons
                - Resolving power is theoretically 0.1 nm, but practically 2 nm
                - Reveals cell ultrastructure - cell anatomy
                - Must kill specimen
            - Transmission electron microscope - electrons go through thin section of specimen
                - Cell slice must be coated with atoms of heavy metals
                - Shows internal structure
            - Scanning electron microscope - electrons reflect off surface of substance
                - Sample must be coated with a thin coat of gold foil
                - Gives depth of field
            - Cytology - the study of cell structure
        - Cell biologists can isolate organelles to study their functions
            - Cell fractionation - taking apart part cells and separating major organelles to study their functions
            - Ultracentrifuges - Spin cell parts around really fast to separate parts by density
                - First slow spin breaks up some cells
                - Next spin separates pellet that contains nuclei and other cellular debris
                - Next spin separates pellot of mitochondria (and chloroplasts if from plant)
                - Then pellet contains pieces of plasma membranes and internal membranes
                - Last pellet contains ribosomes
                - Supernatant - liquid above pellet
                - Allows researchers to prepare bulk quantities of specific cell parts
    - A Panoramic View of the Cell
        - Prokaryotic(Pr) and eukaryotic(Eu) cells differ in size and complexity
            - Cytosol - semifluid substance within the membrane of both cell types
                - Contains organelles
            - Nucleoid - place where DNA is concentrated in Pr cells
            - Nucleus - membrane bound organelle that holds DNA in Eu cells
            - Cytoplasm - region between nucleus and plasma membrane in both cell types

        - Eu cells are generally much bigger than Pr cells
        - Both have size limit from decreasing SA:V ratio
        - Plasma membrane - selective barrier that allows sufficient passage of O, nutrients, and wastes to service the entire volume of the cell
            - Generally composed of a lipid bilayer with proteins stuck in it
            - Large organisms have more cells, not larger ones
    - Internal membranes compartmentalize the functions of a eukaryotic cell
        - Different membrane protected compartments can create different microenvironments for specific metabolic functions to occur
- The Nucleus and Ribosomes
    - The nucleus contains a eukaryotic cell's genetic library
        - Nucleus - contains most of the genes in an Eu cell and is generally the most conspicuous organelle
        - Nuclear envelope has two lipid bilayers
        - Envelope is perforated by nuclear pores where the inner and outer membranes are fused
        - Nuclear lamina - netlike array of intermediate filaments that line the inner layer of the nuclear envelope and maintain the shape of the nucleus
        - Chromatin - a fibrous material the DNA and some proteins are arranged into
        - Chromosomes - structures that the DNA and proteins condense into to separate
            - Humans have 46 in somatic cells, 23 in gametes
        - Nucleolus - dense part of granules and fiber adjoining part of the chromatin in the nucleus that functions in production of ribosomes (rRNA and associated proteins)
    - Ribosomes build a cell's proteins
        - Made of a large subunit and a large subunit
        - Cells that have higher levels of protein synthesis (Ex: pancreas cells) have more ribosomes
        - Free ribosomes are suspended in the cytosol and make proteins that function in the cytosol
        - Bound ribosomes are bound to rough ER and make proteins to be secreted
        - They are structurally identical and can switch roles when needed
- The Endomembrane System
        - Endomembrane system - the system of membranes in a Eu cell
            - Connected by physical continuity or by vesicles
            - Vesicle - tiny membrane sac that can transfer membrane and needed chemicals around the endomembrane system
    - The endoplasmic reticulum (ER) manufactures membranes and performs many other biosynthetic functions
        - The ER is an extensive membrane labyrinth that consists of over half the total membrane in many Eu cells
        - Cisternae - tubules and sacs that make up the ER
        - Smooth ER - ER that appears smooth because the surface lacks ribosomes
            - Synthesizes lipids, metabolizes carbohydrates, detoxifies drugs and poisons, and helps muscle cells contract
                - Lipids made include oils, phospholipids, and steroids
                - Steroids produced include sex hormones and steroids secreted by adrenal glands
                - The cells that make these hormones are rich in smooth ER
                - Carb metabolization includes when liver cells remove the phosphate from glucose phosphate so it can leave to cell
                - Detox usually involves adding hydroxyl groups to drugs to make them more soluble and easier to flush out
                - Tolerance caused by drugs inducing proliferation of smooth ER
                - Smooth ER pumps Ca ions from the cytosol to the cisternal space. When a muscle cell is stimulated by a nerve impulse, Ca rushes out of the ER and

triggers contraction of the muscle cell

- Rough ER - ER studded with ribosomes that creates proteins for excretion
    - As polypeptide chains assemble, they are threaded into the cisternal space where they fold
    - Glycoproteins - proteins covalently bonded to oligosaccharide, main secretion of rough ER
        - Oligosaccharide - carbohydrate made of relatively few sugar units
    - Transport vesicles - vesicles in transit from one part of the cell to another, help move secretory glycoproteins from cisternal space to plasma membrane
    - Rough ER also contains enzymes that make phospholipids and the made proteins are often studded directly into the wall of the vesicle. These can be sent to other membranous organelles or the plasma membrane as a source of membrane

- The Golgi apparatus finishes, sorts, and ships cell products
    - After leaving the ER, most transport vesicles travel to the Golgi apparatus
        - Here, products of the ER are modified, stored, and then sent to their destinations
    - Extensive in cells specialized for secretion
    - Also consists of flattened cisternae (looks like a stack of pita bread)
    - Many differences between cis side (receiving) and trans side (shipping)
        - thickness and molecular composition
    - ER products are generally modified during transit from cis pole to trans pole of Golgi
        - Oligosaccharides are modified
    - Golgi also manufactures certain macromolecules by itself
        - Pectins and certain other noncellulose polysaccharides incorporated in plant cell walls
    - Different cisternae have unique teams of enzymes to refine the products in stages
    - Phosphate groups and other external molecules are added to the vesicles for targeting purposes
        - Organelles often have “docking sites” to recognize the molecules
- Lysosomes are digestive compartments
    - Lysosome - a membrane-bound sac of hydrolytic enzymes that cells use to digest macromolecules
        - Can hydrolyze proteins, polysaccharides, fats, and nucleic acids (all classes)
        - Lysosome provides isolated area for digestion so the enzymes don’t digest the rest of the cell
            - The enzymes work best at the pH 5 in the lysosomes so if they leak, there won’t be too much damage in the cell’s neutral pH
            - Too much leaking can destroy a cell, however, by autodigestion
        - Hydrolytic enzymes and lysosomal membranes are made by rough ER and sent to Golgi apparatus for further processing
        - Proteins on the inner surface of the lysosomal membrane and the digestive enzymes have 3d conformations that protect vulnerable bonds from digestion
        - Phagocytosis - cell “eats” stuff by forming a food vacuole around it; used by most protists
            - Food vacuole bonds with lysosome and enzymes digest molecules
    - Autophagy - lysosomes use their enzymes to digest and recycle the cell’s own organic material
    - Apoptosis - programmed cell death caused by releasing of lysosomal enzymes
- Vacuoles have diverse functions in cell maintenance
    - Food vacuoles - made by phagocytosis engulfing food particles
    - Contractile vacuoles - pump excess water out (for osmoregulation of freshwater protists)
    - Central vacuole - holds lots of water and other solutes(sap) for plant cells
        - Storage (organic compounds such as proteins, inorganic ions), disposal site, pigment,

            poisonous compounds for defense, growth (makes cell bigger while keeping SA:V low)
        - Tonoplast - membrane that encloses central vacuole; selective to create a sap with different composition than cytosol
- Other Membranous Organelles
    - Mitochondria and chloroplasts are the main energy transformers of cells
        - Mitochondria - sites of cell respiration, the catabolic processes that generate ATP by extracting energy from sugars, fats, and other fuels with the help of O
            - Found in nearly all Eu cells
            - Enclosed with two membranes, outer is smooth and inner has infoldings
            - Cristae - infoldings of inner mitochondrial membrane to increase surface area
            - Mitochondrial matrix - space enclosed by inner membrane in mitochondria
        - Chloroplasts - sites of photosynthesis, converting solar energy into chemical energy by absorbing sunlight and using it to drive the creation of organic compounds from CO_2 and H_2O, in only plants and algae
            - Plastids - family of closely related plant organelles that includes chloroplasts
                - Amyloplasts - colorless, store starch, in tubers and roots
                - Chromoplasts - have pigments that give fruits and flowers orange and yellow hues
                - Chloroplasts - have the green pigment chlorophyll along with enzymes and other molecules that function in photosynthesis
            - Double membrane with additional membrane system inside forming thylakoids
                - Thylakoid - Flat pancake stack shaped membrane things (each pancake)
                - Granum - Stack of thylakoids
                - Stroma - Fluid outside thylakoids, but inside chloroplast
        - Not part of the endomembrane system because the membranes are created by free ribosomes in the cytosol and ribosomes contained within the organelles themselves
        - The organs also have their own DNA to create their own proteins in their own ribosomes
        - They move, grow, and divide by themselves within cytoplasm
    - Peroxisomes generate and degrade H_2O_2 in performing various metabolic functions
        - Peroxisome - specialized metabolic compartment bound by a single membrane
            - Transfers H from various substrates to O, forming H_2O_2
            - Then degrades H_2O_2 into H_2O and O_2
            - Glyoxysomes - specialized peroxisomes that convert fatty acids to sugar; found in fat storing tissues of plant seeds
        - Not endomembrane system, they grow by incorporating lipids and proteins from the cytosol and split in two when they reach a certain size
- The Cytoskeleton
        - Cytoskeleton - a network of fibers extending throughout the cytoplasm
    - Providing structural support to the cell, the cytoskeleton also functions in cell motility and regulation
        - Most important function is to give mechanical support and maintain cell shape, especially for animal cells
        - Cell motility - changes in cell location and movements of parts within cell; controlled by cytoskeleton
            - Muscle contraction involves sliding of microfilaments past each other, movement of cilia and flagella involves sliding of microtubules
            - Moving of organelles has them attached to a motor protein that "walks" along a microtubule track
        - Microtubules - hollow rods made of tubulin dimers (25 nm diameter)
            - Form centrioles and spindle fibers to reel in chromosomes
            - Form skeleton of cilia and flagella
                - Cilia are smaller and more numerous than flagella

            - Both are locomotor appendages that protrude from many cells
            - 9+2 pattern with 9 microtubule doublets around perimeter of flagellum/cilium and two single tubules in center
            - Basal body - structurally identical to centriole; anchors flagellum/cilium to cell
                - Basal body in sperm becomes centriole in zygote
            - Dynein - large proteins that connect doublets to each other; walks the doublets down each other to cause flagellum/cilium to bend
    - Microfilaments (actin filaments) - solid rods made of actin (7 nm diameter)
        - Twisted double chain of actin subunits
        - In addition to other proteins, they form a 3d net right inside the plasma membrane, helping support the cell's shape and giving the cortex (outer cytoplasmic layer) a gel like consistency
        - Make microvilli to increase surface area
        - Myosin - makes up fibers that lay alternating with actin filaments and help in muscle contraction
            - Same mechanism forms cleavage furrow in dividing animal cells
            - Pseudopodia - cellular extensions that pull a cell, allowing it to crawl across a surface; uses same actin-myosin contraction to pull cytoplasm along
        - Cytoplasmic streaming - circular flow of cytoplasm within a cell that speeds distribution of materials and is brought about by actin filaments
    - Intermediate filaments - constructed of various molecular subunits in family of proteins called keratins; diameter ranges from 8-12 nm
        - Most permanent element of cytoskeleton
        - Especially important in reinforcing shape of cell and fixing the position of certain organelles
        - Makes up nuclear lamina
        - In cases where shape of entire cell is correlated with function (Ex: neurons), intermediate filaments support the shape
- Cell Surfaces and Junctions
    - Plant cells are encased by cell walls
        - Cell wall - wall of plant cell that protects the cell, maintains its shape, and prevents excessive uptake of H_2O
            - Walls of various cells hold up the whole plant against gravity
            - Thickness varies from 0.1 micrometers to several micrometers
            - Cellulose microfibrils are embedded in a matrix of other polysaccharides and proteins
            - Primary cell wall - secreted first by plants; thin and flexible
            - Middle lamella - a thin layer rich in sticky polysaccharides called pectins between primary cell walls
            - Secondary cell wall - stronger, deposited in several layers, gives protection and support
    - The extracellular matrix of animal cells functions in support, adhesion, movement, and regulation
        - Main ingredients are glycoproteins secreted by cells
            - Most abundant glycoprotein is collagen
            - Collagen - forms strong fibers outside animal cells; half of all protein in human body
            - Proteoglycans - woven into a matrix that collagen is embedded into; rich in carbs
            - Fibronectins - glycoproteins that attach to integrins and connect some cells to ECM
            - Integrins - proteins that span the membrane and bind on their cytoplasmic side to microfilaments of the cytoskeleton
                - Integrate changes occurring outside and inside cell
        - ECM can influence cell behavior, and activity of genes
    - Intercellular junctions help integrate cells into higher levels of structure and function

        - Plasmodesmata - perforation in plant cell walls that connect the cells
        - Tight junctions - membranes of neighboring cells are fused to prevent leakage of extracellular fluid across a layer of epithelial cells
        - Desmosomes - like rivets that fasten cells together into strong sheets
        - Gap junctions - cytoplasmic channels between adjacent cells; surrounded by pore that is just wide enough to allow salt ions, sugars, amino acids, and other small molecules to pass

- Chapter 8: Membrane Structure and Function
    - Membrane Structure
            - Amphipathic - has hydrophilic and hydrophobic regions
            - Fluid mosaic model - membrane is a fluid structure with various proteins embedded in or attached to a bilayer of phospholipids
        - Membrane models have evolved to fit new data
            - Davson-Danielli model - phospholipid bilayer is sandwiched between protein layers
                - Accepted until 1970's when fluid mosaic model was proposed and proven
        - Membranes are fluid
            - Held together by hydrophobic interactions so lipids and proteins drift laterally
                - Very rarely, phospholipids flip flop across bilayer
            - Some proteins drift, others move with purpose, others stay still, caused by cytoskeleton
            - Membrane fluidity decreases with temperature as movement slows down
                - Unsaturated hydrocarbon tails increase membrane fluidity because kinks prevent molecules from packing as tightly
                - Cholesterol wedges between phospholipids to lower fluidity at high temps by making molecules more packed and increasing it at lower temperatures by keeping them from packing super tightly
                - Unsaturated can change to saturated and vice versa in response to temp changes
        - Membranes are mosaics of structure and function
            - Integral proteins - go through lipid bilayer
            - Peripheral proteins - loosely bound to surface of membrane, often to integral proteins
            - Both often held in place by cytoskeleton
            - Both sides of plasma membrane are very different biochemically
            - Membrane functions in: transport, enzymatic activity, signal transduction, intercellular joining, cell-cell recognition, attachment to cytoskeleton and ECM
        - Membrane carbs are important for cell-cell recognition
            - Usually branched oligosaccharides with fewer than 15 units
                - Some are covalently bonded to lipids to form glycolipids
                - Most are bonded to proteins, forming glycoproteins
            - Variation among oligosaccharides allow for cell-cell recognition
    - Traffic Across Membranes
        - A membrane's molecular organization results in selective permeability
            - With just lipid bilayer, hydrophobic molecules like hydrocarbons, CO_2, or O_2, can easily cross lipid bilayer
            - Ions and polar molecules cannot cross easily because they are hydrophilic and won't go into region between phospholipids (even water!)
            - Transport proteins - integral proteins that allow for increased permeability of the plasma membrane to various compounds
                - Some work by providing a hydrophilic channel, others physically move molecules across membrane
        - Passive transport is diffusion across a membrane
            - Diffusion - tendency of molecules to spread out into the available space (increases entropy)
                - Stops at dynamic equilibrium when molecules cross both ways at equal rates
            - Substances diffuse down concentration gradient spontaneously

        - Molecules follow their own concentration gradient independent of the gradients of other solute molecules
    - Passive transport is named so because energy is not expended, concentration gradient represents PE and drives diffusion
- Osmosis is passive transport of water
    - Hypertonic - higher concentration of total solutes
    - Hypotonic - lower solute concentration
    - Isotonic - same solute concentrations
    - Water diffuses from hypotonic to hypertonic solution if membrane does not allow diffusion of solute molecules
- Cell survival depends on balancing water uptake and loss
    - For cells without walls, they can neither take up too much water (cells lyse, or burst) or lose too much (cells shrivel up)
    - Most animals must live in an isotonic environment
        - Osmoregulation - control of water balance
    - For cells with walls, taking up excess water causes wall to exert back pressure and making cell turgid (normal state for plant cells.
    - In isotonic, plants are flaccid (limp), and hypertonic, plasmolyzed (cell shrivels up and shrinks away from wall)
        - Plasmolysis is usually lethal
- Specific proteins facilitate the passive transport of water and selected solutes: a close look
    - Facilitated diffusion - passive transport with help of transport proteins
        - Proteins are specific to solute
        - Can be saturated and turned on or off
    - Channel proteins - provide a channel for small molecules and ions to flow through
        - Aquaporins - channels for water to flow through for osmosis
    - Gated channels - stimulus causes them to open or close (action potential)
    - Some proteins undergo a small shape change to move the solute binding site across the membrane
    - Many diseases cause transport systems to be defective or missing
- Active transport is the pumping of solutes against their gradients
    - Requires energy to move solutes against concentration gradients “uphill”
    - Major factor in the ability of a cell to maintain internal concentrations of small molecules that differ from concentrations in its environment
    - ATP provides energy by phosphorylating protein (like Na-K pump)
- Some ion pumps generate voltage across membranes
    - Voltage - electrical PE by separation of opposite charges
    - Inside of cell is more negative
    - Ions not only diffuse towards lower concentration, but also towards opposite charge
    - Electrochemical gradient - concentration and charge, decides way of diffusion
    - Electrogenic pump - generates voltage
        - Main one in animals is Na-K
    - Proton pump - used in plants, bacteria, and fungi, pumps protons out of cell
- In cotransport, a membrane protein couples the transport of two solutes
    - Cotransport - ATP powered pump that transports a specific solute can indirectly drive the active transport of several other solutes
        - Ex: One pump sends out protons, protons and sugar both needed in facilitated diffusion protein, the protons help the sugar diffuse in against electrochem gradient
- Exocytosis and endocytosis transport large molecules
    - Exocytosis - cell secretes macromolecules by the fusion of vesicles with the plasma membrane
        - Vesicles bud from Golgi apparatus and move along cytoskeleton
        - Used often with secretory cells with hormones and neurotransmitters

        - Endocytosis - rewind exocytosis
            - Phagocytosis - pseudopodia wrap around particle and form large vacuole, which fuses with lysosome for digestion
            - Pinocytosis - cell "gulps" droplets of extracellular fluid into many tiny vesicles
                - Not specific in solutes transported
            - Receptor-mediated endocytosis - receptors open to extracellular fluid on membrane
                - Ligands - molecules that bind to receptors
                - After suitable ligands bind, vesicle forms, ligands are used, and receptors are recycled.
                - Allows bulk acquiring of substances normally not in high concentrations
        - Exocytosis and endocytosis balance out approximately to keep cell membrane size constant

- Chapter 9: Cell Respiration: Harvesting Chemical Energy
    - The Principles of Energy Harvest
        - Cell respiration and fermentation are catabolic, energy-yielding pathways
            - Organic compounds store energy in their arrangement of atoms
            - Some energy is taken to do work, rest is lost as heat
            - Fermentation - partial degradation of sugar without help of O_2
            - Cell respiration - must more efficient, oxygen is consumed with organic fuel
                - Has $\Delta G = -686$ kcal/mol glucose
            - Processes do not directly do work, they make ATP to transfer energy
        - Cells recycle the ATP they use for work
            - Chemical spring of ATP "relaxes" by losing third phosphate
            - Enzymes re-attach phosphate
            - A working muscle cell recycles 10 million ATP molecules per second
        - Redox reactions release energy when electrons move closer to electronegative atoms
            - Redox reactions - transfer of electrons
                - OIL RIG: Oxidation is loss, reduction is gain (of electrons)
                - Reducing agent gets oxidized, oxidizing agent gets reduced
            - Some reactions just change the degree of electron sharing in covalent bonds
            - O is great oxidizing agent because of large electronegativity
            - Redox reactions usually move electrons closer to oxygen, releasing energy
        - Electrons "fall" from organic molecules to oxygen during cellular respiration
            - Organic molecules with plenty of H are excellent fuels because they have many electrons at high PE that can fall far
            - Fats and Carbs are reservoirs of H electrons held back only by activation energy
            - Enzymes lower activation energy to allow for the glucose to be oxidized.
        - The "fall" of electrons during respiration is stepwise, via NAD^+ and an electron transport chain
            - Molecules have to be oxidized in several steps to allow for more of the energy to be harnessed
            - NAD^+ - accepts H and an e during cell respiration to become NADH without letting the electron lose very much of its PE
            - Electron transport chain - breaks the fall from electrons to O into several energy-releasing steps instead of one explosive reaction
            - Electron transfer from NADH to O is exergonic with $\Delta G = -53$ kcal/mol
            - Electrons follow path: food → NADH → electron transport chain → O
    - The Process of Cellular Respiration
        - Respiration involves glycolysis, the Krebs cycle, and electron transport
            - Glycolysis - occurs in the cytosol, breaks glucose into two molecules of pyruvate
            - Krebs cycle - decomposes a derivative of pyruvate into CO_2
            - During both, NADH and a little ATP is made
            - Electron transport chain - products of first two steps donate electrons to be passed down finally to O where they are combined with H to make H_2O

        - Oxidative phosphorylation - redox reactions that take electrons from food to O, making ADP into ATP
        - Substrate-level phosphorylation - enzyme transfers a phosphate group from a substrate molecule to ADP in glycolysis or Krebs cycle
    - Glycolysis harvests chemical energy by oxidizing glucose to pyruvate
        - Glycolysis - splitting of sugar (latin)
        - Energy investment phase: in goes 1 glucose and 2 ATP
        - Energy payoff phase: Out comes 4 ATP, 2 NADH, and 2 pyruvate
        - Net: 2 pyruvate (and 2 H_2O), 2 ATP, and 2 NADH (and 2 H^+)
        - Glycolysis always occurs, O or not (still used in fermentation)
    - The Krebs cycle completes the energy yielding oxidation of organic molecules
        - Only occurs if O is present (though O isn't needed here)
        - After entering the mitochondrion, pyruvate is converted to acetyl coenzyme A
            - Energyless carboxyl group given off as CO_2
            - Oxidized with electrons going to NAD^+ to make NADH
            - CoA is attached by unstable bond
            - This can then be fed into the Krebs cycle
        - Cycle incorporates Acetyl CoA into Oxaloacetate, which goes through the cycle giving off (per pyruvate) 3 NADH, 1 $FADH_2$, and 1 ATP while giving off two CO_2
    - The inner mitochondrial membrane couples electron transport to ATP synthesis: a closer look
        - So far, only 4 ATP molecules have been produced and these all by substrate-level phosphorylation
        - Cristae increase surface area for thousands of electron transport chains
        - Chain goes - NADH, FMN, FeS, Q, Cyt b, FeS, Cyt c1, Cyt c, Cyt a, Cyt a3, O_2
        - FADH, FeS, Q, etc
        - Cytochromes are similar to hemoglobin, but they transport electrons instead of O
        - Entire chain serves to create and maintain H^+ gradient with more protons out of cell (attached to protein complexes that pump protons out)
        - Then, H^+ gradient powers protein complex "mill" that makes ATP
            - Rotor in membrane spins when H^+ flows past
            - Stator anchored in membrane holds knob stationary
            - Rod also spins, activating catalytic sites in knob
            - Knob joins phosphate to ADP to make ATP
        - Chemiosmosis - coupling mechanism used above
        - H^+ gradient is referred to as proton-motive force
        - Chemiosmosis isn't only used in cell respiration, plants use it to make ATP in photosynthesis
    - Cell Respiration.... a review
        - Makes about 38 molecules of ATP, efficiency of about 40% (cars are 25%)
- Related Metabolic Processes
    - Fermentation enables some cells to produce ATP without O
        - Glycolysis still occurs
        - Fermentation is an extension of glycolysis that produces ATP from only substrate level phosphorylation
            - Recycles NAD^+ by transferring electrons from NADH to pyruvate after glycolysis
        - Alcohol fermentation - pyruvate is converted into ethyl alcohol in two steps.
            - CO_2 is released from pyruvate
            - Remaining acetaldehyde reduced by NADH to ethanol
            - Used by bacteria
        - Lactic acid fermentation - pyruvate is reduced directly by NADH to form lactate as a waste product with no release of CO_2.
            - Used in dairy industry to make yogurt and cheese
            - Used by humans when O supply is scarce, lactase causes pain and fatigue

            - Fermentation makes 2 ATP molecules in contrast to cell respiration's 38
            - Facultative anaerobes - can use either fermentation or respiration
            - Because glycolysis is used everywhere and occurs in cytosol, it is believed to have been used in first prokaryotes.
        - Glycolysis and Krebs cycle connect to many other metabolic pathways
            - Glycolysis can accept a wide range of carbs
            - Proteins can be broken up into amino acids, then converted into intermediates of glycolysis and Krebs cycle
                - Nitrogenous refuse must be excreted because amino group has to be removed
            - Beta oxidation - breaks down fats into two carbon fragments that enter the Krebs cycle as acetyl CoA
            - Intermediates of glycolysis and Krebs cycle can be diverted into anabolic pathways
                - These consume ATP rather than generating it
            - Also some kinds of molecules can be changed into others with these mechanisms (carbs into storage fat)
        - Feedback mechanisms control cellular respiration
            - If end product of any step (anabolic or catabolic) is too common, then the pathway can be shut off
            - Phosphofructokinase - catalyzes step 3 of glycolysis, can be slowed down or sped up to change rate of entire catabolic process
                - ATP inhibits, AMP stimulates

- Chapter 10: Photosynthesis
    - Photosynthesis in Nature
        - Plants and other autotrophs are the producers of the biosphere
            - Autotrophs - sustain themselves without eating other organisms or substances derived from other organisms
                - Produce organic molecules from CO_2 and other inorganic raw materials from environment
            - Photoautotrophs - use light as a source of energy
            - Use only chemical compounds for molecules and energy
            - Heterotrophs - obtain organic material by consuming products produced by other organisms
                - Includes not only eating, but decomposing and parasitism
        - Chloroplasts are the sites of photosynthesis in plants
            - Although all green parts of plants have chloroplasts, leaves are the major sites of photosynthesis in plants
            - Color of leaves comes from chlorophyll, a green pigment in chloroplasts
                - Chlorophyll absorbs light energy that can be used for photosynthesis
            - Mesophyll - internal tissue of leaf; where most chloroplasts are found
            - Stomata - microscopic pores in the leaves where CO_2 enters and O_2 exits
            - Typical mesophyll cell has 30-40 chloroplasts, each of which is watermelon shaped
            - Thylakoid membrane system separates stroma from thylakoid space
            - Thylakoids sacs are stacked in columns called grana
    - The Pathways of Photosynthesis
        - Evidence that chloroplasts split water molecules enabled researchers to track atoms through photosynthesis
            - First discovery was that O given off from plants is from H_2O instead of CO_2
            - Electrons are transferred along with H ions from water to CO_2, reducing it to sugar
            - Energy boost provided by light
        - The light reactions and the Calvin cycle cooperate in converting light energy to the chemical energy of food: an overview
            - Light reaction - absorbs light

    - NADP+ reduced to NADPH
    - Photophosphorylation - light powered changing of ADP into ATP
    - Happens in thylakoids
  - Calvin cycle - ~~Uses solarbeam~~ uses energy to build sugars
    - Carbon fixation - incorporation of carbon into organic molecules; done with CO_2 in Calvin cycle
    - Then uses reducing power from NADPH to reduce fixed carbon into carbs
    - Happens in stroma
- The light reactions convert solar energy to the chem energy of ATP and NADPH
  - Light is an electromagnetic wave
  - Wavelength - distance between the crests of EM waves
  - EM spectrum - range of wavelengths from less than a nm (gamma rays) to more than a km (radio waves)
  - Visible light - thin slice in 380-750 nm; called such because it is detected by human eye, NOT because it has some special property only in that slice
  - Photon - discrete particle of light (light is a wave and a particle)
  - Pigments - substances that absorb light
  - Different substances absorb different wavelengths, showing different “colors”
  - Spectrophotometer - measures the ability of a pigment to absorb various wavelengths of light
  - Absorption spectrum - graph of pigment’s light absorbed (not light transmitted or reflected)
  - Chlorophyll a - blue-greenish
  - Chlorophyll b - slight structural difference from chl a, absorbs yellow-green
  - Carotenoids - hydrocarbons that absorb shades of orange and yellow
    - Help protect plant by absorbing extra light
  - Action spectrum - for photosynthesis, profiles relative performance of the different wavelengths (aerobic bacteria growth experiment)
  - When photons hit chlorophyll and excite it, then an electron is sent to an excited state. It falls back down to ground state and emits another photon that can excite a new molecule
    - Reason certain pigments absorb certain wavelengths is that the photon must have the same energy as the difference between ground state and excited state
  - Fluorescent pigments (including chlorophyll) emit light and heat when electron drops back to ground state instead of just heat
  - Photosystem - place where chlorophyll is organized with proteins and other small molecules
  - Variety of pigment molecules allows the photosystem to collect a wide range of wavelengths
  - Reaction center - where the final chlorophyll excites the primary electron acceptor with redox
    - Happens when primary electron acceptor traps excited electron before it falls back to ground state
    - Isolated chlorophyll glows because the electron can freely fall, not be trapped
  - Two types of photosystems: I and II, in order of discovery (opposite order in chronologically)
    - I is best at absorbing far red (700 nm, reaction center is P700)
    - II is best at absorbing mid red (680 nm, reaction center is P680)
    - Both are chlorophyll a, just different interactions with thylakoid membrane proteins
  - Noncyclic electron flow - predominant path to make NADPH and ATP
    - II absorbs light and electron from reaction center chlorophyll is sent to primary electron acceptor, making oxidized chlorophyll a very strong oxidizing agent
    - Enzyme extracts electrons from water and gives them to the P680. O bonds with another O to make O_2 right away and is released
    - Excited electron is passed down electron transport chain to I
    - Exergonic fall is used to make ATP through noncyclic photophosphorylation
    - Electron fills “hole” in P700 and is passed to a smaller electron transport chain when transmits them to Fd (iron containing protein) then to NADP+ to lead to NADPH
  - Cyclic electron flow - uses I, not II, to just make ATP through cyclic phosphorylation

            - Calvin cycle consumes more ATP, but ATP and NADPH are made in equal amounts in noncyclic flow, so cyclic makes up for it
            - Stimulated by rise in NADPH, inhibited by rise in ATP
            - Electron goes from I to primary acceptor, then to Fd, then to cytochrome complex, then makes ATP as it goes down to PC and back to I
        - Both chloroplasts and mitochondria use chemiosmosis to generate ATP
        - In both, the electron is passed to increasingly electronegative molecules to make an H+ gradient
            - In CR, H+ is concentrated in intermembrane space, in P, it's in thylakoid space
        - Both have similar ATP synthase, but they get energy for it from different sources
        - Change in pH can be a thousandfold difference in H+ concentrations across a membrane
    - The Calvin cycle uses ATP and NADPH to convert CO_2 to sugar: a closer look
        - Similar to Krebs cycle in that beginning reactant is regenerated at end
        - Carb produced is not glucose, but a 3 C carb called G3P
            - 3 CO_2 molecules must be fixed
        - First step is each CO_2 is fixed to a 5 C sugar
            - Catalyzed by rubisco - most common protein in plants and probably on earth
        - Molecules split to form 6 3C sugars, these are phosphorylated and reduced for more energy
        - One sugar leaves as output
        - Rest of the sugars rearrange to form 3 5C sugars again with help of ATP
        - To make 1 G3P, 9 molecules of ATP and 6 molecules of NADPH are used
            - G3P can be used in other metabolic pathways, including making glucose
    - Alternative methods of carbon fixation have evolved in hot, arid climates
        - When stomata open to exchange gases, water is lost, so many plants close stomata on hot, dry days, causing photorespiration
        - C3 plants are normal in that the first organic product of carbon fixation is a 3 carbon compound
        - Unfortunately, rubisco can accept O_2 instead of CO_2 when the O_2 concentration is too high.
            - Photorespiration, when the above happens and no ATP or organic products are produced, rather they are taken up
            - Evolutionary baggage, happens because in the ancient atmosphere, there was so little oxygen, photorespiration wasn't a problem
        - Avoided by C4 and CAM plants
        - C4 plants fixate carbon onto a 4 C compound where the enzyme has less affinity for O
            - Sugarcane, corn, grass family
            - Bundle-sheath cells - form a tight sheath around the veins
            - Carbon is incorporated to form PEP (with high affinity to CO_2) in mesophyll cells
            - PEP turns into malate and travels down to bundle-sheath cell to drop off a CO_2
            - The CO_2 can join Calvin cycle in bundle-sheath cells as usual
            - In short, C4 cells pump enough CO_2 into the bundle-sheath cells to keep the rubisco there accepting CO_2 over O_2
        - CAM plants exchange gases at night and generate ATP and NADPH to fix them during day
            - Similar to C4 cycle in which CO_2 is first fixed, then passed on to the Calvin cycle
                - In C4, steps are structurally separated, in CAM, they are separated by time
        - Photosynthesis is the biosphere's metabolic foundation: a review
            - Non photosynthetic cells depend on organic molecules shipped out from leaves

- Chapter 11: Cell Communication
    - An Overview of Cell Signaling
        - Cell signaling evolved early in the history of life
            - A type of yeast cell has two mating types, a and alpha
            - Two cells grow towards each other when their receptors bind to factors of the other type that bind to them

- Signal-transduction pathway - process by which a signal on a cell's surface is converted into a specific cellular response
  - Molecular details are very similar, even between yeasts and animal cells
  - Suggests that the process evolved much before the first multicellular life appeared
- Communicating cells may be close together or far apart
  - Local regulator - influences cells in the vicinity
    - Paracrine signaling - secretor discharges regulator into extracellular fluid
    - Synaptic signaling - nerve cell releases neurotransmitter molecules into a synapse
    - Helps signals travel fast
  - Hormones - chemicals for long-distance signaling
  - Hormonal signaling (endocrine signaling) - endocrine cells release hormone molecules into circulatory vessels
  - Cells can also communicate through direct contact
    - Cell junctions
    - Surface molecules
- The three stages of cell signaling are reception, transduction, and response
  - Sutherland's experiment - some hormones (epinephrine) have to attach to cell surface and initiate pathway (could not break down glycogen when isolated with it in a test tube)
  - Reception - target cell's detection of a signal coming from outside cell; signal binds to cellular protein, usually on cell surface
  - Transduction - binding of signal molecule changes the receptor protein, initiating transduction of the signal to a form that can bring about a specific cellular response
    - Often happens with a series of changes in different molecules, a signal transduction pathway
  - Response - transduced signal triggers a specific cellular response

- Signal Reception and the Initiation of Transduction
  - A signal molecule binds to a receptor protein, causing the protein to change shape
    - Ligand - a small molecule that specifically binds to a larger one
    - Binds like a key in a lock and makes the protein undergo a change in conformation
  - Most signal receptors are plasma membrane proteins
    - G-protein-linked receptor - plasma membrane receptor that works with the help of a G protein
      - 7 alpha helices spanning the membrane
      - G protein - loosely attached to cytoplasmic side of the membrane; a switch that is on or off depending on whether GDP (inactive) or GTP (active) is bound
      - 1: Ligand bonds to receptor and activates it, causing it to bind to an inactive G protein
      - 2: GTP replaces GDP and activates G protein
      - 3: G protein then binds to another protein, usually an enzyme, and alters its activity
      - 4: Enzyme triggers next step and G protein hydrolyzes its bound GTP to GDP
      - G protein receptors are extremely widespread, many diseases just mess with it
    - Tyrosine kinase receptor - generally used for growth factors - enzyme that catalyzes the transfer of phosphate groups from ATP to the amino acid tyrosine
      - Before ligand binds, the receptor proteins are inactive and separated
      - 1: Ligand binding causes two receptor polypeptides to join, forming a dimer
      - 2: This activates tyrosine-kinase parts of both polypeptides, each of which adds phosphates to the tyrosines on the tail of the other one
      - 3: Activated receptor molecule is recognized by relay proteins in cell, each of which binds to a specific phosphorylated tyrosine and is activated (so multiple proteins can be activated)
      - 4: All of the relay proteins trigger many different signal-transduction pathways
      - Some kinds of cancer are caused by tyrosine-kinase receptors joining without ligand
    - Ligand-gated ion channels - channels for a specific ion that open or close in response to a

ligand
            - Ligand binds on the extracellular side
            - Important to nervous system
        - Some molecules are hydrophobic enough to diffuse across the membrane to activate receptors within the cells
            - Steroid hormones, thyroid hormones, NO (gas)
        - Activated hormone receptor proteins turn on genes by acting as transcription factors
- Signal-Transduction Pathways
    - Pathways relay signals from receptors to cellular responses
        - Signal activated receptor activates a protein, which activates another molecule, etc.
        - Original signal molecule isn't relayed, just the information it carried
    - Protein phosphorylation, a common mode of regulation in cells, is a major mechanism of signal transduction
        - Protein kinase - an enzyme that transfers a phosphate from ATP to another protein
        - Most act on other proteins, phosphorylating either serine or threonine (amino acids)
        - Most of the relay molecules in signal transduction are protein kinases and they act on each other
        - Protein phosphatases - remove phosphates to terminate signal
    - Certain small molecules and ions are key components of signaling pathways
        - Second messengers - small, nonprotein, water-soluble molecules or ions
        - Cyclic AMP - second messenger made from ATP
            - Adenylyl cyclase - enzyme built into the plasma membrane that converts ATP into cAMP in response to an external signal
            - When signal is gone, the cAMP is quickly made by another enzyme into AMP
            - Pathways with cAMP include G proteins, G-protein-linked receptors, and protein kinases
            - Other G-protein systems inhibit adenylyl cyclase
            - Many diseases interrupt with production and destruction of cAMP
        - Ca2+ is even more widely used than cAMP as a second messenger
            - In animal cells, used in muscle cell contraction, secretion of certain substances, and cell division
            - In plant cells, used in pathways for coping with environmental stress, like drought or cold
            - Can function because generally cytosolic concentrations of Ca are much lower than those in the environment
            - This happens when ER pumps in Ca, making ER lumen very concentrated
            - Signal transduction pathways open the channels that allow Ca back into the cytosol
            - Pathways to open Ca channels involve other second messengers (DAG and IP3)
            - Although Ca could be called a third messenger, it and other "third messengers" are collectively called second messengers
            - Calmodulin - protein that binds Ca to mediate Ca-regulated processes
- Cellular Responses to Signals
    - In response to a signal, a cell may regulate activities in the cytoplasm or transcription in the nucleus
        - In cytoplasm, signals generally cause opening or closing of ion channels or changes in cell metabolism
        - Others influence gene expression
    - Elaborate pathways amplify and specify the cell's response to signals
        - Signal amplification - at each step in the cascade, the number of activated product molecules is much higher than in the step before it
            - Happens because each protein stays active for long enough to process numerous molecules of substrate before they inactivate
        - Different cells have different proteins so the same signal can cause different responses to the

same signal
- Different pathways may have some matching molecules, but the overall pathway is different
  - Branched pathways and interaction between pathways
- Scaffolding protein - holds together many different molecules (steps of the pathway) to increase efficiency

- Chapter 12: The Cell Cycle
  - The Key Roles of Cell Division
    - Cell division functions in reproduction, growth, and repair
      - When unicellular organisms divide, they make a new organisms
      - Division allows multicellular sexually reproducing organisms to develop from a zygote
      - Cells that die can be replaced by division
      - Division is complex because genetic material must also be copied in addition to organelles
    - Cell division distributes identical sets of chromosomes to daughter cells
      - Genome - a cell's DNA genetic information
      - Typical human cell has 3 m of DNA
      - Chromosomes - structures DNA is packaged into
        - Each chromosome is 1 long molecule
        - Chromatin - all of the uncoiled chromosomes with their associated proteins
        - Sister chromatids - each identical half of a duplicated chromosome
        - Centromere - "waist" region where chromatids are held together
      - Somatic cells - all cells except sex cells
      - Gametes - sex cells, have half as many chromosomes as somatic cells
      - Mitosis - division of nucleus
      - Cytokinesis - division of cytoplasm (immediately after mitosis)
      - Number of chromosomes changes throughout cell cycle
        - Start with 23 from each parent, added to 46
        - Meiosis - variation of cell division that makes gametes
        - Gametes have 23 again
  - The Mitotic Cell Cycle
    - The mitotic phase alternates with interphase in the cell cycle: an overview
      - Interphase - 90% of cycle, cell grows and copies chromosomes
        - G1 phase - cell grows
        - S phase - cell copies chromosomes
        - G2 phase 0 cell keeps growing and prepares for M phase
      - M phase - includes mitosis and cytokinesis, shortest part of cell cycle
        - Prophase - chromatin fibers coil up, nucleoli disappear, mitotic spindle begins to form (microtubules from centrosomes), centrosomes move away from each other
        - Prometaphase - Nuclear envelope fragments - mitotic spindle goes through nuclear area, chromosomes are finished condensing, spindles attach to kinetochore region in centromere, chromosomes begin to move to center.
        - Metaphase - chromosomes are convened on metaphase plate, spindle spans cell and is connected to kinetochores of every chromosome
        - Anaphase - chromatids separate and are pulled apart by spindle fibers
        - Telophase/cytokinesis - non kinetochore fibers lengthen cell and daughter nuclei form at the two poles, nuclear envelopes begin to form around unwinding chromatin, cleavage furrow pinches cell in two.
    - The mitotic spindle distributes chromosomes to daughter cells: a closer look
      - Mitotic spindle - arrangement of microtubules and associated proteins that forms during prophase to elongate cell and pull chromatids apart
      - Centrosome - non membranous organelle that organizes the cell's microtubules
        - Not necessary, plants don't have it and animal cells divide normally even if its

destroyed by a laser

- Kinetochore - a structure of proteins and specific sections of chromosomal DNA at the centromere
  - The two kinetochores face opposite directions
  - Soon as spindle fibers attach to one kinetochore, the chromosome starts being tugged in, until another spindle fiber attaches to the other kinetochore and they have a tug of war that ends in a draw at metaphase
  - Kinetochore eats up microtubule and pulls along chromosome pacman style
  - Non kinetochore microtubules slide past each other like with flagellum to lengthen cell

- Cytokinesis divides the cytoplasm: a closer look
  - Cleavage furrow - a shallow groove in the cell that eventually pinches it in two (animal cells)
    - Formed by contractile ring of microfilaments and actin and myosin
  - Cell plate - divides cells by forming a cell wall between them by joining vesicles with cell wall material in them (plant cells)
- Mitosis in eukaryotes might have evolved from binary fission in bacteria
  - Binary fission - single, circular DNA molecule that prokaryotes carry genetic information on divides, then new membrane grows to elongate cell and it pinches off
    - Origin of replication - place where division of DNA starts
    - How bacterial chromosomes move is still a mystery
  - There are many living intermediates between prokaryote and eukaryote cell division
    - Prokaryotes - DNA divides and just moves apart somehow
    - Dinoflagellates - microtubules go through intact nuclear envelope
    - Diatoms - whole pulling apart happens within nucleus
    - Most eukaryotes - nuclear envelope degrades

- Regulation of the Cell Cycle
  - A molecular control system drives the cell cycle
    - Driven by specific chemical signals present in the cytoplasm
      - Experiment joined M phase cell with G1 phase cell, G1 cell went into M phase even though its genome was unduplicated
    - Cell cycle control system - a cyclically operating set of molecules in the cell that both triggers and coordinates key events in the cell cycle
    - Checkpoint - a critical control point where stop and go-ahead signals regulate the cycle
      - Signals check of crucial cellular processes have been completed correctly
      - 3 major checkpoints are in G1, G2, and M
      - G1 checkpoint - "restriction point" after which cell division will be completed, most important checkpoint
      - G0 phase - non dividing state cells go into if they fail G1 checkpoint
      - Cells can be called back to cycle by environmental cues
    - Cyclin - protein with a cyclically fluctuating concentration that binds to kinases
    - Cyclin-dependent kinases - activity rises and falls with concentration of cyclin partner
    - Cyclin + Cdk = MPF (think M-phase promoting factor)
    - MPF acts both directly and indirectly in many different pathways
    - Switches itself off later in the M phase by destroying its cyclin to go past M phase checkpoint
  - Internal and external cues help regulate the cell cycle
    - Internal signals: messages from the kinetochores
      - At anaphase, the checkpoint cannot be passed unless all of the chromosomes line up to prevent missing or extra chromosomes in the daughter cells
      - When chromosomes are lined up, "wait" signal ceases and M phase continues
    - External signals: growth factors
      - Growth factor - a protein released by certain body cells that stimulates other cells to

            divide
        - PDGF is required for the division of fibroblasts (type of connective tissue) in culture and helps proliferate fibroblasts to heal wounds
            - Binds to tyrosine-kinase receptors
        - Density-dependent inhibition - crowded cells stop dividing
        - Anchorage dependence - cells must be attached to ECM or inside of a culture jar to divide
    - Cancer cells have escaped from cell cycle controls
        - Cancer cells don't respond normally to the body's control mechanisms
        - Do not display density-dependent inhibition or anchorage dependence
        - Can make their own growth factors or have abnormal cell cycle controls that don't need them
        - When they do stop dividing, it is at random points in the cycle instead of at normal checkpoints
        - In culture, they can divide forever if given nutrients and can be said to be "immortal"
        - Transformation - when a single cell in a tissue becomes a cancer cell, starts cancer
        - Tumor - if the cell escapes destruction, it proliferates into a mass of abnormal cells
        - Benign tumors - don't cause problems and can be surgically removed
        - Malignant tumors - invasive and impair function of one or more organs
            - An individual with a malignant tumor has cancer
            - Cells in this may have unusual number of chromosomes, deranged metabolisms, and no attachment to ECM
            - Metastasis - separating from the tumor and spreading through the blood or lymph

- Chapter 13: Meiosis and Sexual Life Cycles
    - An Intro to Heredity
        - Offspring acquire genes from parents by inheriting chromosomes
            - Genes - hereditary units that pass coded info to offspring
            - Language formed by the different nucleotides
            - Most genes program proteins that determine the organism's inherited traits
            - Except for some DNA in mitochondria and chloroplasts, DNA is subdivided into a certain number of chromosomes within the nucleus
            - Lucus - a gene's specific location along the length of the chromosome
        - Like begets like, more or less: a comparison of asexual and sexual reproduction
            - Asexual reproduction - single individual is sole parent and passes copies of all of its genes to its offspring to create an genetically identical clone
            - Sexual reproduction - two parents give rise to offspring that have unique combinations of genes inherited from both parents
                - There is family resemblance, but each offspring is unique
    - The Role of Meiosis in Sexual Life Cycles
            - Life cycle - the generation to generation sequence of states in the reproductive history of an organism, from conception to production of its own offspring
        - Fertilization and meiosis alternate in sexual life cycles
            - Human life cycle as an example
                - Somatic cell - non gamete, has 46 chromosomes
                - Karyotype - display of all of the chromosomes aligned in decreasing size order
                - Homologous chromosomes - pair of chromosomes that have the same length, centromere position, and staining pattern (each carries a different copy of the gene)
                    - All genes have a copy (maybe for a different version of the trait) on the homologous chromosome
                - Sex chromosomes - determine sex, only small parts of the X chromosome are homologous to the tiny Y chromosome
                - Autosomes - non sex chromosomes

        - The reason we have two copies of each gene is there is one from each parent
        - Gametes - reproductive cells with only one copy of each chromosome (and of each gene)
            - Called a haploid cell (has 23 chromosomes in humans)
        - Fertilization (syngamy) - joining of haploid sperm from father and haploid ovum from mother
        - Zygote - resulting fertilized egg, 1 diploid cell
        - As zygote divides by mitosis, the diploid set of genes is accurately passed on to all of the cells
        - Meiosis - cell division that makes 4 cells and reduces diploid cell to haploid cells
        - Human cycle is typical of most animals
    - Plants, algae, and fungi have different life cycles distinguished by the amount of time the organism spends in the haploid vs diploid stage
        - Fungi and some protists - haploid multicellular organism makes gametes by mitosis, they come together by fertilization to make zygote, zygote undergoes meiosis while still a single cell, these cells form new multicellular haploid organisms
            - Remember, only diploid stage is single cell zygote
            - Remember location of fertilization and meiosis
        - Alternation of generations - used by plants and some algae, includes both haploid and diploid multicellular stages
            - Sporophyte - multicellular diploid stage, makes haploid spores by meiosis
            - Gametophyte - multicellular haploid stage, arises by mitosis of spores, produces gametes by mitosis, which join into a zygote which grows into the sporophyte
- Meiosis reduces chromosome number from diploid to haploid: a close look
    - Meiosis I - first half of meiosis, separates homologous chromosomes, produces two haploid cells with unique and replicated chromosomes
        - Prophase I - synapsis connects pairs of chromosomes into tetrads with crossings called chiasmata, chromosomes trade segments here
            - Rest is same as mitosis
        - Metaphase I - Same as mitosis, but the chromosomes arrange as homologous pairs
        - Anaphase I - Homologous chromosomes separate
        - Telophase I/cytokinesis - Cells separate and may reform nuclear envelope, but there is no DNA replication
    - Meiosis II - essentially haploid mitosis (review mitosis if needed)
    - Chiasmata are a physical manifestation of crossing over

- Origins of Genetic Variation
    - Sexual life cycles produce genetic variation among offspring
        - Independent assortment - in anaphase I, for each homologous pair, the chance of a chromosome from a certain parent going to a certain cell is 50-50, independent of how other pairs assort
            - Gives 2^n possibilities, where n is the haploid number of chromosomes
        - Crossing over - produces recombinant chromosomes, each having genetic material from both the mother and father
            - Occurs in prophase I
            - Since the sister chromatids in metaphase II are no longer identical, they can be oriented either way and add more possibilities
        - Random fertilization - the number of possibilities of a gamete can be squared because any of one parent's gametes can meet with any of the other parent's
    - Evolutionary adaptation depends on a population's genetic variation
        - Variation allows individuals with a favorable combination of genes to survive and pass them on

        - Sexual reproduction helps in adaptation by providing variety in offspring

- Chapter 14: Mendel and the Gene Idea
    - Gregor Mendel's Discoveries
        - Mendel brought an experimental and quantitative approach to genetics
            - Used experiments with garden peas
            - Character - a heritable feature such as flower color
            - Trait - a variant of a character, such as purple flowers
            - True-breeding - when the plants self pollinate, the offspring are all of the same variety; Mendel used varieties like this
            - Hybridization - crossing of two true breeding varieties
            - P generation - the original true breeding plants
            - F1 generation - the offspring of the P generation
            - F2 generation - offspring resulting from allowing F1 generation to breed, important in Mendel's insights
        - By the law of segregation, the two alleles for a character are packaged into separate gametes
            - Alternative versions of genes account for variation in inherited characters
                - Alleles - alternative versions of a gene
            - For each character, an organism inherits two alleles, one from each parent
                - Homologous chromosomes have one allele on each chromosome
            - If the two alleles differ, then one, the dominant allele, is fully expressed; the other, the recessive allele, has no noticeable effect on the organism's appearance
            - The two alleles for each character segregate during gamete production
                - Each gamete only gets one of the alleles so they can combine with other gametes for a unique combination
            - Law of segregation - gametes have an equal chance of having each of the alleles, but only get one
            - Punnett square - used to predict genotypes and phenotypes of offspring of parents with a known genotype
            - Homozygous - has two identical alleles for the gene
            - Heterozygous - has two different alleles, not true-breeding
            - Phenotype - organism's traits
            - Genotype - organism's genetic makeup
            - Testcross - if the genotype of an organism displaying the dominant phenotype is unknown, it can be crossed with a homozygous recessive individual. If the offspring are all dominant, the organism was homozygous, if the offspring are half dominant and half recessive, the organism was heterozygous
        - By the law of independent assortment, each pair of alleles segregates into gametes independently
            - Monohybrids - F1 hybrids produced where only a single character was followed
            - Dihybrids - heterozygous for two characters
                - These assort independently, giving 9:3:3:1 ratio in F2 generation
            - Law of independent assortment - segregation of each pair of alleles during gamete formation happens independently
        - Mendelian inheritance reflects rules of probability
            - Multiplication - for two individual events to both happen, multiply probability
            - Addition - if an event can happen in multiple ways, add up the probabilities of each way
    - Extending Mendelian Genetics
        - The relationship between genotype and phenotype is rarely simple
            - Mendel was lucky in picking plant traits that followed simple rules, most don't
            - Incomplete dominance - heterozygote is a blend of both homozygote traits
                - P: Red and White, F2: 1 Red, 2 Pink, 1 White
            - Complete dominance - Mendel's situation, heterozygote phenotype = homozygous dominant

phenotype
- Codominance - both alleles affect the phenotype in separate, distinguishable ways
    - Blood groups - I gives nothing, Ia gives a antigens, and Ib gives b antigens
- Many traits are somewhere on the scale from complete to codominance
- Dominant alleles don't subdue recessive alleles
    - Ex: In Tay-Sachs disease, only homozygous recessive individuals have the disease because having one copy of the allele produces enough of the required enzyme to have the same effect as dominant
- Dominant alleles aren't always the most common
    - Ex: allele for extra fingers or toes is dominant, but is still rare
- Multiple alleles - many genes have more than 2 possible alleles
    - Blood groups have I, Ia, and Ib, even though only 2 of them are in an individual
- Pleiotropy - gene affects multiple phenotypic traits
- Epistasis - The expression of one gene can affect the expression of another
    - A dog can be brown or black from one gene, and a second gene determines if it's white. If the second gene happens to be expressed, it doesn't matter if the first gene specified black or brown, the dog will be white
    - Produces 9:3:4 ratio
- Polygenic inheritance - vary among a population along a continuum, caused by multiple genes
    - Quantitative characters - affected by polygenic inheritance, individuals roughly follow a normal distribution curve
    - Environmental factors can make the graph a smooth curve by slightly changing phenotypes
- Norm of reaction - range of phenotypes that can result from a given genotype
    - Phenotypes can be vastly changed by nurture
    - Nature and nurture can have varying influences between different traits
    - Broadest for polygenic traits
    - Multifactorial traits - affected by many traits both genetic and environmental

- Mendelian Inheritance in Humans
    - Generation time is long and relatively few offspring are produced so Mendel style analysis is difficult in people
    - Pedigree analysis reveals Mendelian patterns in human inheritance
        - Pedigree - a family tree showing gender, relations, and presence of a certain phenotype
            - Can help us predict future offspring by determining genotypes of potential parents
    - Many human disorders follow Mendelian patterns of inheritance
        - Recessively inherited disorders
            - Albinism, cystic fibrosis, Tay-Sachs disease, sickle-cell disease
            - Carriers - heterozygotes who perpetuate the allele without having the disease
                - Sickle cell carriers have slight harmful effects, but gain the benefit of being malaria resistant, so the sickle-cell allele is much more common in Africans than other races
            - Inbreeding is dangerous because both could be carriers of a dangerous allele and could both pass it to their offspring
        - Dominantly inherited disorders
            - Dwarfism, Huntington's disease, extra fingers and toes
            - Can only be perpetuated when they still allow reproduction because even heterozygotes have the disease
        - Multifactorial diseases - also known as lifestyle diseases, include heart disease, diabetes, alcoholism, etc
            - Genetics can give a predisposition for the disease, but they don't usually cause it
    - Technology is providing new tools for genetic testing and counseling
        - With pedigree analysis scientists can determine the probability that a couple will have a child

with a dangerous sickness, allowing the couple to choose if they want to have a child
- Chemical tests can determine if people are carriers of recessive disorders to also provide probabilities of a child having a dangerous disease
- Amniocentesis - tests beginning in 14th to 16th week of pregnancy that can determine if the fetus has a disease such as Tay-Sachs disease by extracting amniotic fluid and culturing fetal cells sloughed off
- Chorionic villus sampling - fetal tissue from the placenta is suctioned out
  - Better than amniocentesis because amniotic fluid cells require weeks for culturing, while placenta cells are already dividing rapidly enough, karyotyping can be carried out immediately, bring results within 24 hours
  - Also can be performed in 8th to 10th week of pregnancy
  - Less widely available
- Ultrasound - using sound waves to produce an image of the fetus in a noninvasive procedure
- Fetoscopy - a needle thin tube containing a viewing scope and fiber optics is inserted into the uterus
- Some genetic disorders can be detected at birth by simple screening tests that are now routine
- With all, there is the ethical question of if the parents want to know or not
  - If the fetus does have a dangerous sickness, do they want to have a diseased child, or abort it?

- Chapter 15: The Chromosomal Basis of Inheritance
  - Relating Mendelism to Chromosomes
    - Mendelian inheritance has its physical basis in the behavior of chromosomes during sexual life cycles
      - Chromosome theory of inheritance - Mendelian genes have specific loci on chromosomes and the chromosomes undergo segregation and independent assortment
    - Morgan traced a gene to a specific chromosome
      - Used fruit flies for genetic studies because it has a short generation time, isn't harmful, makes hundreds of offspring, only has 4 chromosomes, can be kept in a small space
      - Wild type - natural phenotype
      - Sex-linked genes - genes located on a sex chromosome
        - Generally located on nonhomologous part of X chromosome so males have much higher chance of having the trait
      - Linked genes tend to be inherited together because they are located on the same chromosome
        - With a cross between a heterozygous double wild type and a homozygous double mutant (two traits), there are more offspring that have the same double wild type and double mutant than mixed of one mutant one wild type
        - This happens because the genes are on the same chromosome so they are inherited together unless separated by crossing over
    - Independent assortment of chromosomes and crossing over produces genetic recombinations
      - Genetic recombination - production of offspring with new combinations of traits inherited from two parents
      - Independent assortment recombines unlinked genes
        - Parental types - offspring with the same combination of (usually two) traits as the parent
        - Recombinants - offspring with different combinations of traits
        - For unlinked genes, frequency of recombination is 50%
      - Crossing over recombines linked genes
        - During crossing over, part of a chromosome might switch with part of another chromosome and separate two genes
    - Geneticists can use recombination data to map a chromosome's genetic loci
      - Genetic map - an ordered list of the genetic loci along a particular chromosome
      - Higher recombination frequencies between linked genes result from the physical distance

between the genes on the chromosome because there's more of a chance that the place where the chromosome crosses over is between the genes
- Linkage map - a genetic map based on recombination frequencies
- Map unit - unit of distance between chromosomes, equal to 1% recombination frequency
- If genes are more than 50 map units apart, they are almost certain to cross over and are treated as unlinked
  - When the distance is far, but not enough to "unlink" the genes, the recombination frequency actually decreases because of the probability of two crossing over's occurring and canceling the recombination
  - Things like this create multiple numerical discrepancies so the positions on a linkage map are relative
  - Cytological map - shows genes with respect to chromosomal features, such as stained bands, shares sequence with linkage map, but not spacing

- Sex Chromosomes
  - The chromosomal basis of sex varies with the organism
    - For humans, a male develops from an X and a Y chromosome and a female develops from two X chromosomes
      - The X and Y chromosomes in males behave like homologous chromosomes even though they are only partially homologous and very little crossing over occurs between them
    - When the embryo is less than two months old, no anatomical signs of sex of emerged
      - SRY - gene in the Y chromosome responsible for the development of testes
  - Sex-linked genes have unique patterns of inheritance
    - Punnett squares can be created like with Mendelian genes, except the mother contributes two alleles that could contribute to the trait (X+ or X) and the father only one (his other row just has a Y chromosome)
      - Therefore, fathers pass sex-linked alleles to all of their daughters and none of their sons, while mothers pass them to all offspring
    - If the trait is due to a recessive allele, then females will only express it if they are a homozygote, while males will express it as long as they receive a recessive allele from their mother (with only one X chromosome, males cannot be referred to as homozygous or heterozygous with sex-linked genes)
      - This makes sex-linked conditions much more common in males than females because males only have to receive a recessive allele from the mother while the female has to receive from the mother and a father with the condition
    - Duchenne muscular dystrophy, hemophilia (common in many royal families)
    - Barr body - inactivated second X chromosome in each female cell, either chromosome can be inactivated in any of the cells
      - Females are a mosaic of cells expressing different X genes
      - Usually, the different genes "average out"
      - Provide mottled black and orange in tortoiseshell cats
      - Inactivation caused by attachment of methyl group (-CH3) group to cytosine
      - Methylation stimulated by XIST gene being present
- Errors and Exceptions in Chromosomal Inheritance
  - Alterations of chromosome number or structure cause some genetic disorders
    - Nondisjunctions - either homologous chromosomes fail to separate during meiosis I or chromatids fail to separated during meiosis II
    - Aneuploidy - an abnormal chromosome formed when at least one of the gametes has had nondisjunction
      - Symptoms magnify as aneuploidy is present in all body cells
    - \Trisomic - having three copies of a chromosome instead of 2 (total of 2n+1 chromosomes)
      - Trisomy 21 is what causes Down's syndrome

        - Monosomic - having only one copy of a chromosome (total of 2n-1 chromosomes)
        - Polyploidy - having more than 2 complete sets of chromosomes (3n or 4n chromosomes)
            - Triploidy can be caused when a normal sperm fertilizes an abnormal diploid egg formed by full nondisjunction
            - Tetraploidy can be caused when the first division of the zygote only replicates genes, doesn't actually divide cell
            - Very common in plant kingdom and evolution of plants
            - Rare in animal kingdom, only sometimes in fish and amphibians
            - Makes less of a difference than aneuploidy
        - Deletion - a chromosomal fragment lacking a centromere is lost during cell division
            - Usually lethal
        - Duplication - when the missing fragment is attached as an extra segment on a sister chromatid
            - Harmful effects, but not as bad as deletion
        - Inversion - fragment re-attaches to original chromosome, but the wrong way
        - Translocation - fragment joins nonhomologous chromosome
            - Along with inversion, usually not too bad because the genes are still present in the right quanitites
        - Usually aneuploidy is serious enough for spontaneous abortion of the embryo
            - When it's not as serious, the embryo survives, but has a disease such as Down's syndrome (trisomy 21)
            - Klinefelter syndrome - extra X in males
                - Extra Y just makes them taller than average
                - Trisomy X (females) is also harmless
            - Turner syndrome - Only 1 X in females
            - Cri du chat, CML
    - The phenotypic effects of some mammalian genes depend on whether they were inherited from the mother or the father (imprinting)
        - Genomic imprinting - some genes are silenced by addition of a methyl group to cytosine based on whether they are from the mother or father
            - Different effects based on parent
    - Extranuclear genes exhibit a non-Mendelian pattern of inheritance
        - Extranuclear DNA is found in mitochondria and plant plastids (including chloroplasts)
            - Both mitochondria and chloroplasts reproduce themselves and transfer genes to daughter organelles and cells when the cell divides and splits the organelles
        - Mitochondrial genes are inherited only by the mother
            - Throughout our lives, mutations gradually accumulate in our mitochondrial DNA, believed to contribute to natural aging process

- Chapter 16: The Molecular Basis of Inheritance
    - DNA as the Genetic Molecule
        - The search for genetic material lead to DNA
            - People first thought proteins were the genetic material because of their diversity
            - Transformation - change in genotype and phenotype due to the assimilation of external DNA into a cell
            - Bacteriophages (phages) - viruses that infect bacteria
            - Nucleic acids discovered to be genetic material by experiment where they radioactively marked the proteins and nucleic acids in bacteria to see which stayed in the cell
            - Chargaff's rules - A=T and C=G
        - Watson and Crick discovered the double helix by building models to conform to X-ray data
            - Double helix - twisted ladder shape of DNA, rungs are paired nitrogenous bases while the sides are alternating phosphate groups and pentose sugars
            - Purines - A and G, about twice as wide as pyrimidines

        - Pyrimidines - T and C, contain only 1 ring unlike purines, which have 2
- DNA Replication and Repair
    - During DNA replication, base pairing enables existing DNA strands to serve as templates for new complementary strands
        - In replication, the strands split and new nucleotides are attached to each in the way described by Chargaff's rules
        - Semiconservative model - each new DNA molecule has one of the old strands and one new strand
            - Contrast to conservative model, where one molecule has both old strands and dispersive model where all four strands have old and new pieces
    - A large team of enzymes and other proteins carries out DNA replication
        - Origin of replication - places where the strands split and new DNA is deposited on either side; prokaryotes have 1 and eukaryotes have hundreds
            - Speed up replication in Eu's by allowing replication to happen in many places at once
            - Bubbles grow and eventually fuse, separating the two new DNA molecules
        - Replication fork - edge of a bubble
        - DNA polymerases - catalyze elongation of a new DNA strand at a replication fork
            - Triphosphate monomers (like ATP, but with deoxyribose instead of ribose) join onto the growing strand and lose two of their phosphates
        - The two DNA strands are antiparallel - the structure of the strands runs opposite on one side of the other
            - 3' ends with -OH attached to terminal deoxyribose
            - 5' ends with last phosphate attached to "bent" bond
        - DNA polymerase can only attach nucleotides to the free 3' end of the growing DNA strand
            - Leading strand - the strand on one side of the replication fork where the DNA polymerase can continuously add nucleotides
            - Lagging strand - the strand where the direction of replication is opposite of the direction DNA polymerase adds nucleotides
                - Okazaki fragments - DNA along the lagging strand is made in pieces
                - DNA ligase - enzyme that joins together Okazaki fragments
        - DNA polymerase can only add nucleotides onto growing strand, they can't initiate it
            - Primase - enzyme that makes an RNA primer (short segment)
            - A type of DNA polymerase later replaces the RNA in the primer with DNA
        - Helicase - unzips the two DNA strands
        - Single-strand binding protein - lines up along the unpaired DNA strands and holds them apart while the new strands are being added
        - Most likely model is that the enzymes stay as a stationary complex that "reels" in parent DNA and "spits" out two daughter strands
    - Enzymes proofread DNA during its replication and repair damage in existing DNA
        - While errors in completed DNA molecules happen about once per billion base pairs, initial replication has an error rate of 1 per ten thousand base pairs
        - DNA polymerase itself proofreads as it's adding (like using the delete key when typing)
        - Mismatch repair - cells use special enzymes to fix incorrectly paired nucleotides that escaped the DNA polymerase proofread
            - Some cancers are caused by this fixing not happening, which causes cancer causing mutations to accumulate in dividing cells
        - Reactive chemicals, radioactive emissions, X-rays, UV light, and spontaneous changes can change nucleotides
            - Because of these, DNA must be constantly monitored and repaired
            - Nuclease - cuts out damaged DNA, which is repaired with DNA polymerase and ligase (nucleotide excision repair)
            - UV light causes covalent linking of adjacent thymines, thymine dimers cause DNA to

buckle and disrupt replication
        - Fixed by nucleotide excision repair, individuals lacking enzymes to fix this are hypersensitive to light and get skin cancer easily
    - The ends of DNA molecules are replicated by a special mechanism
        - When DNA is replicated, the primer on the 5' end cannot be changed into DNA because the DNA polymerase doesn't have a DNA 3' to connect to, so that piece of DNA is lost
            - Telomeres - long, repetitive stretches of DNA at the ends of chromosomes to "weather the damage"; serve as an aging mechanism because cells can only divide so many times
            - Telomerase - an enzyme that restores telomeres and is present ONLY in cancerous cells

- Chapter 17: From Gene to Protein
    - The Connection Between Genes and Proteins
        - The study of metabolic defects provided evidence that genes specify proteins
            - One gene → one polypeptide (though proteins are more commonly referred to as the products of gene expression)
        - Transcription and translation are the two main processes linking gene to protein
            - RNA is chemically similar to DNA except it has ribose as a sugar, uracil instead of thymine, and is usually single stranded
            - Translation - synthesis of RNA under the direction of DNA
                - Makes messenger RNA (mRNA)
            - Translation - actual synthesis of a polypeptide, occurs under the direction of mRNA
            - In Pr cells, transcription and translation are coupled, so the mRNA could be running through a ribosome while it is still being transcribed
                - In Eu cells, the processes are separated across the nuclear envelope
            - RNA processing - yields finished mRNA from pre-mRNA made from transcription
            - Primary transcript - more general term for initial RNA transcript
        - In the genetic code, nucleotide triplets specify amino acids
            - Triplet code - each three bases specify an amino acid
                - Codon - mRNA base triplet
                - Codons are read in the 5' → 3' direction along the mRNA
            - Template strand - the strand of DNA that is for ordering the sequence of nucleotides in an RNA transcript
                - RNA molecule is complementary, not identical to DNA template strand
            - When all of the 64 possible codons were discovered, there was redundancy (multiple codons differing in the last base coded for the same amino acid) and start/stop codons
            - Reading frame - making sure you have "the red dog saw the cat" instead of "her ed ogs awt hec at"
        - The genetic code must have evolved very early in the history of life
            - Code is nearly universal, genes can be transcribed and translated after being moved to a different species
                - Bacteria can be made to produce human proteins
                - In some single cell organisms, translation of a few codons differ
    - The Synthesis and Processing of RNA
        - Transcription is the DNA-directed synthesis of RNA
            - RNA polymerase - pries the DNA strands apart and adds RNA nucleotides as they base pair along the DNA template
                - Can only add onto 3' of new nucleic acid
            - Promoter - the DNA sequence where RNA polymerase attaches and initiates transcription
            - Terminator - the sequence that signals the end of transcription
            - Direction of transcription is "downstream" (5' to 3'), other way is "upstream

- Transcription unit - the stretch of DNA that is transcribed into mRNA (doesn't include promoter or terminator)
- Promoter includes transcription start point as well as dozens of bases "upstream"
- Transcription factors - a collection of proteins that mediate the binding of RNA polymerase and the initiation of transcription
- Transcription initiation complex - all of the bound transcription factors with RNA polymerase
- TATA box - DNA promoter sequence that repeats "TATA" and is what is recognized by the first transcription factor of the transcription initiation complex
- RNA polymerase adds nucleotides onto 3' end and the DNA double helix reforms after the RNA polymerase passes
  - A single gene can be transcribed simultaneously by several molecules of RNA polymerase following each other like trucks in a convoy
  - The growing strands of mRNA from each indicate how far the enzyme has gone
  - This helps the cell make the encoded protein in large amounts
- RNA polymerase continues for 10-35 nucleotides past transcription signal (repeating AAUAAA) before pre-mRNA is cut free

■ Eukaryotic cells modify RNA after transcription
- 5' cap - modified guanine (3 phosphates), protects the mRNA from hydrolytic degradation, signals ribosomes to attach to it
- Poly (A) tail (3' end) - 50-250 adenines that inhibit degradation and may signal to ribosomes
- RNA splicing - cutting out large sections of the mRNA and pasting together what remains
  - Introns - intervening segments, cut out
  - Exons - expressed segments, pasted together
  - Terms used for both DNA and RNA
  - Small nuclear ribonucleoproteins (snRNP) - recognize the splicing sites, composed of proteins and snRNA
  - Spliceosome - complex of several snRNP's with other proteins
    - Almost as big as a ribosome, in nucleus, "edits" mRNA before it reaches the cytoplasm, cuts at specific points to release intron before immediately joining the exons together
- Ribozymes - RNA molecules that function as enzymes, encouraged idea of snRNP's playing a catalytic role in spliceosome assembly
  - Some introns are ribozymes that catalyze their own splicing
- Introns may play a hand in a variety of processes, such as regulation, control of gene activity, and the splicing process may aid in the passage of mRNA from nucleus to cytoplasm
- Alternative RNA splicing - using different segment as introns and exons to produce different polypeptides from the same gene
  - Allows humans to get by on relatively few genes (20,000) compared to other complex organsisms
- Domains - modular parts of a protein, each with its own function, each coded for by its own exon
- Introns also allow for crossing over on more non-coding sequence to move around genes without damaging their functions

■ Translationis the RNA-directed synthesis of a polypeptided
- Transfer RNA (tRNA) - interprets codons in mRNA by bringing the corresponding amino acids
  - Each tRNA has an anticodon (a nucleotide triplet complementary to its targeted codon) and carries its amino acid stocked from the cytoplasm
  - The genetic message is translated into a polypeptide as the tRNAs that bond to the specific codons bring their amino acids that attach to the polypeptide chain
  - Transcribed from the nucleus like mRNA and travels to cytoplasm
  - Each tRNA molecule picks up the amino acid, binds to the mRNA, and drops off the

amino acid multiple times
    - Consists of a single RNA strand about 80 nucleotides long that folds back on itself to have an amino acid binding site on one side and an anticodon on the other
    - Wobble - there are only 45 types of tRNA (instead of 61, 64 minus 3 stop codons) which is caused by the last base often having Inosine as the third base
    - Inosine can bond to U, C, or A, allowing for flexibility among tRNA molecules
  - Aminoacyl-tRNA synthetase - binds tRNA to its correct amino acid
    - There are 20 types of these enzymes in the cell, one for each amino acid
    - Catalytic process driven by ATP
  - Ribosomes - facilitate the specific coupling of tRNA anticodons to mRNA codons during protein synthesis
    - Constructed from proteins and ribosomal RNA (rRNA, made in nucleus)
    - Because of the large number of ribosomes, rRNA is the most abundant RNA in the cell
    - Ribosomes consist of a small subunit and a large subunit which only come together when they attach to mRNA
    - Has A site (incoming tRNA), P site (joining of the amino acid), and E site (exit site)
    - Ribosomes hold the tRNA and the mRNA together and position the amino acid for addition onto the polypeptide (catalyzed by ribosomes too)
  - Building a polypeptide consists of initiation, elongation, and termination, the first two being powered by GTP
  - Initiation brings together the first tRNA, the ribosomal subunits, the first amino acid, and the mRNA
    - First, the small subunit binds to the mRNA and to an initiator tRNA
    - Then GTP powers attachment of the large subunit to place the initiator tRNA in the P site and leaving the A site empty for additional binding
  - Elongation - incoming amino acids are added to the polypeptide chain
    - Codon recognition - incoming tRNA binds to the codon in the A site with help of 2 GTPs
    - Peptide bond formation - rRNA molecule in the large subunit catalyzes the movement of the polypeptide chain from the tRNA in the P site to the one in the A site
    - Translocation - the mRNA with the tRNAs and the polypeptide moves through the ribosome so what was in the A site is in the P site. The amino acid that was in the P site moves to the E site and leaves. This is helped by GTP and mRNA moves in 5' to 3' direction through ribosome
  - Termination - at stop codon, a release factor (protein) binds to the codon and adds a water molecule instead of an amino acid, causing the polypeptide to hydrolyze from the tRNA
    - The rest of the translation assembly comes apart
  - Polyribosomes - trails of ribosomes that all go down the same mRNA molecule in a row, allowing for mass production of a protein
  - As it forms, a protein spontaneously begins to fold and can be assisted by a chaperone protein
    - Then, stuff can be stuck on and the leading amino acid can be removed before proper folding
    - Also, the chain can be split, often allowing the separate chains to join for quaternary structure
- Signal peptides target some eukaryotic polypeptides to specific destinations in the cell
  - When a free ribosome starts making a polypeptide, the first few amino acids can make a signal peptide that is recognized by a signal-recognition particle (SRP) that brings the ribosome to a receptor protein in the ER membrane so the polypeptide is secreted into the ER
- RNA plays multiple roles in the cell
  - mRNA - carries information specifying amino acid sequence of proteins from DNA to

ribosomes
- tRNA - translates mRNA codons into amino acids
- rRNA - plays structural and catalytic roles in ribosomes
- Primary transcript - precursor to other types of RNA, may be spliced or split
- snRNA - plays structural and catalytic roles in spliceosomes
- SRP RNA - protein-RNA complex that recognizes signal peptides targeted to the ER

- Comparing protein synthesis in prokaryotes and eukaryotes
  - In pr cells, the transcription and translation are not separated by the nucleus so many RNA polymerases can be transcribing a cell while polyribosomes translate it along each strand
  - Segregation in eu cells allows for more regulation at steps
- Point mutations can affect protein structure and function
  - Mutations - changes in the genetic material of a cell
  - Point mutations - chemical changes in just one base pair
  - Substitution - switching of one base pair
    - Silent mutation - has no effect because of wobble
    - Missense mutation - function of protein is noticeably changed, whether for the better or worse
    - Nonsense mutation - mutation creates a stop codon so the protein isn't made
  - Insertions/deletions - additions or losses of one or more nucleotides
    - Frameshift mutation - changes reading frame and causes a ton of missense
    - Frameshift can also make a stop codon and make nonsense
    - Frameshift isn't caused if the number of nucleotides added or taken out is a multiple of 3
  - Mutagens - physical and chemical agents that interact with DNA to cause mutations
    - Radiation, base pair analogues (attach in DNA like a nucleotide, but don't pair right), and things that insert themselves into the DNA to distort the shape
  - Most mutagens are carcinogenic
- What is a gene?
  - A gene is a region of DNA whose final product is either a polypeptide or an RNA molecule

- Chapter 18: Microbial Models: The Genetics of Viruses and Bacteria
  - The Genetics of Viruses
    - A virus is a genome enclosed in a protective coat
      - The smallest viruses are smallest than a ribosomes
      - Viruses can crystallize, unlike cells
      - Viral genomes consist of a single linear or circular genome that consists of single or double stranded DNA or RNA
      - Capsid - protein shell that encloses the viral genome
        - Can be rod-shaped, polyhedral, or more complex
        - Made from protein subunits called capsomeres
      - Viral envelopes - membranes cloaking viral capsids
        - Made from host membrane with a few viral proteins and glycoproteins
      - Bacteriophages have the most complex capsids
    - Viruses can reproduce only within a host cell
      - Viruses lack ribosomes or any other protein making mechanisms, so they are just a packaged set of genes in transit from one host cell to another
      - Host range - the limited range of cells a certain virus can infect
        - Specified by "lock and key" receptors
        - Range varies from several eukaryotic species to a single bacterial species
        - Most Eu infecting viruses are tissue specific
      - Infection starts once the viral genome is in a cell
        - DNA viruses use cell's DNA polymerase

            - RNA viruses must make their own RNA polymerases that can use an RNA template
            - Assembly of capsid proteins and viral genomes into viruses is spontaneous
            - Cell is destroyed as hundreds of viruses burst out of it
- Phages reproduce using the lytic or lysogenic cycles
    - Lytic cycle - cycle that ends in death of host cell
        - Virulent phage - reproduces only by lytic cycle
        - Cycle can destroy an entire bacterial colony in just a few hours
        - Only reason bacteria aren't all wiped out is they adapt to have receptors not recognized by viruses (which causes the viruses to adapt to recognize the new receptors)
        - Also, viruses can be less destructive and enter the lysogenic cycle (helps them by preserving their host population)
    - Lysogenic cycle - replicates the phage genome without destroying the host
        - Temperate phages - can use both cycle types
        - In lysogenic cycle, the phage genome is incorporated into the host genome by recombination
        - Prophage - phage DNA added to host DNA, silenced
        - As the bacteria reproduces the prophage is spread
        - Radiation or certain chemicals can make the prophage exit the host genome and enter the lytic cycle
        - Some prophage genes are expressed during the lysogenic cycle and cause the symptoms of some diseases
- Animal viruses are diverse in their modes of infection and replication
    - Classified by type of nucleic acid in genome, presence of a membrane
    - Viral envelopes help allow viruses enter cells, are derived from host membranes, and allow some viruses to exit cell without lysing it
    - RNA can be either single or double stranded as a viral genome
        - For these viruses, a complimentary strand is made, which functions as the mRNA and the template for further replication
        - Retroviruses - use reverse transcriptase to make DNA from their RNA template, which integrates into the nucleus of the animal cell
            - Provirus - integrated retrovirus DNA
            - Unlike a prophage, a provirus never leaves, the host's cell mechanisms transcribe the virus DNA into mRNA which serves as the genome for new viruses and codes for the proteins for the viruses
            - Includes HIV, which causes AIDS
    - Viral disease is caused by viruses making lysosomes release hydrolytic enzymes, making the cell make toxins, and having toxins themselves in the envelope proteins
    - Vaccine - a harmless variant or derivative of the pathogen that can be used to prime the immune system in case the actual pathogen attacks
    - Curing viral diseases is much more difficult than bacterial diseases (antibiotics)
    - New viruses emerge from large number of mutations in RNA, spreading of viruses between species, transportation of viruses from small, isolated communities
    - Some viruses (retroviruses, adenoviruses, and herpesviruses) cause cancer
    - Oncogenes - viral genes that trigger cancerous characteristics in cells
        - Proto-oncogenes are found in normal cells and affect the cell cycles
        - Some cells just turn on or off certain proto-oncogenes more than they should be
- Plant viruses are serious agricultural pests
    - Horizontal transmission - plant is infected from an external source
        - Virus must get through epidermis, happens more under stressful conditions
    - Vertical transmission - inherited infection from a parent
- Viroids and Prions are infectious agents even simpler than viruses

        - Viroids - tiny molecules of naked circular RNA
            - Can disrupt plant metabolism and stunt plant growth
        - Prions - proteins that replicate by binding to healthy proteins and causing them to distort into a prion
            - Cause mad cow disease
            - Present in brain cells
    - Viruses may have evolved from other mobile genetic elements
        - Assumed to have arisen after cells from pieces of nucleic acid that could move between cells
        - Viral genomes have more in common with their host cells than with other viruses
        - Could have come from plasmids or transposons
            - Plasmids are small, circular DNA molecules separated in chromosomes; can replicate separately can move around and between cells
            - Transposons are DNA segments that move between locations of a cell's genome
- The Genetics of Bacteria
    - The short generation span of bacteria helps them adapt to changing environments
        - Nucleoid - densely packed region of one double stranded, circular DNA molecule
            - Not bound by membranes
        - Bacteria divide by binary fission and relatively quickly
        - With so much fast division, mutations arise quickly, allowing for easy adaption
    - Genetic recombination produces new bacterial strains
        - Transformation - alteration of the bacterial cell's genotype by the uptake of naked, foreign DNA from the surrounding environment
            - Ex: when heat killed, pathogenic bacteria are mixed with harmless, live bacteria, the live ones become pathogenic
            - Many bacteria have special proteins on their surface to aid in transformation
        - Transduction - phages carry bacterial genes from one host cell to another
            - Generalized transduction - occasionally, a bacterial DNA fragment is packaged into a phage capsid. The phage infects a host cell where crossing over combines the bacterial genomes (can send any genes)
            - Specialized transduction - prophage DNA exits taking some bacterial DNA with it. This infects another bacteria and gives it viral and bacterial DNA (also only sends certain genes, the ones by the prophage site)
        - Conjugation - direct transfer of genetic material between two bacterial cells that are temporarily joined (bacterial sex)
            - "Male" uses sex pili (appendages) to grip the "female" and pull the cells close enough for a cytoplasmic bridge to form
            - The "male" cell sends over DNA (one way transfer)
            - F factor (f for fertility) - plasmid of genes that allow a cell to become a "male"
        - Plasmid - a small, circular, self-replication DNA molecule separate from the bacterial chromosome
        - Episome - a genetic element that can exist either as a plasmid or as part of a chromosome
            - Temperate phages qualify as episomes
        - Plasmids are differentiated by viruses by a lack of a protein coat and a lack of extracellular activity
            - Have a small number of genes, all of which are not required for survival and reproduction of the bacteria under normal conditions
            - Can give bacteria advantages in stressed conditions
        - F plasmid - contains about 25 genes, most for making sex pili
            - F+ cell designates "male" cell, condition is heritable
            - F- cell is female, condition is also heritable, however the F factor is copied from the male cell to the female cell in conjugation, making both F+
            - Hfr cells have the F plasmid incorporated into their chromosomes. When they

conjugate with F- cells, the F factor starts to copy into the new cell, dragging a copy of the rest of the chromosome until the conjugation bridge breaks

- The new DNA recombines with the F- cell's original DNA

- R plasmid - store genes that destroy antibiotics (resistance)
  - Some R plasmids carry as many as 10 resistance genes, making them very adaptable
  - When one is treating an illness, the cells with the resistance genes survive and help others by spreading the gene with conjugation
- Transposon - transposable genetic element, a piece of DNA that can move from one location to another in a cell's genome
  - Unlike episomes or prophages, transposons can't exist independently.
  - Bring many resistance genes into a single R plasmid by moving the genes from different plasmids
  - Can "cut and paste" or "copy and paste"
  - What distinguishes transposons with other forms of genetic recombination is that the transposons can move to anywhere in the genome, not just places similar to where they've existed before
- Insertion sequences - simplest bacterial transposons that only consist of the DNA necessary for the act of transposition
  - Transposase gene (enzyme that catalyzes movement from one location to another) flanked with two inverted repeat sections
    - Inverted repeat sections are made so what's on one strand on one side is backwards on the other strand on the other side
    - Recognized by transposase as boundaries for the transposon
  - Other enzymes also help the moving, such as when DNA polymerase helps create identical regions of DNA (direct repeats) that flank a transposon in its new site
  - Can mutate genes by inserting within them (really rare), intrinsic source of mutation
  - Give no known benefit to bacteria
- Composite Transposons - longer and more complex than insertion sequences
  - Contain extra genes sandwiched between two insertion sequences
  - Direct repeats (not considered part of transposon) on both ends outside inverted repeats
  - Can help bacteria adapt to new environments, such as when many antibiotic resistance genes are moved onto the same R plasmid
  - Transposons are also in eu genomes
    - Barbara McClintock's corn experiment

- The control of gene expression enables individual bacteria to adjust their metabolism to environmental change
  - Cells can adjust the numbers of specific enzyme molecules made and the activity of enzymes already made
    - Negative feedback regulated by operons
  - Operons - operator, promoter, and all of the genes they control
    - Often, related enzymes will all be regulated by one promoter and be transcribed as one long mRNA molecule for convenience of a single on-off switch
    - Operator - a "switch" segment of DNA that controls the access of RNA polymerase to the genes
      - Positioned within or downstream from the promoter
  - Trp operon regulates synthesis of repressible enzymes (repressible operon)
    - Repressor - protein that can attach to the operon and turn it off (can only attach when it has a tryptophan attached to it, changing its shape)
    - Regulatory gene - makes inactive repressor protein and is located far from operon
    - Corepressor - a small molecule that cooperates with a repressor protein to switch an operon off (tryptophan in this example)

        - Lac operon regulates synthesis of inducible enzymes (inducible operon)
            - Repressor is active without lactose and is bound to the operator, blocking transcription
            - Regulatory gene makes active repressor
            - Inducer - small molecule that binds to the repressor and inactivates it (allolactose, an isomer of lactose, in this example)
        - Repressible enzymes generally function in anabolic pathways, while inducible enzymes function in catabolic pathways
            - Both are negative control because the gene is shut off by the active repressor
            - This makes allolactose more of a de-repressor than an inducer
        - In the pathway for degradation of lactose to glucose, positive control is used
            - Cyclic AMP accumulates when glucose is scarce
            - cAMP binds to the cAMP receptor protein (CRP), which bends DNA to make it easier to transcribe by RNA polymerase
            - When cAMP levels fall, CRP is inactivated and the transcription is still carried out, but at a much lower level
            - CRP functions in other catabolic pathways because a low level of glucose needs to allow for breakdown of any other energy giving substance. However, the negative control is what chooses a specific pathway based on the presence of the compound it breaks down
            - This suits bacteria that cannot control what their host eats

- Chapter 19: The Organization and Control of Eukaryotic Genomes
    - Eukaryotic Chromatin Structure
        - Chromatin structure is based on successive levels of DNA packing
            - Histones - proteins responsible for the first level of DNA packing in eukaryotic chromatin
                - Mass of histones in chromatin is approximately equal to the mass of DNA
                - Histones have + charged R groups that bind tightly to the negative DNA
                - Histones are similar between eukaryotes and even some prokaryotes
            - Nucleosome (10 nm) - basic unit of DNA packing, DNA wound around a protein made of 8 histones, bead on a string
                - DNA has width of about 2 nm
            - 30 nm chromatin fiber - string of nucleosomes wound up into a chromatin fiber 30 nm in width
            - Looped domains - 30 nm fibers are looped and attached to a nonhistone protein scaffold
            - Metaphase chromosome - scaffolding protein folds even further and compacts into chromosomes
            - Heterochromatin - highly condensed DNA present during interphase, is not transcribed (may exist for the purpose of coarse gene regulation)
            - Euchromatin - normal, less compacted chromatin
    - Genome Organization at the DNA Level
        - Repetitive DNA and other noncoding sequences account for much of a eukaryotic genome
            - Tandemly repetitive (satellite DNA) - 10-15% of the genome of mammals, short sequences repeated, has different density because of unique repetitiveness
                - Microsatellite - 10-100 repetitions
                - Minisatellite - 100-100,000 repetitions
                - Regular satellite - 100,000-10 million repetitions
                - Many genetic disorders are caused by abnormally long stretches of satellite DNA
                - Satellite DNA may play a structural role in telomeres and centromeres
                - It may also help organize chromatin within the interphase nucleus
                - Interspersed repetitive DNA - repeated sequences scattered throughout the genome instead of being next to each other
                - Alu elements - a family of similar sequences of IRDNA that make up at least 5% of the

genome and are an exception to the notion that repetitive DNA isn't transcribed
            - Function, if any, is unknown
    - Gene families have evolved by duplication of ancestral genes
        - Multigene family - a collection of identical or very similar genes
            - Like repetitive DNA, but each unit is an entire gene
            - Identical multigene families usually code for RNA products (exception: histone genes)
                - Having many copies of the gene allows for mass production of the RNA product (Ex: rRNA gene is repeated thousands of times and all can be transcribed simultaneously)
            - Nonidentical multigene families are more diverse
                - Ex: the gene families for the two types of hemoglobin have many slightly different members that work ideally in different environments
        - Genes can be copied over time through mistakes in replication and recombination
            - Nonidentical families made through unique mutations in each copy
            - Pseudogenes - DNA segments with sequences very similar to those of the genes they are close to, but the pseudogene makes no products
                - Shows the functionality of some gene copies is destroyed over time by excessive mutations
    - Gene amplification, loss, or rearrangement can alter a cell's genome during an organism's lifetime
        - Gene amplification - selective replication of certain genes to increase production of their products
            - Cancer cells that survive treatment have undergone gene amplification to make copies of the genes that confer drug resistance
        - Some genes are lost in certain tissues in insect development
        - Transposons and Retrotransposons can change the loci of genes in somatic cells
            - Transposons make up 50% of the maize genome and 10% of the human genome
            - Retrotransposons - move within a genome by means of an RNA intermediate, a transcript of the retrotransposon DNA
                - The RNA is made into DNA by reverse transcriptase (retroviruses!) so it can be repackaged into the genome elsewhere
                - Retrotransposons make up most of the eukaryotic transposons
                - Retroviruses may have evolved from escaped and repackaged retrotransposons
        - Immunoglobulin - proteins that specifically recognize and help combat viruses, bacteria, and other threats
            - Each is highly specialized, put together from genes all around the genome
            - Different variable sections are put next to the gene for the constant section by deletion of intervening DNA, making a huge variety of antibodies
- The Control of Gene Expression
    - Each cell of a multicellular eukaryote expresses only a small fraction of its genes
        - Cellular differentiation - divergence in form and function as cells become specialized during an organism's development
            - Typical cell only expresses 3-5% of its genes at a given time
    - Chromatin modifications affect the availability of genes for transcription
        - Physical state of DNA (coiledness) and location (distance from nucleosomes) can affect whether a gene is transcribed
        - DNA methylation - attachment of methyl groups (-CH3) after the DNA is made
            - Decreases transcription
            - Genomic imprinting - methylation permanently turns off either the maternal or paternal copy of a gene
        - Histone acetylation - attachment of acetyl groups (-COCH3) to certain histone amino acids

- Acetylation makes the histones grip DNA less tightly, making it easier to transcribe
- Transcription initiation is controlled by proteins that interact with DNA and with each other
  - Control elements - segments of noncoding DNA that help regulate transcription of a gene by binding proteins (transcription factors)
    - Include promoters and more distant segments
  - Enhancers - distant control elements that can help transcription by bending of the DNA to bring the enhancers to the gene
    - This allows transcription factors bound to enhancers to bind to the promoter to start the transcription initiation complex
    - Activator - a transcription factor that binds to an enhancer and stimulates transcription of a gene
    - DNA binding domain - a part of the 3d structure of a transcription factor that binds to DNA
      - Helix-turn-helix - literally two helices with a turn between them, found in lac and trp
      - Zinc finger - each finger holds an alpha helix and a beta sheet with a zinc atom
      - Leucine zipper - two alpha helices with regularly spaced leucines wrap around each other, joining two polypeptides toether
      - All function as things to fit in the "groove" of DNA to lodge into it
  - In eukaryotes, every gene has its own promoter, no clustering like with prokaryotes
    - Genes with the same control elements are activated by the same chemical signals
- Post-transcriptional mechanisms play supporting roles in the control of gene expression
  - Alternative RNA splicing - allows for multiple RNA fragments to be made from the same primary transcript by treating different segments as introns and exons
  - Genes for the lifetime of an RNA molecule are contained within the trailer region on the 3' end
  - Translation can be stopped by elements added to the 5' cap
    - Some proteins can start or stop translation throughout the cell
  - Proteasomes - giant protein complexes that degrade tagged proteins
  - Ubiquitin - a protein that tags other proteins for destruction
  - When cell cycle proteins are impervious to degradation, it can lead to cancer
- The Molecular Biology of Cancer
  - Cancer results from genetic changes that affect the cell cycle
    - Oncogenes - cancer causing genes from retroviruses
    - Proto-oncogenes - normal cellular genes that stimulate normal cell growth and division
    - Proto-oncogenes are made into oncogenes from movement of DNA within the genome, amplification of a proto-oncogene, or a point mutation in a proto-oncogene
      - The proto-oncogene could be moved next to an especially active promoter
      - The mutation could make the protein more resistant to degradation
    - Tumor-suppressor genes - the proteins they normally encode help prevent uncontrolled cell growth
      - Mutations can cause lack of suppression
  - Oncogene proteins and faulty tumor-suppressor proteins interfere with normal signaling pathways
    - Ras gene - makes Ras, a G protein that relays a growth signal from a growth factor receptor on the plasma membrane to a kinase cascade
      - Mutation makes the cascade happen without the growth signal
    - P53 gene makes p53, a protein that fixes damaged DNA and makes p21, which binds to CDK to slow cell cycle so p53 can finish repair
      - When damage is irreparable, p53 activates suicide genes that kill the cell to prevent cancer
  - Multiple mutations underlie the development of cancer
    - Slowly, genes like ras and p53 lose their function

        - Telomerase gene activated
        - Cancer predisposition can be inherited because some existing mutations in the tumor suppressing genes can be passed on

- Chapter 20: DNA Technology and Genomics
    - DNA Cloning
        - DNA tech makes it possible to clone genes for basic research and commercial application
            - The desired gene is inserted into a bacterial plasmid, where the bacteria can replicate and make the gene product, which is usually a desired protein
        - Restriction enzymes are used to make recombinant DNA
            - Restriction enzymes - enzymes that cut DNA molecules at a limited number of specific locations
                - First discovered in bacteria to cut up foreign DNA as a protective measure
                - They look for a specific nucleotide sequence to cut at
                - Bacteria protect their own DNA by adding methyl groups to the A's and C's on the recognition zone
                - Restriction site - recognition sequence on the DNA molecule
                - Restriction fragments - what's left after restriction, always the same for a DNA molecule
                - Sticky end - a single stranded end at the end of a restriction fragment
                    - Sticky ends can only temporarily connect to complementary sticky ends by the natural H bonds that form. Ligase has to seal the bond
        - Genes can be cloned in recombinant DNA vectors
            - Cloning vector - the original plasmid, a DNA molecule that can carry foreign DNA into a cell and replicate there
            - 1. The cloning vector and the human DNA are both prepared
            - 2. They are both processed by a restriction enzyme, which leaves sticky ends, letting the recombinant plasmid form
            - 3. Bacteria take up the plasmids by transformation
            - 4. Cells are cloned as colonies on a nutrient medium. The colonies that contain certain genes intact and certain foreign genes that make the bacteria react differently in different mediums
                - This allows us to figure out which colonies contain bacteria with recombinant plasmids
            - 5. We can look for the gene itself or protein products to identify which colony is the one we want
                - Nucleic acid hybridization - a method to detect DNA of a gene by base pairing between the gene and a complementary strand
                - Once the desired cell is found, it can be cultured in large tanks so the produce can be easily harvested
            - Expression vector - a cloning vector that contains the requisite prokaryote just upstream of a restriction site where the eukaryotic gene can be added
            - Also, processed mRNA must be reverse transcriptase'd into DNA to avoid the intron problem
                - This is called complementary DNA (cDNA)
            - Scientists can bypass these compatibility issues between prokaryotes and eukaryotes by using yeasts instead of bacteria and making yeast artificial chromosomes instead of plasmids
                - Also, some eukaryotic proteins won't function without some processing, like adding of an oligosaccharide, so growing them in a eukaryote makes sure that's done
                - Electroporation - brief electrical pulse makes a hole in the yeast membrane to allow DNA to go in (eukaryotes don't have transformation)
        - Cloned genes are stored in DNA libraries
            - Because of a lack of specificity in the previously described approach for making recombinant plasmids, hundreds of different ones are made

        - These are stored together in a genomic library
      - Some bacteriophages are common cloning vectors for making genomic libraries
      - cDNA library - when a researcher takes mRNA from a cell to make into cDNA, many different RNA molecules are obtained; these together make up most of the cell's genome and can be stored together as cDNA as a genome library
    - The polymerase chain reaction (PCR) clones DNA entirely in vitro
      - DNA is placed in a test tube with a kind of DNA polymerase, a supply of nucleotides, and short primers
        - The DNA is heated to separate the strands, cooled to allow primers to bond, then DNA polymerase finishes the job; this cycle can be repeated many times for much replication
        - PCR is really fast, it can make billions of DNA molecules in hours
        - PCR uses much specificity, but is limited by errors in replication so only so many cycles can be run
- DNA Analysis and Genomics
  - Restriction fragment analysis detects DNA differences that affect restriction sites
    - Gel electrophoresis sorts fragments by length so differences in DNA can easily be seen
      - Restriction fragments cut up DNA, slightly negative DNA is placed on a gel next to a cathode (negative electrode) with an anode across the gel (positive electrode)
      - The DNA fragments migrate at different speeds based on their size (larger moves slower)
    - Southern blotting - uses radioactive probes to mark segments of our choosing because only electrophoresis makes too many bands to distinguish
      - Gel from electrophoresis is placed under paper towels and above an alkaline solution to denature the DNA and transfer it to paper
      - The paper is put in a plastic bag with a DNA probe in it that is complementary to the desired strands and radioactive so when film is put across the paper, only the strands of interest show up.
    - Restriction fragment length polymorphisms (RFLPs) - differences in DNA sequence on homologous chromosomes that can result in different restriction fragment patterns, abundant in our genome
      - Inherited in the Mendelian fashion, so they can be used as genetic markers for making linkage maps
  - Entire genomes can be mapped at the DNA level
    - Human Genome Project - mapping our entire genome
    - Many genomes have been mapped out, including yeast, nematode, fruit fly, and mouse
      - First, make a linkage map of several thousand genetic markers spaced evenly throughout the chromosomes
      - Next, cut the space between markers into overlapping segments so they can be ordered
      - These pieces can be further cut until they are about 1000 nucleotides and can be easily sequenced
    - Sanger method - let fragments of DNA replicate with normal and altered versions of the nucleotides in the test tube (4 test tubes, each has 1 altered form and all of the normal forms). The altered form (dATP, dGTP, dCTP, dTTP) is incorporated at a random point and stops replication. When the segments are put through gel electrophoresis, each test tube gets its own row. Then, the shortest fragment will be in the row with the first letter, next shortest with next letter, etc.
    - Whole-genome shotgun approach - split the DNA straightaway into a bunch of small fragments and do the overlapping short segments step right away
  - Genomic sequences provide clues to important biological questions
    - Humans have very few genes (and genes per million base pairs) compared to much "simpler"

organisms
            - We get more complexity because alternative RNA splicing allows for more different protein products per gene
            - Our polypeptides are more complex than those of invertebrates
            - Our proteins have more complex interactions so less protein types can do more
        - DNA microarray assays - grid that represents many pieces of DNA to check their expression
            - A large number of single stranded DNA fragments representing different genes are spaced in a tightly spaced array
            - The fragments are tested for hybridization with several cDNA, each which has been marked with fluorescent markers
        - In vitro mutagenesis - introduces specific changes into the sequence of cloned gene to find its function
            - The cell can then be returned to the organism to see the function of the gene in the whole organism
        - RNA interference (RNAi) - uses double stranded RNA molecules matching the function of a particular gene to trigger breakdown of the gene's mRNA
        - Proteomics - the systematic study of the full protein sets encoded by genomes
            - Difficult because of alternative RNA splicing and post translational modifications make the number of proteins much higher than the number of genes
        - Bioinformatics - application of computer science and math to genetics and other biological info
        - Single nucleotide polymorphisms (SNPs) - single base-pair variations in the genome, make up most of the differences between different humans
- Practical Applications of DNA Technology
    - DNA technology is reshaping medicine and the pharmaceutical industry
        - Genetic illnesses and diseases like HIV can be diagnosed by detecting their known DNA
        - Carriers of harmful alleles can be found
        - Even if the sequence for a harmful allele is unknown, it can be found with high accuracy by finding RFLP markers really close to it that are generally inherited with it because of the low probability of crossing over with the proximity
        - Gene therapy - the alteration of an afflicted individual's genes, generally to fix genetic illnesses
            - The cells that multiply throughout the patient's life must be the one that get the allele changed
            - Bone marrow stem cells are taken out, "fixed", then injected back
            - Often, the productivity of added alleles decreases quickly, making gene therapy only partially successful
            - Because of concerns, most gene therapy is not going towards fixing genetic defects, rather fighting killers like cancer and heart disease
            - Morally questionable, both because it is messing with what makes us up and it decreases genetic variety that could help in some circumstances
        - DNA tech helped to make insulin and human growth hormone (HGH)
            - Later, TPA was make, reduces clotting to prevent subsequent heart attacks after a first
        - Vaccines can be made from protein molecules on the pathogen's surface by cloned plasmids (subunit vaccines)
            - Also, vaccines can be used to alter the pathogen's immune system to make the entire cell harmless (more effective than subunit vaccines)
    - DNA tech offers forensic, environmental, and agricultural applications
        - DNA left at a crime scene can be matched to suspects with great certainty (southern blotting)
            - DNA fingerprint - specific pattern of bands that is of forensic use
            - Now, length of satellite DNA is used more for identification than RFLPs
            - PCR can help amplify DNA in poor conditions or minute quantities
        - DNA can be used to clean up the environment by putting genes in microbes to take up heavy

metals and incorporate them into compounds that are readily available
            - Microbes function in cleaning and mining back of the minerals
        - DNA tech can improve agricultural productivity
            - Transgenic organism - carries genes from another species
            - Some are used to increase the amount of normal farm products produced
                - Ex: genes for muscle growth in cows, better wool in sheep, etc.
            - Others are used to produce a large amount of an otherwise rare biological substance for medical use
                - The products, such as hormones, can be excreted in milk and purified
            - Transgenic organisms are made by injecting the desired genes directly into the egg nucleus
        - Plants are more often genetically engineered, usually for increased productivity and hardiness
            - A single tissue can grow into an entire plant
            - Ti plasmid - a plasmid from the soil bacterium, agrobacterium tumefaciens that is used to introduce new genes into plant cells
                - Incorporates its T DNA into the plant cell, then a new plant can be grown from the cell
                - Ti only infects dicots, so electroporation and DNA guns are used more now
            - Plants are bred to be resistant to weed killers, have more nutrients, and to produce drugs
    - DNA technology raises important safety and ethical questions
        - Recombinant organisms that are dangerous and difficult to kill could escape
            - Microbes are crippled to ensure they couldn't survive outside the lab
        - Many are concerned about possible dangers of GM foods
        - Who should have the right to see someone else's genes and what the genes determine about the person's health?

- Chapter 21: The Genetic Basis of Development
    - From Single Cell to Multicellular ORganism
        - Embryonic development involves cell division, cell differentiation, and morphogenesis
            - Differentiation - becoming specialized in structure and function
            - Morphogenesis - the physical processes that give an organism its shape
                - In animals, moving cells create form, not just direction of division
                - Plants grow throughout their lives
                    - Apical meristems - perpetually embryonic regions in the tips of shoots and roots
        - Researchers study development in model organisms to identify general principles
            - Model organism - the organism selected for a study
            - Frogs have clear eggs, so animal development can be easily observed (used in the past most)
            - Fruit flies are small, easily grown in laboratories, have short generation times, and produce lots of offspring
                - Embryos develop outside the mother's body
                - Only fault is early development includes mitosis without cytokinesis, making one cell with many nuclei, which is unlike the development of most organisms
            - Nematode (C. elegans) can live in soil in petri dishes, is only about a mm long, has a simple transparent body, and an even shorter generation time that fruit flies
                - Hermaphrodites, allowing recessive mutations to be easily detected through self-fertilization
                - Cell lineage - ancestry of the adult cells, completed in nematodes because every one has exactly 959 cells
            - Mouse - close to us, genes can be easily manipulated
                - Some faults are the embryo develops inside the embryo and mice are still very

complex

- Zebrafish - 2-4 cm long, easily bred in labs, transparent embryos develop outside mother, early development proceeds quickly
  - Has a long generation time (2-4 months)
- Wall cress (arabidopsis thaliana) - can be grown in a test tube, each flower makes both ova and sperm, thousands of progeny can be made 8-10 weeks, has a small (and sequenced) genome

- Differential Gene Expression
  - Different types of cells in an organism have the same DNA
    - Cloning (plants) - using a single somatic cell from a multicellular organism to make one or more genetically identical individuals (each is a clone)
      - Fact that a cell can de-differentiate and re-differentiate shows that there is no change in the DNA
      - Totipotent - cells retain the zygote's potential to form all parts of the mature organism (in plant cells)
    - In animals, the nucleus of an unfertilized egg cell can be destroyed with UV rays and replaced with a nucleus from a differentiated cell
      - The older the organism from which the differentiated cell come from, the less of a chance it will divide when transplanted into the egg cell
      - Caused by alterations in chromatin structure (methylation)
      - These changes are reversible, as shown with the cloning to make Dolly, the sheep
    - Stem cells - relatively unspecialized animal cells that continue to reproduce themselves and can specialize into cells of one or more types
      - Some stem cells are in bone marrow (to make blood cells) or the brain (to make neurons)
      - Much easier stem cells to culture are those from early embryos, they make telomerase and can differentiate into any cell type, not just a group of related cells
      - Stem cells have the potential to repair damaged or diseased organs, give insulin making pancreatic cells to diabetics, give brain cells to those with Parkinson's, etc.
      - Moral issue with using embryos make using adult stem cells more feasible (though more difficult)
  - Different cell types make different proteins, usually as a result of transcriptional regulation
    - Determination - the process that leads up to the observable differentiation of a cell
      - When cell cannot turn back and become something different, it is "determined"
      - Makes the cell express tissue-specific proteins that give the cell its characteristic structure and function
      - The cells can then be specialized to mass produce their product (Ex: lens cells use 80% of their protein production to make crystallins, transparent fiber proteins)
      - Myoblast - looks like embryonic cell, but has been determined at a chemical level
      - First, a master "switch" gene is turned on, then its product can turn on other genes that act towards specializing a cell
        - The product of the master gene is powerful, it can turn differentiate cells like fat or liver cells into muscle cells, for example (if myoD is expressed)
        - Some cells aren't transformed because other regulatory proteins are needed that are present in fat and liver cells
  - Transcriptional regulation is directed by maternal molecules in the cytoplasm and signals from other cells
    - Substances are distributed unevenly in the egg cell, so divisions lead to cells that have the potential for differentiation
      - Cytoplasmic determinants - the maternal substances in the egg that influence the course of early development
    - Induction - as some cells differentiate, they can encourage other cells to differentiate into

things based on relative location by sending signal molecules

- Genetic and Cellular Mechanisms of Pattern Formation
  - Genetic analysis of Drosophila reveals how genes control development
    - Cytoplasmic determinants can place the dorsal-ventral axis and the anterior-posterior axis
    - 1. After fertilization and egg laying, mitosis begins without cytokinesis or increasing of cytoplasmic volume
    - 2. After the tenth division, the nuclei migrate to the edge of the embryo
    - 3. At division 13, plasma membranes partition the approximately 6000 nuclei into separate cells
    - 4. Clearly visible segments develop, though they are identical
    - 5. Some cells move to new positions and organs form before the larva hatches
    - 6. Larva forms a pupa enclosed in a case
    - 7. During metamorphosis, each segment differentiates
    - Some scientists wanted to find the genes that lead to segment formation in fruit flies, but the obstacles included the large number of genes (13,000), the fact that flies with a mutation in one of the genes would die early and could not breed, and researchers would have to also look at maternal genes because of cytoplasmic determinants
      - They exposed flies to mutagens, then examined the dead descendents of the flies for segmentation mutants (recessive genes)
  - Gradients of maternal molecules in the early embryo control axis formation
    - Maternal effect genes - the mother's genes that code for cytoplasmic determinants
      - When the gene is mutated, it causes a mutation in the offspring, regardless of whether the offspring received the mutation
      - They make proteins or mRNA's that are placed in the eggs while the egg is still in the ovary
      - Also egg-polarity genes because they set up orientation and axes (dorsal-ventral, anterior-posterior)
    - Morphogens - substances coded for by maternal effect genes, form a gradient through the embryo to form axes and other features of its form
  - A cascade of gene activations sets up the segmentation pattern in Drosophila
    - Segmentation genes - direct the actual formation of segments after the major axes are defined
      - Gap genes - map out the basic subdivisions along the anterior-posterior axis
        - Mutations cause "gaps" in the animal's segmentation (lacking segments)
      - Pair-rule genes - define the modular pattern in terms of pairs of segments
        - Mutations cause half of the segments to be gone (either the odds or the evens, depending on the mutations)
      - Segment polarity genes - set the anterior-posterior axis of each segment
        - Mutations make embryos have the normal number of segments, but a part of each segment is replaced by a mirror-image repetition of some other part of the segment
      - All of these genes make transcription factors that activate the next set of genes in the hierarchical scheme of pattern formation (same order as going down above list)
  - Homeotic genes direct the identity of body parts
    - Homeotic genes - master regulatory genes that set the anatomical identity of the segments
      - Mutations made mutants such as flies with legs instead of antennae
      - They also make transcription factors to activate genes for the body part that belongs in a particular place
      - Many pattern formation genes in flies (especially homeotic genes) have close counterparts throughout the animal kingdom
    - Hierarchy: Maternal effect genes (egg-polarity genes) → Gap genes → Pair-rule genes → Segment polarity genes → Homeotic genes of the embryo → Other embryo genes
  - Homeobox genes have been highly conserved in evolution
    - Homeobox - a 180 nucleotide sequence included in all homeotic genes, specifies a 60 amino

acid homeodomain
        - Nearly identical between all animals
        - Also called Hox genes
        - Some genes have the homeobox, but aren't homeotic genes (especially segmentation genes), but not the other way around
        - Homeodomain binds to the DNA when the protein functions as a transcription factor, caused by 3 alpha helices in the homeodomain
            - Other domains help interact with other transcription factors to specify enhancers or promoters in the DNA
- Neighboring cells instruct other cells to form particular structures: cell signaling and induction in the nematode
    - In formation of the vulva in nematodes, an anchor cell secretes the first inducer to vulval precursor cells
        - The cells closest to the anchor cell have the most effects (division and differentiation to make the skin fold in)
        - The cells too far away to receive the signal just become epidermal cells
        - Illustrates:
            - In the developing embryo, sequential inductions drive the formation of organs
            - The effect of an inducer can depend on its concentration (gradient)
            - Inducers produce their effects via signal-transduction pathways similar to those operating in adult cells.
            - The induced cell's response is often the activation/inactivation of genes, producing gene activity characteristic of a kind of differentiated cell
    - Apoptosis - programmed cell death
        - Occurs exactly 131 times in nematodes
        - At exactly the same points for each worm, signals trigger a cascade of "suicide" proteins in cells destined to die
        - The cells shrink, their nuclei condense and break down, neighboring cells engulf and digest the remains
        - Ced-3 and ced-4 code for the proteins Ced-3 and Ced-4, these are always present, but in an inactive form
        - Ced-9 activates proteases (main ones of apoptosis are caspases) and nucleases, master switch of apoptosis
        - In humans and other mammals, mitochondria are also involved in apoptosis; the leak proteins that promote apoptosis, including cytochrome c
        - Cells with irreparable DNA damage usually use apoptosis, so do we when the webbing between our fingers and toes gets destroyed
- Plant development depends on cell signaling and transcriptional regulation
    - Because of the presence of cell walls, plants depend more on differing planes of cell division and selective cell enlargement than moving of cells
        - Both still depend on induction and transcriptional regulation
        - Embryonic development occurs inside seed, making it more difficult to study
    - Apical meristems are triggered by environment (day length, temperature) to become floral meristems, bumps of cells with 3 layers (L1, L2, L3)
    - Chimeras - mutant flowers with extra flower parts homozygous for the fasciated allele
        - Number of flower parts in the L3 layer (innermost) induces extra parts in the other layers
    - Organ identity gene - determines the type of structure that will grow from a meristem (petal vs stamen)
        - Gene A affects the two outermost whorls (out of 4), B affects the second and third, and C affects the first and the second

        - If either A or C is missing, the other takes its place in the gene expression
      - Plants don't have homeoboxes, instead they have genes with similar functions that may be just as old

- Chapter 22: Descent With Modification: A Darwinian View of Life
  - The Historical Context for Evolutionary Theory
    - Western culture resisted evolutionary views of life
      - Natural theology - philosophy dedicated to discovering the Creator's plan by studying nature
      - Taxonomy - the branch of biology concerned with naming and classifying the diverse forms of life
        - Linnaeus made the binomial naming system and adopted a hierarchy of groups
      - Catastrophism - Cuvier's theory that boundaries between strata correspond in time to a catastrophe, such as a flood or drought, that had destroyed many of the species living there at that time
    - Theories of geologic gradualism helped clear the path for evolutionary biologists
      - Gradualism - Hutton's theory that profound change is the cumulative product of slow but continuous processes
        - Uniformitarianism - geologic processes haven't changed through earth's history (including present time)
      - Lamarck placed fossils in an evolutionary context
        - First one to propose a theory of evolution, but incorrectly assumed it depended on inheritance of acquired characteristics
  - The Darwinian Revolution
    - Field research helped Darwin frame his view of life
      - Read Lyell's geography book and noted adaptation to environments
    - The Origin of Species developed two main points: the occurrence of evolution and natural selection as its mechanism
      - Descent with modification - phrase used by Darwin, unity+diversity
      - Linnaeus, who believed species are fixed, helped Darwin with his method of classification showing in what order species could have diverged in
      - Darwin had 5 observations and 3 inferences
        - O1. All species would expand exponentially if possible
        - O2. Populations tend to remain stable in size except for seasonal fluctuations
        - O3: Environmental resources are limited
        - I1: Production of more individuals than the environment can support leads to a struggle for resources
        - O4: Individuals in a population vary extensively in the characteristics
        - O5: Much of the variation is heritable
        - I2: Survival in the struggle depends in part on the hereditary constitutions of the individuals
        - I3: The unequal ability of individuals to survive and reproduce will lead to a gradual change in a population, with favorable characteristics accumulating over the generation
      - Malthus - essay talked about how human suffering was inescapable because of the potential for the population to increase faster than its resources
      - Artificial selection - humans selecting favorable traits rather than environmental stresses
        - Darwin used it to illustrate how much selection in general could change species
    - Examples of natural selection provide evidence of evolution
      - Insects with insecticide, drug-resistant HIV evolution
    - Other evidence of evolution pervades biology
      - Homology - similarity in characteristics resulting from common ancestry
        - Anatomical homologies (homologous structures) - common structure of mammal

forelimbs
        - Vestigial organs - homologous structures that are historical remnants of structures that had important functions in ancestors
        - Embryological homologies - during stages of embryonic development, embryos of different, but related species look similar
        - Molecular homologies - things like the genetic code and proteins that show relatedness that's not visible
        - Homologies can be used to make a tree of life because one can observe how small the group of organisms that share that homology is
      - Biogeography - species tend to be more closely related to other species from the same area than to other species with the same way of life, but living in different areas
        - Shown with islands, flying squirrels being very different from sugar gliders, etc.

- Chapter 23: The Evolution of Populations
  - Population Genetics
    - The modern evolutionary synthesis integrated Darwinian selection and Mendelian inheritance
      - Population genetics - emphasizes the extensive genetic variation within populations and recognizes the importance of quantitative characters
      - Modern synthesis - combined ideas of importance of populations as the units of evolution, the central role of natural selection as the most important mechanism of evolution, and the idea of gradualism to explain how large changes can evolve as an accumulation of small changes occurring over long periods of time
    - A population's gene pool is defined by its allele frequencies
      - Population - a localized group of individuals belonging to the same species
      - Species - a group of populations whose individuals have the potential to interbreed and produce fertile offspring in nature
      - Gene pool - all of the alleles at all gene loci in all individuals of the population
        - Fixed alleles - all members have homozygous for the same allele
    - The Hardy-Weinberg theorem describes a nonevolving population
      - The frequencies of alleles and genotypes in a population's gene pool remain constant over the generations unless acted upon by agents other than Mendelian segregation and recombination of alleles
      - Basically, shuffling of alleles due to meiosis and random fertilization has no effect on the overall gene pool of a population
      - HW equation - $p+q = 1$, $p^2+2pq+q^2 = 1$, where p is one allele, and q the other
      - Theorem only holds if 5 main conditions are satisfied
        - Very large population size - can't have genetic drift
        - No migration - causes gene flow
        - No net mutations - changing one allele into another alters the gene pool
        - Random mating - if certain traits are represented more in the new offspring, then the random mixing of gametes required for the equilibrium does not occur
        - No natural selection - differential survival and reproductive success of genotypes will alter their frequencies
  - Causes of Microevolution
    - Microevolution is a generation-to-generation change in a population's allele frequencies
    - The two main causes of microevolution are genetic drift and natural selection
      - Genetic drift - a change in a population's allele frequencies due to chance
        - Bottleneck effect - genetic drift due to improper representation of allele frequencies after a drastic reduction in population size
        - Founder effect - genetic drift in a new colony due to the small number of individuals that make up the new population and the bottleneck effect
      - Natural selection

            - differential success, only mechanism of microevolution that adapts a population to its environment
        - Gene flow - genetic exchange due to the migration of fertile individuals of gametes between populations
        - Mutation - a change in an organism's DNA, can propagate by above mechanisms, changing allele frequencies
- Genetic Variation, the Substrate for Natural Selection
    - Genetic variation occurs within and between populations
        - Polymorphism - when two or more forms of a discrete character are represented in a population
            - A population is polymorphic for a character if two or more distinct morphs are represented in high enough frequencies to be readily noticeable
        - Gene diversity - the average percent of loci that are heterozygous between individuals
        - Nucleotide diversity - how many specific nucleotides on average differ between individuals
        - Geographic variation - differences in gene pools between populations or subgroups of populations
            - Cline - geographic variation where this a graded change in some trait along a geographic axis
                - Ex: Average plant height decreases with altitude
            - Some geographic variation consists of discrete differences between isolated populations
    - Mutation and sexual recombination generate genetic variation
        - New alleles can only arrive through mutation, though these mutations have to happen in germ cell lines for the new allele to be passed on
        - Most mutations are silenced because they affect introns or because of wobble
        - Most mutations are harmful and beneficial ones usually are just ones that had been harmful in a previous, stable environment, but help the individual under changing environmental stresses
        - Chromosomal mutations are usually either terrible (by ruining a working gene) or neutral (by keeping genes intact). They are rarely beneficial when the movement causes genes to be inherited in a package in a way that benefits the organism
        - In microorganisms with very small generation spans, mutation generates genetic variation very quickly
        - For most animals and plants, generation-to-generation adaption is based more on shuffling of alleles
    - Diploidy and balanced polymorphisms preserve variation
        - Recessive alleles that may harm the individual may hide behind dominant phenotypes until their effect becomes beneficial from a changing environment
        - Balanced polymorphisms - the ability of natural selection to maintain stable frequencies of two or more phenotypic forms in a population
            - Heterozygote advantage - heterozygotes are more fit than either homozygote type, preserving both alleles
        - Frequency-dependent selection - the survival and reproduction of any one morph declines if that phenotypic form becomes too common in the population
            - If parasites are killing out their hosts, then they will select to attack a slightly different host until the new host starts to die off and the old one regains numbers
        - Neutral variation - seems to confer no selective advantage
            - Ex: human fingerprints
            - Variation is often neutral to a degree, not completely neutral
- A Closer Look at Natural Selection as the Mechanism of Adaptive Evolution
    - Evolutionary fitness is the relative contribution an individual makes to the gene pool of the next generation
        - Relative fitness - the contribution of a genotype to the next generation compared to the contributions of alternative genotypes for the same locus

        - Survival alone doesn't guarantee reproductive success, having many more offspring at the expense of one's own lifespan increases Darwinian fitness
        - A certain allele that is beneficial might not be passed on because the organism(s) that have it may also have other alleles that impede the beneficial allele's function
    - The effect of selection on a varying characteristic can be directional, diversifying, or stabilizing
        - Directional selection - a shift of the frequency curve for variants in some phenotypic character in one direction or the other
            - Often happens during times of changing conditions
            - Ex: A volcano drops a layer of soot over an area, so dark mice are selected for over light mice
        - Diversifying selection - phenotypes on both ends of the range are selected over intermediate phenotypes
            - Mice move to an area where there is black soil studded with white rocks, so dark and light mice survive more than brown ones
        - Stabilizing selection - more common intermediate variants are selected for over the extreme phenotypes
            - Brown soil makes the light and dark mice stand out
    - Natural selection maintains sexual reproduction
        - Sex seems counterintuitive because half of the offspring produced cannot reproduce themselves, but are needed for reproduction (males), while in asexual reproduction, all of the offspring can reproduce alone
        - It prevails because sex allows for genetic recombination to make good combinations of alleles and it creates genetic variety for a generation-to-generation basis
    - Sexual selection may lead to pronounced secondary differences between the sexes
        - Sexual dimorphism - differences in appearance between genders besides that of sex organs; includes size, plumage, antlers
            - Males are usually the showier sex
        - Intrasexual selection - direct competition among individuals of one sex (usually males) for mates of the opposite sex
            - Ex: male jackrabbits kick-box to determine superiority
        - Intersexual - mate choice, individuals of one sex (usually females) are choosy in selecting their mates from individuals of the other sex
            - More common than intrasexual selection
            - Although the traits that females look at in selection are usually neutral or detrimental in the male's survival, they can be a reflection of the male's general health and fitness
    - Natural selection cannot fashion perfect organisms
        - Evolution is limited by historical constraints - evolution doesn't just scrap ancestral anatomy and build each new complex structure from scratch
        - Adaptations are often compromises - giving fish legs to walk would make them worse at swimming
        - Not all evolution is adaptive - chance plays a large role in the genetic structures of populations through genetic drift
        - Selection can only edit existing variations - new alleles do not arise on demand

- Chapter 24: The Origin of Species
        - Anagenesis (phyletic evolution) - accumulation of changes associated with the transformation of one species into another
        - Cladogenesis (branching evolution) - the budding of one or more new species from a parent species that continues to exist; promotes biodiversity by increasing the number of species
    - What is a Species
        - The biological species concept emphasizes reproductive isolation
        - Prezygotic and postzygotic barriers isolate the gene pools of biological species

            - Prezygotic barriers - impede mating between species or hinder the fertilization of ova if members of different species attempt to mate
                - Habitat isolation - different habitats within the same area
                - Behavioral isolation - mating and courtship behaviours are too different
                - Temporal isolation - species mate during different times of day, month, season, year, etc.
                - Mechanical isolation - two species are anatomically incompatible even if they try to mate
                - Gametic isolation - the gametes fail to join to produce a zygote
            - Postzygotic barriers - prevent the hybrid zygote from developing into a viable, fertile adult
                - Reduced hybrid viability - hybrids do not survive or are very frail
                - Reduced hybrid fertility - hybrids are completely or largely sterile
                - Hybrid breakdown - offspring of the hybrids are frail or infertile
        - The biological species has some major limitations
            - It is impossible to check if extinct animals could interbreed to determine if they were the same species
            - Doesn't work for asexual life-forms
        - Biologists have proposed several alternative concepts of species
            - Ecological species concept - defines a species in terms of its ecological niche
            - Pluralistic species concept - the factors that are most important for the cohesions of individuals as a species vary
                - Can use biological species definition, ecological species definition, or some combination
            - Biological, Ecological, and Pluralistic are all explanatory concepts, but none are useful in identifying various species in nature
                - Morphological species concept - characterizes each species in terms of a unique set of structural features; most popular currently
                - Genealogical species concept - defines a species as a set of organisms with a unique genetic history
    - Modes of Speciation
            - Allopatric speciation - takes place in populations with geographically separate ranges
            - Sympatric speciation - takes place in geographically overlapping populations
        - Allopatric speciation: Geographic barriers can lead to the origin of species
            - More of a chance of speciation of the separated population is small and isolated, but this also increases the chance of the population dying out
            - Occasionally, the species naturally come back into contact and are still alike enough to hybridize back into one species
            - Adaptive radiation - one species is transferred to an island where it undergoes allopatric speciation. As some members of the population go to other islands, speciate, and continue to move on or back, the single common ancestor becomes many related species across many islands
            - While this geographic isolation doesn't count as a reproductive barrier (those are intrinsic to the organism), it may allow some to coincidentally form
            - Ex: Dodd's experiment where she separated flies into starch mediums and maltose mediums
        - Sympatric speciation: A new species can originate in the geographic midst of the parent species
            - Polyploid - extra chromosomes in a plant that make it a new species
                - Autopolyploid - an individual that has more than two chromosome sets, all derived from a single species
                    - Right away has postzygotic barrier of hybrid sterility because of the difference in chromosome number from the parent species
                - Allopolyploid - contribution of two different species to a polyploid hybrid; more common than autopolyploids

                ■ Usually the hybrid is sterile, but it may be more vigorous than either parent species and it may propagate itself asexually
                ■ Occasionally, various mechanisms with strange mating can then change a sterile hybrid into a fertile polyploid
            ○ Most food plants are polyploid
        ● In animals, polyploid generation is much more rare than in plants, so other mechanisms must contribute to sympatric speciation
            ○ Ex: Female cichlids in Lake Victoria pick mates based on certain colorings, though if the females are shown the males under monochromatic lighting, they will mate with the other species and create viable hybrids
            ○ Ex: Wasps that have a genetic change that cause them to pollinate different fig species would isolate them from the parent wasp species
    ■ The punctuated equilibrium model has stimulated research on the tempo of speciation
        ● Some say ancient animals and plants evolved gradually and constantly, just most of the differences are too subtle to notice in fossils
        ● Others say species stayed the same for most of the time, then changed and speciated in sudden bursts, as is shown in the fossil record
- ○ From Speciation to Macroevolution
    - ■ Most evolutionary novelties are modified versions of older structures
        - ● Eye progressed from a patch of pigmented cells (limpets) to an eyecup (mollusk) to a pinhole camera-type eye (nautilus) to an eye with a primitive lens (marine snail) to a complex camera-type eye (squids, humans)
        - ● Exaptations - structures that evolve in one context but become co-opted for another function
            - ○ Ex: honeycombed bones evolved in some dinosaurs not as an anticipation of flight, but rather for some grond purpose, like agility. Then, they were later used in conjunction with other adaptations for flight
    - ■ "Evo-devo": Genes that control development play a major role in evolution
        - ● Allometric growth - how the shape of an organism depends in part on the relative growth rates of its different parts during development
        - ● Heterochrony - evolution of morphology that arises by a modification in the allometric growth
            - ○ Ex: In tree dwelling salamanders, adapted to have shorter limbs and more webbing than ground dwelling salamanders
        - ● Paedomorphosis - changing the timing of reproductive development relative to development of somatic organs
            - ○ Ex: Axolotl remains in the juvenile state of living in water throughout its adult life
            - ○ Makes the new species seem very different from its ancestor despite the relatively small change
        - ● Homeotic genes - determine where basic features will develop, these can also be mutated
            - ○ Ex: more Hox gene expression in the tips of limb buds helped in the development of full limbs instead of small fins
    - ■ An evolutionary trend does not mean that evolution is goal oriented
        - ● Ex: while it may appear that horses have gotten bigger in general, the full set of species that developed show horses of many sizes, all of them but Equus just died out
        - ● Species selection - creates an evolutionary trend by treating species as individuals: speciation is their birth, extinction is their and new species are offspring
            - ○ Trends form by certain types of species lasting longer
            - ○ Differential speciation plays a role in macroevolution similar to the role of differential reproduction in microevolution
        - ● If environmental conditions change, any trend could change or even be reversed

- ● Chapter 25: Phylogeny and Systematics
    - ○ The Fossil Record and Geologic Time

- Sedimentary rocks are the richest source of fossils
    - Occasionally, organic material is preserved as thin films pressed between layers of sandstone or shale
    - Fossils are rocks that form as replicas of the organisms
- Paleontologists use a variety of methods to date fossils
    - Relative dating - organisms that are further down in the stratum of sedimentary rocks are older than the ones closer to the surface
        - Index fossils - shells of sea animals that were widespread
    - Geologic time scale - groups time periods into 4 main eras based on the life found at those times
        - Boundary between two eras represents a mass extinction, other, more minor extinctions mark the boundaries between some periods
    - Absolute Dating (radiometric dating) - Measures N 14 in the organism that forms from decaying C 14
        - Uses half-life - the time it takes for half of something (the C 14 in this case) to decay
        - For fossils that are billions of years old, U 238 is instead used, though it's only found in the rocks around where the fossil formed, not in the organism itself
        - Also, organisms make L-isomer amino acids, though these slowly turn into D-isomers after the organism's death, so the proportion of D-isomers can be used
    - Timeline with Era, Period, Epoch
    - Cenozoic
        - Quaternary
            - Recent - Historical time
            - Pleistocene - Ice ages, humans appear
        - Tertiary
            - Pliocene - Apelike ancestors of humans appear
            - Miocene - Continued radiation of mammals and angiosperms
            - Oligocene - Origins of many primate groups, including apes
            - Eocene - Angiosperm dominance increases; continued radiation of most modern mammalian orders
            - Paleocene - Major radiation of mammals, birds, and pollinating insects
    - Mesozoic - "Age of the reptiles"
        - Cretaceous - Flowering plants (angiosperms) appear; many groups of organisms, including dinosaurs, become extinct at the end of this period
        - Jurassic - Gymnosperms continue as dominant plants; dinosaurs abundant and diverse
        - Triassic - Cone-bearing plants (gymnosperms) dominate landscape; radiation of dinosaurs
    - Paleozoic
        - Permian - Extinction of many marine and terrestrial organisms; radiation of reptiles; origins of mammal-like reptiles and most modern orders of insects
        - Carboniferous - Extensive forests of vascular plants; first seed plants; origin of reptiles; amphibians dominant
        - Devonian - Diversification of bony fishes; first amphibians and insects
        - Silurian - Diversity of jawless fishes; first jawed fishes; diversification of early vascular plants
        - Ordovician - Marine algae abundant; colonization of land by plants and arthropods
        - Cambrian - Radiation of most modern animal phyla (cambrian explosion)
    - Precambrian
        - 600 (millions of years ago) - Diverse soft-bodied invertebrate animals; diverse algae
        - 2,200 - Oldest fossils of eukaryotic cells
        - 2,700 - Atmospheric oxygen begins to accumulate

        - 3,500 - Oldest fossils of cells (prokaryotes)
        - 3,800 - Earliest traces of life
        - 4,600 - Approximate time of origin of earth
    - The fossil record is a substantial, but incomplete, chronicle of evolutionary history
      - Very rare for something to fossilize because the organism had to die in the right place in the right time, then the rock layer had to escape destruction or distortion, then a river or canyon had to reveal the fossil, then someone actually had to find it
    - Phylogeny has a biogeographic basis in continental drift
      - Similarities of species on distantly separated coasts can be explained by the coasts having been connected earlier before moving apart from continental drift
    - The history of life is punctuated by mass extinctions
      - Small physical (temperature, ocean level) or biological (adaption of hard body parts) could cause many species to disappear, though mass extinctions are only noticed when the species that went extinct were hard-bodied
      - There were 5-7 mass extinctions, though the two most studied were the Permian and the Cretaceous
      - Permian mass extinction defined the boundary between the Paleozoic and Mesozoic eras and claimed about 90% of the species of marine animals
        - 8 out of 27 orders of Permian insects disappeared
        - The whole extinction occurred in less than 5 million years
        - Caused by merging of continents into Pangaea, massive volcanic eruptions in Siberia, and reduced temperatures
      - Cretaceous mass extinction delineates the boundary between the Mesozoic and Cenozoic eras
        - Killed over half of the marine species and exterminated many families of terrestrial plants and animals, including the dinosaurs
        - Climate became cooler and shallow seas receded, large volcanic eruptions happened in India
        - Layer of iridium suggests a meteorite struck, but other studies indicate that it was a final blow, not the cause of the extinction
  - Systematics: Connecting Classification to Phylogeny
    - Taxonomy employs a hierarchical system of classification
      - Binomial system - species name has two parts
        - Genus - category to which a species belongs; makes up the first part of the species' name
        - Specific epithet - refers to a single species within a genus; makes up the second part of the name
      - Further classification follows: domains, kingdoms, phyla, classes, orders, families, genii, species
      - Phylogenetic trees - reflect the hierarchical classification of taxonomic groups nested within more inclusive groups
    - Modern phylogenetic systematics is based on cladistic analysis
      - Cladogram - a phylogenetic diagram based on cladistic analysis, shows branching off of species
      - Clade - each evolutionary branch in a cladogram
        - Monophyletic - consists of an ancestral species and all of its descendent species; only legitimate taxa
        - Paraphyletic - includes an ancestor, but not all of its descendents
        - Polyphyletic - doesn't include the required common ancestor of all of the included descendents
      - When cladograms are constructed, systematists have to distinguish between homologies from relatedness and analogies from convergent evolution
      - When species have more shared homologies, they are usually more closely related

        - Shared primitive character - a homology common to a taxon more inclusive than the one we are trying to define
        - Shared derived character - an evolutionary novelty unique to a particular clade
        - Outgroup - a species or group of species that is closely related to the species we are studying, but know to be less closely related than any study-group members are to each other
        - Ingroup - the species being studied
        - We can look at traits that are in the ingroup, but not in certain outgroups to see when they developed to see where clades can be made based on the traits
        - Phylocode - replacement of Linnaean system; simply names clades without the hierarchical tags based on shared derived characters
    - Systematics can infer phylogeny from molecular data
        - Looks at DNA sequence to see how much similarity there is between genomes
            - Allows comparison of species too close to have many morphological differences and species too far apart to be easily compared (fungi are closer to animals than plants)
        - Ribosomal RNA sequence and mitochondrial DNA can also be used for comparison
    - The principle of parsimony helps systematics reconstruct phylogeny
        - Parsimony - a theory about nature should be the simplest explanation that is consistent with the facts
            - Least evolutionary events; how many times a trait has to evolve (or “unevolve”) in a species line
    - Phylogenetic trees are hypotheses
        - Ex: Although parsimony would say birds and mammals are more closely related than either is to lizards because then the 4-chambered heart would only have to evolve once, growing evidence is supporting that the 4-chambered heart is an analogy between birds and mammals and that birds and lizards are the most closely related
    - Molecular clocks may keep track of evolutionary time
        - Molecular clocks - certain homologous DNA sequences or their protein products where the number of changed nucleotides or amino acids is proportional to the time elapsed since the lineages branched
        - Certain sequences of DNA are sometimes calibrated and used as rough measures of absolute time, though this method is controversial due to the questionable accuracy
    - Modern systematics is flourishing with lively debate
        - Molecular analysis and modern systematics is changing previous lines separating taxa, such as showing that reptiles are a polyphyletic group and that crocodiles should be in Aves
        - Sometimes, molecular data contradicts the fossil record and other evidence

- Chapter 26: Early Earth and the Origin of Life
    - Introduction to the history of life
            - Order of branching off tree of life, soonest to latest: Bacteria, Archaea, Protists, Plants, Fungi, Animals
        - Life on Earth originated between 3.5 and 4.0 billion years ago
            - 3.8 billion year old organic molecules (possibly life) found
            - 3.5 billion year old bacteria found
        - Prokaryotes dominated evolutionary history from 3.5 to 2.0 billion years ago
            - Stromatolites - fossilized mats similar to layered microbial mats made by current prokaryotes; oldest prokaryote fossils found in these
            - Some fossils found in sediments by hydrothermal vents from 3.2 billion years ago
        - Oxygen began accumulating in the atmosphere about 2.7 billion years ago
            - Indicates evolution of cyanobacteria
            - Shown by banded, red iron formation in rock layers
            - Increase could only occur after water had absorbed a lot of oxygen, so cyanobacteria could’ve evolved earlier

        - Oxygen levels shot up to 10% of current levels by 2.2 billion years ago, dooming many prokaryotic species because of oxygen's corrosive, bond breaking effect
    - Eukaryotic life began by 2.1 billion years ago
        - Evolved from a symbiotic community of prokaryotes living within larger prokaryotic cells
        - Researchers suspect that some photosynthetic eukaryotes may have evolved 2.7 billion years ago
        - Mitochondria in eukaryotic cells took advantage of the growing O2 levels
    - Multicellular eukaryotes evolved by 1.2 billion years ago
        - Started with small algae, though jellies and worms appeared by the late precambrian
        - Snowball Earth hypothesis - severe ice age iced over all of earth from 750 to 570 million years ago, making multicellular eukaryotes relatively limited in diversity and distribution until the very late Precambrian
    - Animal diversity exploded during the early Cambrian period
        - Most of the major phyla of animals make their first fossil appearances during the first 20 million years of the Cambrian period
    - Plants, fungi, and animals colonized the land about 500 million year ago
        - Plants evolved from green algae and colonized land in the company of fungi
        - They transformed the landscape, creating opportunities for herbivores and their predators
- The Origin of Life
    - The first cells may have originated by chemical evolution on a young Earth
        - Spontaneous generation - life emerging from inanimate material; believed to have occurred to begin life; more possible in early Earth atmosphere due to the lack of O2 to break apart complex molecules
            - Pasteur proved it doesn't occur in cases like milk "spontaneously" spoiling
        - Biogenesis - "life from life", holds true for all cases except beginning of life
        - Origin of life is hypothesized to have occurred in 4 stages
            - Abiotic synthesis of small organic molecules, like amino acids and nucleotides
            - Joining of these molecules (monomers) into polymers, such as proteins and nucleic acids
            - The origin of self-replicating molecules that eventually made inheritance possible
            - The packaging of all these molecules into "protobionts," droplets with membranes that maintained an internal chemistry different from the surroundings
    - Abiotic synthesis of organic molecules is a testable hypothesis
        - Miller-Urey experiment put water with dissolved inorganic molecules into an early-Earth like atmosphere with electricity (simulated lighting). Eventually, amino acids formed
        - Another hypothetical cause is that the organic molecules formed in space and were brought to earth by meteorites
    - Laboratory simulations of early-Earth conditions have produced organic polymers
        - Polymerization has occurred by dripping solutions containing organic monomers onto hot sand, clay, or rock
        - Waves could've washed monomers onto freshly dried lava, then washed polymers back
    - RNA may have been the first genetic material
        - Short ribonucleotides have been abiotically made that can copy short (5-10 bp) segments of themselves with following base-pairing rules
        - With zinc added as a catalyst, they could copy 40 bp segments with less than 1% error
        - Ribozymes - RNA catalysts that can help in synthesis of new RNA
        - With RNA "natural selection," the phenotype is the shape (and therefore stability) that the molecule takes based on its sequence (genotype)
        - Natural selection could have favored RNA molecules that could hold amino acids that corresponded to base pairs and joined into an enzyme that could speed replication
    - Protobionts can form by self-assembly
        - Protobionts - aggregates of abiotically produced molecules

            - Formed in lab experiments by mixing solutions; simple protobionts included a selectively permeable lipid bilayer that could take in enzymes, then later use them in "processing" chemicals in their habitat
        - Natural selection could refine protobionts containing hereditary information
            - Huge milestone in natural selection when nucleic acids were packaged inside a lipid bilayer because then their products wouldn't help all of the other RNA's as well
            - Various mutations in copying could turn one successfully replicating protobiont into many different, competing types
            - Eventually DNA mutated as a genome molecule and took over
        - Debate about the origin of life abounds
            - All of the steps could have happened, but weren't guaranteed
            - Scientists are unsure where life began (probably around a hydrothermal vent)
            - Where the line of nonlife to life is drawn
            - Possibility of life arising on other planets or moons
    - The Major Lineages of Life
        - The five-kingdom system reflected increased knowledge of life's diversity
            - Separating fungi from plants, protists from bacteria, etc.
        - Arranging the diversity of life into the highest taxa is a work in progress
            - Three-domain system - Bacteria, Archaea, Eukarya
                - Becoming more accepted, though number of kingdoms is disputed

- Chapter 27: Prokaryotes and the Origins of Metabolic Diversity
    - The World of Prokaryotes
        - Bacteria and archaea are the two main branches of prokaryote evolution
            - Domains - taxonomic level above kingdoms, Bacteria, Archaea, and Eukarya
    - The Structure, Function, and Reproduction of Prokaryotes
        - Nearly all prokaryotes have a cell wall external to the plasma membrane
            - Prokaryotes can be killed by plasmolysis, which is why salted food lasts longer
            - Peptidoglycan - polymers of modified sugars cross-linked by short polypeptides that vary from species to species, make up cell walls of bacteria (NOT archaea)
            - Gram stain - a test that separates bacteria into two types
                - Gram positive - cell wall is just a thick peptidoglycan layer over a plasma membrane
                - Gram negative - less peptidoglycan, sandwiched between two plasma membranes, outer membrane has lipopolysaccharides (carbs bonded to lipids)
                    - Cause more diseases because the lipopolysaccharides are often toxic and the outer membrane protects the cell against host defense and drugs
                - Many antibiotics stop cross-linking of peptidoglycan to target only bacteria
            - Capsule - a sticky substance secreted by many prokaryotes that forms another layer outside the cell wall
                - Enables the cells to adhere to their substratum and provides additional protection
            - Pili - surface appendages that allow prokaryotes to attach to each other or a substratum
        - Most prokaryotes are motile
            - Most use flagella that can be scattered over the entire cell surface or concentrated at one or both ends
                - Prokaryotic flagella are 1/10 the width of eukaryotic flagella and aren't covered by an extension of the plasma membrane
            - Spirochetes (helix shaped bacteria) move when the cell itself moves like a corkscrew
            - Some bacteria secrete slimy threads that anchor to the substratum; the cell can glide across these as it continues to secrete
            - Taxis - movement toward or away from a stimulus
                - Prokaryotes use chemotaxis moving toward food or oxygen
                - Phototaxis moves into light for photosynthesis

- The cellular and genomic organization of prokaryotes is fundamentally different from that of eukaryotes
  - Nucleoid region - where the DNA is concentrated as a snarled fiber
    - Relatively little protein (unlike eu genomes with histones)
  - Plasmids have extra genes that help with adaptation, though aren't needed with short term survival and reproduction
  - Slight difference in size and structure of ribosomes
    - Difference is enough for some ribosomes to work by targeting prokaryotic ribosomes, but not eukaryotic ribosome
- Populations of prokaryotes grow and adapt rapidly
  - Binary fission - asexual cell division with almost continuous DNA synthesis
    - Neither mitosis nor meiosis occur within prokaryotes
  - Transformation - prokaryotic cells take up genes from the environment
  - Conjugation - the direct transfer of genes from one prokaryote to another
  - Transduction - viruses transfer genes between prokaryotes
  - Because of a lack of sexual reproduction, mutations are the major source of genetic variation among prokaryotes
    - This works with bacteria because they reproduce so fast, mutations appear much more quickly
  - With unlimited resources, bacteria populations can grow exponentially, some doubling as frequently as every 20 minutes
  - Endospores - resistant cells created when a bacteria divides and stores one cell in a degraded outer cell that serves as a protective layer in poor conditions, dehydrated

- Nutritional and Metabolic Diversity
  - Prokaryotes can be grouped into four categories according to how they obtain energy and carbon
    - Phototrophs use light energy, chemotrophs obtain energy from chemicals in the environment
    - Autotrophs need only inorganic sources of carbon (CO_2), heterotrophs require at least one organic nutrients to make others
      - Photoautotrophs - photosynthetic organisms, plants and algae
      - Chemoautotrophs - obtain energy by oxidizing minerals in stone, use only CO_2 though, only prokaryotes
      - Photoheterotrophs - use light to make ATP, but most take in organic carbon, only prokaryotes
      - Chemoheterotrophs - consume organic molecules for both energy and carbon, includes prokaryotes, protists, fungi, animals, and even some parasitic plants
    - Saprobes - decomposers that absorb nutrients from dead organic matter
    - Parasites - absorb nutrients from the body fluids of living hosts
    - Nitrogen fixation - process in which prokaryotes convert N_2 into NH_4^+, helps plants
    - Obligate aerobes - must use oxygen
    - Facultative anaerobes - will use O if they can, but otherwise do fermentation
    - Obligate anaerobes - poisoned by O_2
      - Some do fermentation, others do anaerobic respiration where a different molecule accepts electrons at the end of the chain
  - Photosynthesis evolved early in prokaryotic life
    - First metabolic pathway was probably glycolysis to make ATP
    - As the early heterotrophs used up all of the organic molecules, natural selection favored prokaryotes that could harness sunlight
    - Also, photosynthesis is spread through many different branches of prokaryote phylogeny, each time having very similar machinery to indicate it is homologous
    - Also, the oldest prokaryotes found were cyanobacteria
      - Hypothesized that cyanobacteria evolved from ancestors with simpler, nonoxygenic photosynthesis
    - Due to the early origin or photosynthesis, cell respiration probably evolved from modification

of photosynthesis

- A Survey of Prokaryotic Diversity
  - Molecular systematics is leading to a phylogenetic classification of prokaryotes
    - Signature sequences - regions of small subunit ribosomal RNA with unique sequences formed by accumulation of mutations
    - Before molecular systematics, they were classified by nutritional mode and gram stain (these categories were scattered, but are still useful in describing organisms)
  - Researchers are identifying a great diversity of archaea in extreme environments and in the ocean
    - Extremophiles - prokaryotes that live in extreme environments
      - Methanogens - obligate anaerobes that use CO_2 to oxidize H_2 to make methane
        - They live in swamps and can be used to convert garbage into fuel
      - Extreme halophiles - live in extremely saline environments, some need the salt, others just tolerate it
        - Bacteriorhodopsin - a photosynthetic pigment similar to what's in our retinas used by halophiles to make a purple-red scum
      - Extreme thermophiles - hot environments (60-80 degrees C)
        - Thought to be the first prokaryotes, making all other life "cold-adapted"
    - All methanogens and halophiles fit into Euryarchaeota, thermophiles are split between that and Crenarchaeota
  - Most known prokaryotes are bacteria
    - Bacteria represent every nutritional mode and contain many divisions
      - Alpha proteobacteria - closely associated with eu hosts, include Rhizobium bacteria that live in root nodules, mitochondria evolved from these
      - Beta proteobacteria - oxidize NH_4^+ into NO_2^-
      - Gamma proteobacteria - sulfur bacteria, E coli, salmonella
      - Delta proteobacteria - colonial, secrete a slimy substratum to glide on through soil, can make a fruiting body in bad conditions, includes predatory bacteria
      - Epsilon proteobacteria - close to Delta, include the bacteria that cause stomach ulcers
      - Chlamydias - lack peptidoglycan, depend on hosts for almost everything (even ATP)
      - Spirochetes - turn when internal flagellum-like filaments make a corkscrew movement
      - Gram-positive bacteria - includes some closely related gram negatives, some make branched colonies, include the mycoplasmas which are the smallest bacteria
      - Cyanobacteria - only ones with plant-like photosynthesis, some do N fixation
- The Ecological Impact of Prokaryotes
  - Prokaryotes are indispensable links in the recycling of chemical elements in ecosystems
    - Decomposers let C, N, and other elements be recycled back to us
    - Autotrophic prokaryotes make organic compounds to pass up the chain
    - Cyanobacteria restore O to the atmosphere and fix N
  - Many prokaryotes are symbiotic
    - Symbiosis - organisms of different species live in direct contact
      - Host - the larger of the two, if there is one
      - Mutualism - both benefit
      - Commensalism - one benefits, other is unaffected
      - Parasitism - parasite benefits at the expense of the host
  - Pathogenic prokaryotes cause many human diseases
    - Opportunistic - normal residents of the host, but can cause illness when the host's defense are lowered
    - Koch's postulates - establish if a pathogen is the cause of a disease
      - Must find the same pathogen in every diseased individual
      - Must isolate the pathogen from a diseased subject and grow the microbe in a pure culture
      - Must induce the disease in experimental animals by transferring the pathogen from

            the culture
        - Must isolate the same pathogen from the experimental animals after the disease develops
      - Exotoxins - proteins secreted by prokaryotes that can produce disease symptoms even without the prokaryotes being present
      - Endotoxins - components of the outer membranes of some gram-negative bacteria that also cause disease symptoms
      - Many or our antibiotics come from a soil bacteria that naturally secretes them to stop other prokaryotes
    - Humans use prokaryotes in research and technology
      - E coli is the lab rat of prokaryotes
      - Bioremediation - removal of pollutants from water, air, and soil by using organisms
        - Ex: prokaryotes decompose our sewage to minerals that can be used as fertilizer
        - Ex: some bacteria decompose petroleum compounds on beaches and oil spills
        - Ex: cheese and yogurt making!
      - Humans are continuing to breed prokaryotes that are better at bioremediation

- Chapter 28: The Origins of Eukaryotic Diversity
  - Introduction to the Protists
    - Systematists have split protists into many kingdoms
      - Paraphyletic, including not only single celled organisms, but simple and complex multicellular organisms, including seaweeds
    - Protists are the most diverse of all eukaryotes
      - Single cell protists are among the most complex of cells because one cell must carry out all of the organism's needs
      - Nutritional modes include autotrophs, heterotrophs, and mixotrophs (Ex: Euglena)
        - Protozoa - animal like protists; ingest food
        - Algae - plant like protists; photosynthesize
        - Absorptive protists - fungus like protists
      - Protists often have flagella or cilia, though these are extensions of the cytoplasm, unlike prokaryotic flagella, which attach to the cell surface
      - Syngamy - the union of two gametes; mode by which some protists reproduce sexually
        - Some protists are entirely asexual
      - Cysts - resistant cells that form from protists to survive harsh conditions
      - Plankton - communities of organisms, mostly microscopic, that drift passively or swim weakly near the water surface; mostly protists
      - Phytoplankton - planktonic algae and cyanobacteria; bases of most food webs
  - The Origin and Early Diversification of Eukaryotes
    - Endomembranes contributed to larger, more complex cells
      - Prokaryotes grew more complex by becoming multicellular (filamentous cyanobacteria), forming complex communities, and compartmentalizing different functions within a single cell
        - Compartmentalizing included infolding of the membrane to make the ER and golgi and endosymbiosis to gain the mitochondria and chloroplasts; it formed the first eukaryotic cells
    - Mitochondria and plastids evolved from endosymbiotic bacteria
      - Plastids - the class of organelles that includes chloroplasts and other photosynthetic and nonphotosynthetic organelles
      - Serial endosymbiosis - mitochondria and chloroplasts were formerly small prokaryotes living within larger cells
        - The smaller cells probably gained access to the larger cells as undigested prey or internal parasites
        - Mitochondria evolved before chloroplasts because mitochondria are more

widespread
        - Supported by similar size between chloroplasts and mitochondria and similar bacteria, similar enzymes and transport systems, similar replication process, similar genome, and presence of ribosomes and enzymes within the mitochondria and chloroplasts that resemble those in prokaryotes
- The eukaryotic cell is a chimera of prokaryotic ancestors
    - Closest relatives to eukaryotic plastids is cyanobacteria
    - Possible transfer of some of the plastid DNA to the host's genome makes it so plastids cannot live independently
- Secondary endosymbiosis increased the diversity of algae
    - Secondary endosymbiosis - some organelles have multiple bilayers because each time they (or the cell they are in) is taken in by another, a new infolding of membrane forms another layer around them
        - Sometimes, the endosymbiont from secondary endosymbiosis still has a remnant of a nucleus, but usually everything degrades except for the plastid
- Research on the relationships between the three domains is changing ideas about the deepest branching in the tree of life
    - The endosymbiosis theory adds "cross branches" to the previously made tree of life
    - New model of tree of life has the three domains collectively rising from a common ancestral community of primitive cells rather than a last universal common ancestor
- The origin of eukaryotes catalyzed a second great wave of diversification
    - First wave of diversification was in prokaryotic metabolic diversity
    - Second wave was in development of the eukaryotic structure
    - Third was the development of multicellular forms
    - SSU rRNA (small sub-unit ribosomal RNA) and amino acid sequences are used to make phylogenetic trees

- A Sample of Protistan Diversity
        - Moving from more distant relations to animals to their closest relatives
    - Diplomonadida and Parabasala: Lack mitochondria
        - Believed to have lost their mitochondria
        - Diplomonads - multiple flagella, two separate nuclei, a simple cytoskeleton, no plastids, and no mitochondria
            - Includes Giardia, which causes abdominal cramps and severe diarrhea and is picked up from drinking contaminated water
        - Parabasilids - Also lacks mitochondria, best known species inhabits the human female vagina and can cause an infection if the pH levels are off
    - Euglenozoa: Includes both photosynthetic and heterotrophic flagellates
        - Euglenoids - anterior pocket from which one or two flagella emerge, have glucose storage molecule (Paramylon), include autotrophs, heterotrophs, and mixotrophs
        - Kinetoplastids - one large mitochondrion associated with the kinetoplast (houses extranuclear DNA), symbiotic or pathogenic
    - Alveolata: Unicellular protists with subsurface cavities (alveoli)
        - Dinoflagellates - abundant components of phytoplankton; make blooms; can be bioluminescent; some eat fish
        - Apicomplexans - parasites of animals; make infectious cells called sporozoites
            - Ex: Malaria
        - Ciliates - solitary cells in fresh water with many, short cilia; undergo conjugation to shuffle alleles
    - Stramenopila: includes the water molds and the heterokont algae
        - Oomycotes (includes water molds, white rusts, and downy mildews) - lack chloroplasts; unicellular or hyphae (analogous to fungal hyphae)
        - Diatoms - glasslike walls forming geometric shells; common in ocean water and later become

oil; fossilized walls of diatoms form sediments

- Golden algae - color results from yellow and brown carotene and xanthophyll pigments; biflagellated; some are mixotrophic
- Brown algae - largest and most complex algae, multicellular and marine, one group of seaweeds

- Structural and biochemical adaptations help seaweeds survive and reproduce at the ocean's margins
  - Thallus - seaweed body that is plantlike, but lacks true roots, stems and leaves
  - Holdfast - rootlike structure that anchors the alga
  - Stipe - stemlike structure that supports leaflike blades
- Some algae have life cycles with alternating multicellular haploid and diploid generations
  - Alternation of generations - the alternation of multicellular haploid forms and multicellular diploid forms
  - Sporophyte - diploid individual, makes reproductive cells called spores (zoospores)
  - Gametophyte - haploid individual, makes gametes
  - Heteromorphic - the sporophyte and gametophyte are structurally different
  - Isomorphic - they look alike though they still differ in chromosome number
- Rhodophyta: Red algae lack flagella
  - Red because of phycoerythrin
  - Evolved from cyanobacteria
  - Multicellular and form seaweeds
- Chlorophyta: green algae and plants evolved from a common ancestor
  - Named for bright green chloroplasts
  - Scientists are considering making one kingdom with both green algae and plants
  - Lichens - fungi that live symbiotically with chlorophytes
  - Larger size and complexity formed by formation of colonies, repeated division of nuclei with no cytoplasmic division, and formation of true multicellular forms
- A diversity of protists use pseudopodia for movement and feeding
  - Pseudopodia - temporary cellular extensions
  - Amoebas (rhizopods) - unicellular, use pseudopodia to move and feed, some secrete protein shells that may be covered in sand grains
  - Heliozoans - life inside glassy or chitinous unfused plate shells with many thin projections
  - Radiolarian - skeleton fused into one delicate piece, usually made from silica
  - Forams - porous shells made from organic material hardened with calcium carbonate, strands of cytoplasm extend through the pores
- Mycetozoa: slime molds have structural adaptations and life cycles that enhance their ecological roles as decomposers
  - "Fungus animals" though they are neither
  - Analogous resemblance to fungi
  - Myxogastrida (plasmodial slime molds) - diploid zygote divides nucleus without ever dividing cytoplasm, "supercell" mass feeds, mass spreads and sends up stalks with little cells inside, some cells fly away as spores, they hatch into either amoeboid cells or flagellated cells that join together to form a diploid amoeboid cell again
  - Cellular slime molds - similar to first multicellular organisms, differ from plasmodial slime molds because each individual nucleus in the aggregate belongs to a single, enclosed cell, cellular slime molds are haploid for most of the life cycle, and cellular slime molds don't have flagellated stage
- Multicellularity originated independently many times

- Chapter 29: Plant Diversity 1: How Plants Colonized Land
  - An Overview of Land Plant Evolution
    - Evolutionary adaptations to terrestrial living characterize the four main groups of land plants
      - Bryophytes (and mosses) - distinguished from algae by reproductive system where offspring develop from multicellular embryos that remain attached to the "mother" plant

        - Ex: Liverworts, hornworts, and mosses
      - Vascular plants - a clade including all plants except for bryophytes; derived character of vascular tissue
        - Vascular tissue - tissue where cells are joined in tubes that transport water and nutrients throughout the plant body
        - Bryophytes are called nonvascular plants
      - Pteridophyes (seedless plants) - vascular plants lacking seeds
        - Ex: Lycophytes, ferns, horsetails, and whisk ferns
      - Seed - a plant embryo packaged along with a food supply within a protective coat
      - Gymnosperms - first seeded plants
        - Ex: Ginkgo, cycads, gnetae, conifers
      - Angiosperms - flowering seeded plants, most common today
    - Charophyceans are the green algae most closely related to land plants
      - Traits such as photosynthesis, cell walls, and types of chlorophyll are shared between plants and other species
      - The sole distinguishing characteristics of plants (but still includes charophyceans - closest relatives of plants) are rosette cellulose cellulose-synthesizing complexes and the enzymes in peroxisomes
      - Additional homologies to link land plants to charophycean algae are flagellated sperm cells and certain details of cell division, such as formation of a phragmoplast - an alignment of cytoskeletal elements and Golgi-derived vesicles across the midline of the dividing cell
    - Several terrestrial adaptations distinguish land plants from charophycean algae
      - Apical meristems - localized regions of cell division at the tips of roots and shoots
      - Placental transfer cells - present in the embryo, transfer nutrients from the parent to the embryo
        - Embryophytes - another name for land plants, comes from their derived character of multicellular, dependent embryos
      - Alternation of generations - both sporophyte and gametophyte are multicellular
      - Walled spores - walls made from sporopollenin (most durable organic material known), made within sporangia, spore mother cells undergo meiosis to generate the haploid spores
      - Multicellular gametangia - organs that produce gametes
        - Archegonia - female gametangia, vase-shaped organ that produces a single egg cell and retains it in the base of the organ
        - Antheridia - male gametangia, make many sperm cells that are released to the environment when mature
      - Cuticle - polyester and wax layer in epidermis of plant leaves to save water and protect against microbial attack
      - Stomata - controllable pores that allow for gas exchange and evaporation
      - Xylem - dead, tube shaped cells that carry water and minerals up from roots
      - Phloem - a living tissue that transports sugars, amino acids, and other organic compounds throughout the plant
      - Secondary compounds - side branches from normal metabolic pathways to produce substances that provide defense against herbivores with bitter tastes, absorb UV radiation, attack pathogenic microbes, and strengthen cell walls
  - The Origin of Land Plants
    - Land plants evolved from charophycean algae over 500 million years ago
      - Similarities include homologous chloroplasts, homologous cell walls, homologous peroxisomes, phragmoplasts, homologous sperm, and molecular systematics
    - Alternation of generations in plants may have originated by delayed meiosis
      - Most charophyceans are all haploid except for a diploid zygote
      - Meiosis in the zygote was delayed, making a sporophyte
      - This increased the number of spores that could be made per zygote
    - Adaptations to shallow water preadapted plants for living on land

        - Plant taxonomists are reevaluating the boundaries of the plant kindgom
            - Deep Green - initiative to name major plant clades
            - Kingdom Streptophyta - the kingdom that would include plants and charophyceans
            - Viridiplantae - kingdom that would include plants and all green algae
        - The plant kingdom is monophyletic
    - Bryophytes
        - The three phyla of bryophytes are mosses, liverworts, and hornworts
            - Bryophytes as a group aren't monophyletic, each phylum diverged independently
        - The gametophyte is the dominant generation in the life cycles of bryophytes
            - Protonema - green, branched, one-cell-thick filaments produced by germinating moss spores
                - Give the moss a large surface area for absorption of water and minerals
            - Gametophore - gamete-producing structure on meristems on buds that rise from protonema when resources are available
            - Rhizoids - long, tubular single cells or filaments of cells that anchor bryophytes close to the ground
            - Sperm swim through water films on the plants
        - Bryophyte sporophytes disperse enormous numbers of spores
            - Sporophyte remains attached to its parental gametophyte through the sporophyte lifetime, dependent on the gametophyte for sugars, amino acids, minerals, and water
            - Moss sporophytes have a foot in the gametophyte, a seta (elongated stalk), and a sporangium (or capsule)
            - Calyptra - gametophyte tissue that protects immature capsules
            - Peristome - upper part of the capsule, specialized for gradual spore discharge
            - Life cycle: Antheridia produces sperm, they swim through moisture to the archegonium and fertilize the egg, the diploid zygote divides by mitosis and forms a sporophyte, the sporophyte elongates and develops specialized parts while making spores, spores are released, they "hatch" and form protonemata that lead to growing of the gametophyte
        - Bryophytes provide many ecological and economic benefits
            - Can be desiccated and survive better than vascular plants and phenolic compounds in the cell wall absorb UV
            - Peat - undecayed organic material made by sphagnum moss, stabilizes carbon dioxide levels
                - Sphagnum itself has been used for diapers, dressing wounds, etc. because of it can absorb 20 times its weight in water
    - The Origin of Vascular Plants
        - Additional terrestrial adaptations evolved as vascular plants descended from mosslike ancestors
            - Protracheophyte - plants that developed before vascular plants, they had branched sporophytes that weren't dependent on gametophytes for growth and were about equal in size to gametophytes
        - A diversity of vascular plants evolved over 400 million years ago
            - Cooksonia - earliest known vascular plant; had lignified cells similar to xylem cells and bulbous sporangia at the ends of branches
    - Pteridophytes: Seedless Vascular Plants
        - Pteridophytes provide clues to the evolution of roots and leaves
            - Most had true roots with lignified vascular tissue
                - Root vascular structure resembles earliest stem vascular structure, suggesting roots evolved from the lowest portion of the stem
            - Microphyll - small leaves with only a single unbranched vein; present in lycophyta, the modern vascular plant that diverged the earliest
            - Megaphylls - normal, multi-vein leaves
                - May have developed from a series of branches lying close together on a stem with webbing developing
        - A sporophyte-dominated life cycle evolved in seedless vascular plants

- Homosporous plants - produce a single type of spore, where each spore develops into a bisexual gametophyte having both female and male gametangia
- Heterosporous - produce megaspores (make female gametophytes) and microspores (make male gametophytes)
- Heterosporous sporophytes were important in the development of seeded plants and were largely absent before then
- With still flagellated sperm, even seedless vascular plants are limited to moist areas
- Life cycle: spore is made, it makes a small, heart-shaped gametophyte, the gametophyte fertilize with others to make a small zygote, which eventually grows out of the gametophyte before producing more spores

- Lycophyta and Pterophyta are the two phyla of modern seedless vascular plants
  - During the Carboniferous period, Lycophyta grew many meters high and made up most of the herbaceous plants and woody trees
  - Many current lycophytes grow on other trees as epiphytes (use the tree as a habitat, not for parasitism)
    - Sporophylls - groups of specialized leaves that bear sporangia and are clustered to form club shaped cones
  - Psilophytes (whisk ferns) - group within Pterophyta that resembles early vascular plants, but is a fern
  - Sphenophytes (horsetails) - Pterophytes that grew many meters tall during the Carboniferous period, but are now small, roadside plants
  - Ferns - most widespread and diverse pteridophytes
    - Sori - clusters of sporangia on the undersides of fern leaves, the pattern of sori arrangement can be used for fern identification
- Seedless vascular plants formed vast “coal forests” during the Carboniferous period

- Chapter 30: Plant Diversity II: The Evolution of Seed Plants
  - Overview of Seed Plant Evolution
    - Reproduction of the gametophyte continued with the evolution of seed plants
      - Sporophyte dependent on gametophyte to large sporophyte and small, independent gametophyte to tiny gametophyte dependent on sporophyte
      - Gametophyte generation still present because it can “test” out the genome in case there is a bad mutation (in which case the gametophyte dies and can’t pass it on) and because sporophyte embryos are still dependent to some extent on tissues of the maternal gametophyte
    - Seeds became an important means of dispersing offspring
      - Seed - consists of a sporophyte embryo packaged along with a food supply within a protective coat, allows the plant to germinate later if conditions are bad
      - Parent sporophyte doesn’t release megaspores, they develop into gametophytes, which nourish a new sporophyte embryo, all within the original sporophyte parent
      - Integuments - layers of sporophyte tissue that envelop the megasporangium; become seed’s protective layer
      - Ovule - the whole structure including integuments, megasporangium, and megaspore
    - Pollen eliminated the liquid-water requirement for fertilization
      - Microspores develop into pollen grains, which mature into the male gametophyte and are carried by wind or animals to the megasporangium
    - The two clades of seed plants are gymnosperms and angiosperms
  - Gymnosperms
    - The Mesozoic era was the age of gymnosperms
      - Lycophytes, horsetails, and ferns were largely replaced by gymnosperms due to the drying climate
    - The four phyla of extant gymnosperms are ginkgo, cycads, gnetophytes, and conifers

        - Ginkgo, cycads, and gnetophytes are all small phyla, only consisting of a few species
        - Coniferophyta - the largest of the gymnosperm phyla, mostly large evergreens, most have needle leaves
    - The life cycle of a pine demonstrates the key reproductive adaptations of seed plants
        - Sporophytes are packed in scalelike sporophylls packed into cones
        - Most trees have male and female cones
        - Life cycle: trees have both pollen and ovulate cones, pollen cone has hundreds of microsporangia in sporophylls that undergo meiosis to make pollen grains, ovulate cones have many scales, each with two ovules
        - Windblown pollen falls into the ovulate cone and is drawn into the ovule through the micropyle (opening in integuments), pollen grain germinates, forming a pollen tube that eats its way to the megasporangium
        - Before fertilization, a single megaspore mother cell undergoes meiosis to make four megaspores, but only one survives
        - The megaspore grows and divides, making the female gametophyte with two or three archegonia
        - A sperm nucleus enters an archegonium and forms a zygote that develops into an embryo, which is released within a seed with the parent's integuments remaining as a seed coat
- Angiosperms (Flowering Plants)
    - Systematists identifying the angiosperm clades
        - Anthophyta - the phylum that contains all angiosperms
        - Previous division of monocots and dicots have changed to include the eudicot clade (mostly just dicots) and multiple other clades
        - Angiosperms have refined vascular tissues (especially xylem)
            - Tracheid - long, tapered cells that function both in support and transport
            - Fiber cells - specialized for support
            - Vessel elements - shorter and wider cells that are arranged end-to-end into continuous xylem vessels that efficiently transport water
    - The flower is the defining reproductive adaptation of angiosperms
        - Flower - an angiosperm structure specialized for reproduction
            - Sepals - modified leaves that enclose the flower before it opens
            - Petals - brightly colored structures that usually aid in attracting insects and other pollinators
            - Stamens - male sporophylls
                - Filament is the stalk and the anther is the terminal sac where pollen is made
            - Carpels - female sporophylls
                - Stigma is sticky tip that receives pollen, style leads to the ovary at the base of the carpel
    - Fruits help disperse the seeds of angiosperms
        - Fruit - a mature ovary
            - As seeds develop after fertilization, the ovary wall thickens
        - Fruits can have adaptations for mobility like dandelions or burrs
        - Others are tasty so animals eat them and deposit the seed with natural fertilizer far away
        - Pericarp - the wall of the ovary and later thickened wall of the fruit
        - Simple fruit - derived from a single ovary (Ex: cherries, soybean pods)
        - Aggregate fruit - results from a single flower that has several carpels (Ex: raspberries)
        - Multiple fruit - develops from a group of flowers tightly clustered together (Ex: pineapples)
    - The life cycle of an angiosperm is a highly refined version of the alternation of generation common to all plants
        - Pollen grains - contain the immature male gametophyte; develops within anthers of stamens; has two haploid cells
        - Ovules - develop in the ovary, contain the female gametophyte, embryo sac

                - Cross pollination - transfer of pollen from flowers of one plant to flowers of a different plant of the same species; generally ensured by measures such as stamens and carpels of a single flower maturing at different times or the organs being arranged in a way that makes self-pollination unlikely
                - Double fertilization - when one of the sperm nuclei joins with the two nuclei in the large center cell of the female gametophyte, making a triploid cell
                    - This cell later forms the endosperm - nutrient rich tissue that nourishes the growing embryo
                - Life cycle:
                    - Anthers produce microspores, which make male gametophytes (pollen)
                    - Ovules produce megaspores that form female gametophytes (embryo sacs)
                    - Double fertilization occurs and the zygote develops into an embryo that is packaged into a seed with the endosperm tissue for food
            - The radiation of angiosperms marks the transition from the Mesozoic era to the Cenozoic era
                - Angiosperms have dominated the plant world for the last 65 million years
            - Angiosperms and animal have shaped one another's evolution
                - Coevolution - mutual evolutionary influence between two species; includes both the herbivore/plant interactions and the pollinator/plant interactions
    - Plants and Human Welfare
        - Agriculture is based almost entirely on angiosperms
            - Angiosperms are eaten as fruits and vegetables, their endosperms are eaten as grains, and various parts of the plants are used for fiber, medications, perfumes, and decoration
            - Agriculture is a unique type of evolutionary relationship between plants and animals where the animals choose the direction the plants are selected in
        - Plant diversity is a nonrenewable resource
            - With the falling of forests, both plant species and animal species are dying out
            - Losing so many species, some still undiscovered, affects us additionally because many rainforest plants are used as medicines, yet so many are being lost

- Chapter 31: Fungi
    - Introduction to the Fungi
        - Absorptive nutrition enables fungi to live as decomposers and symbionts
            - Absorption - small organic molecules are absorbed from the surrounding medium
            - Exoenzymes - powerful hydrolytic enzymes secreted by fungi into their foods
        - Extensive surface area and rapid growth adapt fungi for absorptive nutrition
            - Hyphae - tiny filaments composed of tubular walls surrounding plasma membranes and cytoplasm
            - Mycelium - interwoven mat made up of hyphae; feeding network of fungi
            - Septa - crosswalls that divide cells in some hyphae
            - Chitin - a strong, but flexible N-containing polysaccharide in fungal cell walls and arthropod exoskeletons
            - Coenocytic fungi - hyphae consist of a continuous cytoplasmic mass with thousands of nuclei
            - Haustoria - nutrient-absorbing hyphal tips that penetrate host tissue used by parasitic fungi to prey on plants and occasionally animals
                - Dig through plant cell walls, then push into surface of plasma membrane (like pushing your fingers into a balloon)
                - Hyphae with modified hoops can trap nematodes and digest their inner tissues
            - The thin hyphae grow rapidly and have kilometers of length in cubic centimeters of soil, bringing vast amounts of surface area
        - Fungi disperse and reproduce by releasing spores that are produced sexually or asexually
            - Way too many spores are produced, so they float around everywhere in case they can find a suitable habitat

        - Many fungi have a heterokaryotic stage
            - Heterokaryon - “different nuclei”, two hyphae with genetically different nuclei join, making a genetically heterogenous mycelia
                - Nuclei may stay in different parts of the same mycelium or they may mingle or even exchange genetic material in a process like crossing over
                - Advantage over diploidy because one haploid genome might be able to compensate for harmful mutations in the other
            - Plasmogamy - the fusion of the two parents’ cytoplasm when their mycelia come together
            - Karyogamy - the fusion of the haploid nuclei contributed by the two parents
                - Can happen hours or centuries after plasmogamy
                - Between the two, the mycelium is a heterokaryon
            - Dikaryotic - “two nuclei”, when the haploid nuclei pair off, two to a cell, one from each parent; form of heterokaryon
    - Diversity of Fungi
        - Phylum Chytridiomycota: Chytrids may provide clues about fungal origins
            - Chytrids - mainly aquatic; saprobes and parasites
                - Some are unicellular, thought most form coenocytic hyphae
                - Most primitive fungi, similar to funguslike protists
                - Have flagellated spores (like protists, unlike other fungi)
        - Phylum Zygomycota: Zygote fungi form resistant structures during sexual reproduction
            - Mycorrhizae - mutualistic associations with the roots of plants; zygote fungi
            - Coenocytic with septa only where reproductive cells are formed
            - Zygosporangium - resistant structure produced by plasmogamy where karyogamy and meiosis occur
            - Life cycle of sample zygote fungi
                - Mycelia of opposite mating types form gametangia (hyphal extensions), each walled off around many haploid nuclei by a septum
                - The gametangia do plasmogamy, forming a heterokaryotic zygosporangium with multiple nuclei from each parent
                - The zygosporangium develops a thick, rough coating and can stay resistant for months if needed
                - During favorable conditions, karyogamy happens, the diploid nuclei undergo meiosis, the zygosporangium breaks dormancy, then it forms a short sporangium that disperses genetically diverse spores, which grow into new mycelia
                - Can also reproduce asexually by producing sporangia that make identical spores before plasmogamy
            - Phylum Ascomycota: Sac fungi produce sexual spores in saclike asci
                - Range from unicellular yeasts to complex morel mushrooms
                - Form mutualistic associations with algae (lichen)
                - Some form mycorrhizae, others live inside leaves to protect against insects
                - More extensive heterokaryotic stage than zygomycetes
            - Asci - saclike structures that contain the fungal sexual spores
            - Ascocarps - macroscopic fruiting bodies that carry the asci
            - Conidia - naked spores; asexual reproduction
            - Life cycle:
                - Haploid mycelia of opposite mating types become intertwined and form an ascogonium (“female”) and an antheridium (“male”)
                - A cytoplasmic bridge forms, letting nuclei travel from the antheridium to the ascogonium
                - Dikaryotic hyphae from the ascogonium intertwine to form a much larger ascocarp where the tips of the hyphae are asci at the edges of the ascocarp
                - Karyogamy occurs within the asci and the diploid nuclei divide by meiosis, making

    - four haploid nuclei, which each divide by mitosis to make 8 cells in the ascis
    - Cell walls form around the nuclei to form ascospores before the ascospores in all of the asci are released (quite suddenly with an audible hiss!)
    - Ascospores make new mycelia, which can reproduce asexually when conidia (airborne spores) are made and released
- Phylum Basidiomycota: Club fungi have long-lived dikaryotic mycelia
  - Basidium - transient diploid stage in the organism's life cycle
    - Also called club fungi because of the shape of this stage
    - Important decomposers, also make mycorrhiza
    - Basidiocarp - elaborate fruiting body produced by the dikaryotic mycelium in response to environmental stimuli
    - By concentrating growth to the hyphae of mushrooms, a basidiomycete mycelium can send up a mushroom in just a few hours
  - Life cycle
    - Opposite mating type mycelia undergo plasmogamy, creating a fast growing dikaryotic mycelium that outgrows the parent hyphae
    - Environmental cues (rain, temperature) cause the dikaryotic mycelium to form compact masses that form into basidiocarps (like mushrooms)
    - The dikaryotic mycelia are long-lived, producing a new crop of basidiocarps each year
    - Gills on basidiocarp are lined with terminal cells called basidia, where karyogamy and meiosis occur, yielding four haploid nuclei
    - Each basidium grows four appendages, one for each nucleus, then propels the new basidiospores away
    - The spores germinate and grow into haploid mycelia that quickly become dikaryotic again
  - Fairy rings are produced by an expanding mycelium where the fungus uses all of the nutrients (causing stunted grass under the mushrooms), then makes the next ring a little further out
    - The grass slightly closer in than the stunted grass is lush because of the release of nutrients in the ground from fungal digestive enzymes
- Molds, yeasts, lichens, and mycorrhizae are specialized lifestyles that evolved independently in diverse fungal phyla
  - Mold - a rapidly growing, asexually reproducing fungus
    - Can be saprobes or parasites on many different substrates
    - Imperfect fungi - collective name for molds; not a taxon, just a place to put discovered molds until a sexual stage is discovered and the species can be put in a phylum
  - Yeast - unicellular fungi that inhabit liquid or moist habitats (including plant sap and animal tissues)
    - Reproduce asexually by simple cell division or by pinching of bud cells off parent cell
    - Ones that show sexual stages are classified in either Ascomycota or Basidiomycota, otherwise they are just considered imperfect fungi
    - Bread yeast is an ascomycete and is important because it releases CO_2
      - Also used in research
    - Other yeasts cause infections when the immune system is compromised
  - Lichen - symbiotic association of millions of photosynthetic microorganisms held in a mesh of fungal hyphae
    - Fungus is usually ascomycete, but several basidiomycete lichens are known
    - Merging is so complete, lichens are classified as a single organism
    - Fungus gives the alga a suitable physical environment for growth and receives food and sometimes fixed nitrogen from algae
    - Soredia - small clusters of hyphae with embedded algae; form of lichen reproduction
      - Lichen also reproduce with each organism using its own method, fungi

using ascocarps or basidiocarps and algae using cell division
- Each member can live alone in most cases, the symbiosis is better described as mutual exploitation
  - Some fungi invade and kill the algae, but not as fast as the algae reproduce
- Lichens are good pioneers on newly cleared rock and soil surfaces, leading succession

- Mycorrhizae - mutualistic associations of plant roots and fungi
  - Increase absorptive surface area
  - Extremely important to plants
  - Include fungi from all three phyla

- Ecological Impacts of Fungi
  - Ecosystems depend on fungi as decomposers and symbionts
    - Decomposers release nutrients tied up in organic matter
      - Can even digest lignin and cellulose
      - Air has so many fungal spores that as soon as a leaf falls, or an insect dides, it is covered and quickly decomposed
    - The same mechanisms destroy ripe fruit and oak planks in boats
  - Some fungi are pathogens
    - Life on or inside plants, killing them and sometimes making them toxic to humans
    - Mycosis - fungal infection, includes skin mycoses (annoying, but easily curable) and system mycoses (very serious)
  - Fungi are commercially important
    - Eaten plain, used to make cheese and yogurt, and used to made antibiotics
  - Fungi and animals evolved from a common protistan ancestor
    - Discovered from rRNA data

- Chapter 32: Introduction to Animal Evolution
  - What is an Animal?
    - Structure, nutrition, and life history define animals
      - Multicellular, heterotrophic eukaryotes; most do this by ingestion
      - Lack of cell walls (support provided by extracellular matrix with intercellular junctions
      - Nervous tissue and muscle tissue
      - Sexual reproduction with domination of the diploid stage
        - Cleavage - a succession of mitotic cell divisions that occurs after a small flagellated sperm fertilizes a larger, nonmotile egg to form a diploid zygote
        - Blastula - hollow ball made of cells from cleavage
        - Gastrulation - layers of embryonic tissues that will develop into adult body parts are produced; makes the gastrula
        - Larva - only in some animals; sexually immature form; morphologically distinct from adult; may have different niche completely; undergoes metamorphosis to transform
      - Hox genes control transformation of a zygote to an animal of specific form
        - Hox genes contain homeoboxes, which exist in all animals, but in no other organisms
        - More Hox genes corresponds to more complex anatomy
    - The animal kingdom probably evolved from a colonial flagellated protist
      - Similar to modern choanoflagellate colonies where a few cells with flagella are mounted on a stalk and they filter feed
  - Two Views of Animal Diversity
    - The remodeling of phylogenetic trees illustrates the process of scientific inquiry
    - The traditional phylogenetic tree of animals is based mainly on grades in body “plans”
      - Grade - defined by certain body-plan features shared by the animals belonging to that branch
      - Set of dichotomies branch off
        - Parazoa-Eumetazoa - parazoa means no true tissues and includes only the sponges;

eumetazoa includes all other animal phyla

- Radiata-Bilateria dichotomy - radiata includes Cnidaria and Ctenophora (comb jellies); all other phyla have bilateral symmetry (dorsal-ventral, anterior-posterior)
  - Bilateria also have cephalization (sensory stuff near front), radiata are sessile or drifting, Bilateria have mesoderm germ layer between ectoderm and ectoderm
- Acoelomate, pseudocoelomate, and coelomate grades
  - Acoelomates - solid bodied triploblastic animals; flatworms
  - Body cavity - fluid filled cavity between digestive tract and outer body wall
  - Pseudocoelomates - body cavity partially lined by mesoderm; rotifers and nematodes
  - Coelomates - have a true coelom - fluid-filled body cavity completely surrounded mesoderm tissue
    - Coelom acts as hydrostatic skeleton in soft-bodied animals
- Protostome-Deuterostome Dichotomy (within coelomates)
  - Protostomia - mollusks, annelids, and arthropods; have spiral, determinate cleavage, schizocoelous development, blastopore becomes mouth
    - Spiral cleavage - planes of division are diagonal to vertical axis of embryo
    - Determinate cleavage - once the zygote has split, each cell is rigid in what it'll become
    - Schizocoelous development - initially solid masses of mesoderm split to form the coelomic cavities
  - Deuterostomes - echinoderms, and chordates; radial, indeterminate cleavage, enterocoelous development
    - Radial cleavage - cleavage planes are either parallel or perpendicular to the vertical axis of the embryo
    - Indeterminate cleavage - each cell produced from the early cleavage divisions retains the capacity to develop into a complete embryo
    - Enterocoelous: the mesoderm buds from the wall of the archenteron and hollows out

- Molecular systematists are moving some branches around on the phylogenetic tree of animals
  - SSU rRNA analysis changed some branching ideas
  - Parazoa-eumetazoa and radiata-bilateria are retained
  - Next division is Deuterostomia and Protostomia (instead of division based on coelom)
    - Molecular data supports that the coelom was either simplified (pseudocoelomates) or lost (acoelomates) after development
    - Protostomia split into Lophotrochozoa and Ecdysozoa
      - Ecdysozoa - secrete external skeletons and molts
      - Lophotrochozoa - have lophophore (horseshoe-shaped crown of ciliated tentacles used in feeding) and trochophore larva (several bands of cilia)

- The Origins of Animal Diversity
  - Most animal phyla originated in a relatively brief span of geologic time
    - Ediacaran period - last period of the Precambrian era; origin of animals
    - Cambrian explosion created most of the major phyla as well as the beginning of land animals
  - "Evo-devo" may clarity our understanding of the Cambrian diversification
    - Ecological causes - beginning of predator-prey relationships could lead to a diversity of adaptations such as shells and new modes of locomotion
    - Geologic causes - increase in atmospheric oxygen levels could allow for more active metabolisms
    - Genetic causes - varying in forms of Hox genes

- Chapter 33: Invertebrates
  - Parazoa
    - Phylum Porifera: Sponges are sessile with porous bodies and choanocytes
      - Spongocoel - central cavity of sponge
      - Osculum - opening through which water flows out of a sponge
      - Complex sponges have folded body walls, branched water canals, and several oscula
      - Choanocytes (collar cells) - flagellated cells that line the inside of the spongocoel, generate a current with the flagella, and trap food with the collars
      - The existence of choanocytes reinforces the hypothesis that animals began with colonial choanoflagellates
      - Mesohyl - gelatinous region separating the two cell layers of a sponge body
      - Amoebocytes - cells that wander through the mesohyl and have pseudopodia; take up food from the water and choanocytes, digest it, and carry nutrients to other cells
        - Also form tough skeletal fibers within the mesohyl
      - Hermaphrodites - organisms that can individually function both as a female or a male in sexual reproduction
        - Gametes arise from choanocytes or amoebocytes
        - Eggs stay in the mesohyl, but sperm cells are carried out by the water current
        - Fertilization happens in the mesohyl, where flagellated, swimming zygotes develop and swim away, where they settle on a substratum and develop into a sessile adult
  - Radiata
    - Phylum Cnidaria: Cnidarians have radial symmetry, a gastrovascular cavity, and cnidocytes
      - Basic body plan is a sac with a central digestive compartment (gastrovascular cavity)
      - Polyps - cylindrical forms that adhere to the substratum by the non-mouth side of the body and use tentacles around the mouth to get food
      - Medusa - flattened, mouth-down form of a polyp; moves by a combination of passive drifting and contractions of its bell-shaped body
      - Cnidocytes - cells that function in defense and the capture of prey
        - Contain cnidae, capsule-like organelles that can turn out
        - Nematocysts - stinging cnidae that inject poison into the prey
      - Simple contractile fibers in epidermis and gastrodermis represent earliest form of muscles
        - Use gastrovascular cavity as a hydrostatic skeleton against which the contractile cells can work
      - Simple, radial nerve net coordinates movements and contains simple sensory receptors distributed radially around the organism's body
      - Class Hydrozoa - most alternate polyp and medusa forms
      - Class Scyphozoa - mostly medusas with a small polyp stage
      - Class Anthozoa - sea anemones and corals; only polyps
    - Phylum Ctenophora: Comb jellies possess rows of ciliary plates and adhesive colloblasts
      - Superficially resemble cnidarian medusas
      - Have eight rows of comblike plates composed of fused cilia
        - Largest animals that use cilia for locomotion
      - Simple nerves running from sensory organs for orientations to the combs of cilia
      - Colloblasts - adhesive structures on the comb jelly retractable tentacles that help trap food so the jellies can "wipe" the food into their mouths
  - Protostomia: Lophotrochozoa
      - Urbilateria - the first bilateral animals; relatively complex with a true coelom, this was lost in some branches
    - Phylum Platyhelminthes: Flatworms are acoelomates with gastrovascular cavities
      - Triploblastic, but acoelomate and have a gastrovascular cavity with only one opening
      - Turbellaria (planarians) - free-living flatworms, carnivores
        - Lack organs for gas exchange and circulation, so the flat shape of the body places all

            of the cells close to the surrounding water and fine branching of the gastrovascular cavity distributes food throughout the animal
        - Nitrogenous waste diffuses into the surrounding water
        - Cephalization, move on mucus layer they secrete
        - Can reproduce asexually through regeneration or sexually (hermaphrodites)
    - Monogenea and Trematoda (flukes) - parasites in or on other animals
        - Tough outer covering, inside is nearly all reproductive organs
        - Often have an intermediate host where larvae develop before infecting the final host (usually a vertebrae)
    - Cestoidea (tapeworms) - vertebrae parasites; have hooks that lock the worm to the intestinal lining of the host; long ribbon of proglottids (sacs of sex organs) at the end of the body; absorb nutrients through skin; eggs exit host through feces
- Phylum Rotifera: Rotifers are pseudocoelomates with jaws, crowns of cilia, and complete digestive tracts
    - Although smaller than many protists (0.05 to 2 mm), rotifers are multicellular, have specialized organ systems, and are more complex than flatworms
    - Complete digestive tract - separate mouth and anus
    - Internal organs inside the pseudocoelom where fluid serves as a hydrostatic skeleton and as a medium for the internal transport of nutrients and wastes
    - Crown of cilia draws water into the mouth where jaws (trophi) grind food (mostly microorganisms) suspended in the water
    - Parthenogenesis - reproductive process where females only produce more females from unfertilized eggs
        - Some species also produce eggs that hatch into degenerate males that survive just long enough to make sperm to fertilize eggs, which become resistant zygotes that can survive if the pond dries up
- The lophophorate phyla: Bryozoans, phoronids, and brachiopods are coelomates with ciliated tentacles around their mouths
    - Lophophore - a horseshoe-shaped or circular fold of the body wall bearing ciliated tentacles that surround the mouth
        - Cilia draw water toward the mouth between the tentacles, helping trap food particles
    - Additionally, these phyla collectively lack a distinct head and have a U-shaped digestive cavity
    - Bryozoans - somewhat resemble mosses; consist of a colony encased in a hard exoskeleton with pores through which lophophores extend out
        - Very widespread, some are important reef builders
    - Phoronids - tube-dwelling marine worms that extend lophophores out of the end of chitin tubes and retract back when threatened
    - Brachiopods - lamp shells, distinguished from clams and other bivalve mollusks by having the two halves be dorsal and ventral instead of right and left like in clams
        - Attached to substratum by a stalk
        - Very successful in the past, now, few species remain
- Phylum Nemertea: Proboscis worms are named for their prey-capturing apparatus
    - Acoelomate, but has a small fluid-filled sac that may be a reduced coelom
    - Similar to a flatworm except for the new inclusion of a complete digestive tract and a closed circulatory system - blood is contained in vessels and is distinct from body cavity fluid
        - No heart, blood is circulated by squeezing of muscles
- Phylum Mollusca: Mollusks have a muscular foot, a visceral mass, and a mantle
    - Foot - muscular body part usually used for movement
    - Visceral mass - contains most of the internal organs
    - Mantle - fold of tissue that drapes over the visceral mass and secretes a shell (if there is one)
    - Mantle cavity - houses the gills, anus, and excretory pores; made by the mantle extending past

the visceral mass

- Radula - straplike rasping organ used to scrape up food
- Trochophore - ciliated larva also present in some marine annelids and other lophotrochozoans
- Class Polyplacophora
    -