Biochemistry

* Cells; all living things on Earth are made of cells
  + Plants
  + Animals
  + Bacteria
  + Fungi
  + Viruses are not considered to be made of cells; cells must have mitochondria which make ATP for energy and viruses lack these and other components that cells have like ribosomes to make proteins; most biologists say that they are not alive, however this is currently under debate
* Biochemicals
  + Carbohydrates are monomers, oligomers, or polymers of sugars; often called monosaccharides, oligosaccharides, or polysaccharides, respectively
    - Edible carbohydrates are broken down and turned into blood sugar which is used to produce NADH and FADH2 in the interior of mitochondria in a process known as The Citric Acid (TCA) cycle
      * NADH, FADH2, cytochrome oxidase, oxygen, ATP, and phosphate are used to produce ATP in mitochondrial membranes
      * Every cell in every living thing on earth must continuously produce ATP or die
    - Monomers have formula Cn(H2O)n; one H2O is lost whenever a bond is made to another monomer; for example, two C6(H2O)6 make a C12(H2O)11 dimer
    - Chirality; monomers come in pairs of optical isomers, designated D and L; D isomers are natural, and L isomers are mirror images of D isomers
    - Aldoses and ketoses; monomers can interconvert between open (linear) chain and ring form; in open form aldoses are aldehydes and ketoses are ketones
    - Monomers characterized also by number of carbons they contain; Greek prefixes used for this; example: a ketopentose is a 5-carbon sugar which is a ketone in open form (pent=5)
    - Some common monomers (monosaccharides)
      * Glucose (blood sugar)
      * Galactose (found in various foods like bananas and sweet potatoes)
      * Fructose (fruit sugar)
        + Only the liver can turn fructose into blood sugar
        + Overloading the liver with too much fructose can cause liver damage and insulin resistance, leading to type 2 diabetes
      * Erythrulose
        + Found in raspbrries
        + Is used in self-tanning products along with dihydroxyacetone
    - Some common dimers (disaccharides)
      * Sucrose (table sugar; glucose and fructose)
      * Maltose (malt sugar; 2 glucoses bonded together)
      * Lactose (milk sugar; glucose and galactose)
* Some common polymers (polysaccharides)
* Amylose (soluble potato starch; linear glucose polymer with α-1,4 glycosidic links (bonds)
* Amylopectin (insoluble potato starch; branched glucose polymer with α-1,4 glycosidic links and α-1,6 branches
* Glycogen (liver glucose polymer with the same architecture as amylopectin but much more densely branched)
* Cellulose (linear glucose polymer found in wood and paper with β-1,4 glycosidic links)
  + Lipids; biochemicals which are fat or oil-soluble, sometimes water-insoluble
    - Fatty acids have at least 10 carbons including carboxylic acid carbon in a linear chain of C’s and H’s
      * Saturated; no C=C double bonds; found in animal fats
      * Unsaturated; have one or more C=C double bonds
        + Found in vegetables and vegetable oil
        + Cis fatty acids supposedly healthier than trans
        + Especially healthy if cis C=C double bond is 3 carbons from tail end (ω-3 fatty acids; found in fish)
        + Trans fatty acids supposedly very unhealthy
    - Fats
      * A fat molecule is made from a glycerol (a trialcohol) which has reacted with three fatty acids to create a triester molecule; sometimes called triglycerides
      * Digestion breaks fats down into glycerol and fatty acids
        + Mitochondria and the endoplasmic reticulum can turn fatty acids into acetyl-CoA, which can then enter the citric acid cycle, and thereafter do the same biochemistry that blood sugar does (ultimately enabling ATP production)
        + Glycerol can be turned into blood sugar by the liver and the kidneys in a process known as gluconeogenesis
    - Cholesterol is made by the liver, transported through bloodstream with a lipoprotein (it is not water or blood soluble), and converted into various steroid hormones by adrenal and sex glands
    - Phospholipids are made from glycerol, two fatty acids, and a phosphorus-containing acid; these form cell membranes which surround cells
  + α-Amino acids have amino group, carboxylic acid group, a H atom and some other small fragment (called a sidechain) attached to the same carbon (called the α carbon)
    - These are protein monomers; “peptide” is often used with amino acid chains like saccharide is used with sugar chains; α-amino acids are monopeptides; there are 20 of these in natural proteins
    - Aspartame (NutraSweet artificial sweetener) is a dipeptide methyl ester
    - Oligopeptides are often just called peptides
    - Polypeptides are proteins
    - Amino acids have two optical isomers, D, and L; unlike sugars in amino acids the L isomer is the natural one
  + Proteins
    - Structure
      * Primary (1°); the sequence of amino acids bonded together which make the protein; each amino acid has a name based on the structure of its sidechain; the 20 amino acids are each designated by a single capital letter; example: a primary structure of a hexapeptide (6 amino acids) might look like this AGLKLQ
      * Secondary (2°); hydrogen bonding between the H in an N-H fragment and the O in a C=O fragment in the backbone (not in sidechains) elsewhere in the same protein molecule is repeated many times, giving the protein molecule a 3-dimensional shape
        + the two most common shapes are called α-helix and β-sheet
        + α-helix has a coiled shape like a spring or a Slinky
        + β-sheet has a flat shape like a sheet of paper
* Tertiary (3°); other kinds of attractions between sidechains in different parts of the same protein molecule (S-S bonds from two S-H fragments linking from different sidechains, ionic attraction of oppositely charged sidechains, London force between two nonpolar sidechains, and hydrogen bonding between two different sidechains-not backbone); these fine-tune the shape of a protein molecule
* Quaternary (4°); sidechain attractions between different protein molecules; the individual protein molecules are known as subunits and designated with lower-case Greek letters.
* Proteins need to have exact shapes because enzymes need to react with smaller molecular biochemicals to do specific chemical reactions; of the tens of thousands (>40,000) of biomolecules found in the human bloodstream or inside of cells a particular enzyme protein needs to bind to and react with only one kind of molecule; molecular recognition is done largely by shape, the way a lock fits only a particularly-shaped key
  + - Protein functions
      * Tissue (muscle, organs, blood vessels, etc.)
      * Enzymes
        + Work in conjunction with vitamins and minerals
        + Vitamins are organic chemicals (no metal atoms) which are bound to protein molecules but not made of amino acids; they allow the enzymes to do chemistry that amino acids are unable to do
        + Minerals are inorganic (contain metal atoms, usually ionic) chemicals that allow enzymes to do chemistry that organic chemicals are unable to do, often involving oxidation or reduction, metal ions are more able to transfer electrons than organic molecules are
        + Terminology: apoenzyme = protein part, coenzyme = vitamin and/or mineral, holoenzyme = protein plus coenzyme(s)
* Nucleic acids (DNA and RNA) are polymers of nucleotides
  + Monomers made from a sugar (ribose for RNA or 2-deoxyribose for DNA) bonded to a nitrogenous base by replacing OH group on position 1 with a bond to a N atom, creating a nucleoside, and then bonded to a phosphate group on position 5 to make a nucleotide monomer
  + Nitrogenous bases used to make DNA monomers are adenine, guanine, cytosine and thymine
  + RNA uses uracil rather than thymine
  + Adenine and guanine known as purines; these have two rings
  + Cytosine, thymine, and uracil are known as pyrimidines; these have only one ring
  + After the nitrogenous base is added to the sugar the name of the resulting nucleotide is based on the name of the nitrogenous base and includes “deoxy” for nucleoside precursors to DNA: adenosine, guanosine, cytidine, uridine, deoxyadenosine, deoxyguanosine, deoxycytidine and deoxythymidine
  + After addition of phosphate to a nucleoside to make a nucleotide monomer the monomers are generally just designated by a single capital letter, A, C, G, T, and U based on the first letter of the nitrogenous base attached to the nucleotide; the same letters are normally used for DNA and RNA monomers because whether DNA or RNA is being discussed is generally understood from context; however, DNA monomers really should be abbreviated dA, dC, dG, and dT to avoid confusion (“d” for deoxy); as if that isn’t bad enough these abbreviations are often used to refer to either the nucleotide monomers or the nucleoside precursors to these monomers
  + The sequence of a DNA or RNA polymer therefore looks something like this: …ATGGTTACATC… for DNA or …GUAGCUACGU… for RNA
  + After a nitrogenous base is added to ribose or deoxyribose the resulting nucleoside and the nucleotide with phosphate added have the positions of the sugar component redesignated with primes; sugar carbons 1, 2, 3, 4, and 5 are redesignated 1’, 2’, 3’, 4’, and 5’, respectively
  + The connections which link the nucleotide monomers together are made at positions 3’ and 5’ in both DNA and RNA; these connections (bonds) all occur via the elimination of a water molecule (they are condensation reactions)
  + DNA issues
* DNA is double-stranded; forms a double helix structure
* The two DNA molecules are held together by hydrogen bonds between complementary nitrogenous bases
* C on one molecule is always across from, and forms 3 hydrogen bonds to G on the other molecule (mnemonic: C and G look alike and the three H bonds are D, E, and F)
* A on one molecule is always across from, and forms 2 H bonds to T (mnemonic: A and T are on opposite sides of the alphabet, and the alphabet has 2 sides)
* DNA is found in the nucleus of cells and in mitochondria, which make ATP, and were originally free-living bacteria which were eaten by larger bacteria, forming a symbiotic relationship, where the mitochondria make energy for the host cell and the host cell provides sugar (food) for the mitochondria
* DNA is used to produce RNA which has a complementary sequence to the DNA, which then travels out of the nucleus to a ribosome where it produces a protein whose primary structure is based on the RNA sequence; example the DNA sequence 3’-AGTTCA-5’ will produce the complementary RNA sequence 5’-UCAAGU-3’; these polymers bind to one another in the double helix of DNA and in RNA made from DNA in a head-to-tail manner; the 5’ end of one molecule is aligned with the 3’ end of the other molecule; only one strand of the DNA double helix is used to make RNA (the so-called “template” strand)
* DNA in humans has a very complicated structure; we have 23 pairs of chromosomes, each pair contains 4 DNA molecules, 2 complementary molecules from your mother, and 2 from your father; each double helix is wrapped around a large number of spherical proteins called histones producing supercoils which are wrapped around more histones and scaffold proteins to make coils of coils of coils, etc., eventually resulting in 23 pairs of chromosomes, where each pair is held together in the same superstructure by a protein called a cohesion; the histones and scaffold proteins help to control which specific genes (pieces of DNA) are transcribed in a particular cell type to make particular proteins; all cells have DNA for making all proteins, but a particular cell makes only a small number of the complete set of proteins coded by DNA
  + RNA issues
* RNA is generally single-stranded
* It has a 3-D structure where the nitrogenous bases act kind of like sidechains in creating 3° structure in proteins; A on one part of a RNA molecule forms 2 H bonds to U on another part (complementarity) and G forms 3 H bonds to G; only a few of the nitrogenous bases in RNA are involved in this H bonding scheme unlike DNA where all of the nucleotides in one strand are H bonded to complementary nucleotides on the other strand
* RNA is created in the nucleus of a cell by DNA (process called transcription) and then travels to a nanomolecular machine called a ribosome which is made of RNA and protein, which uses the RNA sequence to create the primary sequence of a protein (called translation)
* RNA created from DNA is often referred to as “messenger” RNA, m-RNA, or simply the “message;” it is “decoded” in the ribosome; the RNA coded message is “written” in 3-letter words; a specific sequence of three letters gives rise to a specific amino acid in a developing protein; example: GUC in m-RNA produces the amino acid valine, symbol V
* Decoding is accomplished by a form of RNA known as transfer RNA, t-RNA, which has an anticodon loop on one end and an amino acid bonded to the other end; example: the t-RNA which has the sequence CAG in its anticodon loop will bind to a piece of m-RNA with the complementary sequence, GUC; this particular t-RNA will always have valine attached to the other side which it will attach to a developing protein in a ribosome in the position where the m-RNA has the GUC sequence.
* Protein synthesis
  + Ribosome is composed of two subunits
  + The larger top subunit moves the amino acid attached to the t-RNA into 3 sites as this machinery attaches an amino acid to a growing protein
    - The A (aminoacyl) site binds to a new amino acid attached to a t-RNA which has just landed with its anticodon loop sitting on top of a complementary piece of m-RNA
    - The P (protein) site breaks the developing protein away from the previous t-RNA molecule and attaches it to the amino acid which is still attached to the new t-RNA which has recently landed on the m-RNA with the newest amino acid to be added to the developing protein
    - The E (exit) site ejects the now empty t-RNA (like a gun ejects a shell casing after a bullet has been fired) which has had the developing protein broken away from it by the P site; the developing protein is now attached to the current t-RNA now occupying the P site; another t-RNA with the next amino acid in the sequence is attached to the A site
    - Mnemonic A, P, and E sites spell APE, like the big hairy animal which eats bananas
  + The smaller lower subunit in the ribosome moves the m-RNA along as the m-RNA is “read” by t-RNA molecules and the protein develops
* CRISPR is a technique used to edit DNA to produce GMO’s (Genetically Modified Organisms)