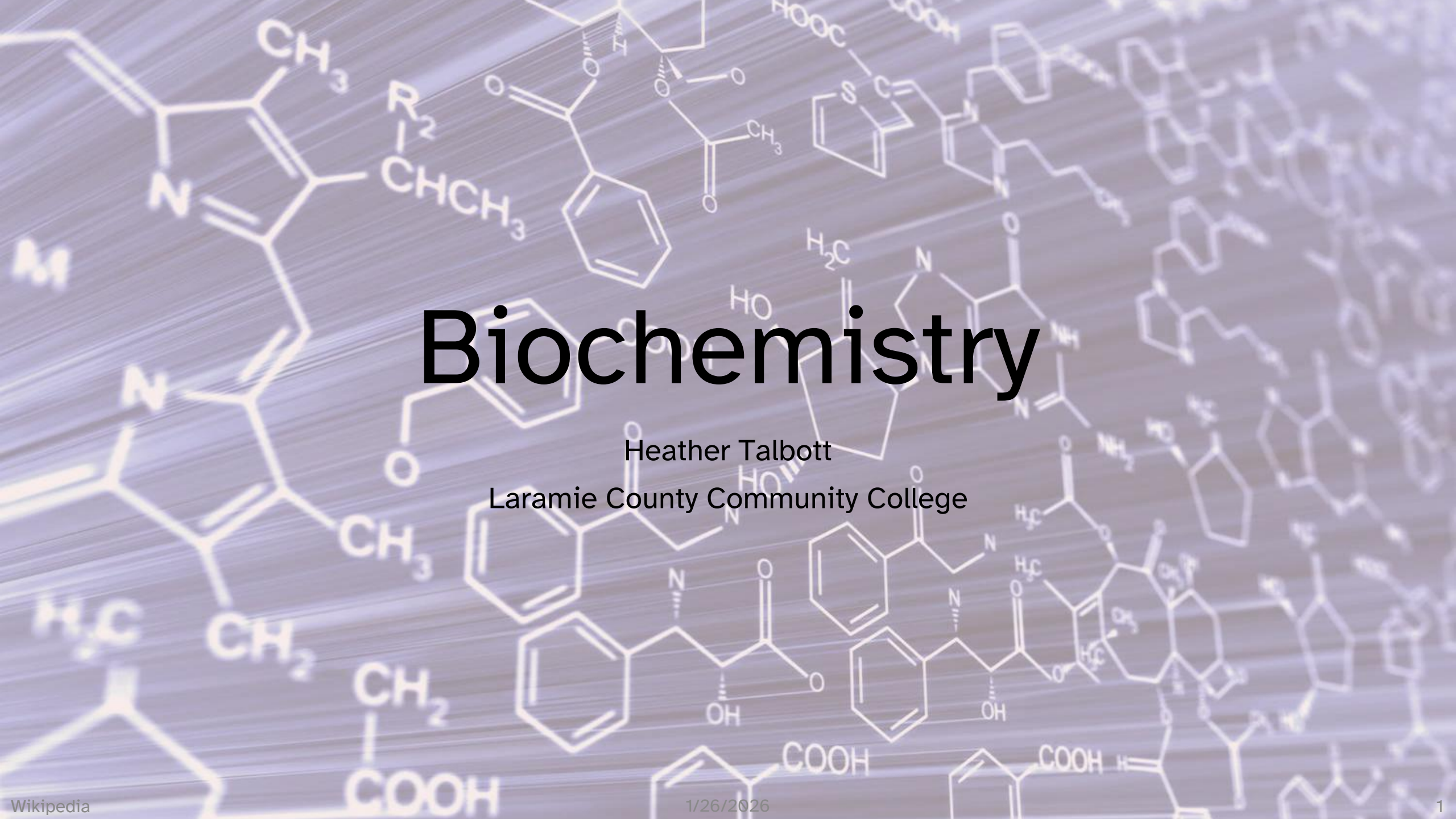


Biochemistry

Heather Talbott

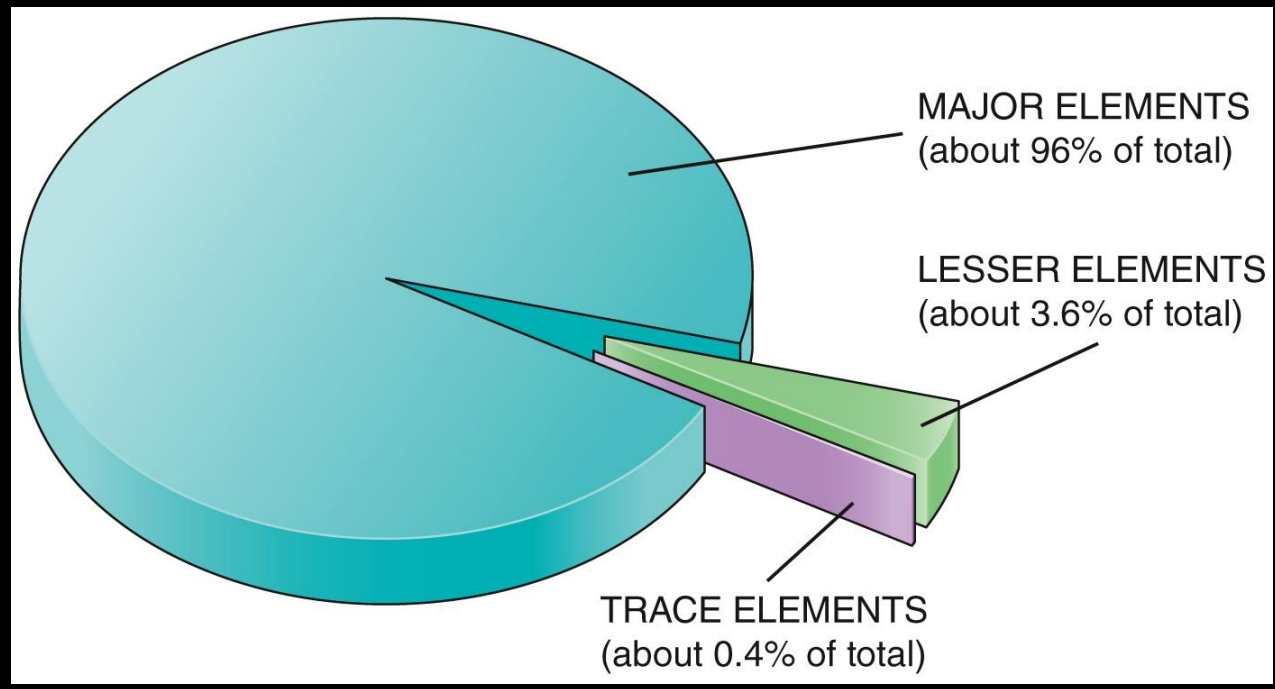
Laramie County Community College

Matter & Elements

- **Chemistry**: the science of structure and interactions of matter = anything that has mass and takes up space
- **Matter**: anything that takes up space and has mass
  - Organisms are composed of matter
- Matter exists in 3 forms:
  1. solids (ex. bones and teeth)
  2. liquids (ex. blood plasma)
  3. gases (ex. oxygen and carbon dioxide)

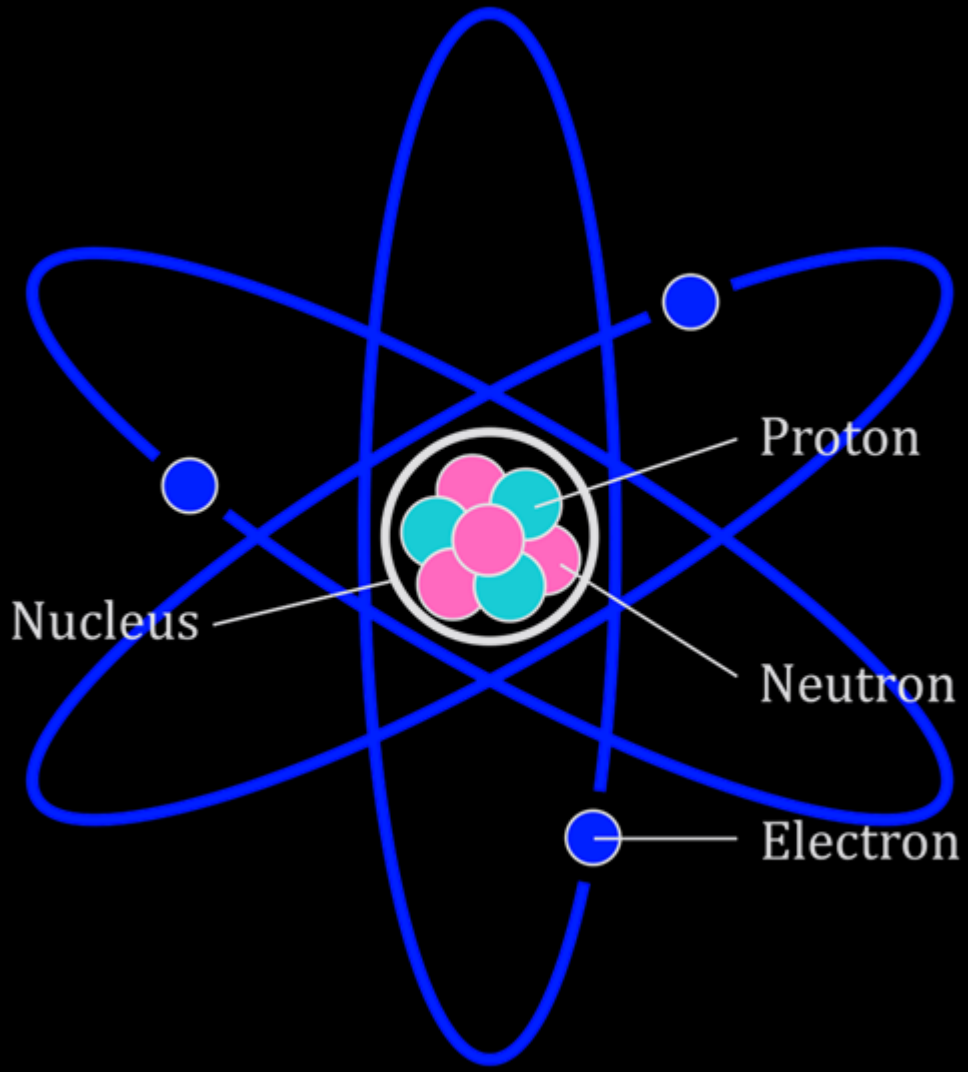
Elements of Humans

- **Element**: a substance that cannot be broken down into other substances by chemical reactions
  - Matter is made up of elements
  - Made up of a single type of atom
  - An element's properties depend on the structure of its atoms
- **Major elements**: constitute 96% of the body's mass
  - oxygen (O), carbon (C), hydrogen (H), nitrogen (N)
- **Lesser elements**: constitute about 3.6% of body mass
  - calcium (Ca), phosphorous (P), potassium (K), sulfur (S), sodium (Na), chlorine (Cl), magnesium (Mg), iron (Fe)
- **Trace elements**: present in tiny amounts, but some are very important for bodily function
  - iodine is needed to make thyroid hormones



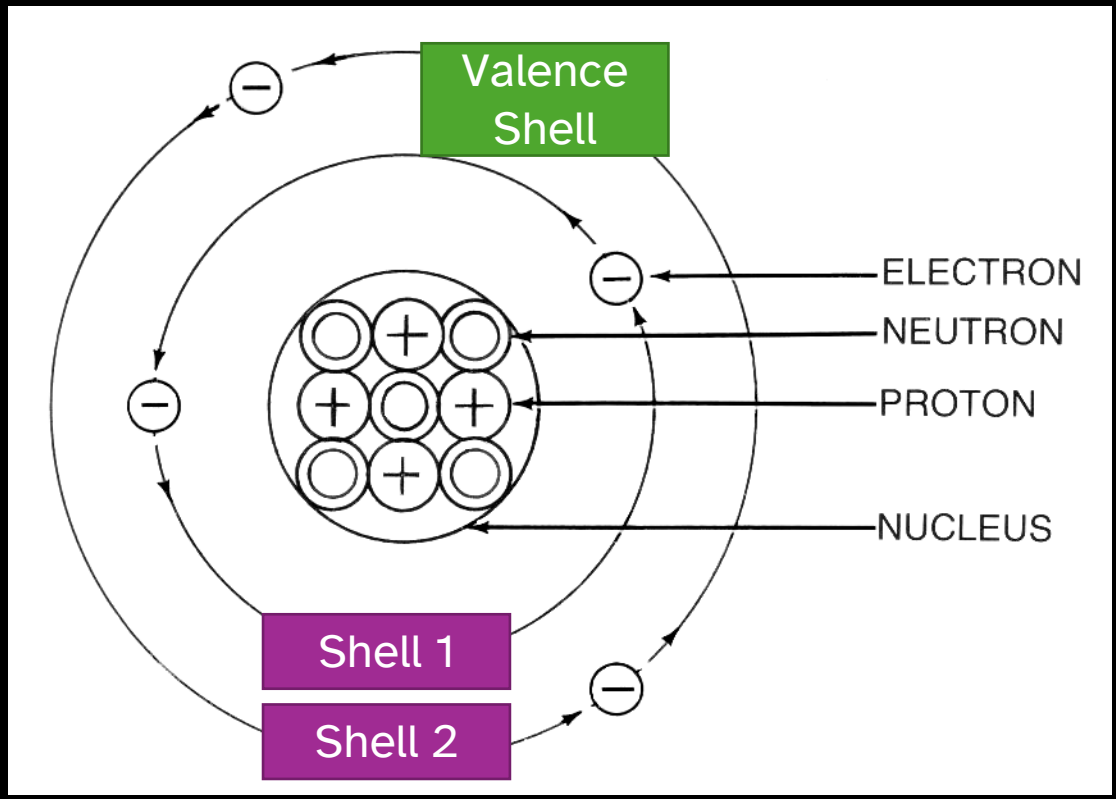
Subatomic Particles

- **Atoms**: the smallest unit of an element that still retains its properties
  - **Protons**: positively charged particles, located in center of atom; defines the element
    - If you change the number of protons, you change the element
  - **Neutrons**: neutrally charged particles, located in center of atom
  - **Electrons**: negatively charged particles, orbit the center of the atom
  - Standard atoms: always have equal numbers of protons, neutrons, and electrons
    - Exception: Hydrogen (H) has 1 P, 0 N, & 1 E



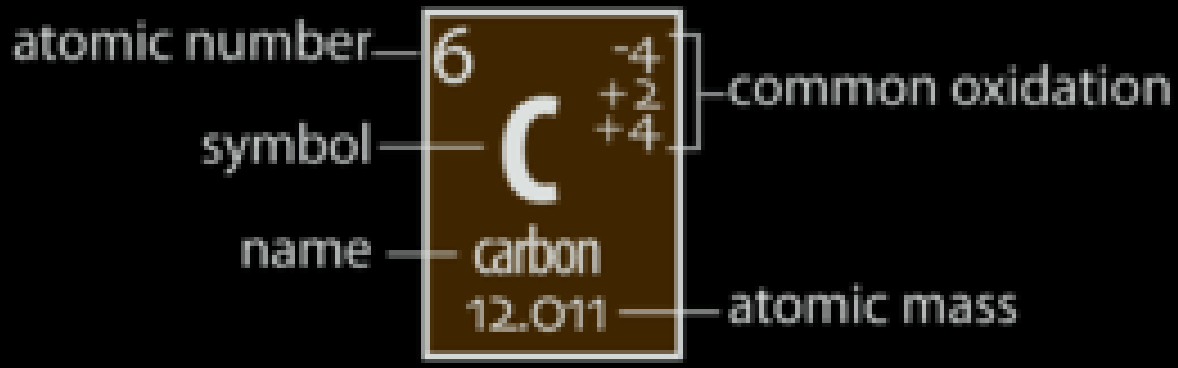
Parts of an Atom

- **Nucleus**: tiny, dense, center of an atom, contains protons (positive) and neutrons (neutral)
- **Electron shell**: a region surrounding atomic nucleus where electrons are found
- **Valence shell**: the outermost electron shell of an atom, containing electrons furthest from nucleus



Periodic table basics

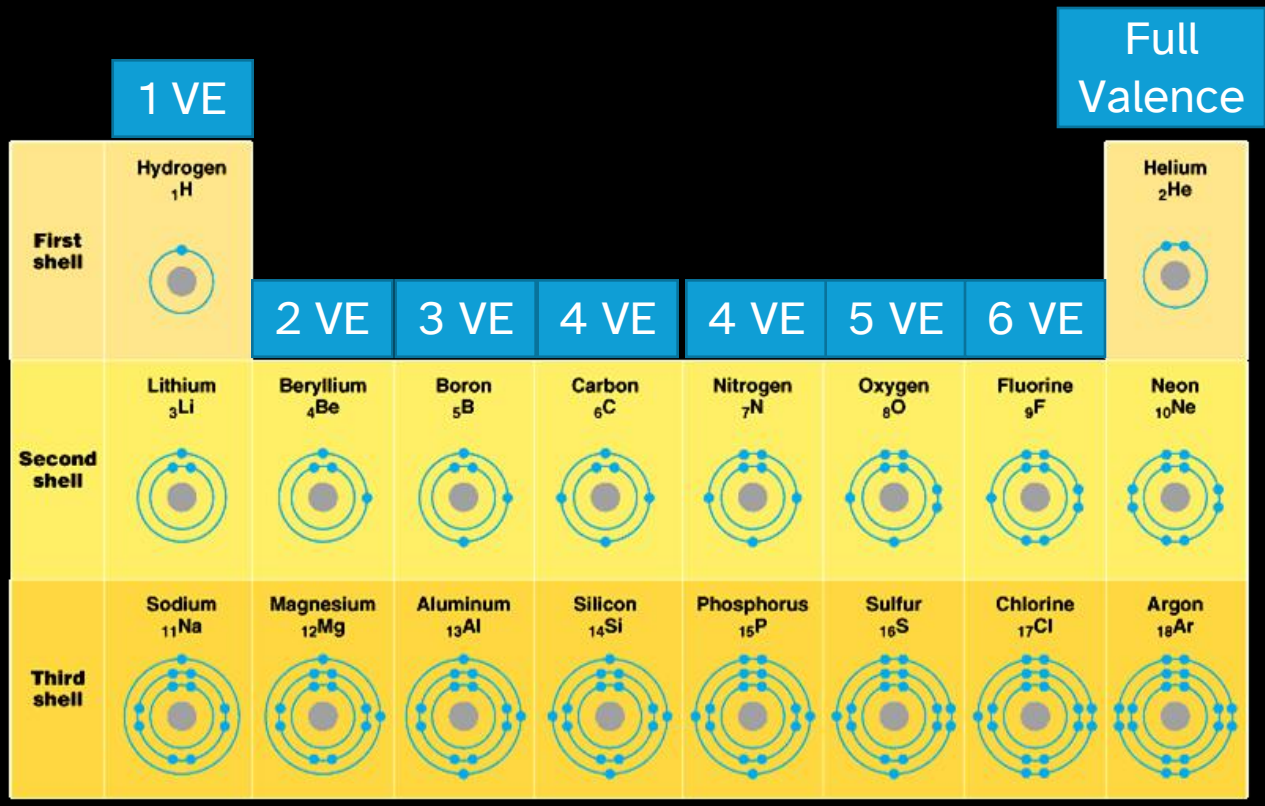
- **Periodic table**: systematic, tabular arrangement of all known chemical elements, ordered by increasing atomic number (number of protons)
  - Organization can help determine many chemical properties of an element
- **Atomic number**: number of protons in the element
- **Symbol**: shorthand for the chemical
- **Atomic mass**: average weight of element



https://commons.wikimedia.org/wiki/File:Periodic_table_AH.png

Periodic table

- **Period**: rows of the table, are used to determine the number of electron shells
- **Group**: columns of the table, are used to determine the number of electrons in the valence shell
- **Nobel gases**: final column of periodic table, have full valence shell and are chemically stable (i.e. don't interact with other chemicals)



https://commons.wikimedia.org/wiki/File:Periodic_table_large.svg

Electronegativity

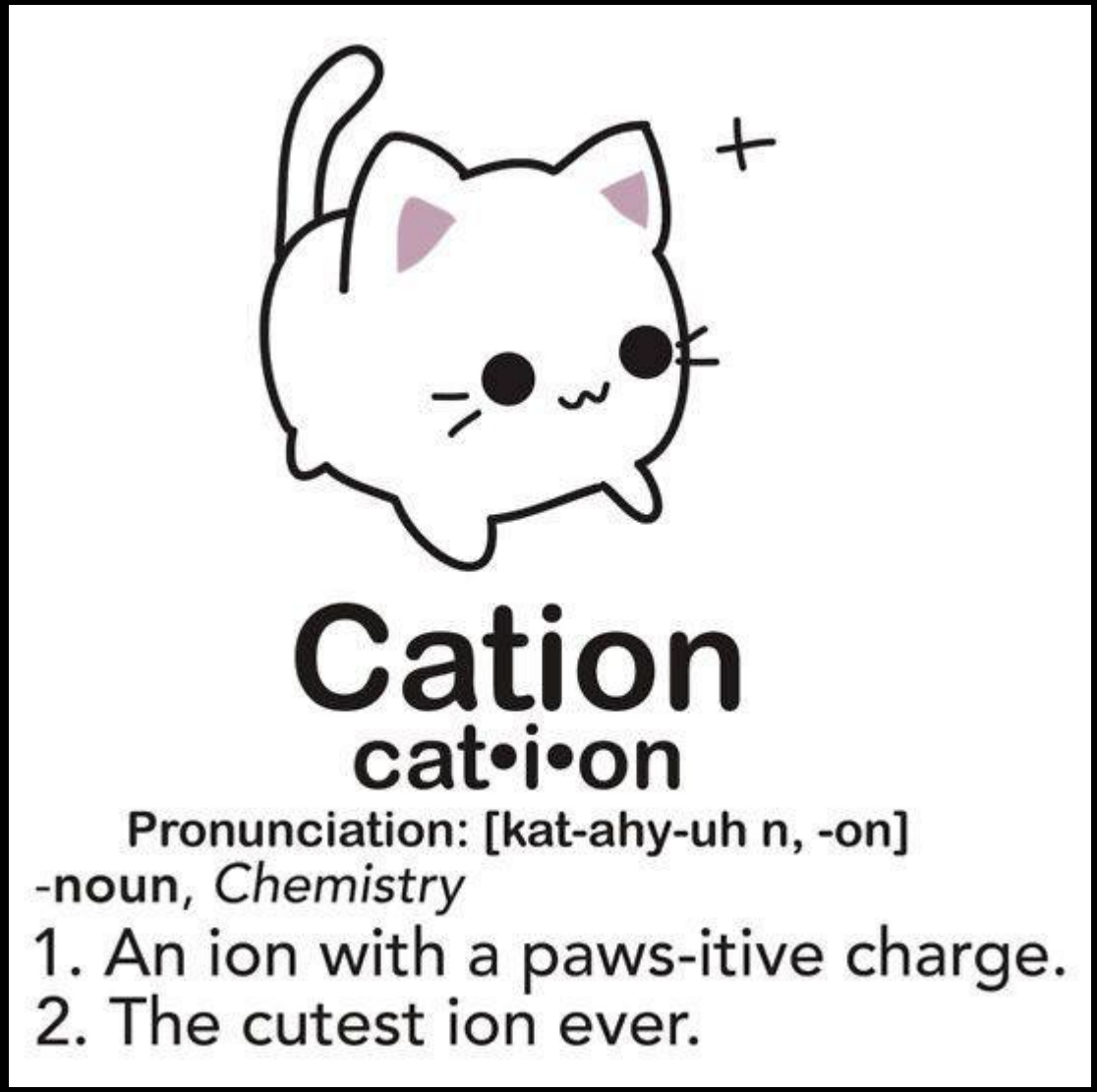
- Electronegativity – tendency of an atom to attract electrons
  - Increases left to right on periodic table (excluding Nobel gases)
  - Increases bottom to top
  - Florine (F) is most electronegative element, explosively so
  - Oxygen (O) is second most <u>electronegative</u> element; this is why we require oxygen

H 2.20																	He
Li 0.98	Be 1.57											B 2.04	C 2.55	N 3.04	O 3.44	F 3.98	Ne
Na 0.93	Mg 1.31											Al 1.61	Si 1.90	P 2.19	S 2.58	Cl 3.16	Ar
K 0.82	Ca 1.00	Sc 1.36	Ti 1.54	V 1.63	Cr 1.66	Mn 1.55	Fe 1.83	Co 1.88	Ni 1.91	Cu 1.90	Zn 1.65	Ga 1.81	Ge 2.01	As 2.18	Se 2.55	Br 2.96	Kr 3.00
Rb 0.82	Sr 0.95	Y 1.22	Zr 1.33	Nb 1.6	Mo 2.16	Tc 1.9	Ru 2.2	Rh 2.28	Pd 2.20	Ag 1.93	Cd 1.69	In 1.78	Sn 1.96	Sb 2.05	Te 2.1	I 2.66	Xe 2.60
Cs 0.79	Ba 0.89	*	Hf 1.3	Ta 1.5	W 2.36	Re 1.9	Os 2.2	Ir 2.20	Pt 2.28	Au 2.54	Hg 2.00	Tl 1.62	Pb 2.33	Bi 2.02	Po 2.0	At 2.2	Rn 2.2
Fr 0.7	Ra 0.9	**	Rf	Db	Sg	Bh	Hs	Mt	Ds	Rg	Uub	Uut	Uuq	Uup	Uuh	Uus	Uuo
*	La 1.1	Ce 1.12	Pr 1.13	Nd 1.14	Pm 1.13	Sm 1.17	Eu 1.2	Gd 1.2	Tb 1.1	Dy 1.22	Ho 1.23	Er 1.24	Tm 1.25	Yb 1.1	Lu 1.27		
**	Ac 1.1	Th 1.3	Pa 1.5	U 1.38	Np 1.36	Pu 1.28	Am 1.13	Cm 1.28	Bk 1.3	Cf 1.3	Es 1.3	Fm 1.3	Md 1.3	No 1.3	Lr 1.291		

Periodic table of electronegativity using the Pauling scale

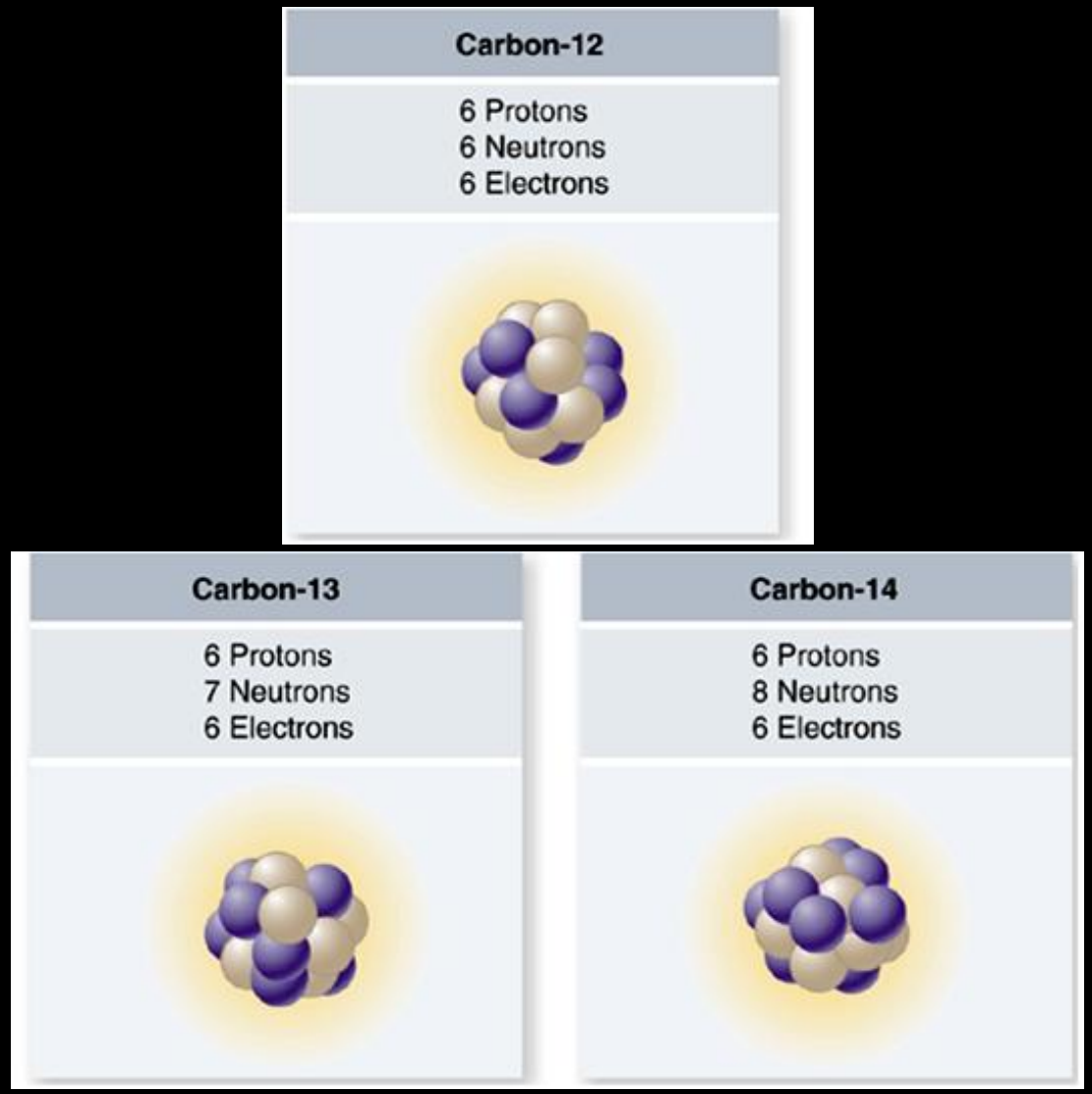
Ions

- Neutral atoms have the same number of protons and electrons
- **Ions:** are charged atoms, formed by changing the number of electrons
  - **Cations**: have fewer electrons than protons and are positively charged
  - **Anions**: more electrons than protons and are negatively charged
  - **Reduction reaction**: the addition of electrons
  - **Oxidation reaction**: the removal of electrons
  - **Redox reaction**: reduction and oxidation reactions must be paired and cooccur
    - OIL RIG (Oxidation is loss; Reduction is gain)
    - Ions are fundamental for life for electrical charge, nerve signals, heart function, and many more functions



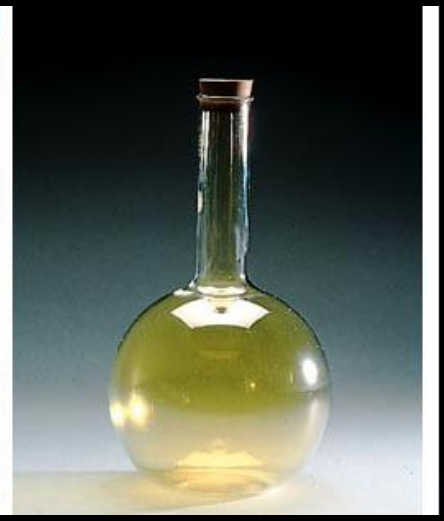
Isotopes

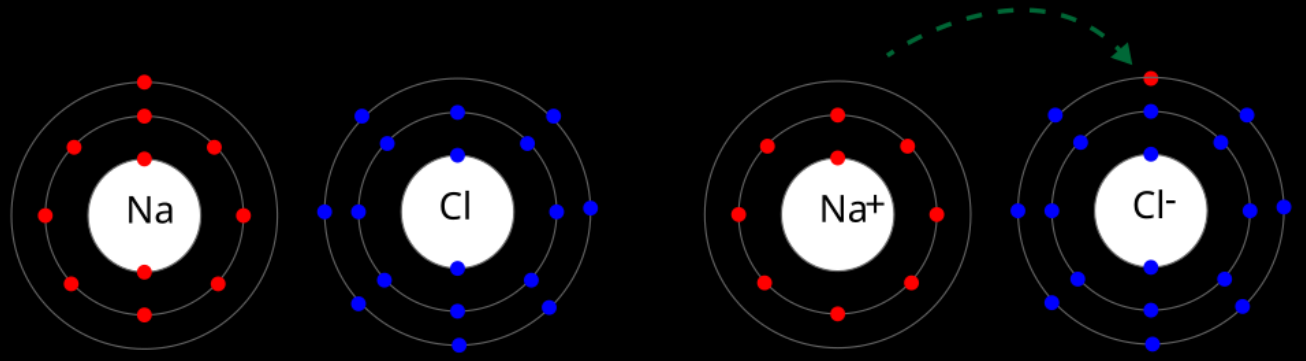
- **Isotopes:** atoms of the same element that have different atomic masses, by changing the neutron numbers
  - Sometimes called heavy or light isotopes
  - **Radioisotopes**: subset of isotopes that have unstable nucleus that emits radiation to transform into a more stable form
  - Important for imaging techniques such as PET, and some cancer treatments
  - ION“I ONce shocked myself” ⚡
  - ISOTOPE“I SO Tired carrying extra neutrons” 😩🎒
- **Atomic mass**: the sum of the protons and neutrons in an atom



Molecules

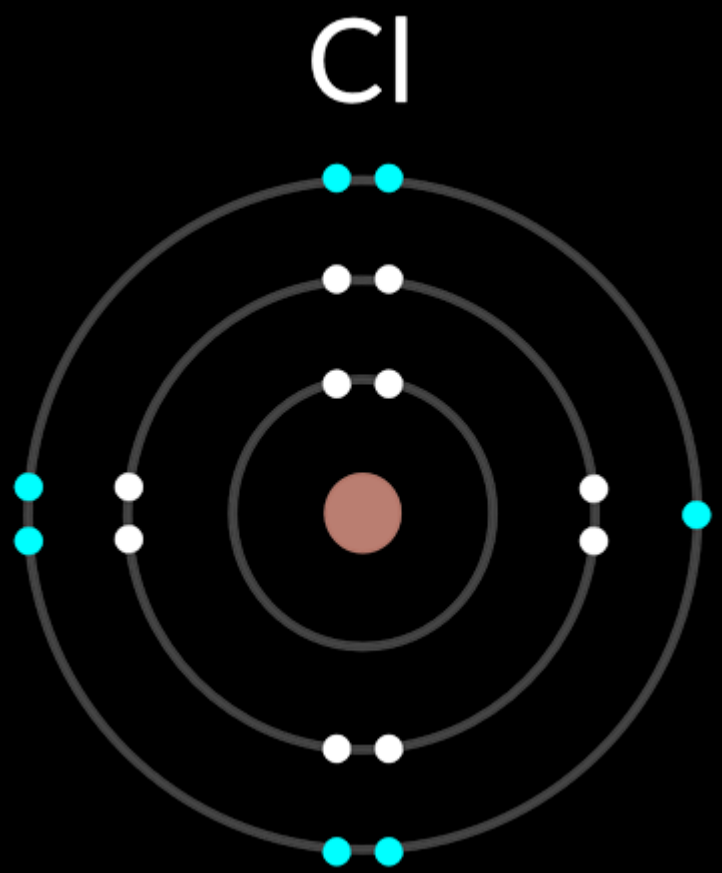
- **Molecule**: any combination of two or more atoms (may be same atom)
  - **Emergent property**: a characteristic, behavior, or capability that a complex system possesses, but which its individual parts do not have on their own
  - Molecules can have characteristics that are different from either of the individual elements = emergent properties
- **Chemical reaction**: occurs when new bonds form or old bonds are broken
- **Reactants**: starting substances
- **Products**: ending substances





Molecule Formation

- How atoms combine is based on how many electrons they have in their outer shell (valence shell)
- Atoms are the most stable when their valence shell is full and are often found in this state
- The first (innermost) shell holds 2 electrons, second holds 8, and third holds 8 (octet rule)

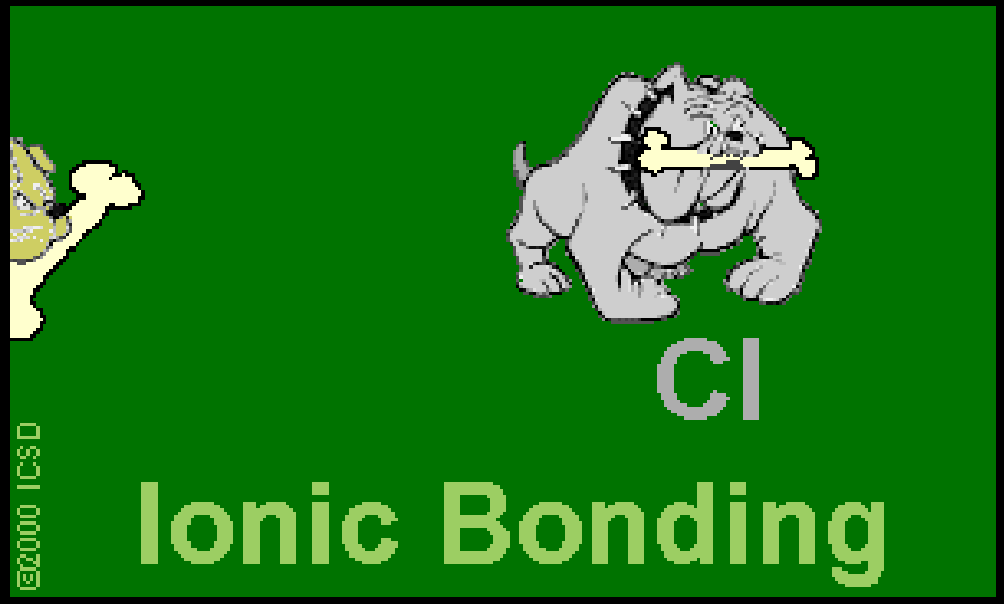


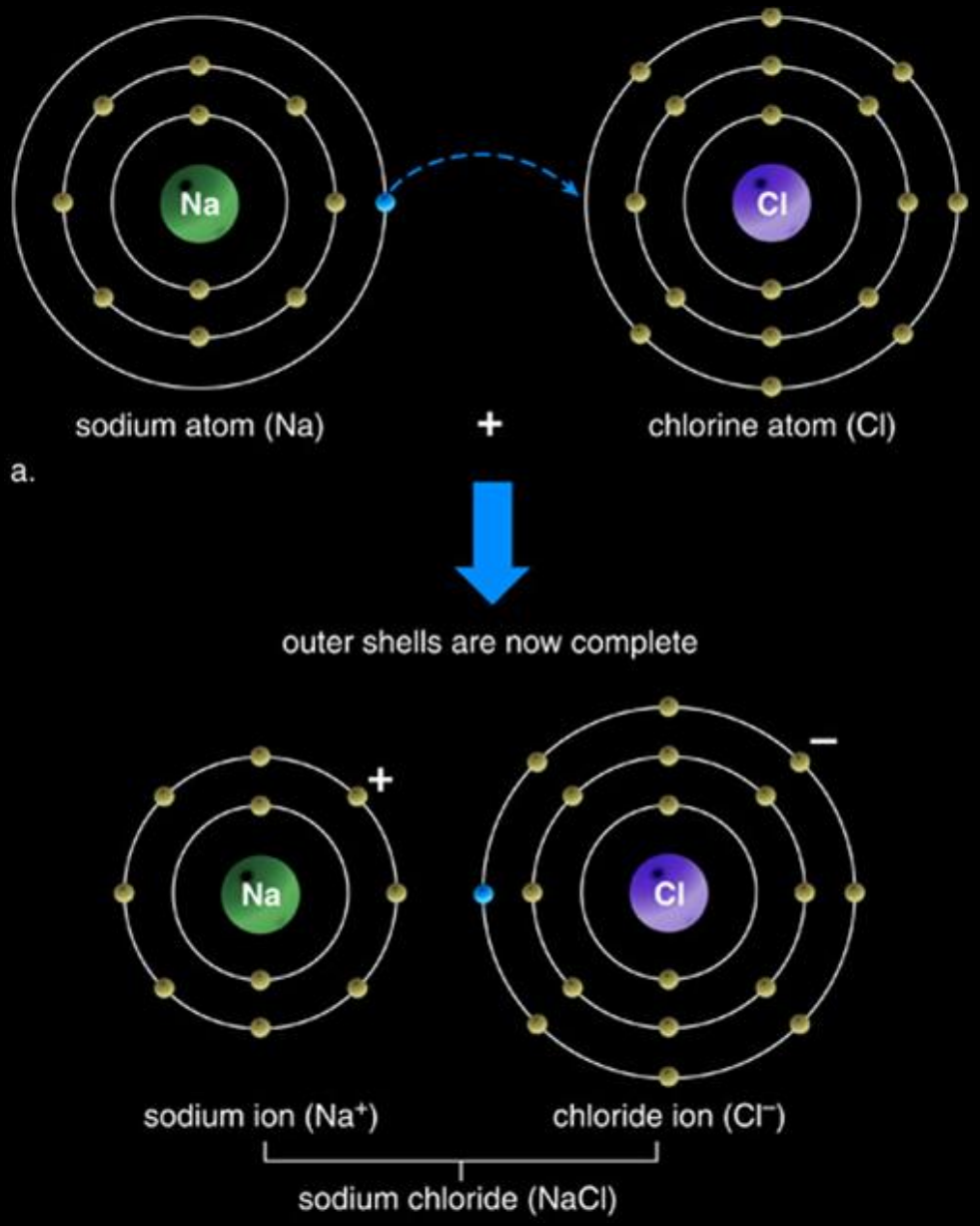
Chemical bonding

- Bonding: elements rearrange electrons between 2+ atoms to “fill” valence shells and provide chemical stability to each atom
- Three types of bonds:
  - Covalent
  - Ionic
  - Hydrogen

Ionic Bonds

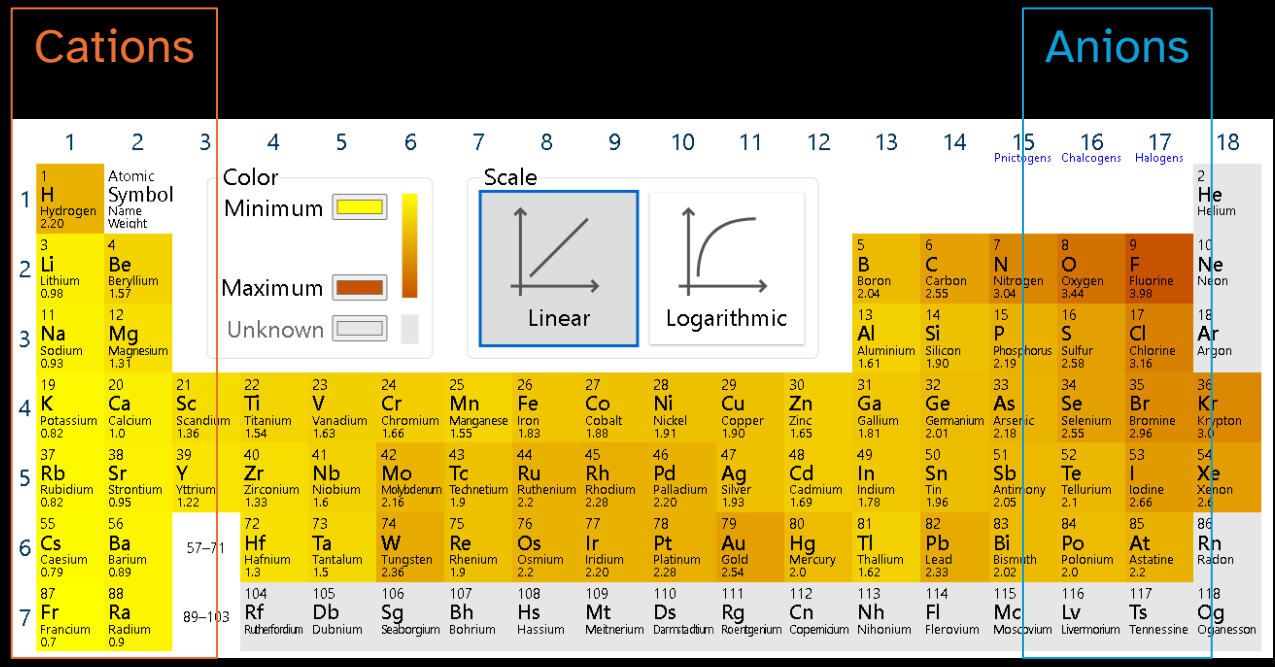
- Ionic bond: an electrical attraction between charged atoms
- Uses a paired redox reactions





Which elements make ionic bonds

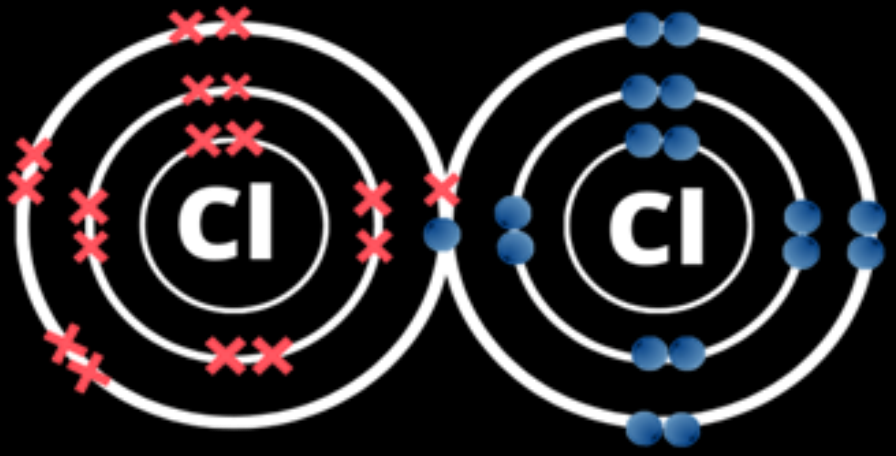
- Ionic bonds are most likely to form between elements on opposite sides of the periodic table (excludes noble gases)
- Written as chemical symbols with associated charges Mg^{2+} Ca^{-}, or if in a pair written side by side $MgCl_2$



https://ptable.com/?lang=en#Properties/Electronegativity

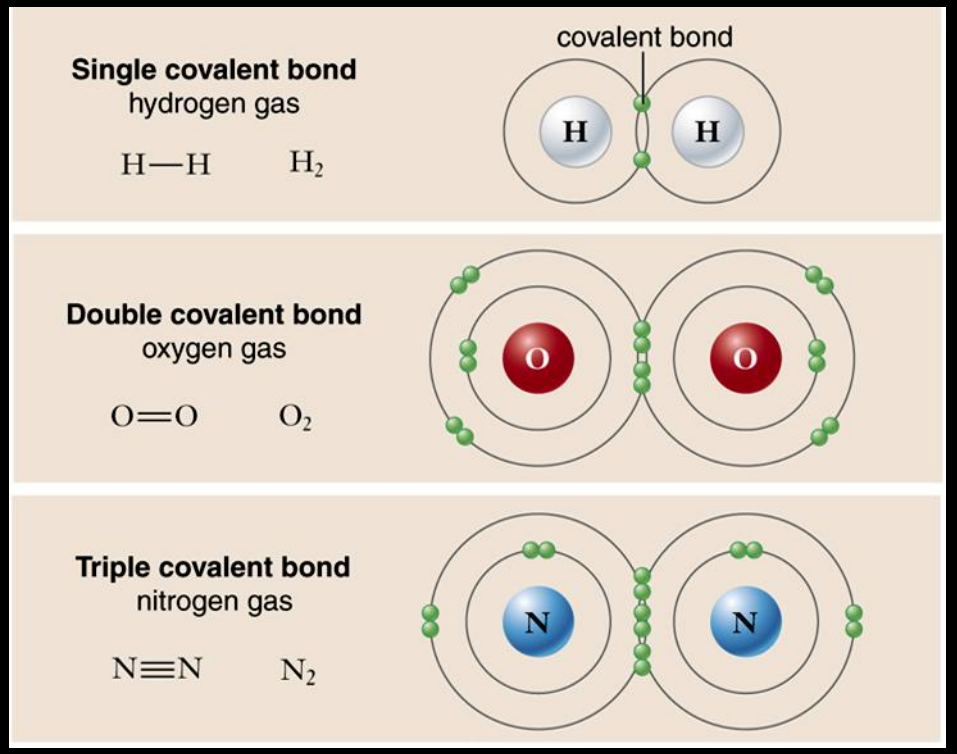
Covalent bond

- Covalent bond: two atoms share one or more pairs of electrons
- This is the strongest chemical bond due to the physical overlap of electrons
- Symbolized with a solid line between atoms



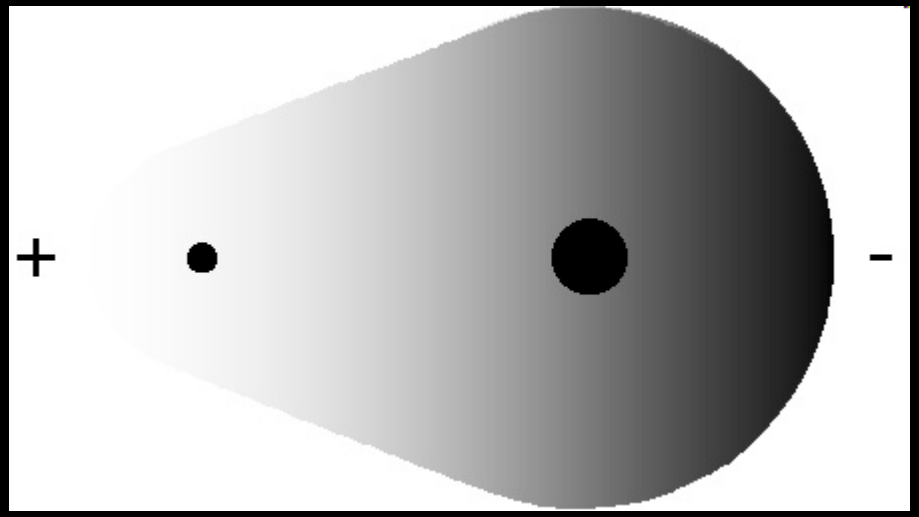
Covalent Bonds – More than one!

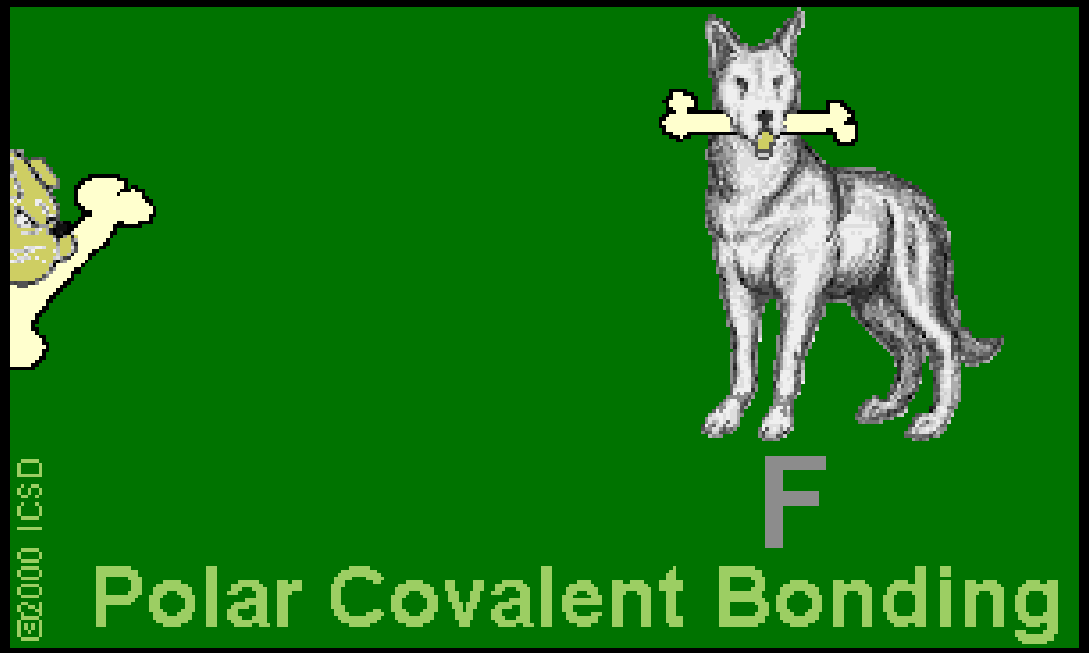
- Covalent bonds can be single, double, or triple bonds, depending on the number of pairs of electrons shared



Unfair Covalent Bonds

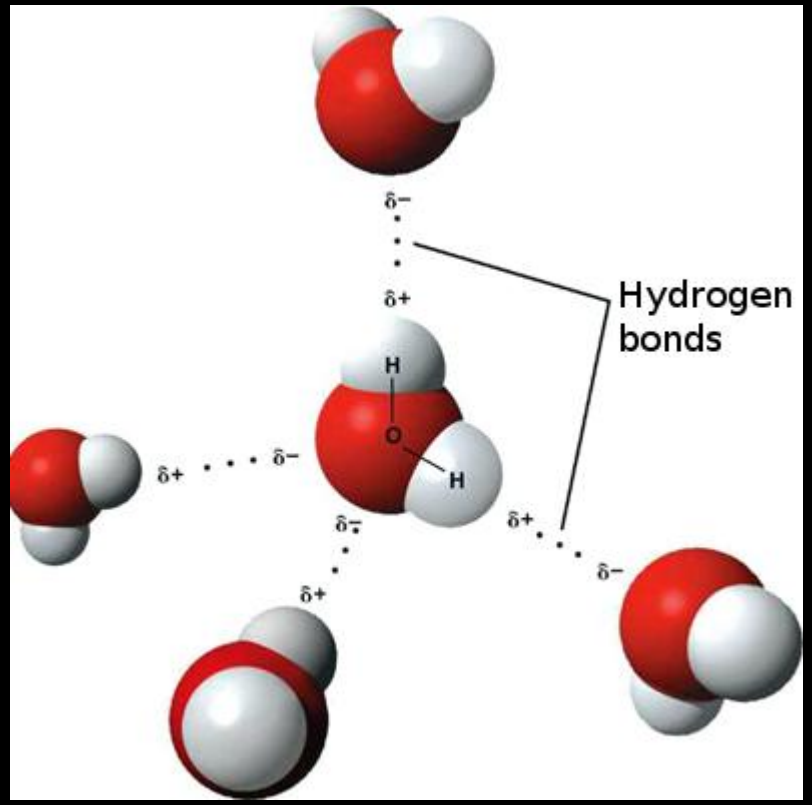
- **Polar**: some covalent bonds do not share electrons equally between atoms





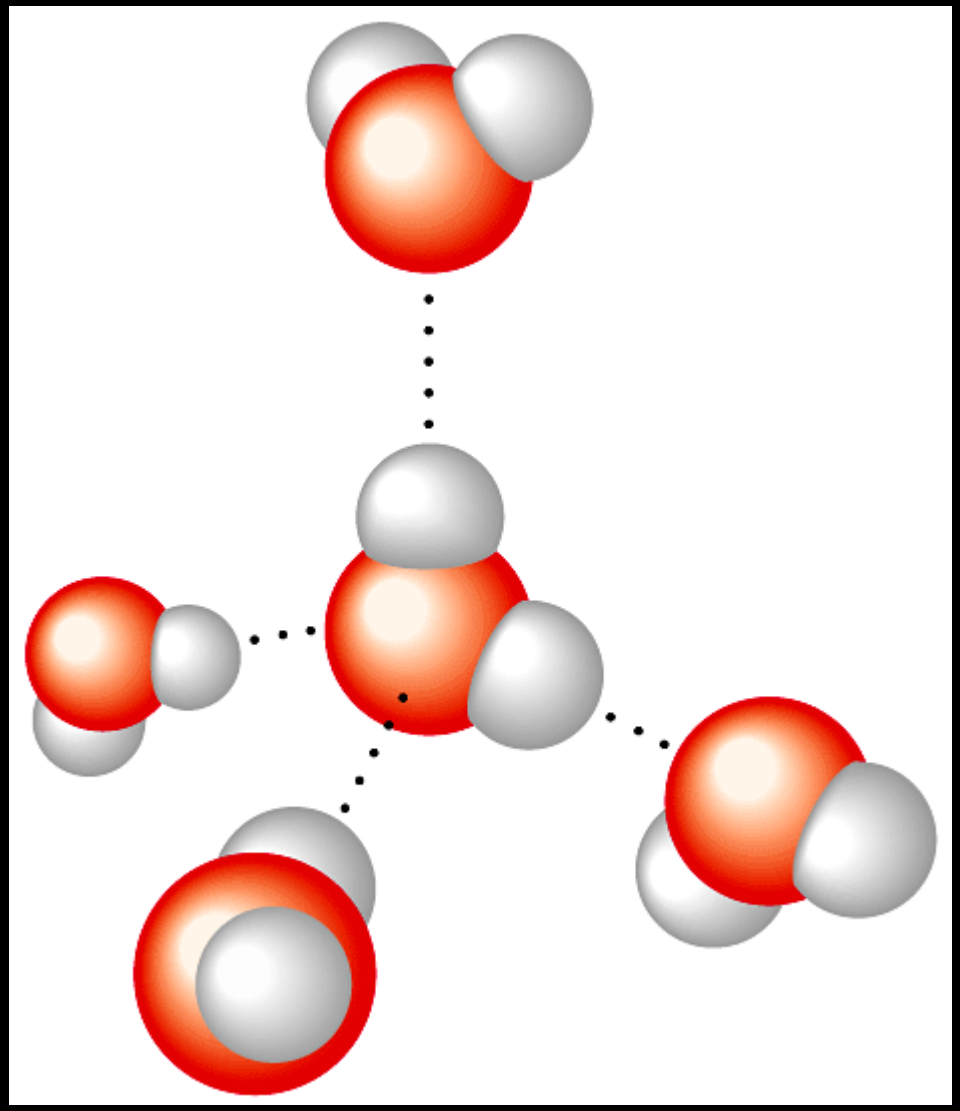
Hydrogen bonds

- **Hydrogen bonds**: small ionic-like bonds between molecules because of polarity in covalent bonds
  - Drawn as dotted lines between molecules
- Which elements make polar covalent bonds?
  - Highly electronegative elements such as oxygen with anything other than oxygen



Water Chemistry

- Water is essential for all life on earth
- Water has special chemical properties that make it ideal for life because it's polar and has hydrogen bonding
  - Has a high specific heat
    - Takes a large amount of energy to change its temperature
  - Is less dense as a solid
  - Is a good solvent
    - many things dissolve in it



Metabolism

- **Metabolism:** all chemical reactions of a cell or organism.

- **Metabolic pathway:** is a series of biochemical reactions that converts one or more substrates into a final product.

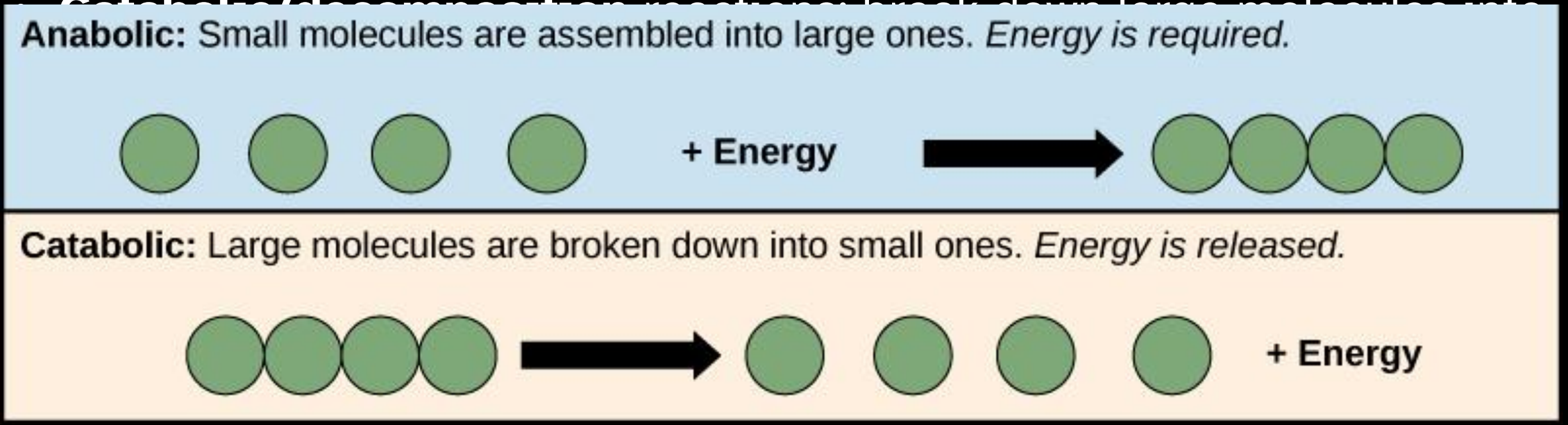
    - For example, energy from the sun is captured during photosynthesis to convert CO_2 and H_2O into glucose ($C_6H_{12}O_6$).

    - The energy stored in glucose is released during cellular respiration, regenerating CO_2 and H_2O. (We will discuss in subsequent lectures.)

Plants, like this oak tree and acorn, use energy from sunlight to make sugar and other organic molecules. Both plants and animals (like this squirrel) use cellular respiration to derive energy from the organic molecules that plants originally produced. (credit “acorn”: modification of work by Noel Reynolds; credit “squirrel”: modification of work by Dawn Huczek)

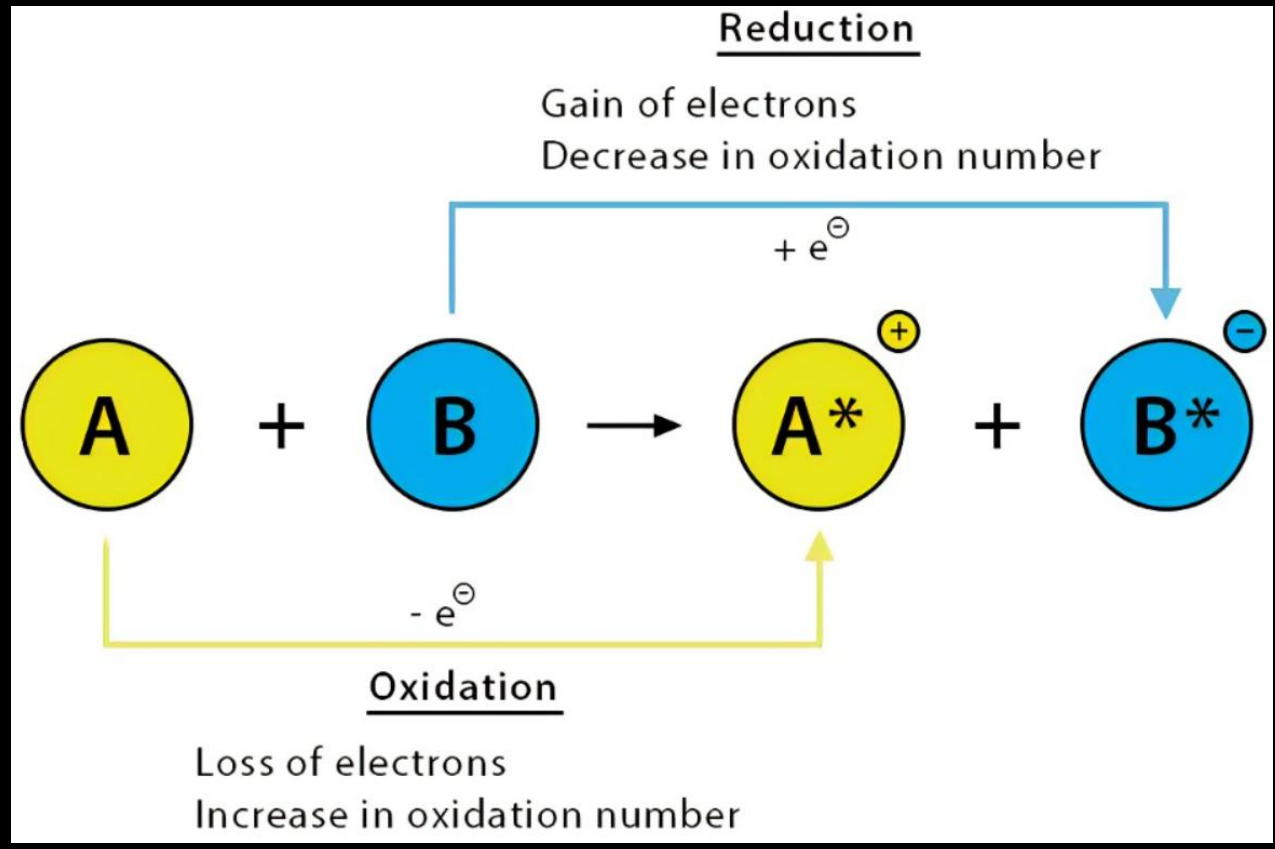
Metabolic Pathways

- Two types of reactions/pathways are required to maintain the cell's energy balance.
- **Anabolic/synthesis** reactions: generate larger molecules and require energy
- **Catabolic/decomposition** reactions: break down large molecules into



Redox Reactions

- **Reduction reaction**: the addition of electrons
- **Oxidation reaction**: the removal of electrons
- **Redox reaction**: reduction and oxidation reactions must be paired and cooccur
  - OIL RIG (Oxidation is loss; Reduction is gain)
  - Ions are fundamental for life for electrical charge, nerve signals, heart function, and many more functions



Energetics of Reactions

- **Energy**: the capacity to do work
  - **Potential energy**: energy stored by matter due to its position
    - E.g. energy stored in water behind a dam
  - **Kinetic energy**: energy associated with matter in motion
    - E.g. when the gates of the dam are opened
  - **Chemical energy**: potential energy stored in the bonds of compounds and molecules

Thermodynamics

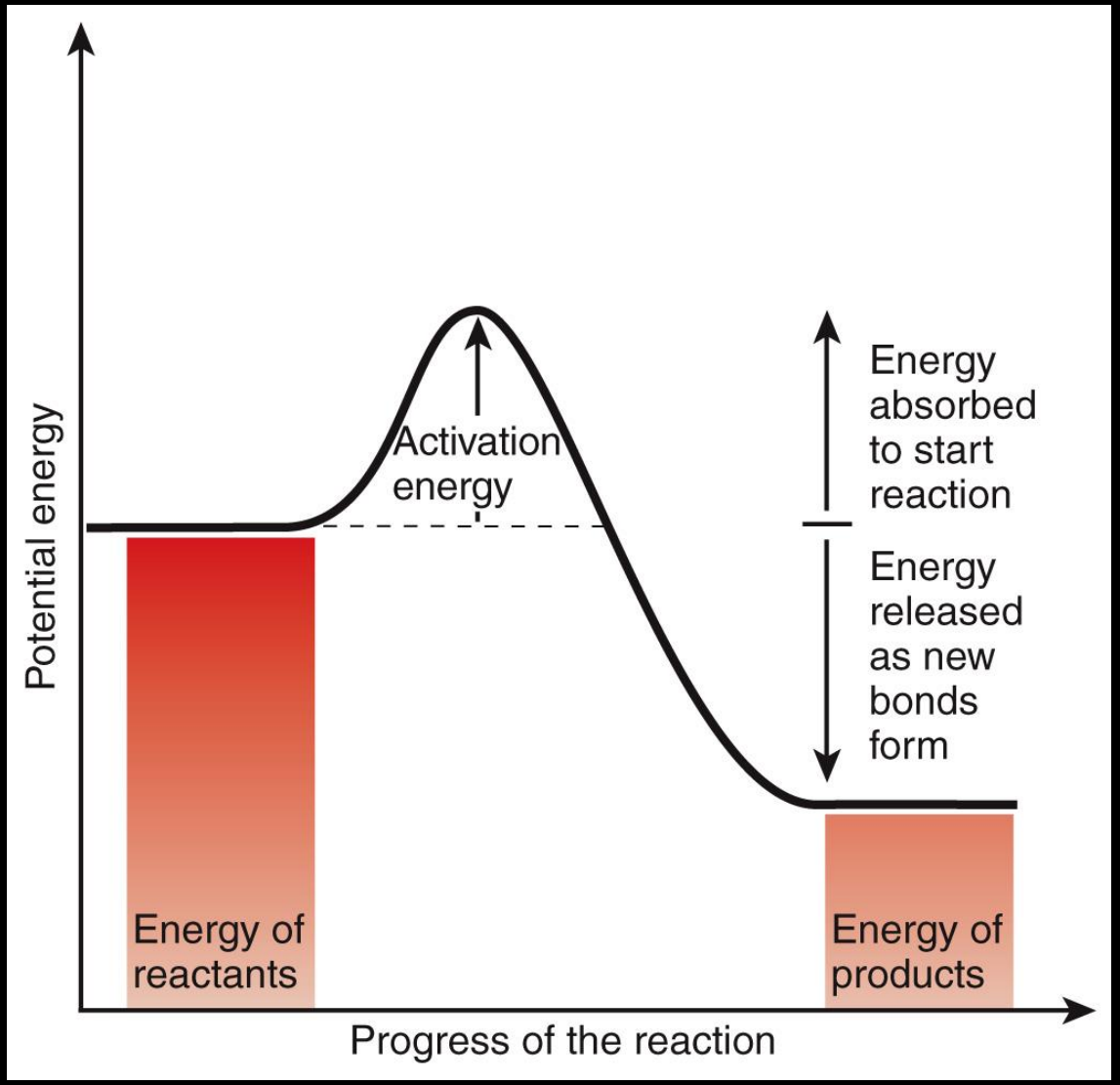
- **Law of conservation of energy**
  - the total amount of energy present at the beginning and end of a chemical reaction is the same
  - energy can neither be created not destroyed, but it can be *converted* from one form to another
  - ex. energy in the foods we consume is eventually converted into various forms of kinetic energy, such as the mechanical energy used to walk

Exergonic/Endergonic

- **Exergonic reaction**: releases more energy than it absorbs
  - in general, exergonic reactions occur as nutrients (ex. glucose) are broken down
  - ex. when a molecule of glucose is completely broken down, the chemical energy in its bonds can be used to produce 32 molecules of ATP
- **Endergonic reaction**: absorbs more energy than it releases
  - a key feature of the body's metabolism is the coupling of exergonic and endergonic reactions; energy released from an exergonic reaction is often used to drive an endergonic one

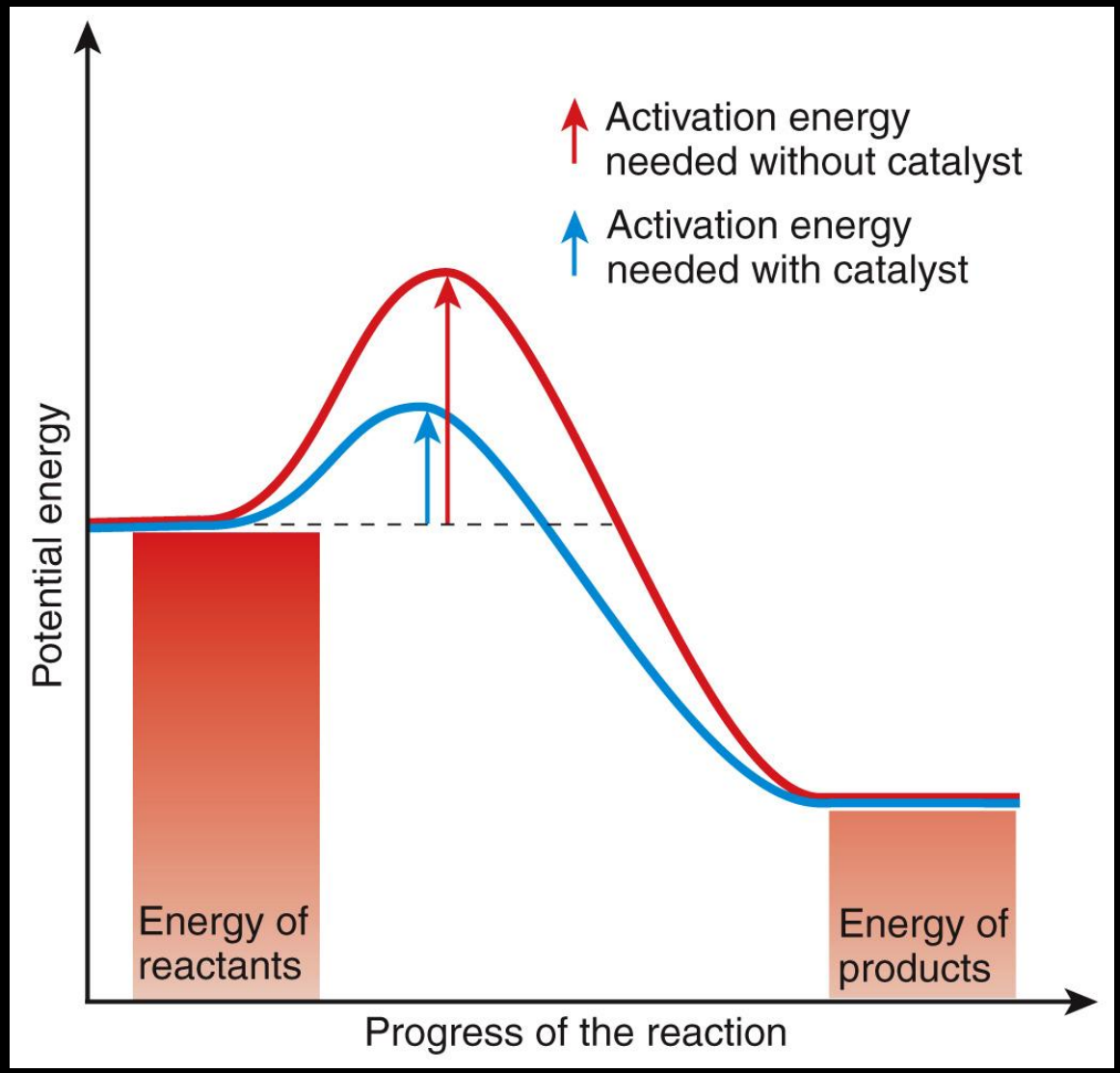
Activation Energy

- **<u>Activation energy</u>:** the energy needed to start a chemical reaction
  - You have to spend money to make money



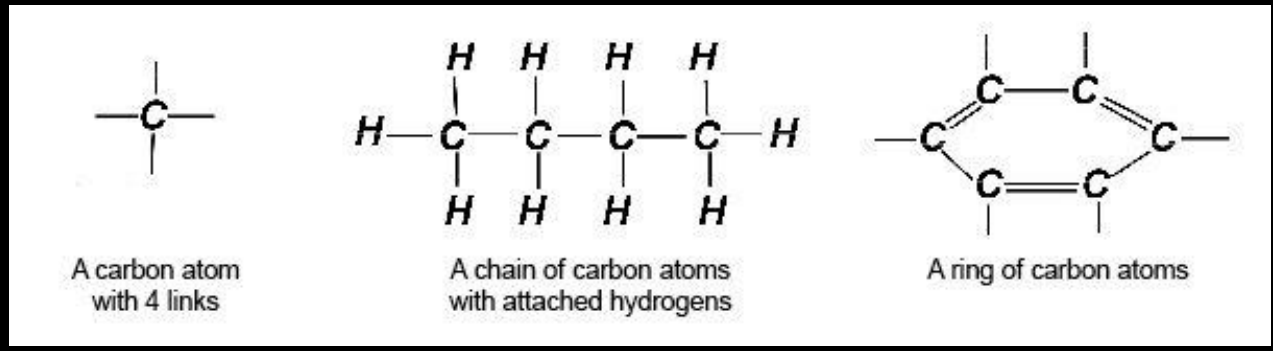
Catalysts

- **Catalyst:** chemical compounds that speed up chemical reactions by reducing the activation energy
- **Enzymes**: proteins that act as catalysts
  - Often denoted with the suffix –ase
  - E.g. lactase (enzyme that breaks down lactose sugar in milk)

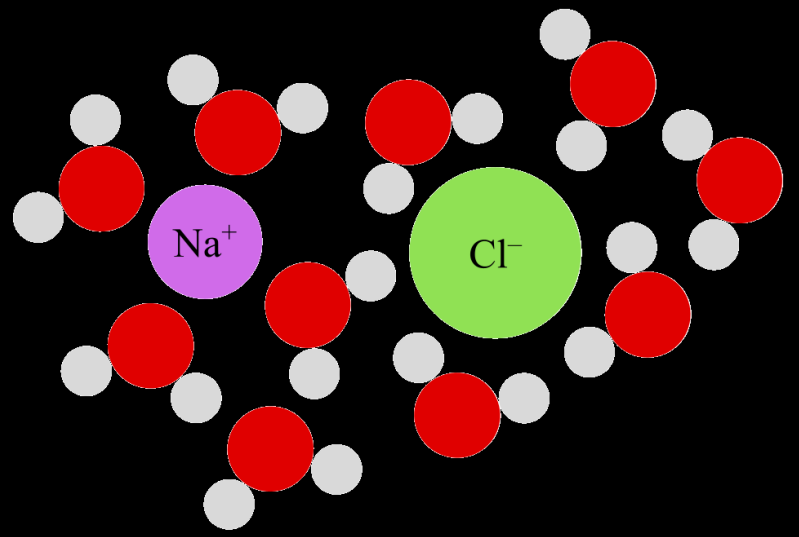


Inorganic vs. Organic Compounds

- **Organic compounds**: carbon-based molecules typically bonded to hydrogen, oxygen, or nitrogen, forming the basis of life (e.g., glucose, proteins)

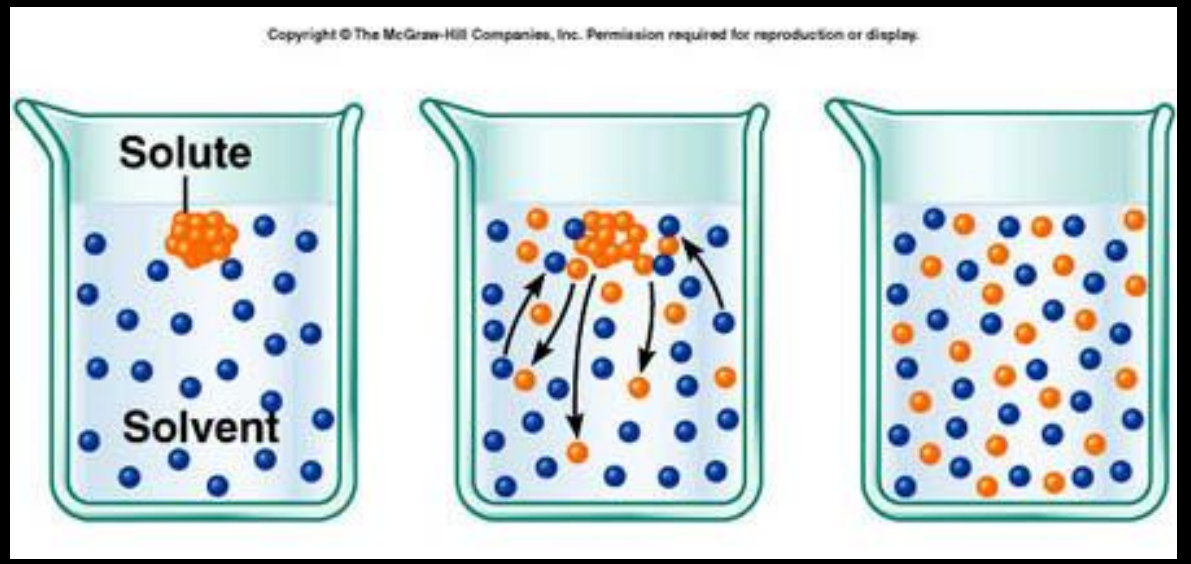


- **Inorganic compounds**: generally lack carbon-hydrogen bonds, often consisting of metals, salts, and minerals (e.g., water, CO_2, NaCl



Solutions

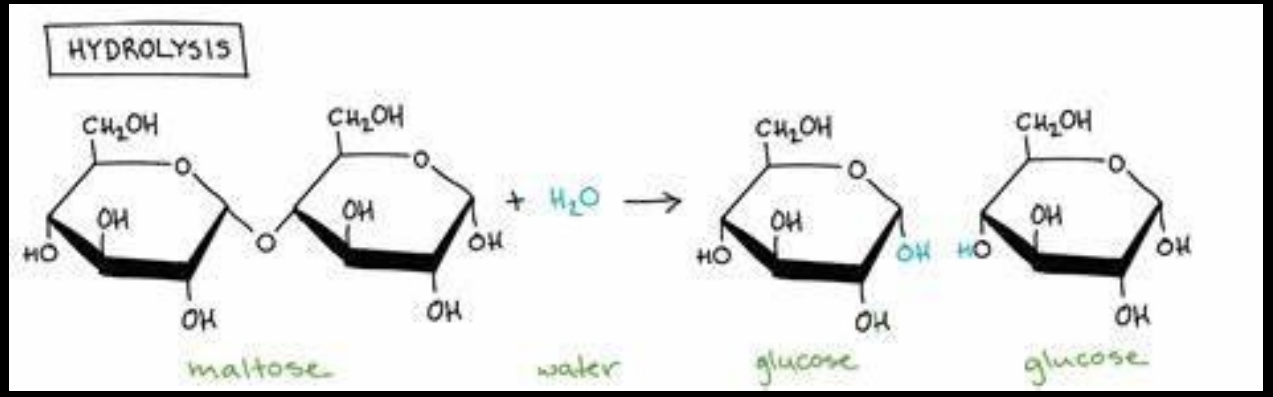
- **Solution**: a mixture of one or more solutes dissolved in a solvent
  - E.g. salt water
- **Solute**: the substance that dissolves to form a solution
  - E.g. salt
- **Solvent**: the substance in which a solute dissolves
  - E.g. water

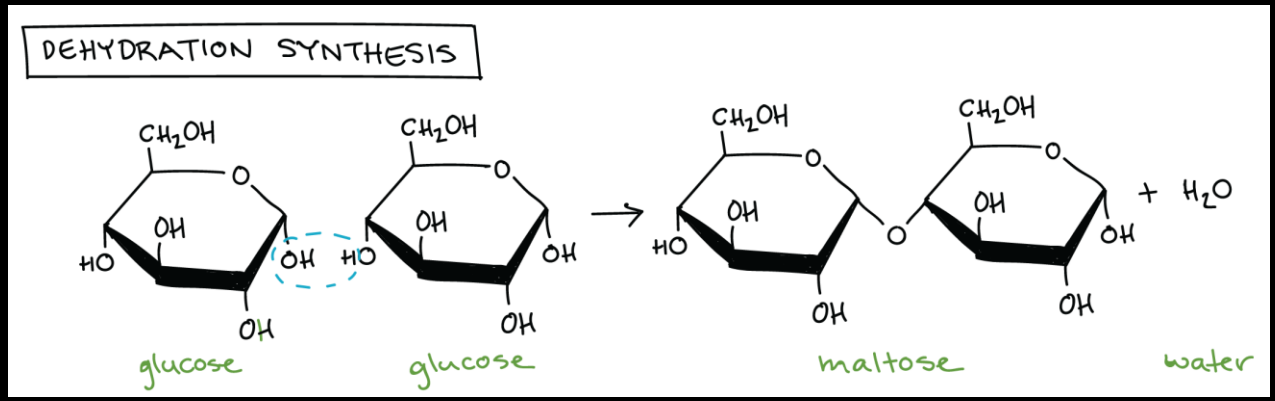


- **Hydrophilic solutes**: contain polar or charged bonds and easily dissolve in water
- **Hydrophobic solutes**: contain non-polar bonds and do not dissolve in water

Organic Reactions

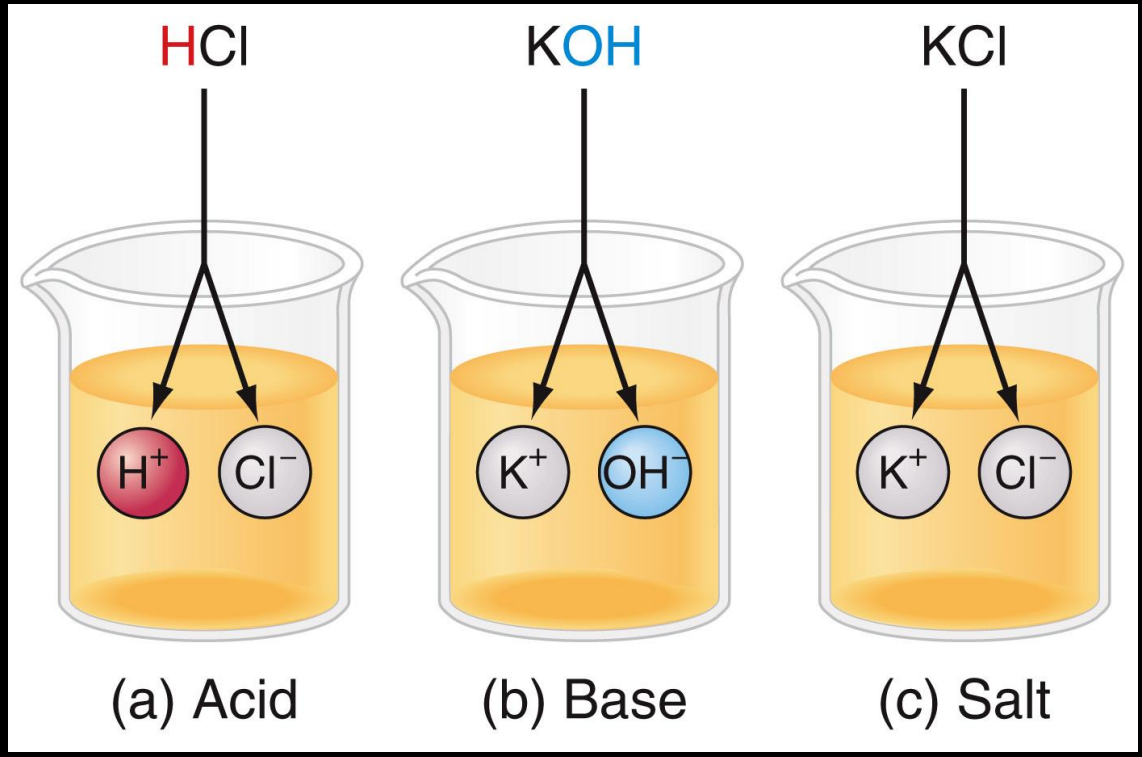
- **Hydrolysis**: a reaction involving the addition of water
  - ex. during breakdown of complex carbohydrates to simple sugars
- **Dehydration synthesis**: a reaction in which water is one of the products
  - ex. occurs during the synthesis of proteins and other large molecules





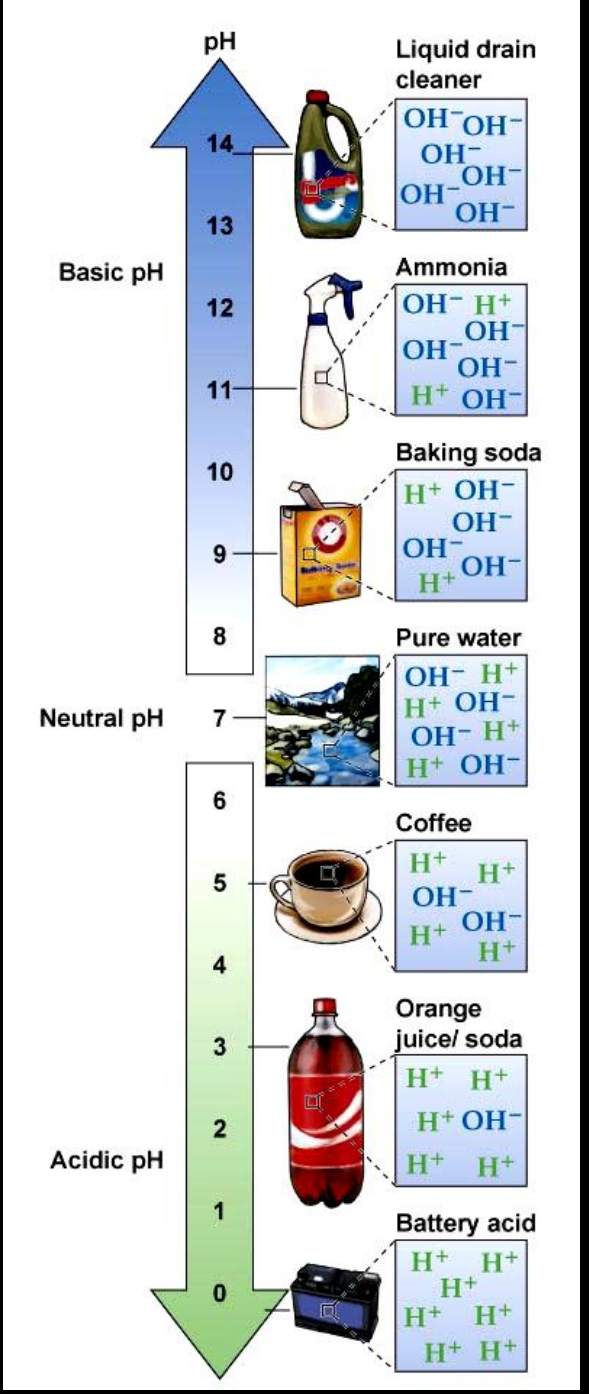
Acids, Bases, and Salts

- When molecules dissolve in water some dissociate and separate into ions in solution
- Acid: substance that dissociates and adds one or more hydrogens ions (H+) into solution; proton donor
- Base: substance that dissociates and adds one or more hydroxide ions (OH-) into solution (or removes a proton; proton acceptor
- Salt: dissociates into cations and anions, neither of which is H+ or OH-

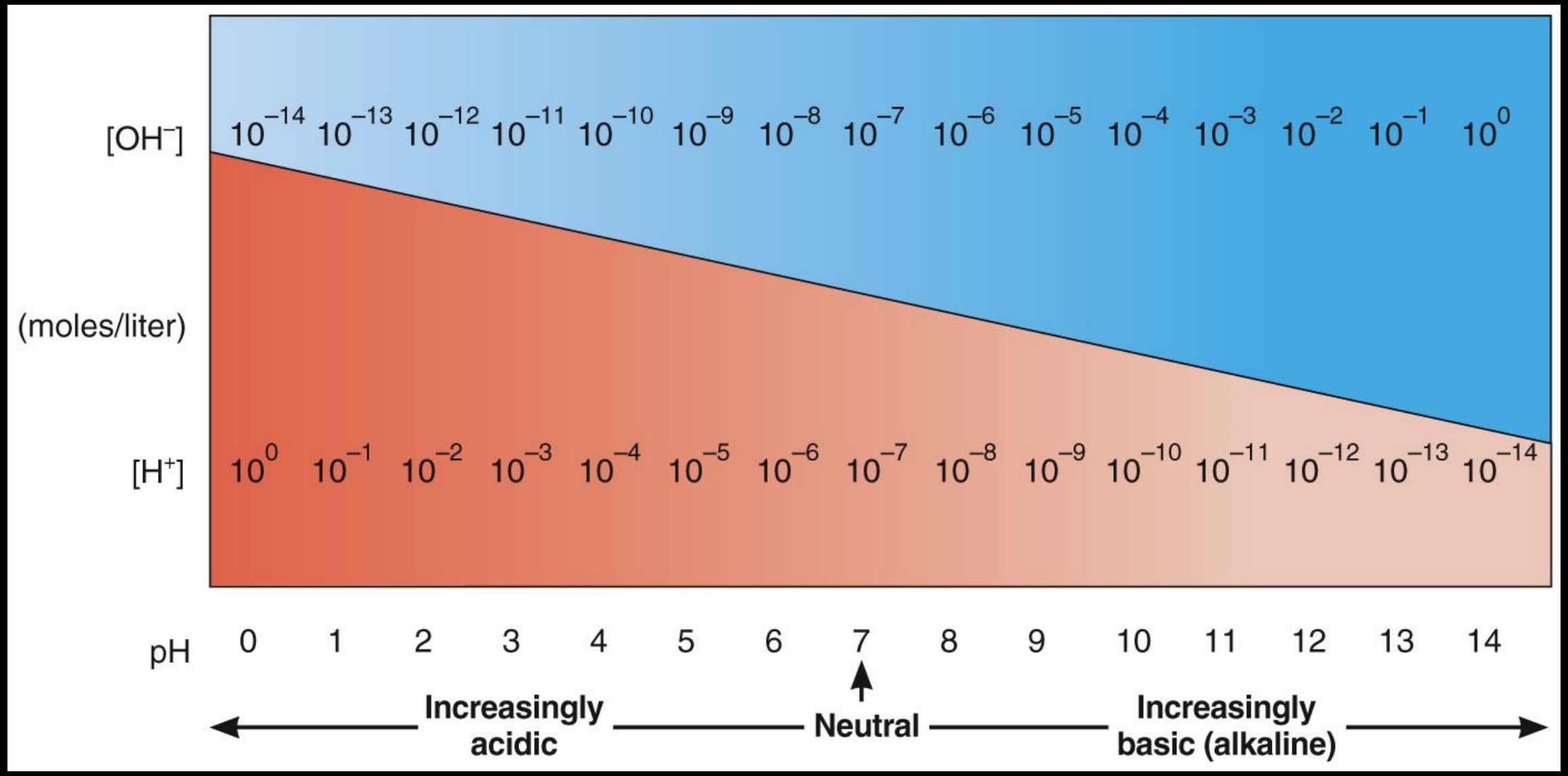


pH

- **<u>pH scale</u>: the amount of H+ in solution and represents a** solution's acidity or alkalinity
  - Logarithmic scale from 0-14
  - Calculation pH = -log[H+]
  - 0–6 is acidic
  - 7 is neutral
  - 8–14 is basic
- Blood pH normal range = 7.35-7.45

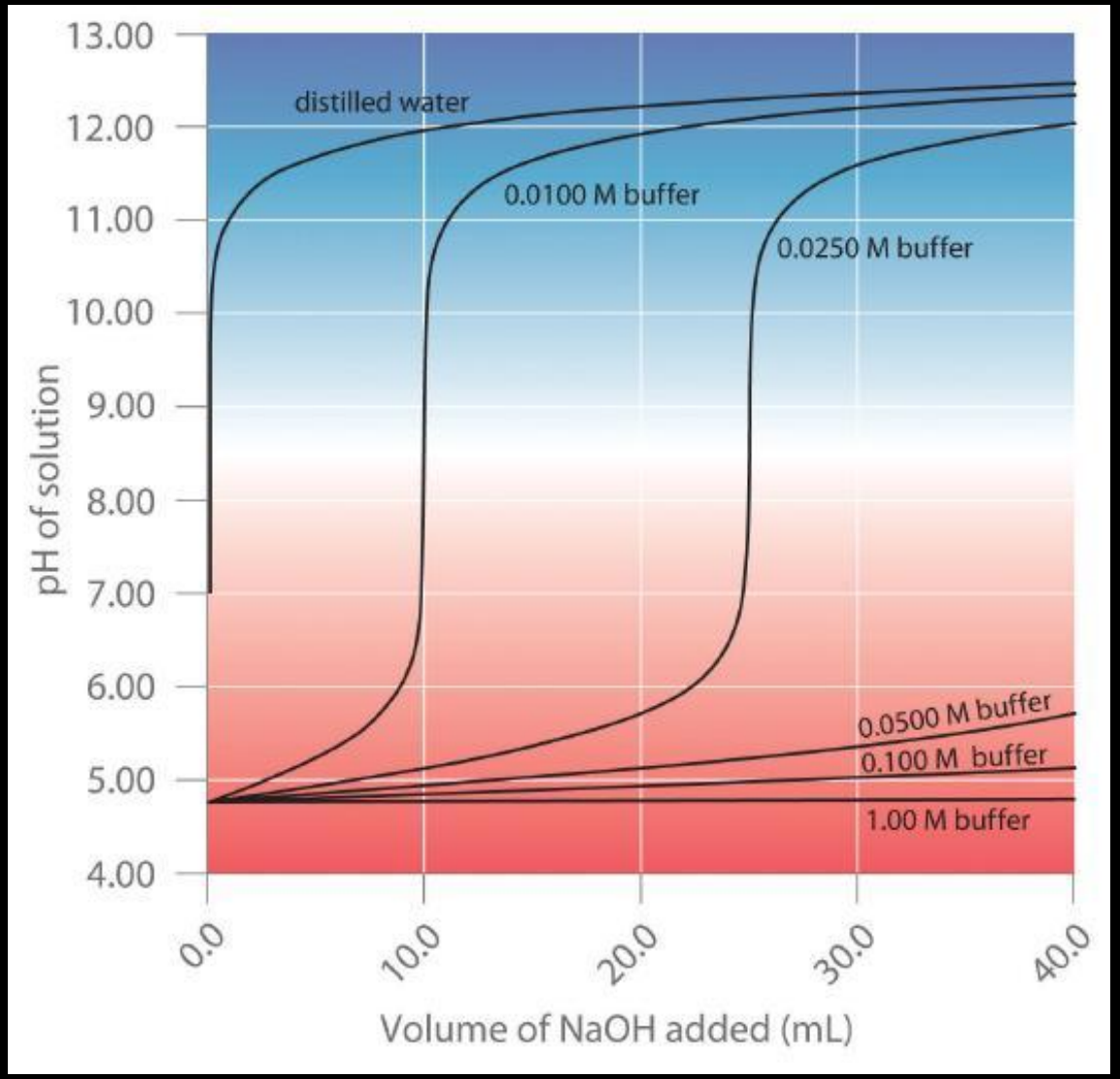


pH Scale


[OH⁻]
(moles/liter)
[H⁺]
10⁻¹⁴ 10⁻¹³ 10⁻¹² 10⁻¹¹ 10⁻¹⁰ 10⁻⁹ 10⁻⁸ 10⁻⁷ 10⁻⁶ 10⁻⁵ 10⁻⁴ 10⁻³ 10⁻² 10⁻¹ 10⁰
10⁰ 10⁻¹ 10⁻² 10⁻³ 10⁻⁴ 10⁻⁵ 10⁻⁶ 10⁻⁷ 10⁻⁸ 10⁻⁹ 10⁻¹⁰ 10⁻¹¹ 10⁻¹² 10⁻¹³ 10⁻¹⁴
pH
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14
Increasingly acidic
Neutral
Increasingly basic (alkaline)

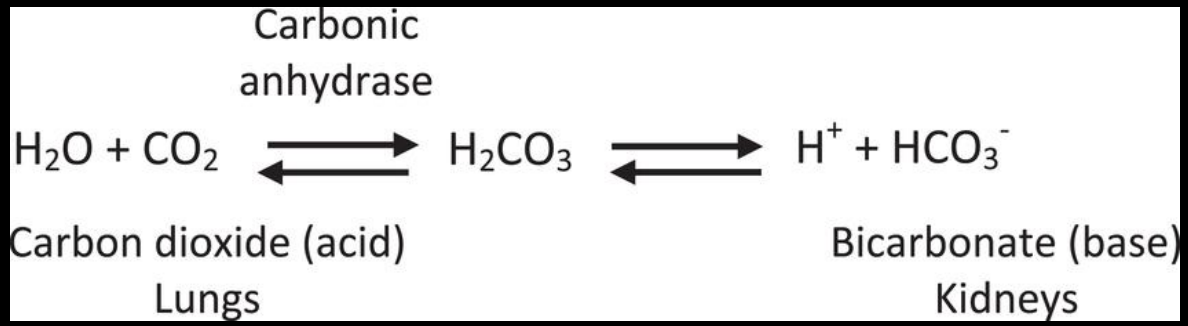
Buffers

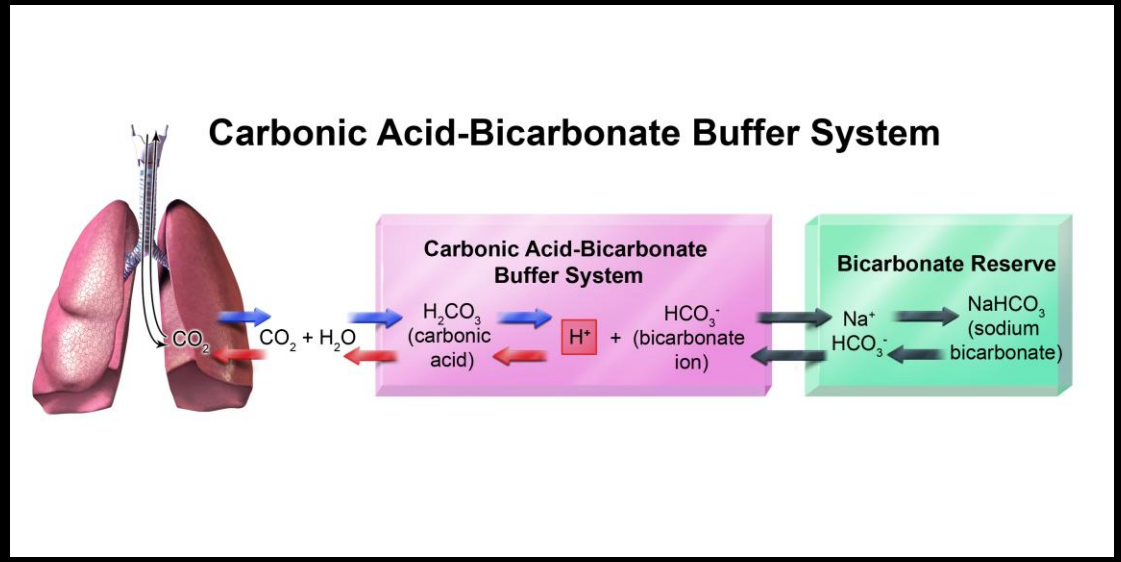
- even though strong acids and bases are continually taken into and formed by the body, the pH of fluids inside and outside of cells remains almost constant
- Buffer system: an aqueous solution that resists significant changes in pH



Blood Buffers

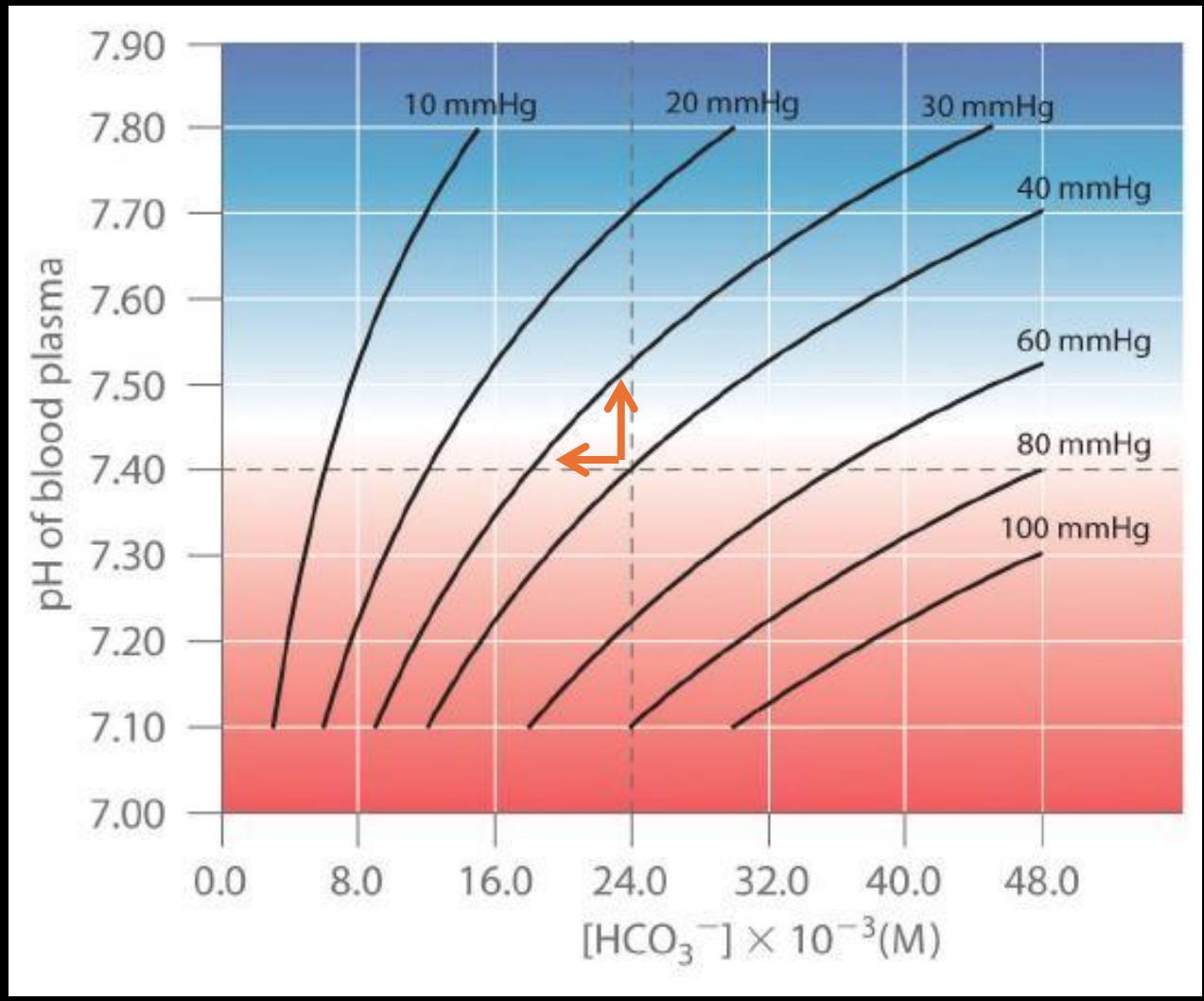
- Carbonic acid – bicarbonate buffer system: main buffering system of blood
- carbonic acid (H_2CO_3) is a weak acid
- bicarbonate (HCO_3-) is a weak base





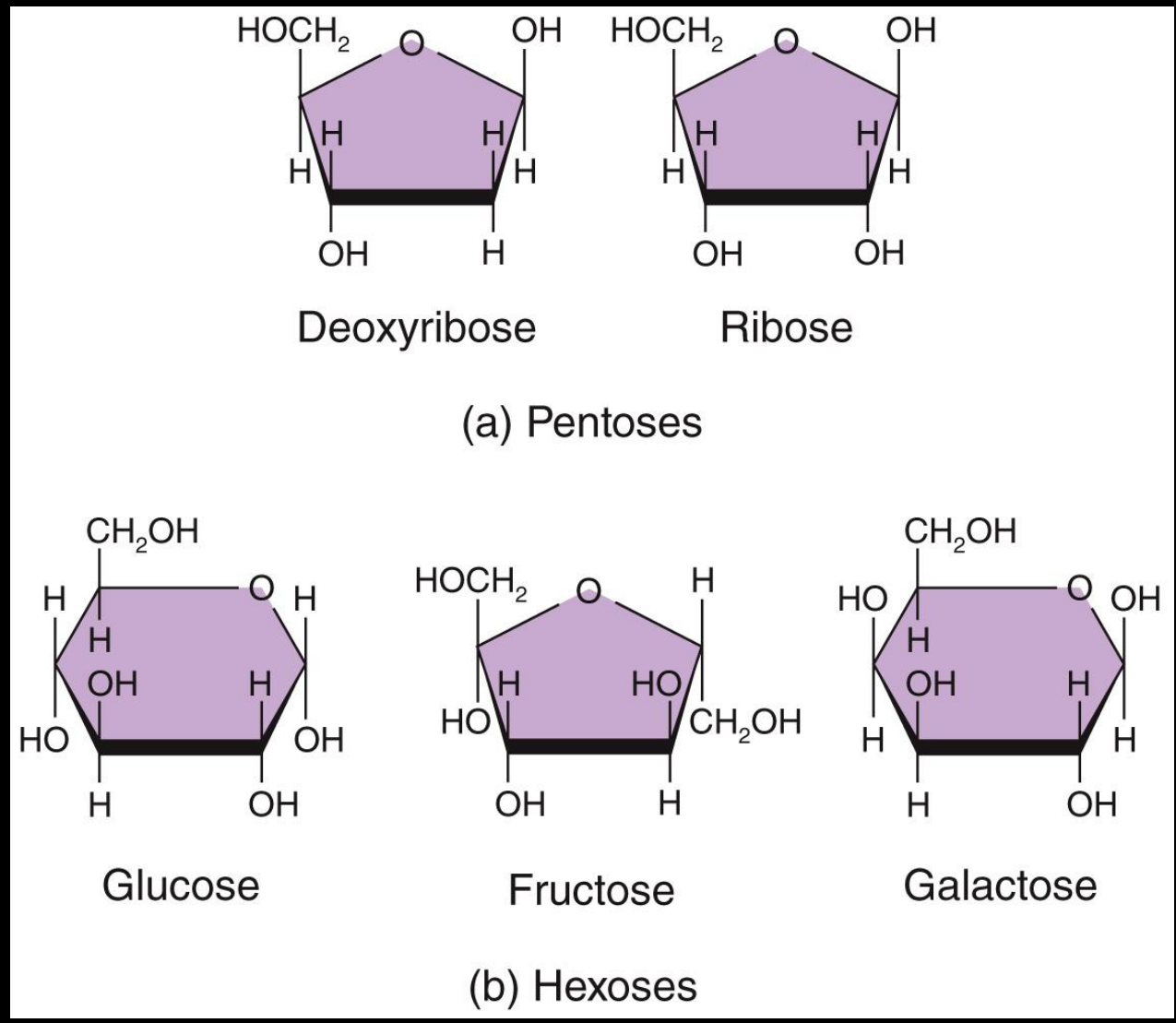
Altitude Sickness

- **Buffering in Blood:**
- pH versus carbonic acid concentration [HCO_3^-]
- Curves shown for different atmospheric pressures
- Denver, Colorado pressure ~30 versus ~40 mmHg at sea level causes a decrease in carbonic acid and an increase in blood pH
- Responsible for the general malaise that many people experience at high altitudes



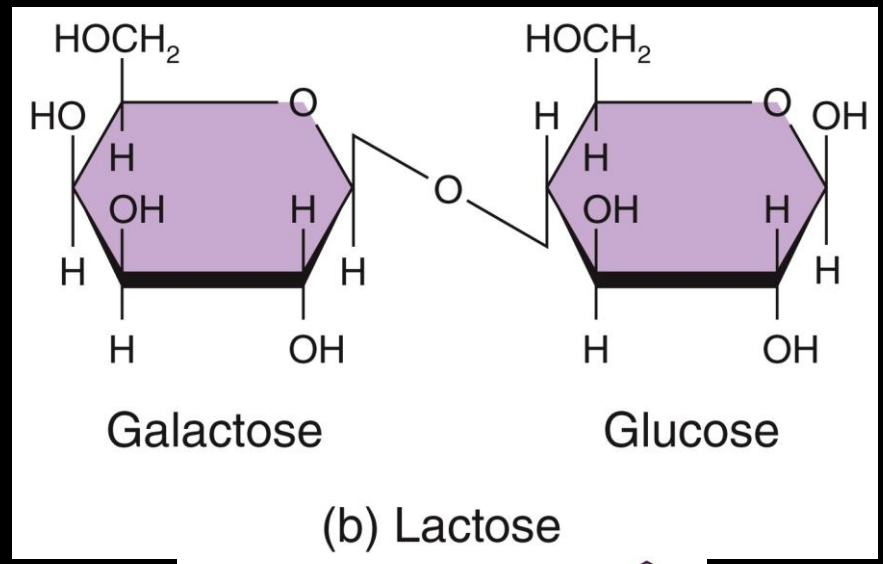
Macronutrients – [1] Carbohydrates

- **carbohydrates**: includes sugars, glycogen, starches, and cellulose function mainly as a source of chemical energy for generating ATP needed to drive metabolic reactions
- **monosaccharides**: monomers containing 3-7 carbon atoms
  ex. tetrose, pentose, glucose, fructose, deoxyribose (in DNA), ribose (in RNA)

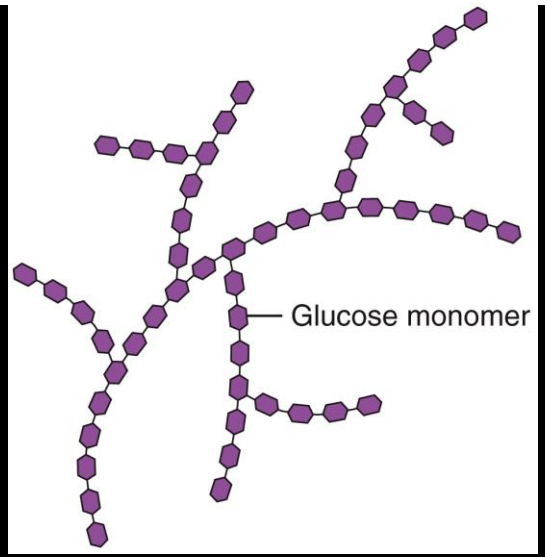


Saccharides

- **disaccharides**: molecule formed from the combination of TWO monosaccharides
  ex. glucose + fructose = disaccharide sucrose (table sugar)
- **polysaccharides**: each polysaccharide molecule contains tens or even hundreds of monosaccharides joined through dehydration synthesis reactions
  main polysaccharide in humans = glycogen

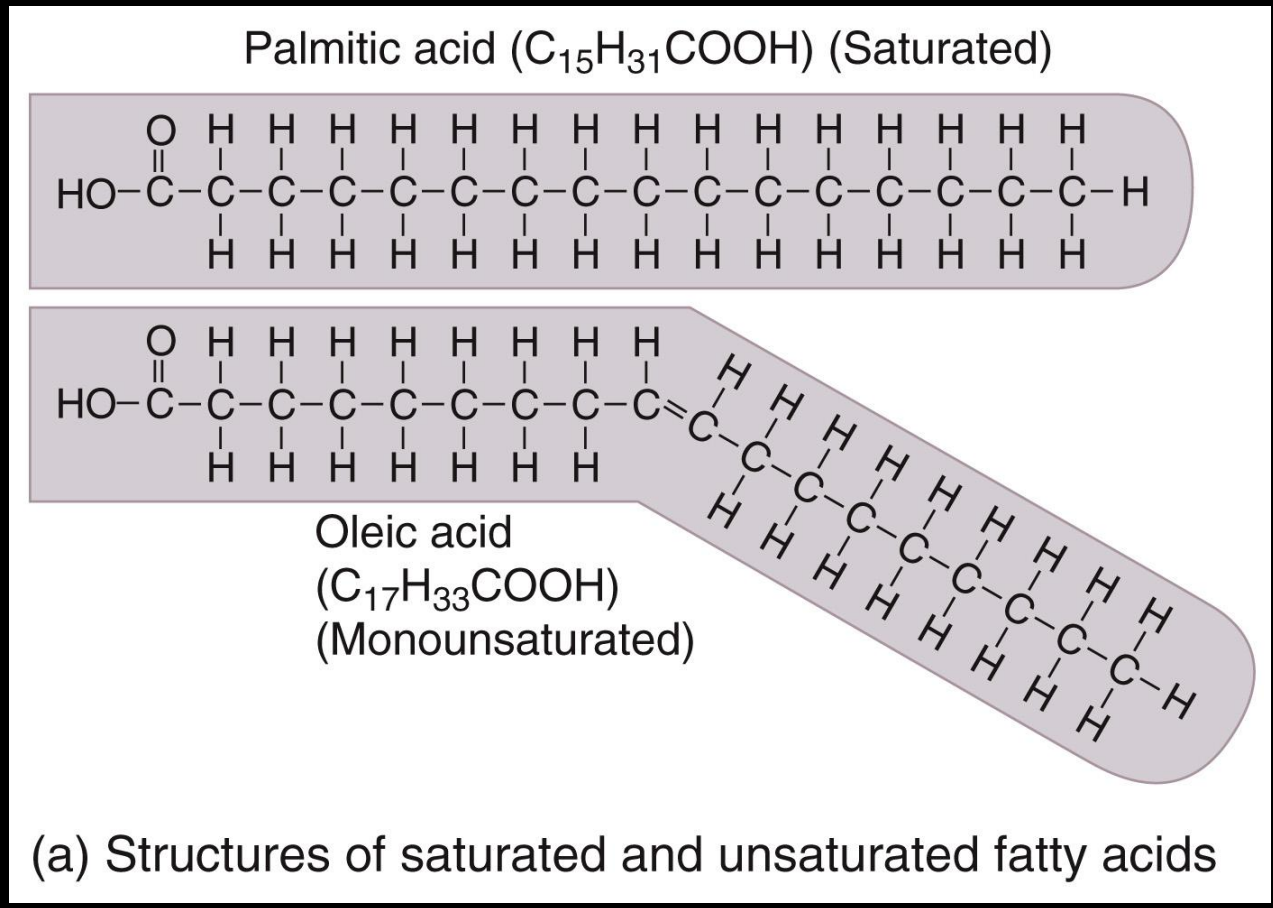


(b) Lactose



Macronutrients – [2] Lipids

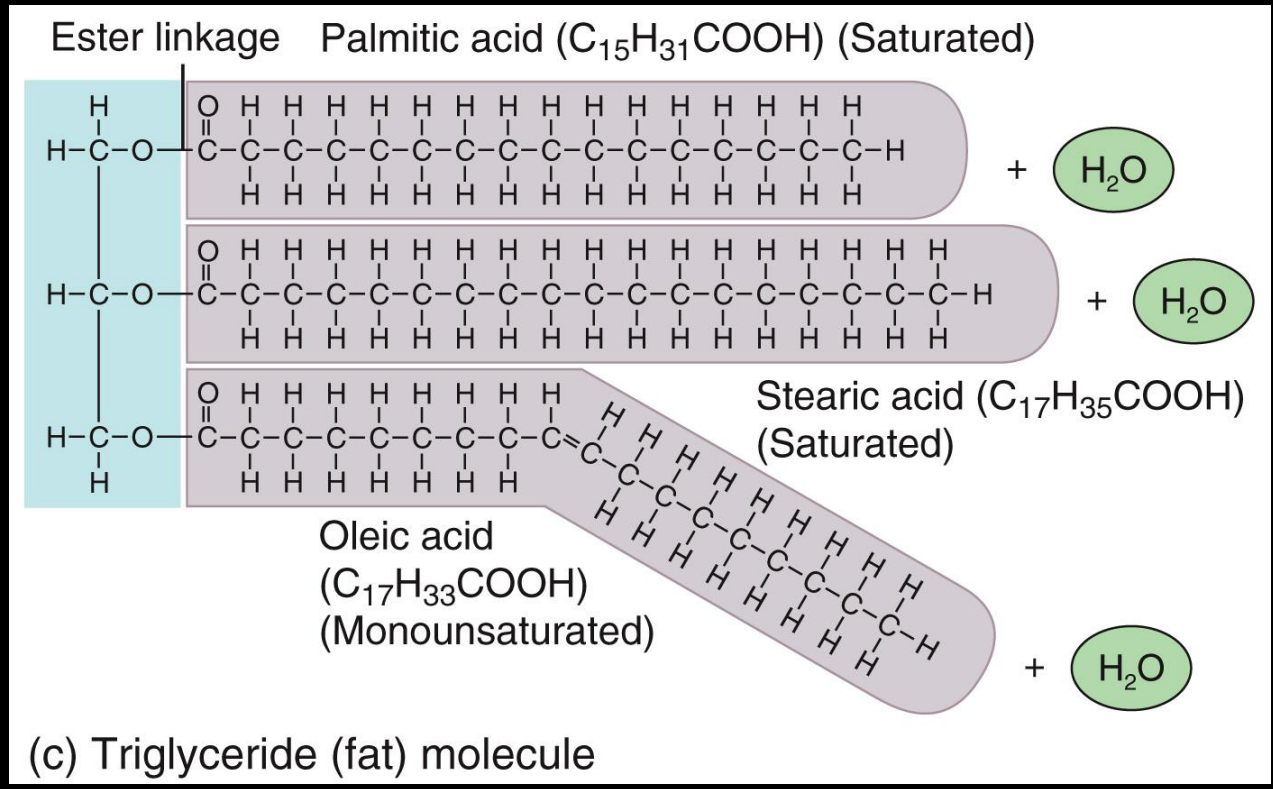
- **Lipids**: broad group of naturally occurring molecules which includes:
- **Fatty acids**: simple lipids used to synthesize triglycerides and phospholipids
  - **saturated** = contains only single covalent bonds
  - **unsaturated** = contains one or more double covalent bond



(a) Structures of saturated and unsaturated fatty acids

Triglycerides

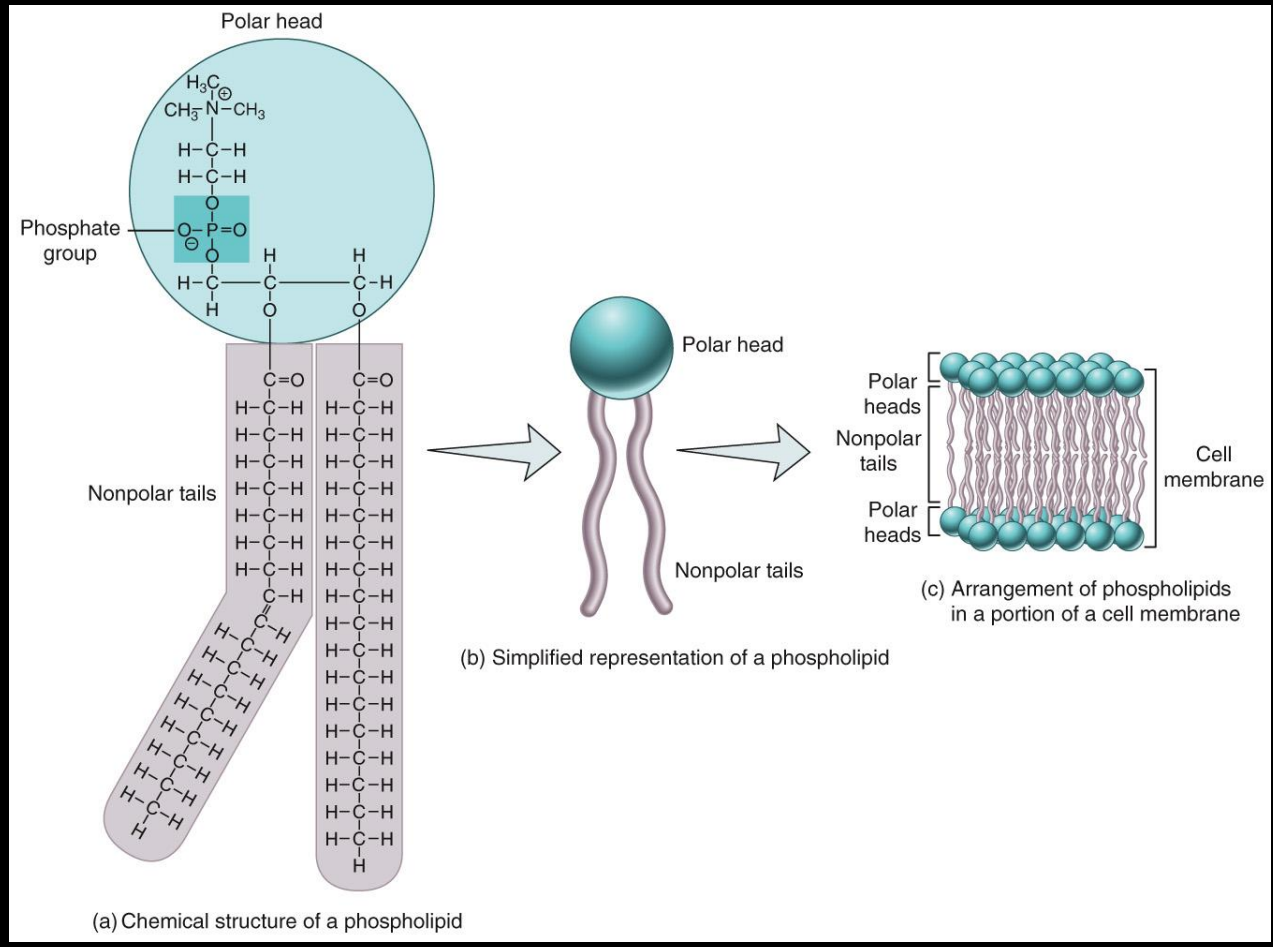
- [2] triglycerides: most plentiful lipids in the body and in our diet consists of 2 building blocks (1) a single glycerol molecule (2) 3 fatty acid molecules



(c) Triglyceride (fat) molecule

Phospholipids

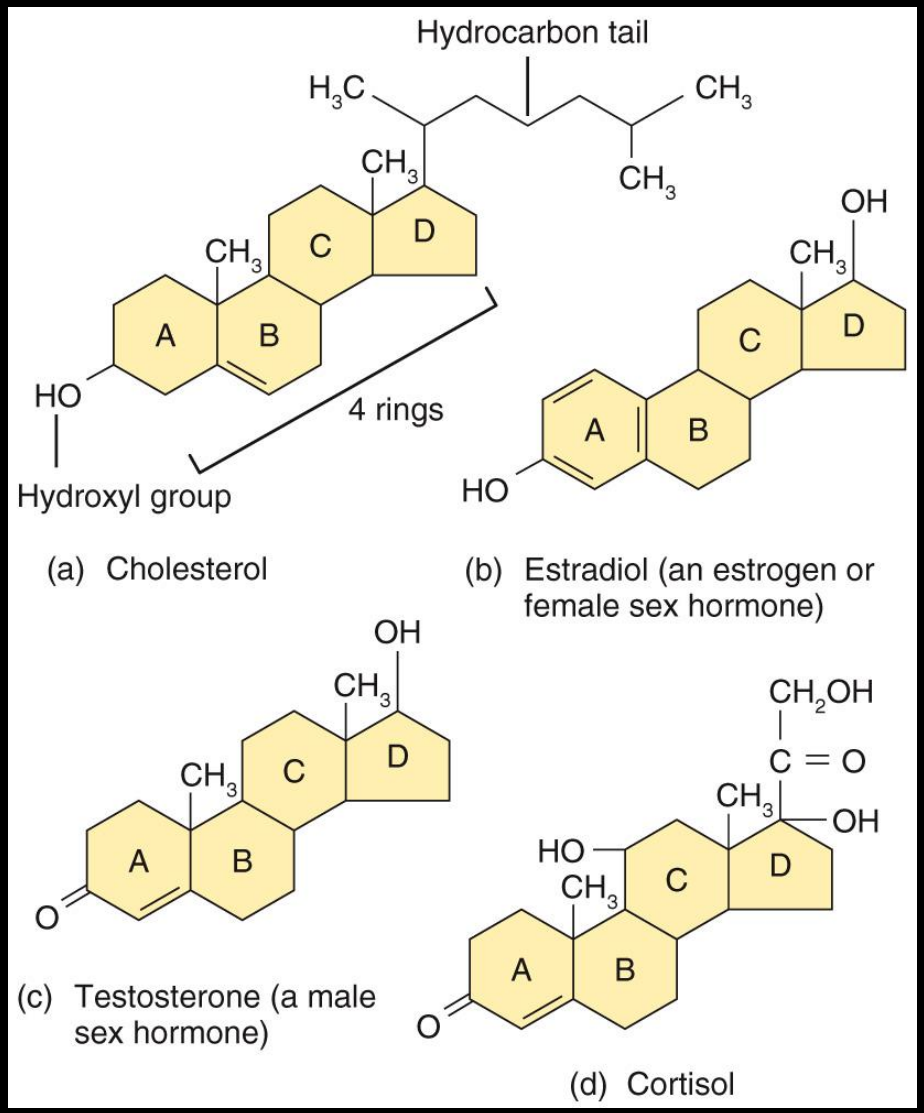
- [3] phospholipids: comprise all animal cellular membranes; have glycerol backbone and two fatty acid chains attached to the first two carbons



Steroids

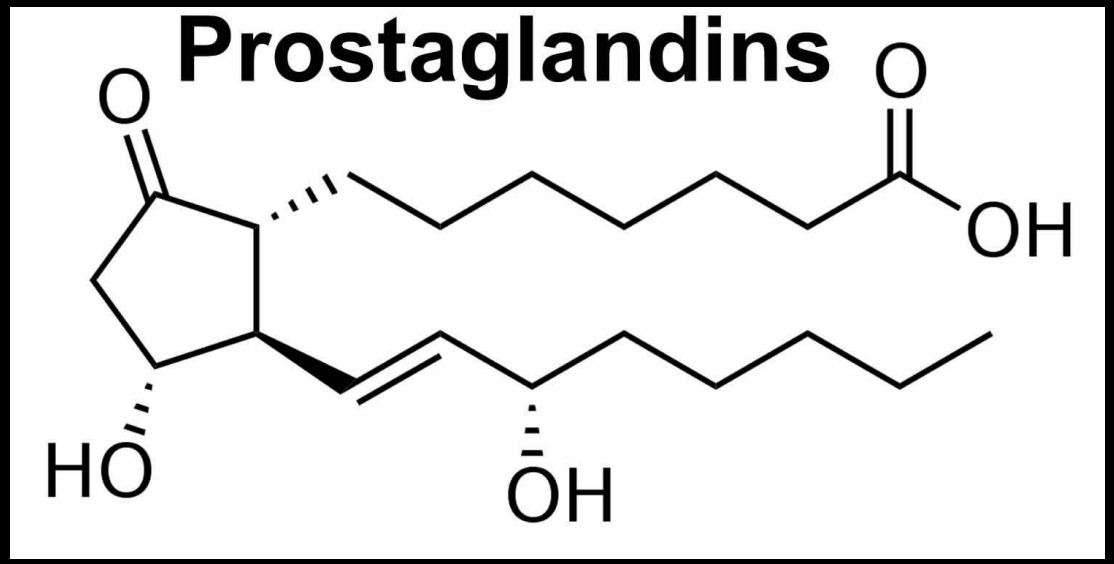
- **[4] steroids:** biologically active compound with 4 carbon rings

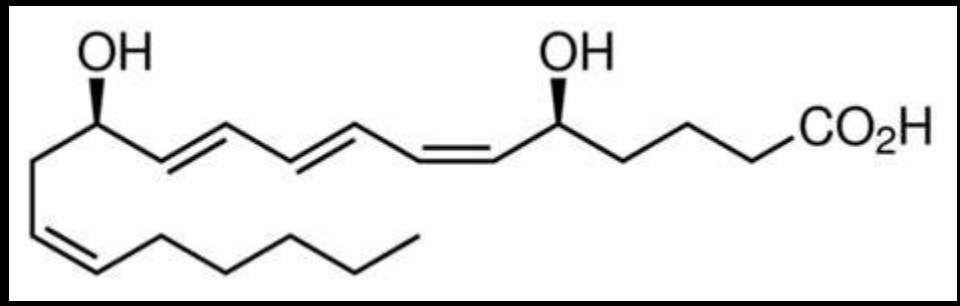
- important components of cellular membranes (cholesterol)
- signaling compounds (estrogen, testosterone)



Eicosanoids

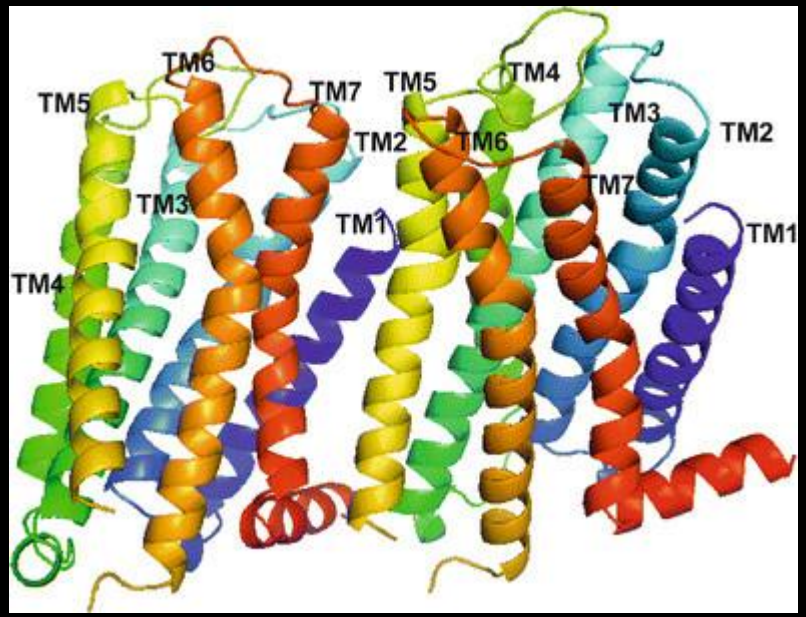
- **[5] eicosanoids**: lipids derived from a 20-carbon fatty acid called arachidonic acid, consist of two classes
  - prostaglandins = contribute to the inflammatory response, prevent stomach ulcers, dilate airways to the lungs, regulate body temperature, influence the formation of blood clots
  - leukotrienes = participate in allergic and inflammatory responses



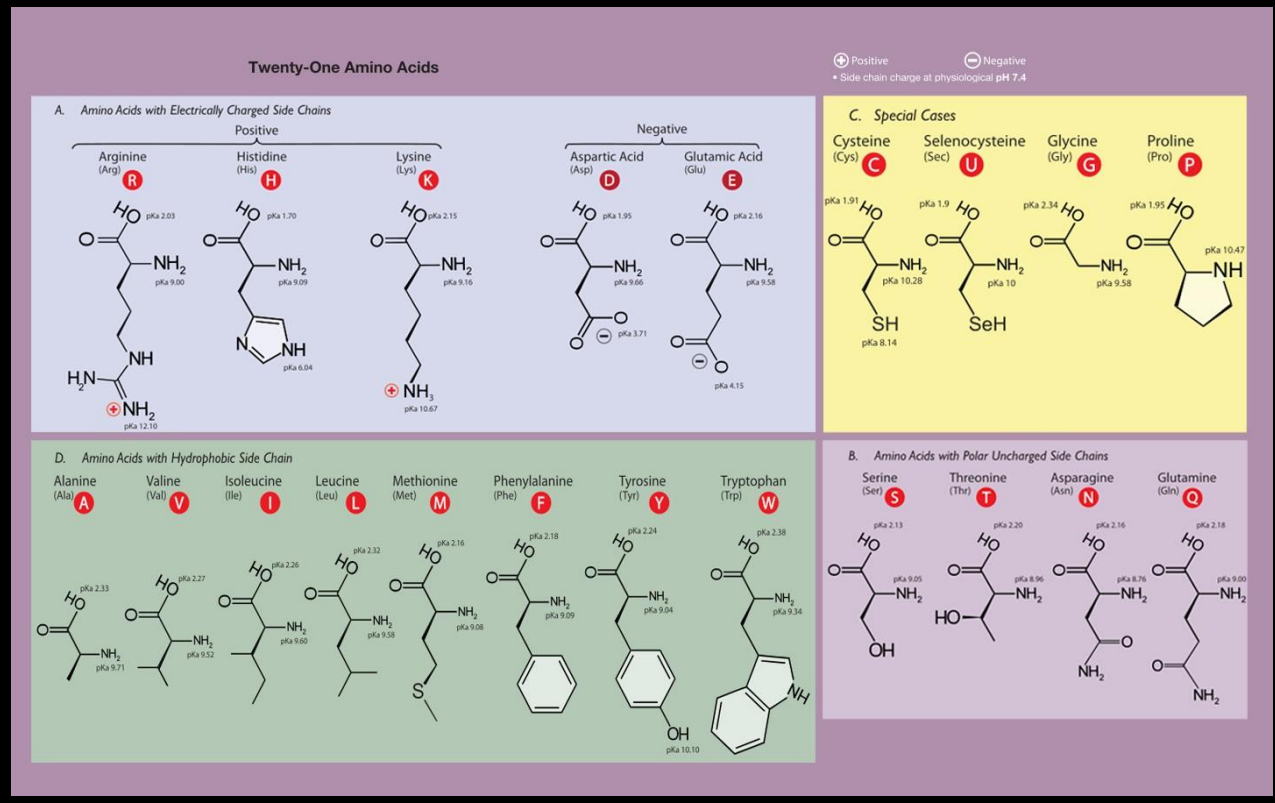


Macronutrients – [3] Proteins

- proteins: large macromolecules that comprise one or more long chains of amino acid residues
- Functions include enzymatic (catalytic), structural, regulatory, contractile, immunological, transport, and more

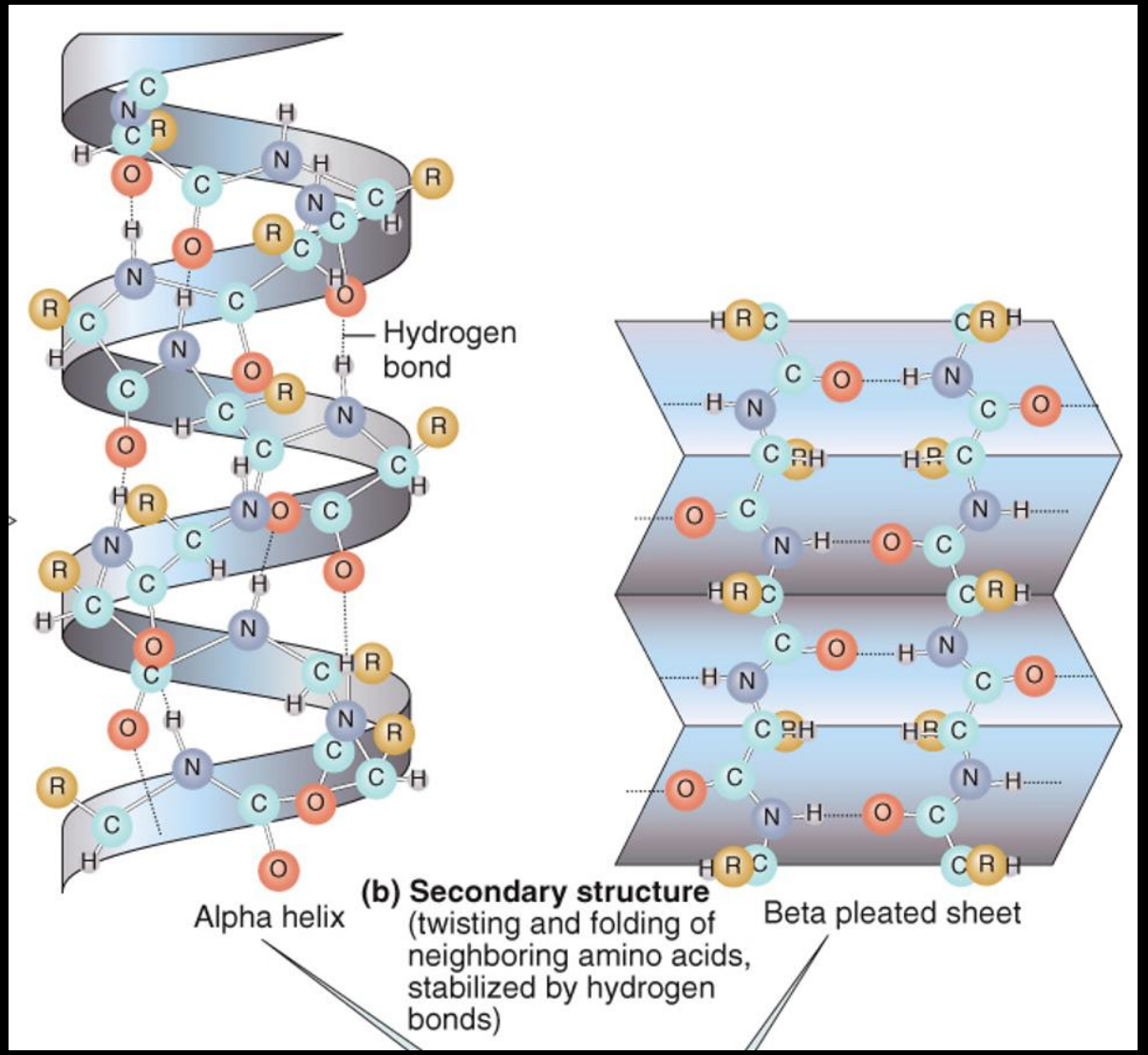


- amino acids = the monomers (small organic molecules) of proteins
  → in total there are 20 amino acids that are used to assemble proteins (ex. tryptophan)
- peptide bond = the covalent bond joining each pair of amino acids

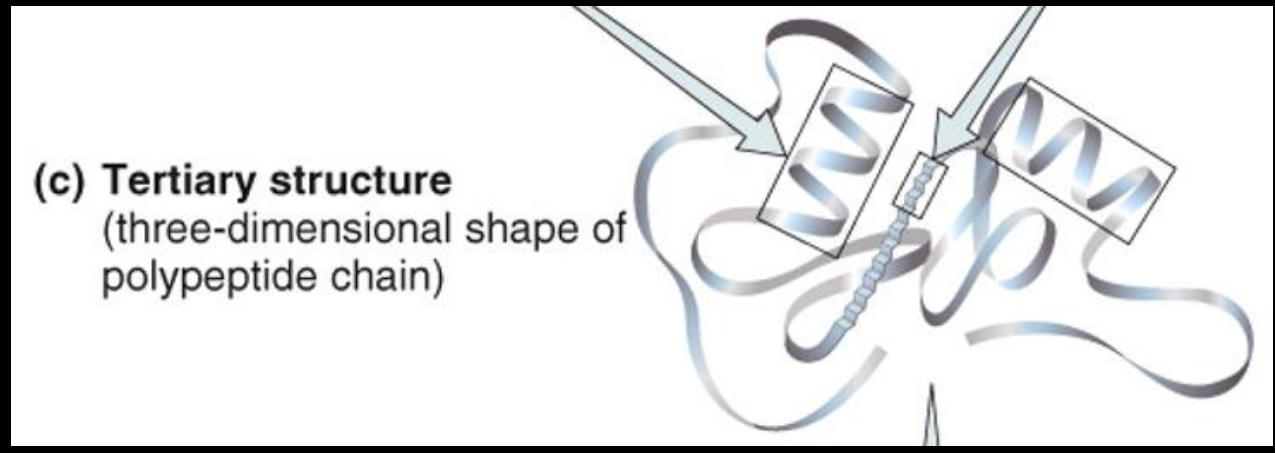


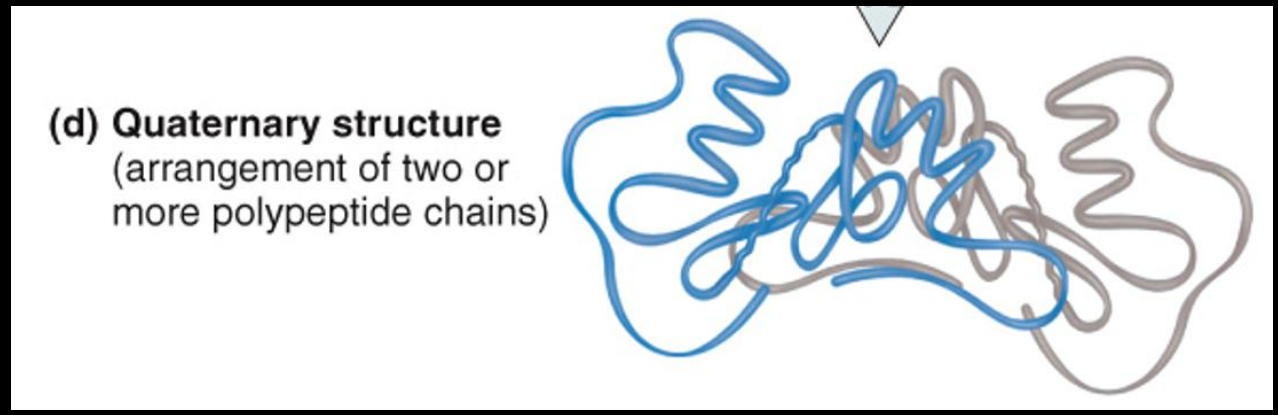
Protein Structure

- Proteins exhibit 4 levels of structural organization:
- **primary structure**: the unique sequence of amino acids that are linked by covalent peptide bonds to form a polypeptide chain
- **secondary structure**: repeated twisting or folding of neighboring amino acids in the polypeptide chain two forms
  - alpha helixes
  - beta pleated sheets



- **tertiary structure**: 3D shape of a polypeptide chain
- **quaternary structure**: the arrangement of the individual polypeptide chains relative to one another in proteins that contain more than one polypeptide chain
  - Not all proteins have quaternary structure





Macronutrients – [4] Nucleic Acids

- nucleic acids: complex organic substances present in living cells whose molecules consist of many “nucleotides” linked in a long chain
- [1] deoxyribonucleic acid (DNA): doubled-stranded structure that forms the inherited genetic material inside each human cell
- [2] ribonucleic acid (RNA): single-stranded structure that relays instructions from the genes to guide each cell’s synthesis of proteins from amino acids

Extracellular Fluid

- Extracellular fluid: the fluid in a tissue that is outside of a cell
- **interstitial fluid:** ECF that fills the narrow spaces between cells of tissues
- **blood plasma:** ECF within blood vessels
- **lymph:** ECF within lymphatic vessels
- **cerebrospinal fluid (CSF):** ECF in and around the brain
- **synovial fluid:** ECF in the joints
- **aqueous humor:** ECF in the eyes
- **vitreous body:** ECF in the eyes

Resources

- Dingess, Paige (2025)
- Grammarly. (2026). Grammarly (Version 14.1268.0) [Software]. https://www.grammarly.com/
- OpenAI. (2026). ChatGPT (GPT-5) [Large language model]. https://chat.openai.com/

Creation and Copyright Information

- Last updated: Jan 26, 2026
- Last updated by: Heather Talbott
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