CHEMISTRY COMES ALIVE

Anatomy & Physiology

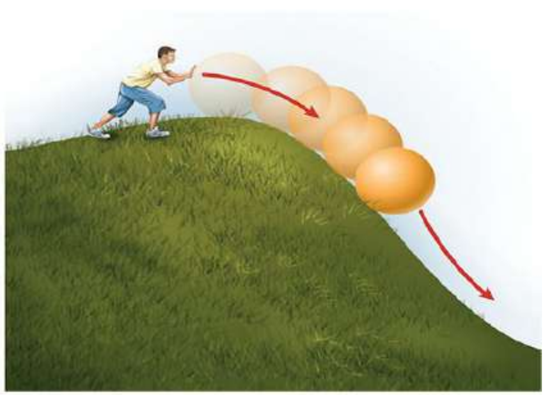
Basic Chemistry

- Matter
  - The "stuff" of the universe.
  - Anything that occupies space and has mass.
  - States of matter
    - Solid
    - Liquid
    - Gas

Basic Chemistry

- Energy
  - Less tangible → no mass, does not take up space, & is only measured by its effects on matter.
  - The capacity to do work or to put matter into motion.
  - Kinetic vs. Potential Energy
    - Kinetic: Energy in action → does work by moving objects.
      - Bouncing ball
    - Potential: Stored energy → inactive energy that has the potential or capability to do work.
      - Batteries in an unused toy.

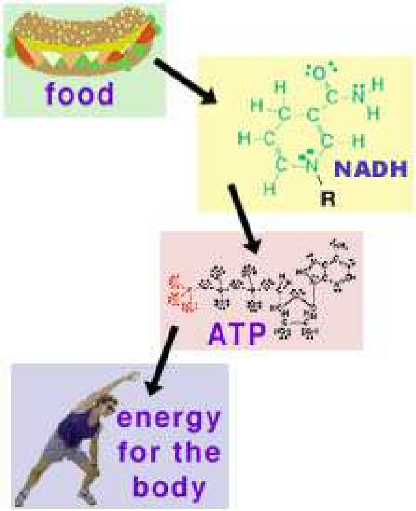
a) Potential energy

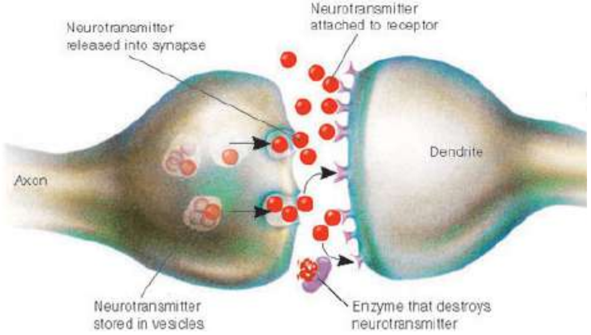


(b) Kinetic energy

Basic Chemistry

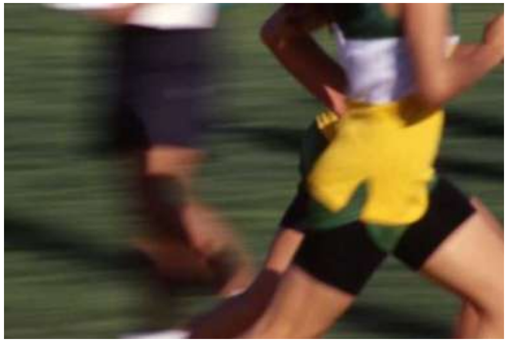
- Forms of Energy
  - Chemical energy
    - Stored in the bonds of chemical substances.
      - Energy in the foods you eat is captured in the bonds of a chemical called ATP (adenosine triphosphate) and later broken and released to do cellular work.
  - Electrical energy
    - Results from the movement of charged particles.
      - In your body, electrical currents are generated when charged particles called ions move across cell membranes.
      - Nerve impulses are also electrical current that transmit messages from one part of the body to another.

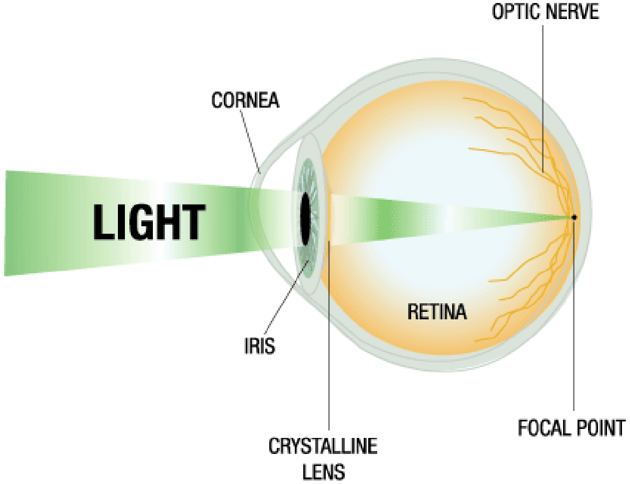




Basic Chemistry

- Mechanical energy
  - Directly involved in moving matter.
    - When you ride a bike your legs provide mechanical energy that move the pedals.
- Radiant or electromagnetic energy
  - Energy that travels in waves.
    - Light energy that stimulates the retinas in eyes is important for vision.



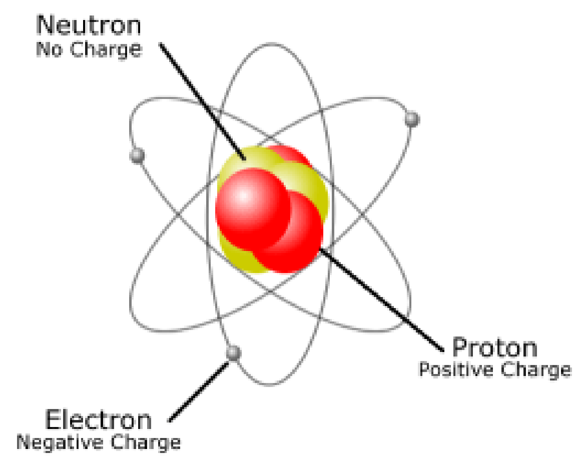


Composition of Matter: Atoms & Elements

- All mater is composed of elements → unique substances that cannot be broken down into simpler substances by ordinary methods.
  - 112 elements are known with certainty
  - 92 occur in nature→ the rest are made artificially.
  - 4 make up 96% of our body weight
    - Carbon
    - Oxygen
    - Hydrogen
    - Nitrogen
  - 20 others are present in the body some in trace amounts.

Composition of Matter: Atoms & Elements

- Elements are composed of building blocks called atoms.
- Every element's atoms differ from those of all other elements and give the element its unique physical and chemical properties.
- Atom comes from a Greek word meaning "indivisible".
  - We know atoms are made up of even smaller particles called protons, neutrons, & electrons.
  - The atom's nucleus contains the neutral neutrons and positive protons and is orbited by negatively charged electrons.



Atomic Structure

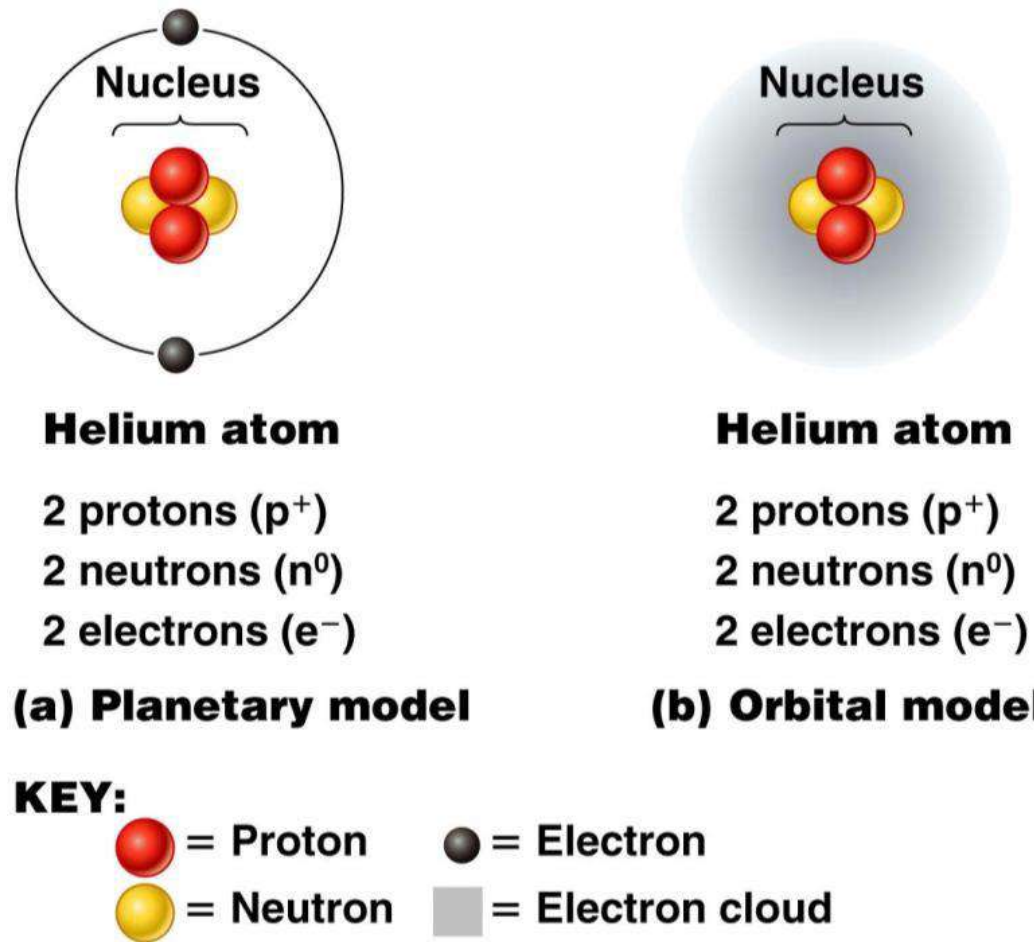
Nucleus

•Protons (p+)

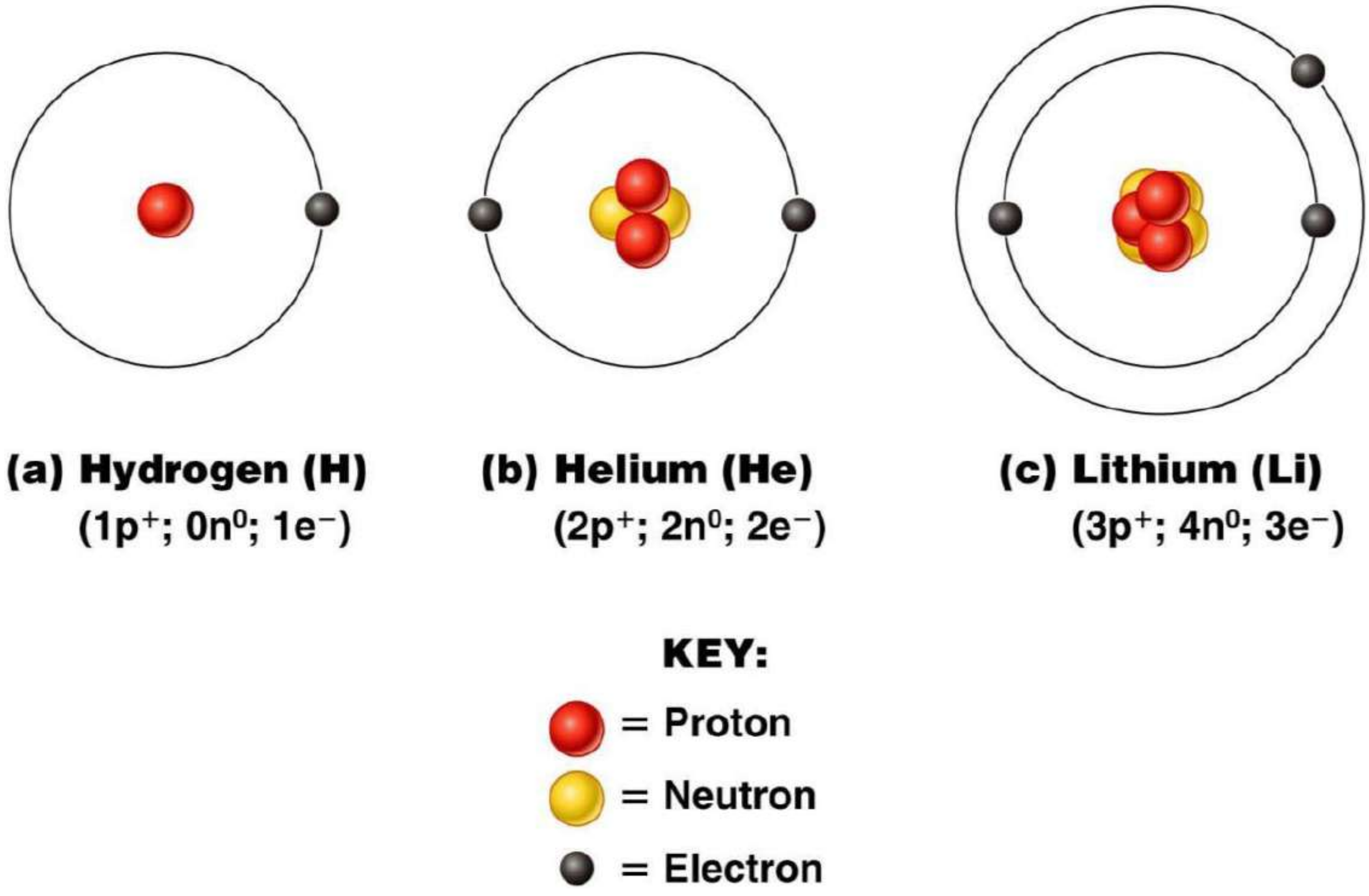
•Neutrons (n0)

Outside of nucleus

•Electrons (e-)



Atomic Structure of 3 Small Atoms



What makes elements unique?

Question: Atoms of elements are made up of the same exact components…protons, neutrons and electrons. So what makes them different?

Answer: atoms of different elements are composed of *different numbers* of protons, neutrons and electrons

Atomic Number

- The atomic number of any atom is equal to the number of protons in its nucleus

- Remember: the number of protons is always equal to the number of electrons in an atom, so the atomic number indirectly tells us the number of electrons in the atom as well

Atomic Mass Number

- The mass number of an atom is the sum of the masses of its protons and neutrons

  - So lets look at Lead…Lead's mass number is 207 and has 125 neutrons. Knowing what we know now, how many protons and electrons does Lead have?

Answer: 82

Isotopes

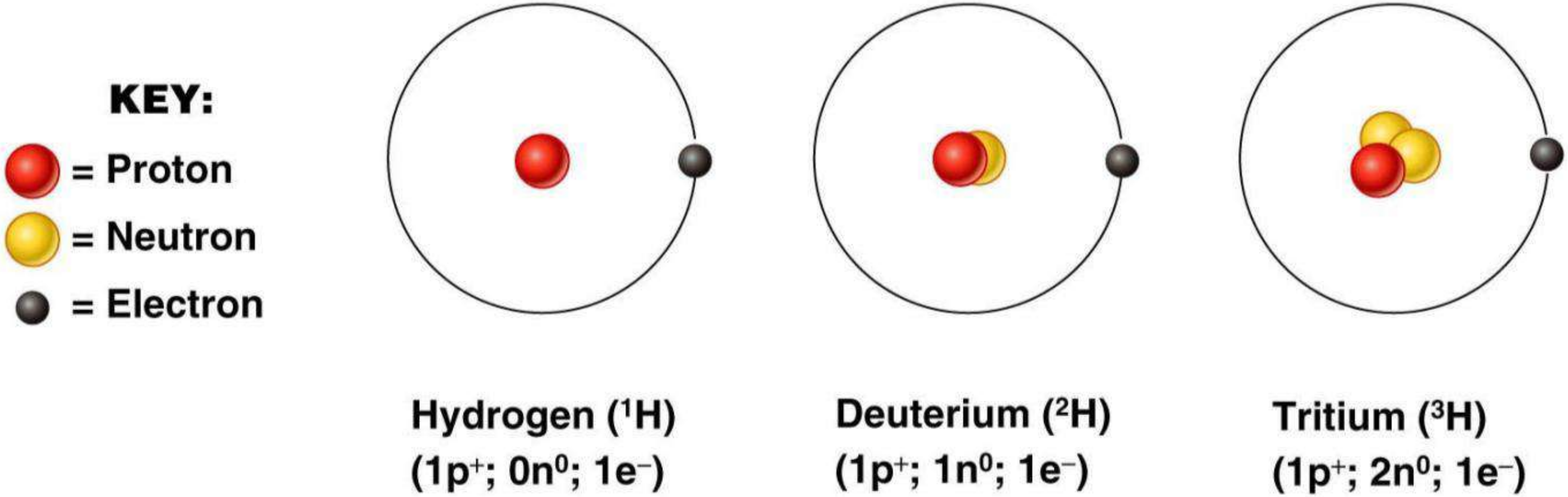
- Nearly all known elements have 2 or more structural variations called isotopes which have the same number of protons (and electrons) but the number of neutrons they contain differ
  - Lets look at Carbon…Carbon has several isotopes

^{12}C, ^{13}C, and ^{14}C

Each Carbon isotope has 6 protons (otherwise it wouldn't be carbon), but ^{12}C has 6 neutrons, ^{13}C has seven, and ^{14}C has eight

Isotopes

Let's look at Hydrogen



Atomic Weight

- Atomic weight is NOT the same thing as atomic mass. Atomic mass refers to the mass of a single atom of an element.

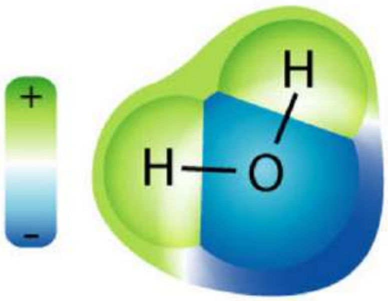
- Atomic weight is an average of the mass numbers of *all* the isotopes of an element, taking into account their relative abundance in nature.
- As a rule, the atomic weight of an element is approximately equal to the mass number of its most abundant isotope.

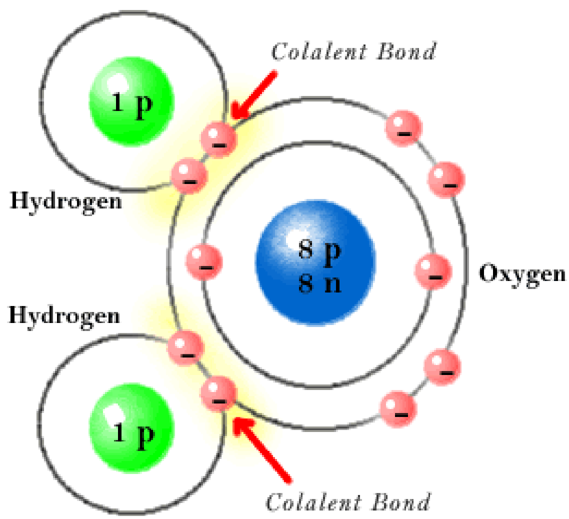
Radioactivity

- Radioisotope
  - Heavy isotope
  - Tends to be unstable
  - Decomposes to more stable isotope sometimes even a different element
- Radioactivity—process of spontaneous atomic decay
- In medicine, radioisotopes are used in PET scans to show live-action pictures of the brain's biochemical activity as well as for treating cancer.

How Matter is Combined: Molecules and Mixtures

- Combinations of two or more atoms held together by chemical bonds is called a **molecule.**
- When two or more atoms of the same element combine the resulting substance is called a molecule of that element.
  - When two oxygen atoms combine they for a molecule of oxygen gas (O_2).
- When two or more different kinds of atoms bind they form molecules of a **compound.**
  - Two hydrogen atoms combine with one oxygen atom to form the compound water (H_2O).

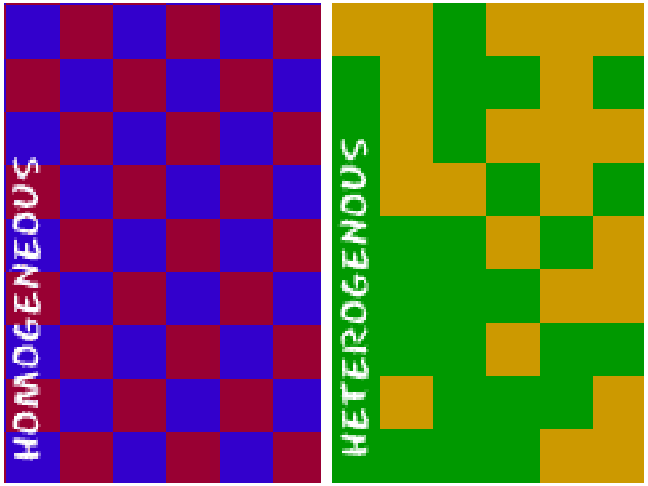




Bohr Model of H_2O

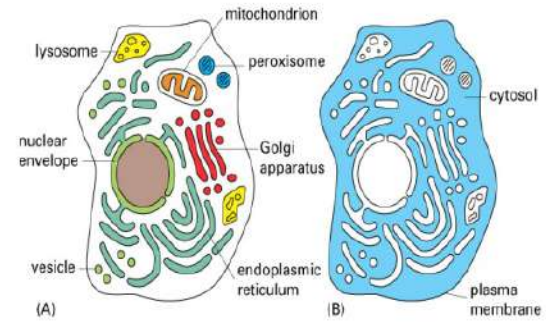
How Matter is Combined: Molecules and Mixtures

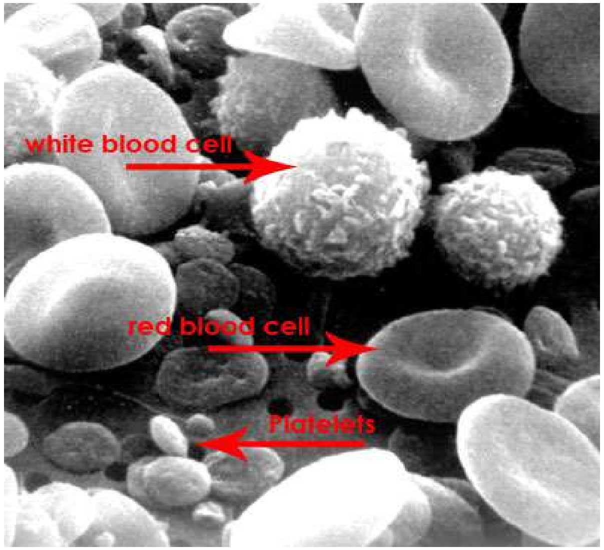
- Mixtures are substances composed of two or more components physically intermixed.
- Solutions are homogenous mixtures of components that may be gases, liquids, or solids.
  - Homogenous means that the mixture has exactly the same composition throughout.
- Substances present in the greatest amount are called solvents and substances present in smaller amounts are called solutes.



How Matter is Combined: Molecules and Mixtures

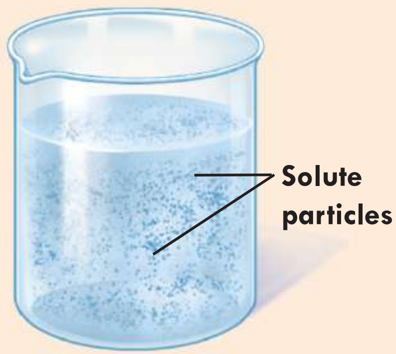
- Colloids are heterogeneous mixtures, which means their composition is dissimilar in different areas of the mixture.
  - Colloids are also called emulsions and are translucent or milky, the solute particles are larger but usually do not settle out.
  - Cytosol the semifluid in living cells is a colloid because it has dispersed proteins.
- Suspensions are heterogeneous mixtures with large often visible solutes that tend to settle out.
  - Blood is an example of a suspension- living blood cells are suspended in the fluid portion of blood- blood plasma.





Solution

Solute particles are very tiny, do not settle out or scatter light.

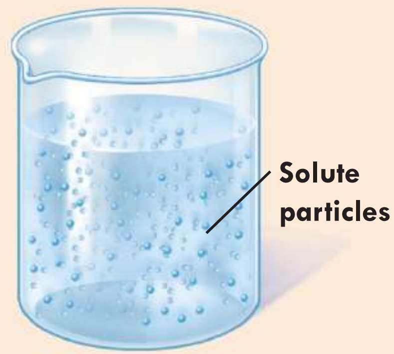


Example

Mineral water

Colloid

Solute particles are larger than in a solution and scatter light; do not settle out.

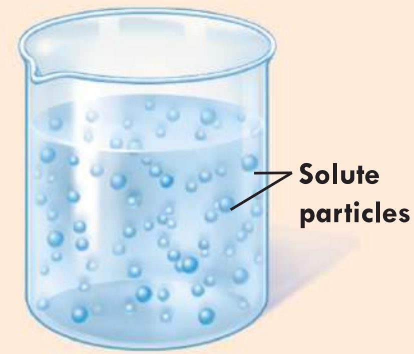


Example

Gelatin

Suspension

Solute particles are very large, settle out, and may scatter light.



Example

Blood

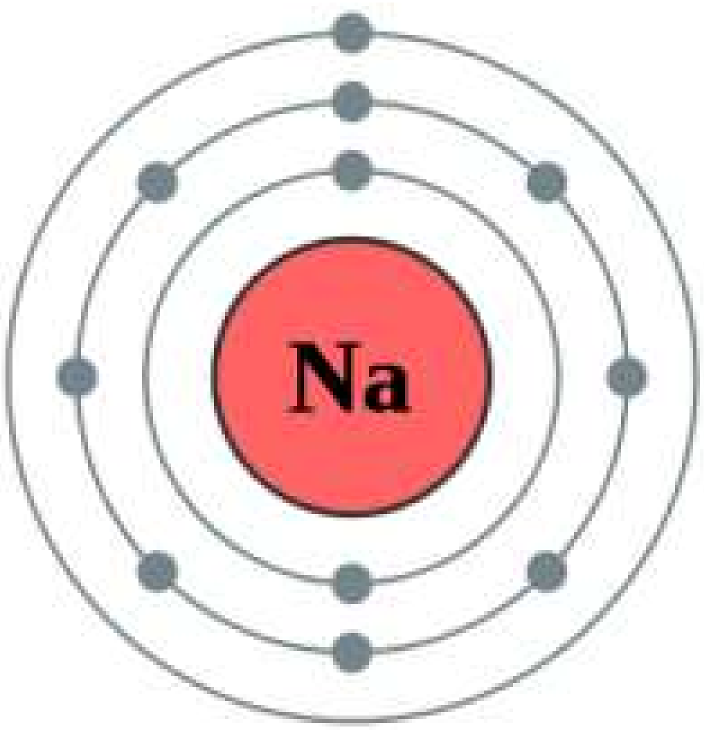
Before we begin bonding…

Remember…electrons occupy energy levels called **electron shells**

- Electrons closest to the nucleus are most strongly attracted
- Each shell has distinct properties
- The number of electrons has an upper limit
- Shells closest to the nucleus fill first

Electrons and Bonding

- Bonding involves interactions between electrons in the outer shell (valence shell)
- Full valence shells do not form bonds



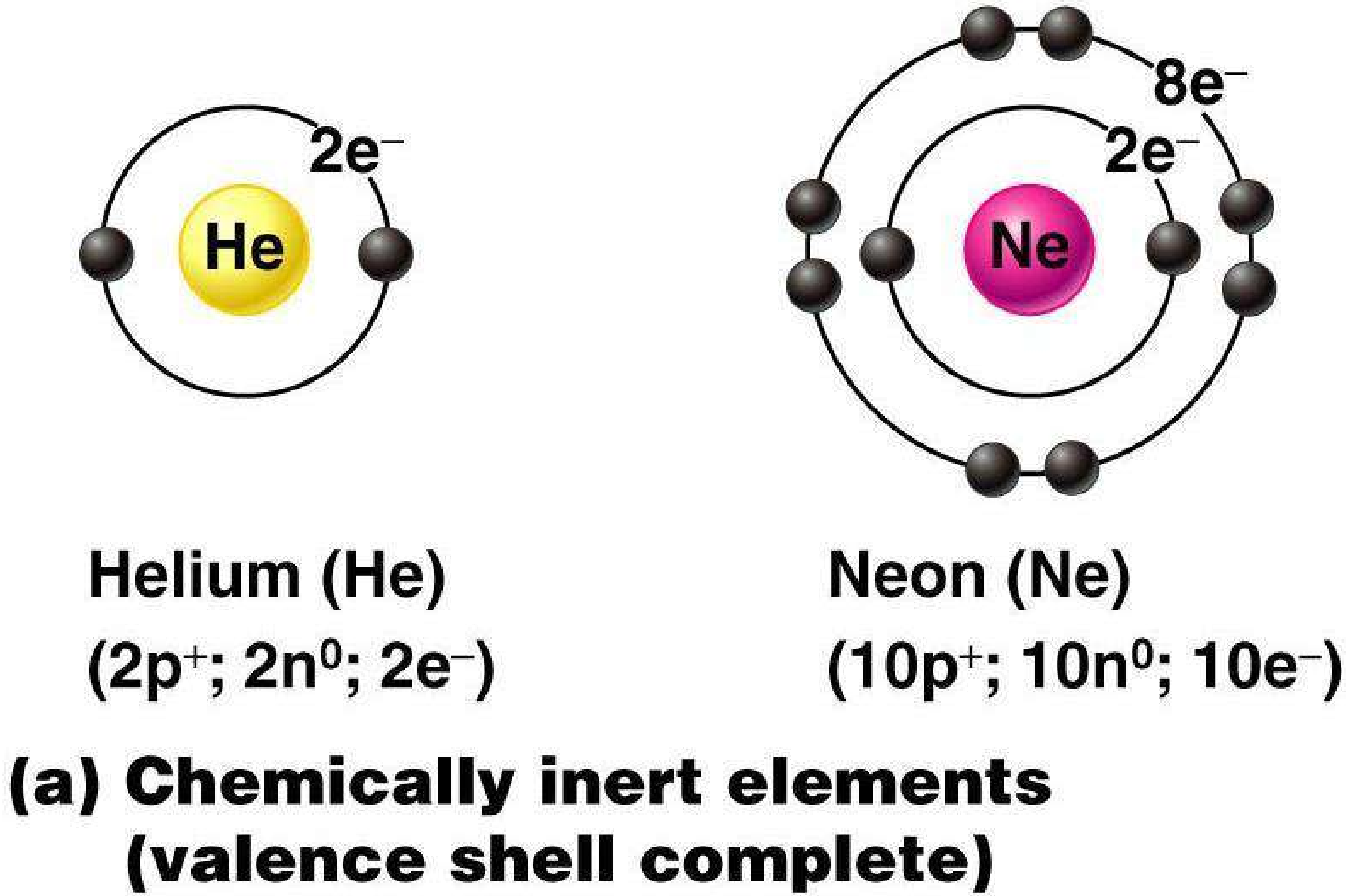
Inert Elements

- Atoms are stable (inert) when the outermost shell is complete
- How to fill the atom's shells
  - Shell 1 can hold a maximum of 2 electrons
  - Shell 2 can hold a maximum of 8 electrons
  - Shell 3 can hold a maximum of 18 electrons

Inert Elements

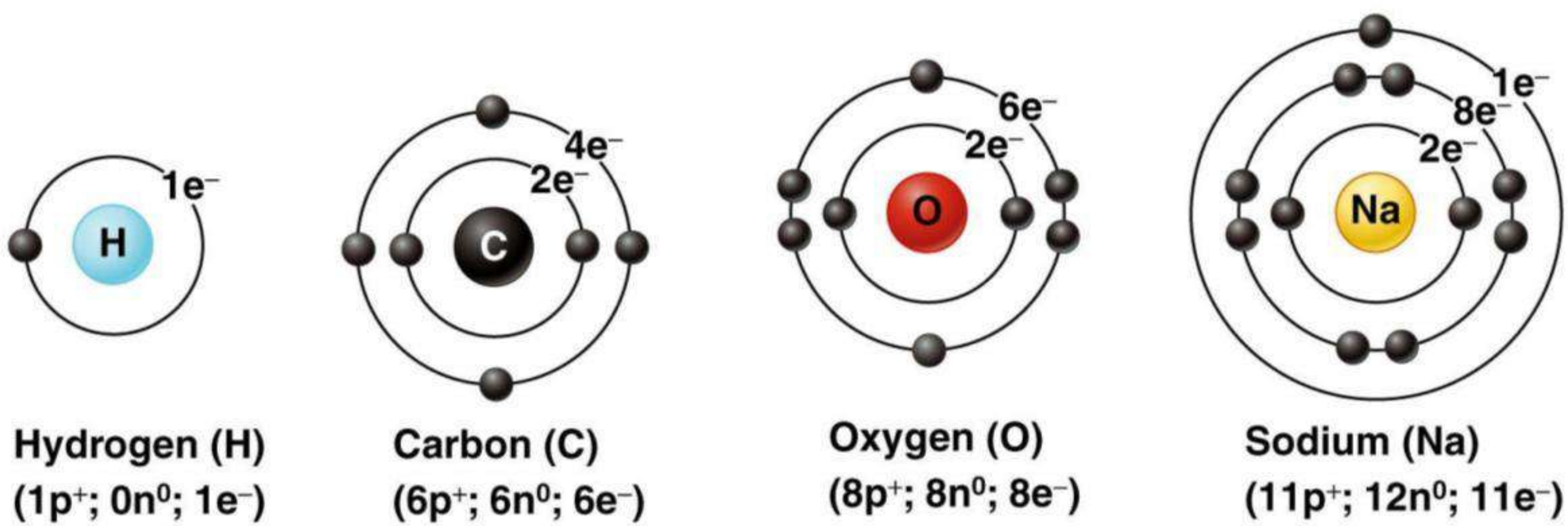
- Atoms will gain, lose, or share electrons to complete their outermost orbitals and reach a stable state
- Rule of eights
  - Atoms are considered stable when their outermost orbital has 8 electrons
  - The exception to this rule of eights is Shell 1, which can only hold 2 electrons

Inert Elements



Reactive Elements

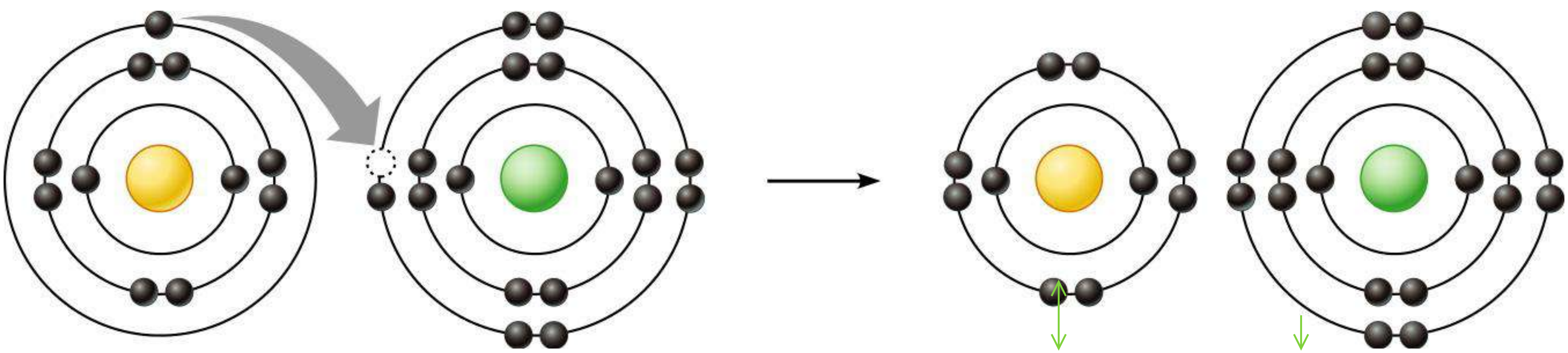
- Valence shells are not full and are unstable
- Tend to gain, lose, or share electrons
  - Allow for bond formation, which produces stable valence



(b) Chemically active elements (valence shell incomplete)

Types of Chemical Bonds

- Ionic Bonds are formed by the complete transfer of electrons from one atom to the other.

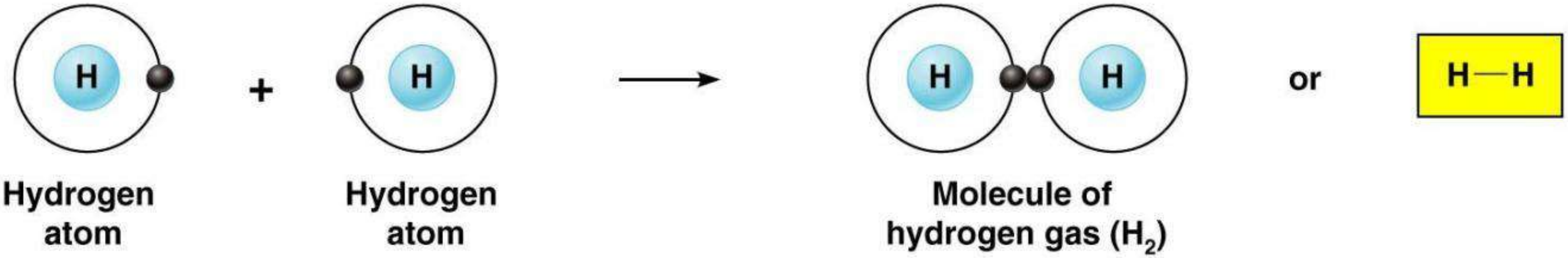


NaCl

NaCL

Covalent Bonds

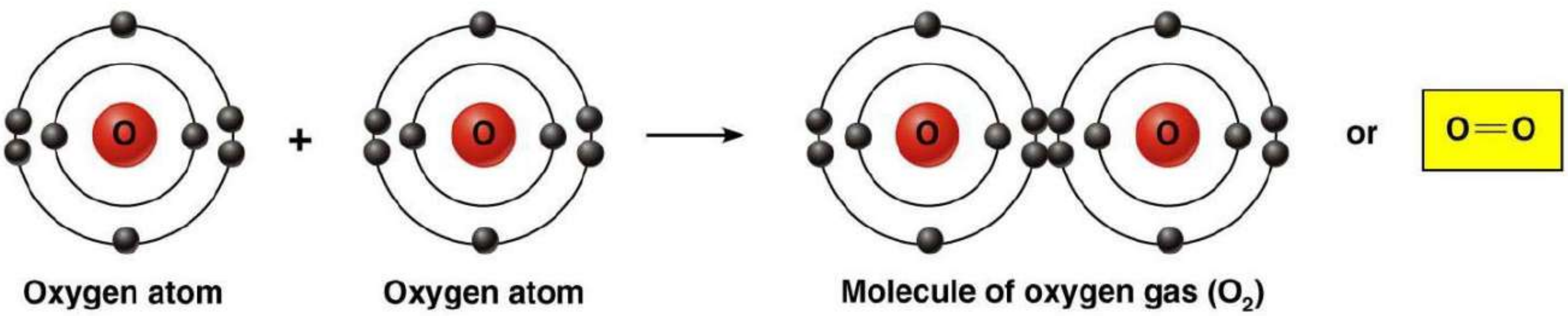
- Electrons do not have to be completely transferred for atoms to achieve stability.
- When electrons are **shared** between atoms this constitutes a covalent bond.



(a) Formation of a single covalent bond

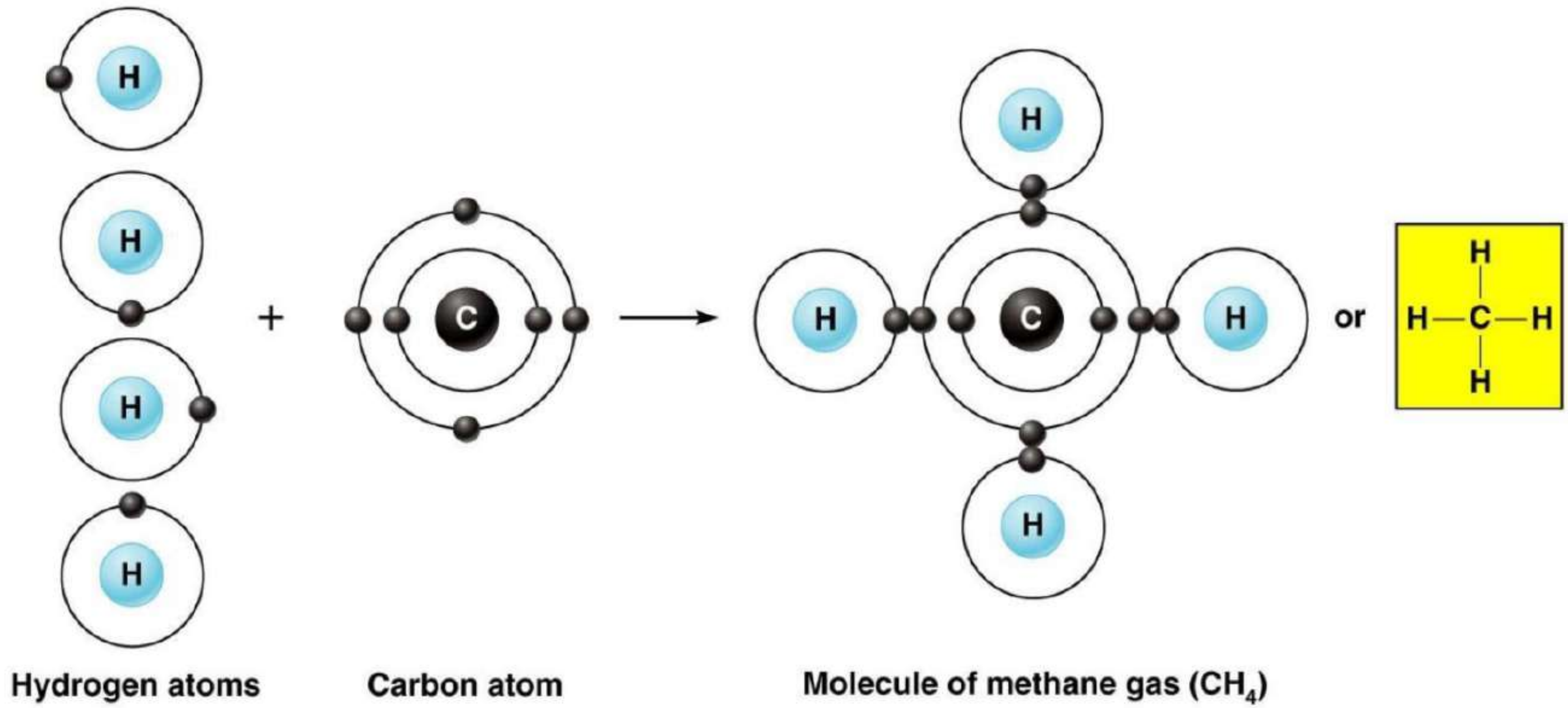
Examples of Covalent Bonds

Covalent bonds may be single, double or even triple bonded



(b) Formation of a double covalent bond

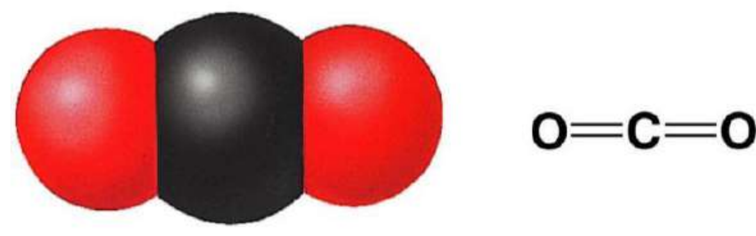
Examples of Covalent Bonds



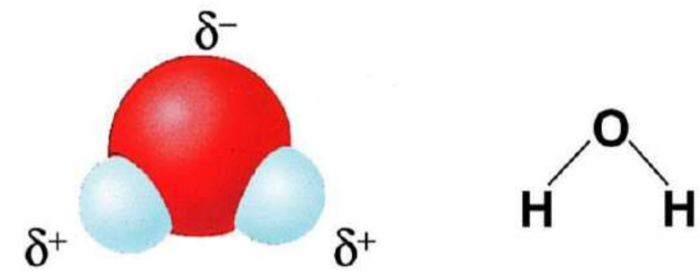
(c) Formation of four single covalent bonds

Polarity

- Covalently bonded molecules
- Some are non-polar
  - Electrically neutral as a molecule
- Some are polar
  - Have a positive and negative side



(a) Carbon dioxide (CO_2)



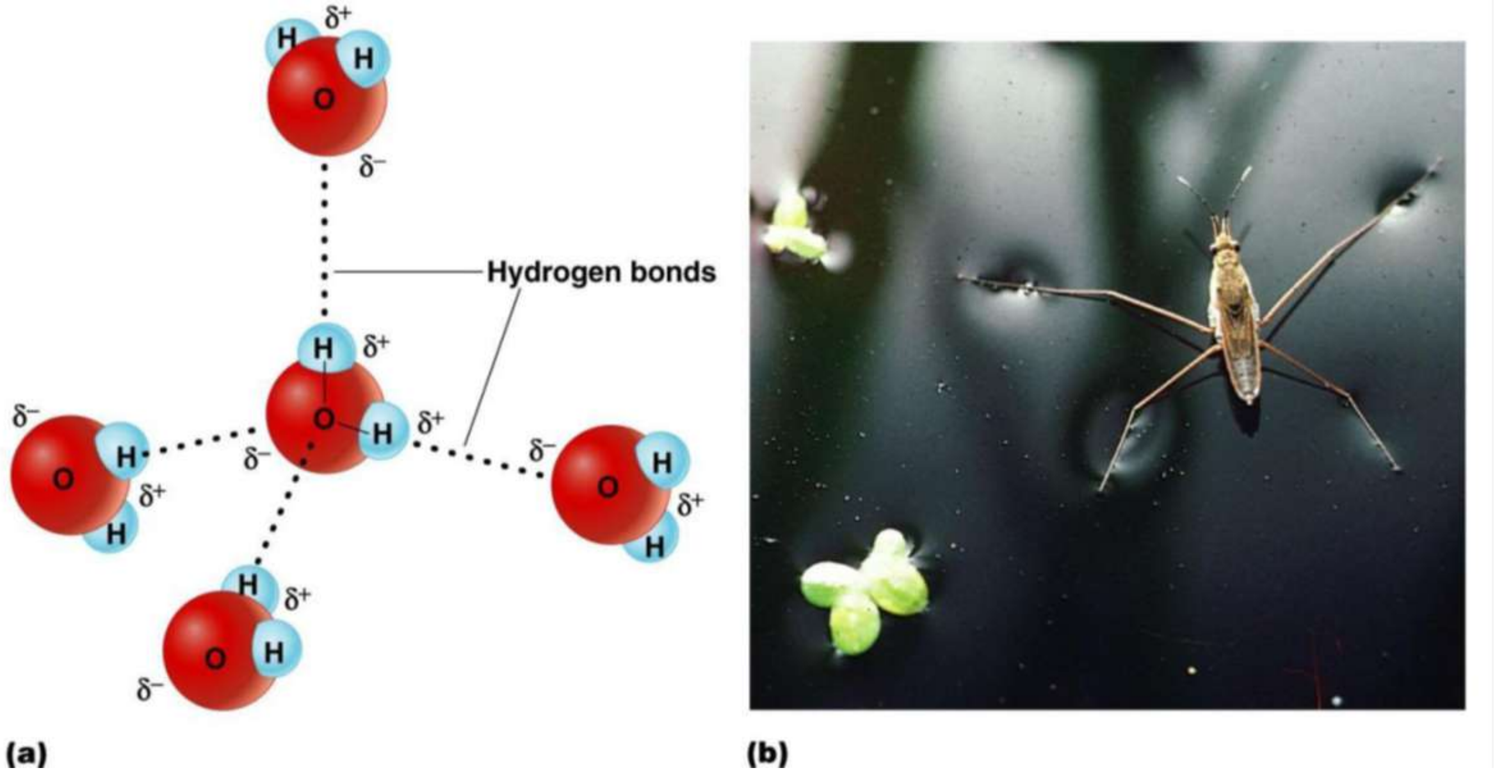
(b) Water (H_2O)

Hydrogen Bonds

- Hydrogen Bonds are more like attractions than true bonds.
- Form when a hydrogen atom is attracted to another electron-hungry atom.
- Hydrogen is attracted to the negative portion of polar molecule

Hydrogen Bonds

- Hydrogen bonding is responsible for the tendency of water molecules to cling together and form films, referred to as surface tension

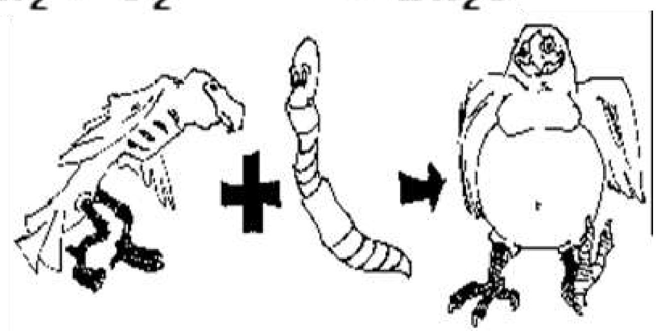


Chemical Reactions

- A chemical reaction occurs whenever chemical bonds are formed, rearranged, or broken.
- Most chemical reactions exhibit one of three patterns: synthesis, decomposition, or exchange reactions.
  - **Synthesis or combination reactions**: atoms or molecules combine to form a larger, more complex molecule.
    - New bonds are formed.

Synthesis Reaction

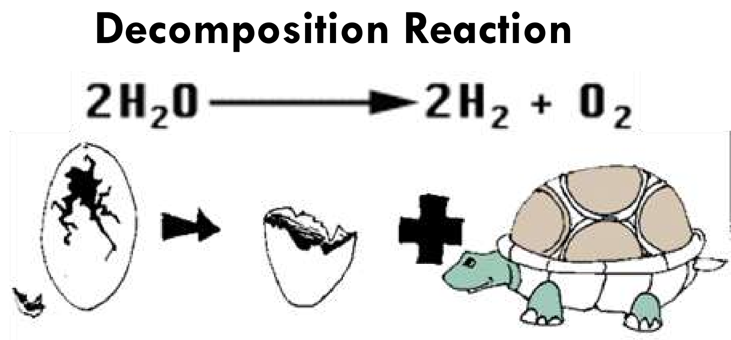
$$2H_2 + O_2 \longrightarrow 2H_2O$$

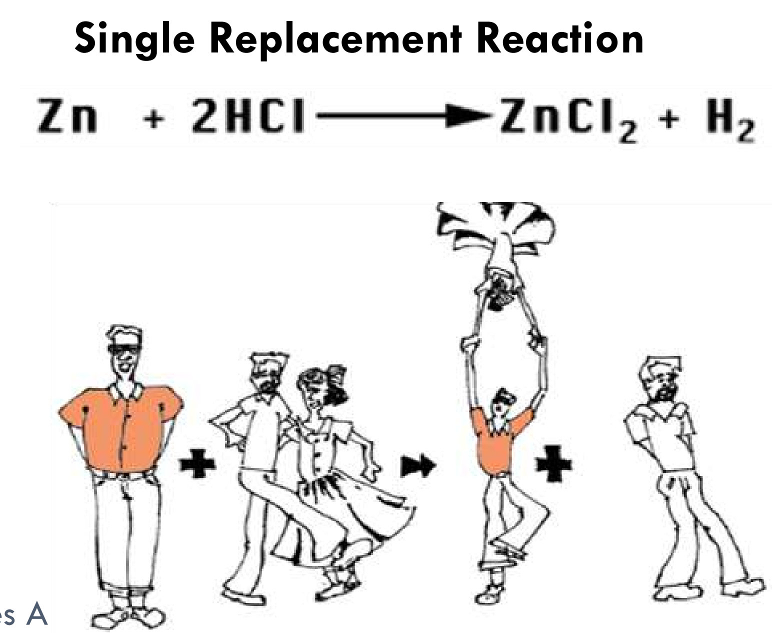


Chemical Reactions

- **Decomposition reactions:** molecules are broken down into smaller molecules or its constituent atoms.
  - Bonds are broken (reverse synthesis).

- **Exchange or displacement reactions:** involve both synthesis and decomposition.
  - Bonds are both made and broken.



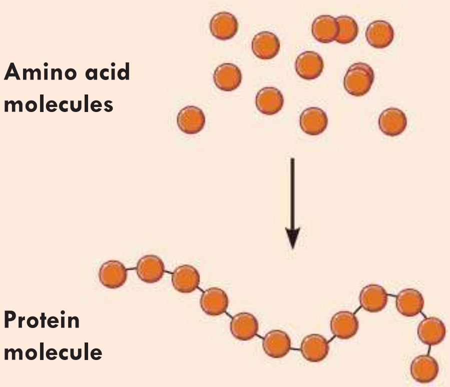


(a) Synthesis reactions

Smaller particles are bonded together to form larger, more complex molecules.

Example

Amino acids are joined together to form a protein molecule.

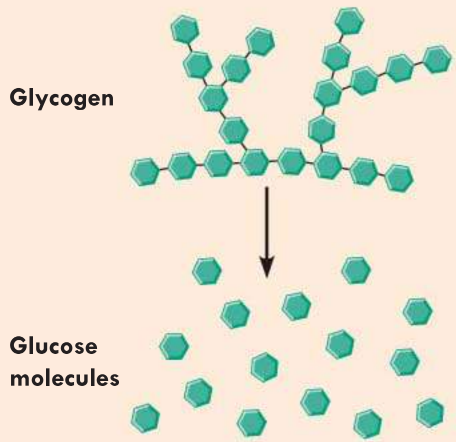


(b) Decomposition reactions

Bonds are broken in larger molecules, resulting in smaller, less complex molecules.

Example

Glycogen is broken down to release glucose units.

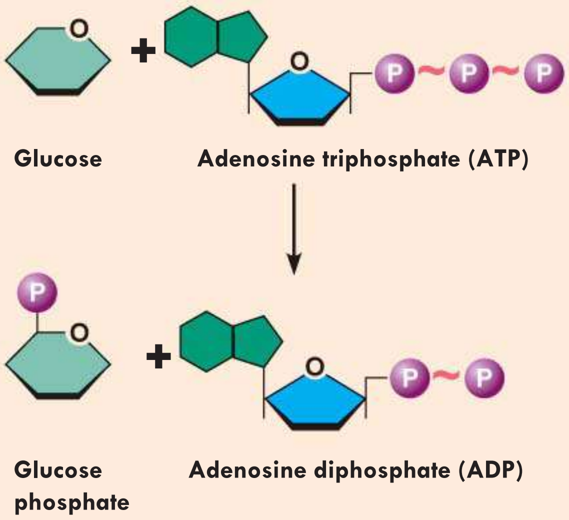


(c) Exchange reactions

Bonds are both made and broken (also called displacement reactions).

Example

ATP transfers its terminal phosphate group to glucose to form glucose-phosphate.



Chemical Reactions

- Factors that influence the rate of chemical reactions include:
  - **Temperature**
    - Increasing temperature speeds up chemical reactions.
  - **Concentration**
    - Chemical reactions progress most rapidly when the reacting particles are present in high numbers because the chance of successful collisions is greater.

Factors Influencing Reaction cont'd

- **Particle Size**
  - Smaller particles move faster than larger ones and tend to collide more frequently and more forcefully.
- **Catalysts**
  - Substances that increase the rate of chemical reactions without themselves becoming chemically changed or part of the product.
  - Biological catalysts are called enzymes.

Biochemistry- the study of chemical composition and reactions of living matter

Organic compounds

- Contain carbon
- Most are covalently bonded
- Example: $C_6H_{12}O_6$(glucose)

Inorganic compounds

- Lack carbon
- Tend to be simpler compounds
- Example: H_2O (water)

Inorganic Compounds

- **Water**
  - 60 – 80% of the volume of most living cells (this means YOU) is made up of water!
  - Most abundant and important inorganic compound in living material mainly due to its several properties:
    - **High heat capacity**
      - Absorbs and releases large amounts of heat before changing in temperature.
      - This property prevents sudden changes in body temperature due to outside factors like sun or wind.

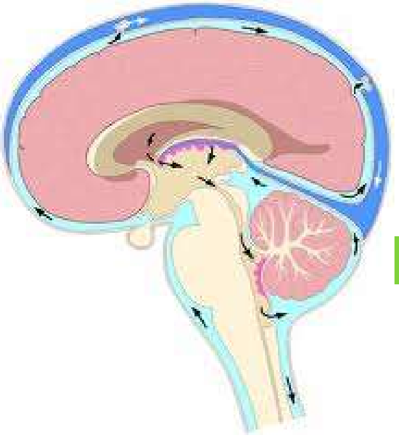
Inorganic Compounds

- **High heat of vaporization**
  - When water evaporates or vaporizes it changes from liquid to a gas- this transformation requires large amounts of heat to break the hydrogen bonds that hold water together.
  - This property is extremely beneficial when we sweat- as perspiration evaporates from our skin large amounts of heat are removed from the body providing cooling.

Inorganic Compounds

- **Polar solvent properties**
  - Universal solvent
  - Because water molecules are polar they orient themselves with their slightly negative ends toward the positive ends this polarity explains why compounds and molecules disassociate in water and become evenly scattered forming true solutions.
  - Water is the body's major transport medium because its such a great solvent- nutrients, respiratory gases, and metabolic wastes carried through out the body are dissolved in blood plasma.

Inorganic Compounds



- **Reactivity**
  - Water is an important reactant in many chemical reactions.
  - Foods are digested to their building blocks by adding a water molecule to each bond to be broken.
- **Cushioning**
  - By forming a resilient cushion around certain body organs, water helps protect them from physical trauma.

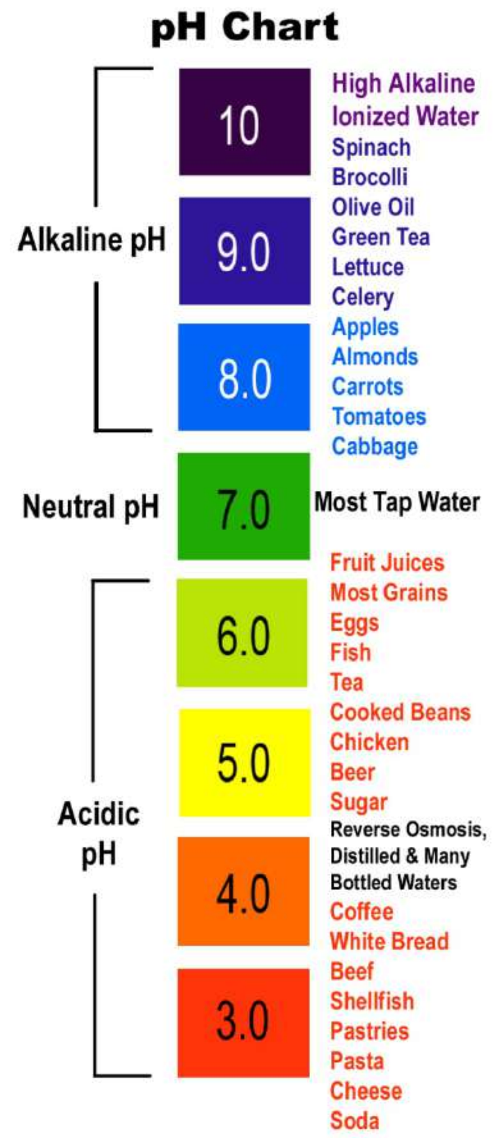
Inorganic Compounds

Salts

- Salts commonly found in the body include NaCl, $CaCO_3$, and KCl.
- Salts are ions and all ions are electrolytes- substances that conduct an electrical current in solution.
- The electrolyte properties of sodium and potassium ions are essential for nerve impulse transmission and muscle contraction.

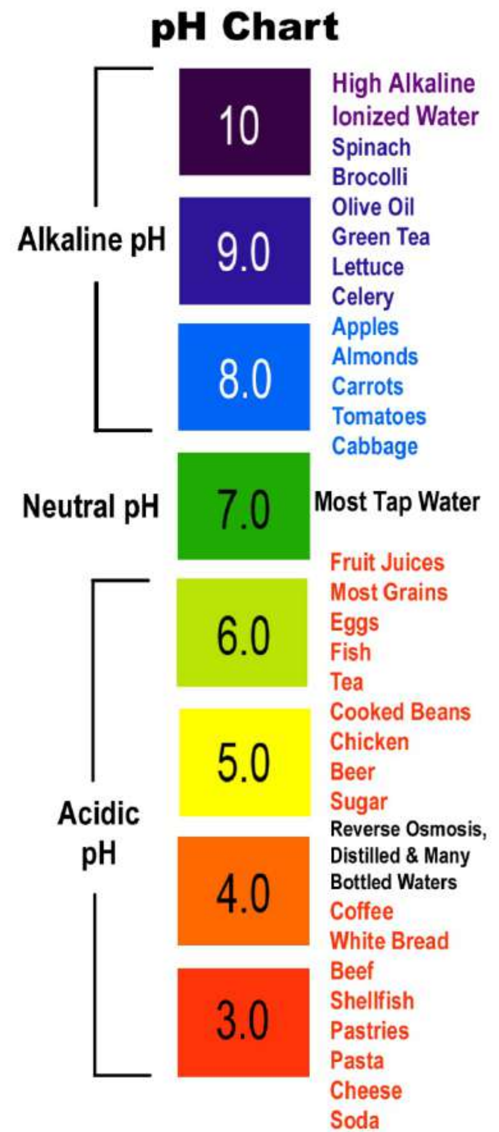
Inorganic Compounds

- **Acids and Bases**
  - Acids and bases are also electrolytes.
  - Acids have a sour taste and can react with many metals.
    - Hydrochloric acid is an acid produced by the stomach cells that aids in digestion.
  - Bases have a bitter taste and feel slippery.
    - Bicarbonate ion is an important base in the body and is abundant in blood.
    - Ammonia, a common waste product of protein breakdown in the body, is also a base.



Inorganic Compounds

- pH scale measures the alkalinity or acidity of substances and is based on the number of hydrogen ions in a solution.
  - the more hydrogen ions in a solution the more acidic it is.
- Buffers resist abrupt and large swings in pH.
  - High concentrations of acids and bases are extremely damaging to living tissues.

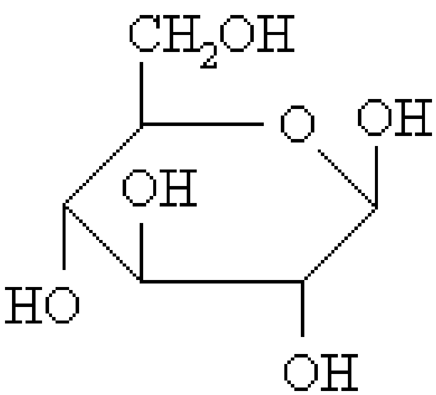


Organic Compounds

- **Carbohydrates**
  - Sugars and starches
  - Contain carbon, hydrogen, and oxygen.
  - The major function of carbs. in the body is to provide a ready, easily used source of cellular fuel.
  - **Monosaccharides**
    - Simple sugars
    - Single-chain or single ring structures containing from 3 to 7 carbon atoms.
    - Ex. Glucose or blood sugar

      Pentose or deoxyribose- part of DNA

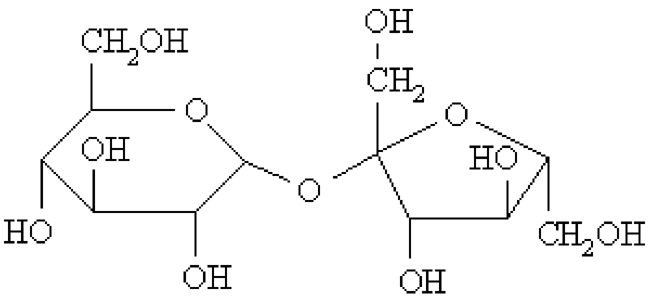
Glucose

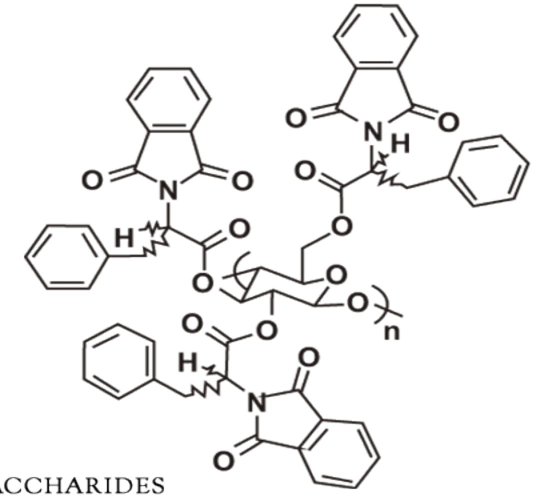


Organic Compounds

- **Disaccharides**
  - A double sugar
  - Formed when two monosaccharides are joined by dehydration synthesis.
  - Ex. Sucrose (glucose + fructose)
    Lactose (glucose + galactose)
    Maltose (glucose + glucose)
- **Polysaccharides**
  - Polymers of simple sugars linked together by dehydration synthesis.
  - Ex. Starch and Glycogen

Sucrose

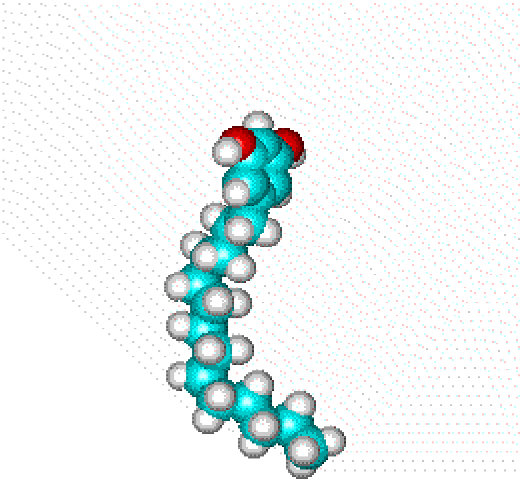




POLYSACCHARIDES

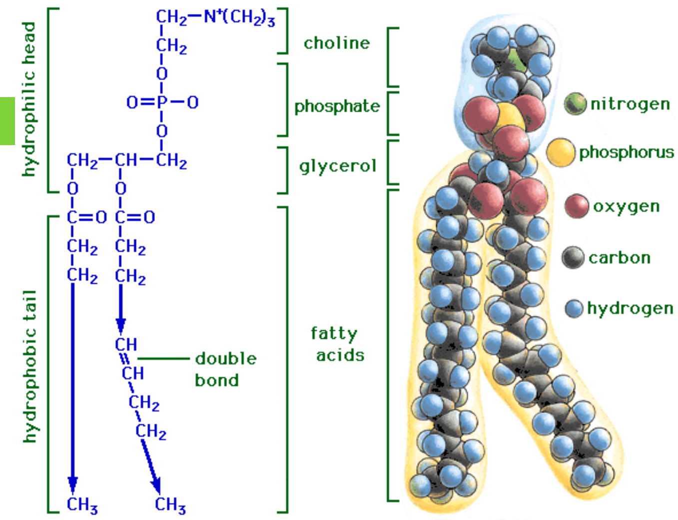
Organic Compounds

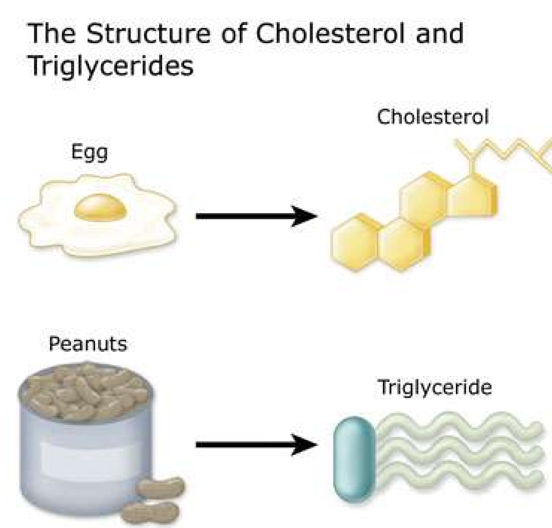
- Lipids
  - Are insoluble in water.
  - Contain carbon, hydrogen, and oxygen.
  - Fat deposits that protect and insulate the organs and that are a major source of stored energy.



Organic Compounds

- **Triglycerides**
  - Fats when solid and oils when liquid
  - Composed of two types of building blocks: 3 fatty acids and a glycerol.
  - Longer fatty acid chains and more saturated fatty acids are common in animal fats such as butter fat and meat fat- these are considered the “bad” fats.



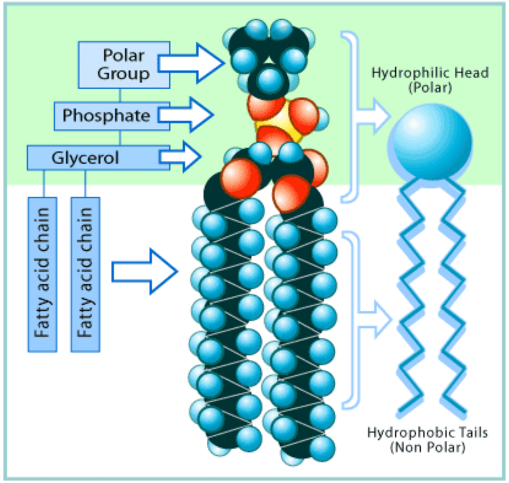


Triglycerides continued

- Unsaturated fat like olive oil is considered “heart healthy”.
- Trans fats common in many margarines are oils that have been solidified by addition of H atoms- these increase the risk of heart disease even more than animal fats.
- Omega-3 fatty acids found naturally in cold-water fish decrease the risk of heart disease.

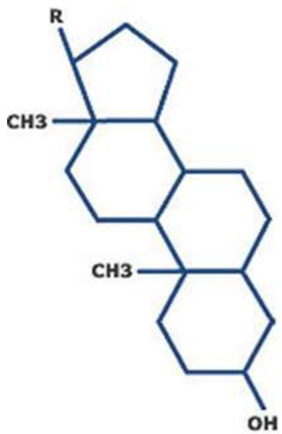
Organic Compounds

- **Phospholipids**
  - Modified triglycerides.
    - Diglycerides with a phosphorous containing group and two fatty acids chains.
  - Used as the chief material for building cellular membranes.



Organic Compounds

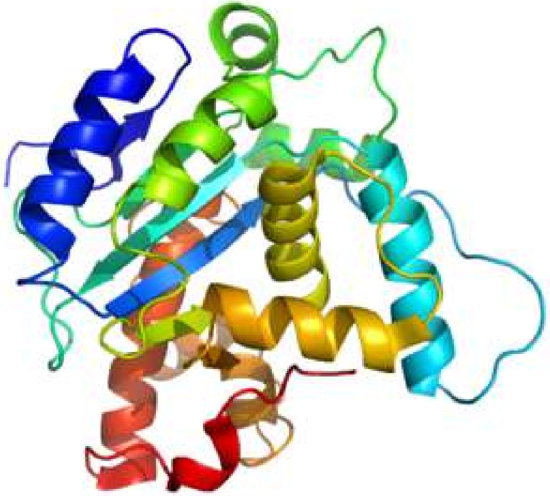
- **Steroids**
  - Flat molecules made of four interlocking hydrocarbon rings.
  - Ex. Cholesterol, bile salts (aid in digestion), Vitamin D, Sex Hormones (estrogen and testosterone), and Adrenocortical hormones (cortisol- regulates blood glucose).



- **Eicosanoids**
  - Found in all cell membranes
  - Prostaglandins- play roles in blood clotting, regulation of blood pressure, inflammation, and labor contractions.

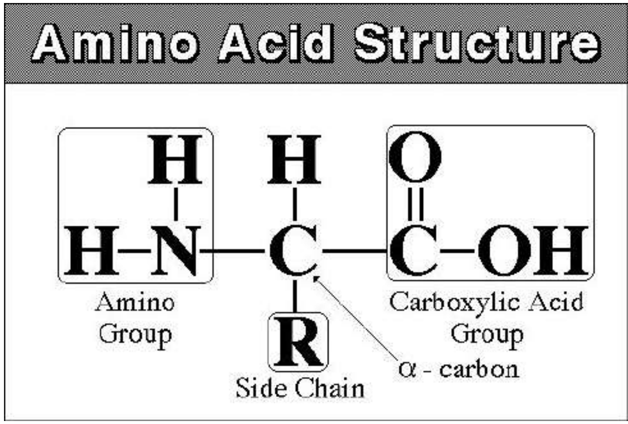
Organic Compounds

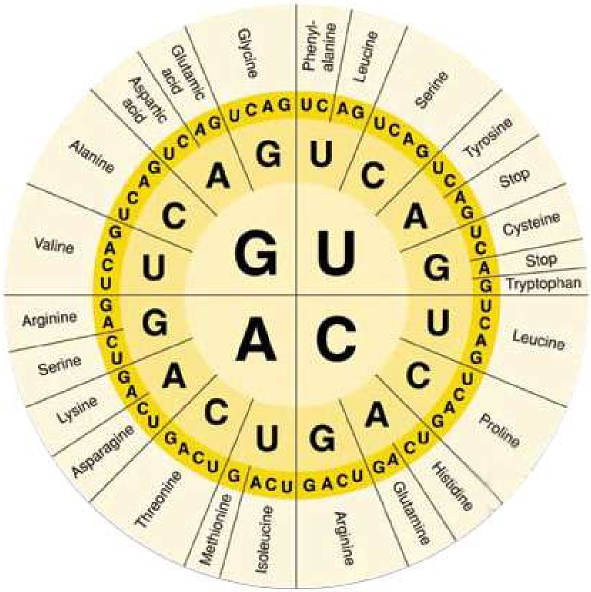
- **Proteins**
  - Composes 10-30% of cell mass and is the basic structural material of the body.
  - Made of amino acids
  - All proteins contain carbon, oxygen, hydrogen, & nitrogen- many also contain sulfur & phosphorous.



Organic Compounds

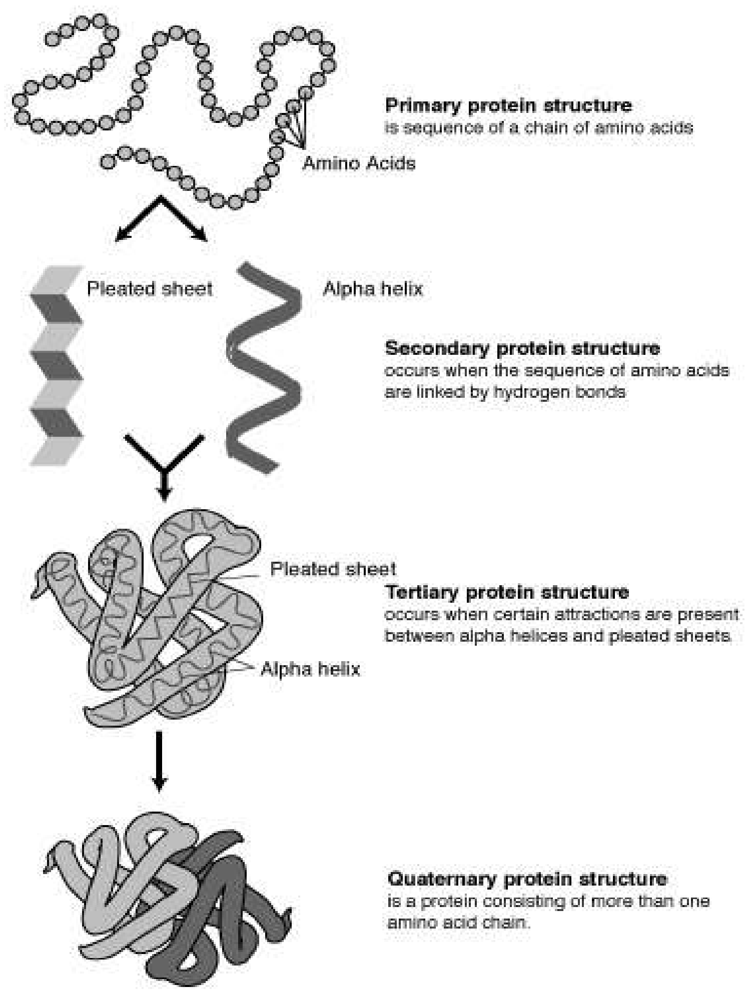
- **Amino Acids & Peptide Bonds**
  - Amino Acids are the building blocks of proteins.
  - 20 common types
  - All have two important functional groups: an amine group (-NH_2) and an organic acid group (-COOH).
  - All amino acids are identical except for their R group- this is what makes each one unique.
  - Proteins are long chains of amino acids joined together by dehydration synthesis
    - Polypeptides < 50 amino acids
    - Proteins > 50 amino acids





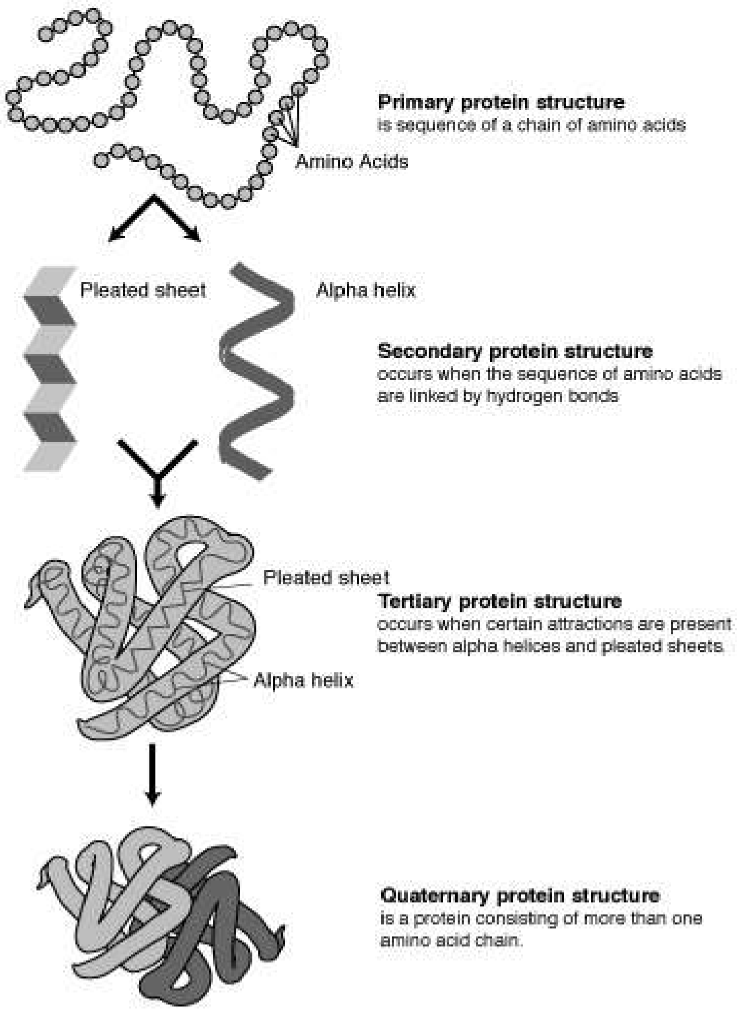
Organic Compounds

- **4 Structural Levels of Proteins**
  - **Primary Structure:** the sequence of amino acids forms the polypeptide chain.
  - **Secondary Structure:** the primary chain forms spirals (α-helices) and sheets (β-sheets).



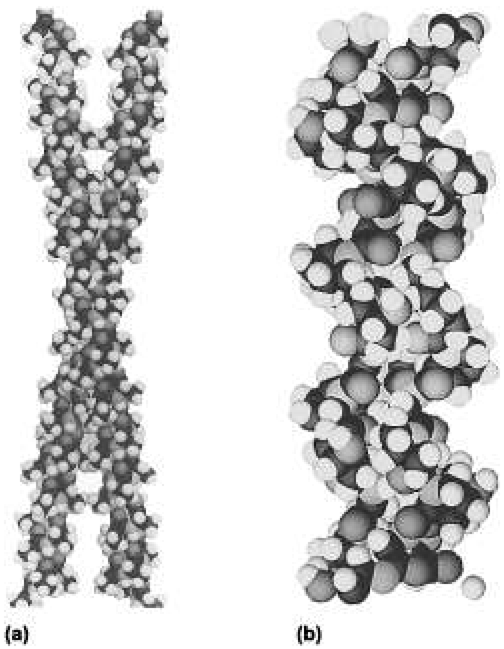
Organic Compounds

- **Tertiary Structure**: superimposed on secondary structure. α-helices and/or β-sheets are folded up to form a compact globular molecule held together by intramolecular bonds.
- **Quaternary Structure**: two or more polypeptide chains, each with its own tertiary structure, combine to form a functional protein.



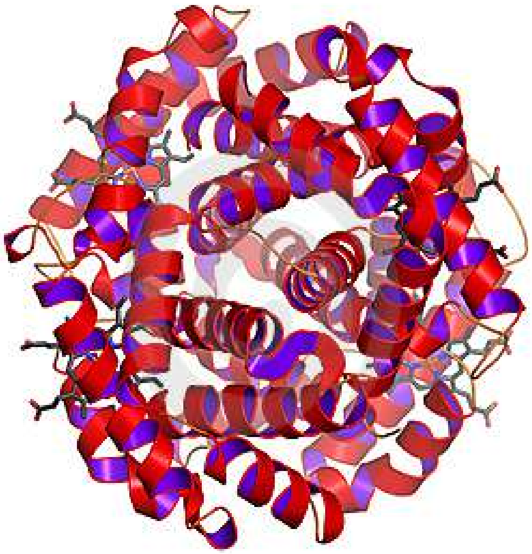
Organic Compounds

- Fibrous and Globular Proteins
  - The structure of a proteins determines its function.
  - **Fibrous proteins** are extended and strand-like.
    - Also known as **structural** proteins.
    - Some exhibit only secondary structure but most have tertiary.
      - Collagen: helical molecules that are packed together to form a strong ropelike structure. Ex. Cartilage is made up of clollagen.



Organic Compounds

- **Globular proteins** are compact, spherical proteins that have at least tertiary structure, some have quaternary.
  - Also known as **functional** proteins.
  - Water soluble, chemically active, and play critical roles in virtually all biological processes.
    - Antibodies- help provide immunity.
    - Protein-based hormones regulate growth and development.
    - Enzymes are catalysts that oversee chemical reactions in the body.



Protein Denaturation

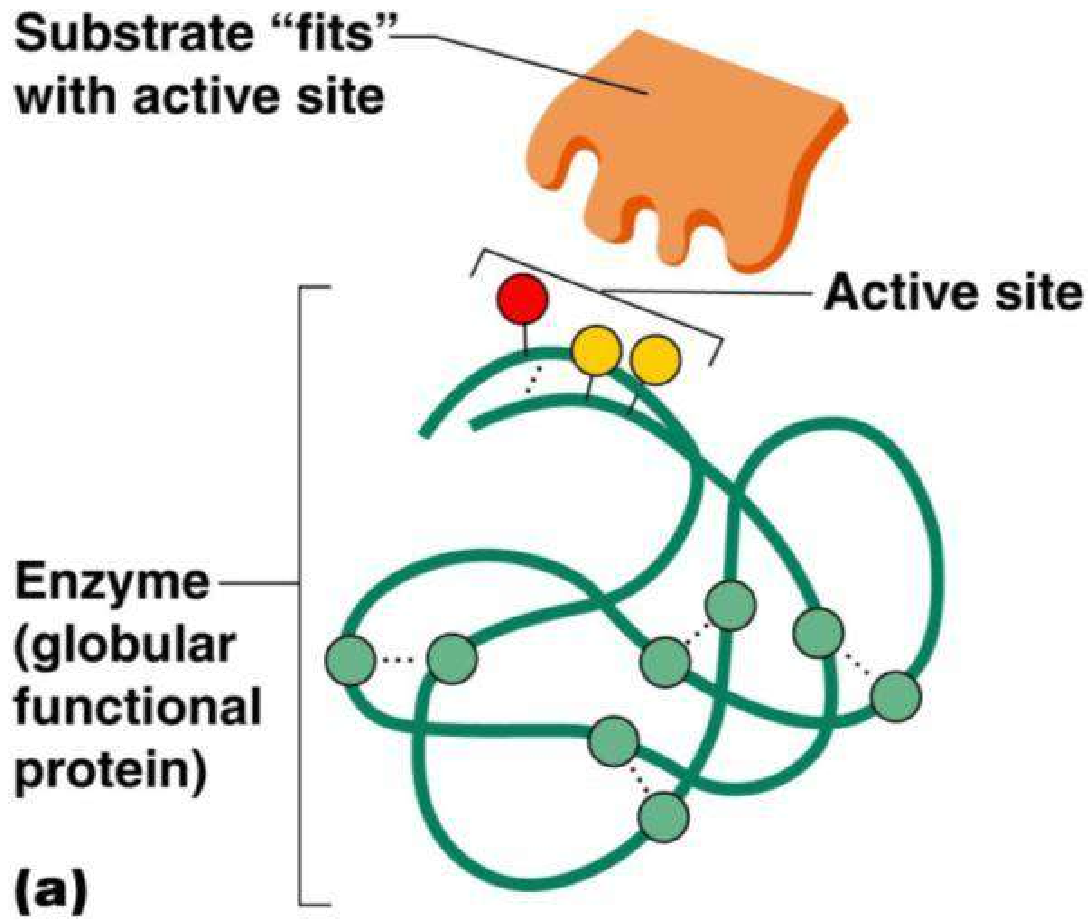
- Globular proteins depend on their 3 dimensional structure created by their hydrogen bonds.
- Can be reversible but if conditions are too extreme, changes are irreversible.
- Hydrogen bonds are sensitive to pH and temperature...
  - When pH drops or temperature rises above nomal, proteins unfold and lose their shape…this is denaturation

Ex. Albumin: egg white…what happens when we boil an egg?

Enzymes

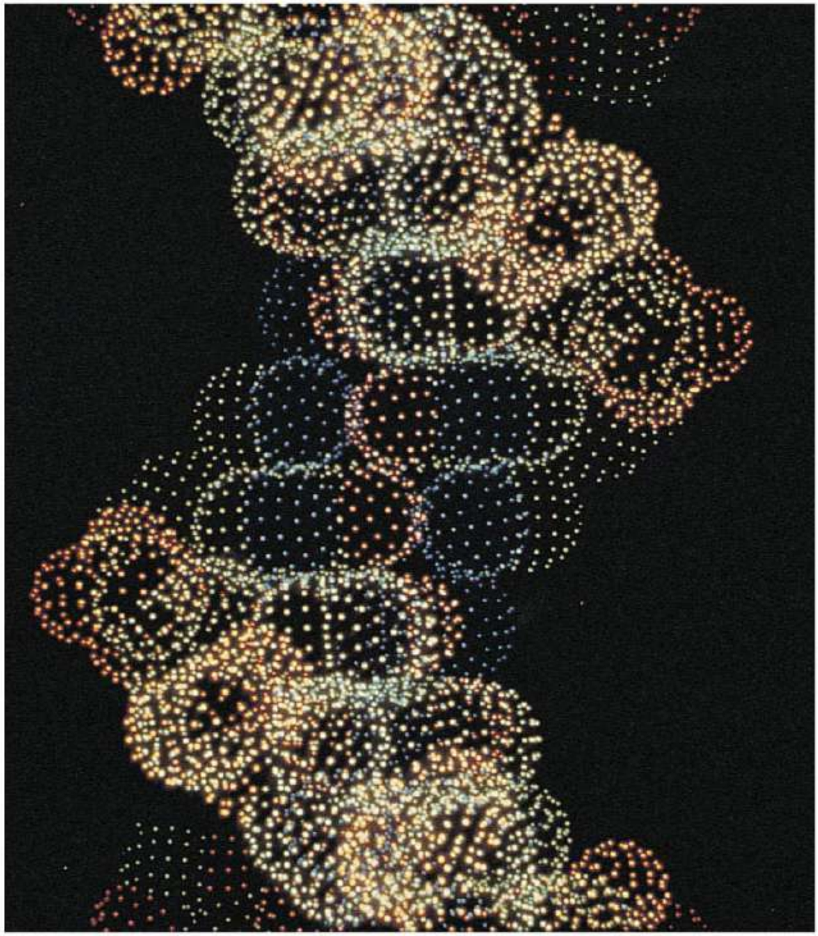
- Act as biological catalysts
- Increase the rate of chemical reactions without being part of the product
- Don't change, reusable, very specific functions, end in suffix –ase
- Some need to be activated before they can function.

Ex. Pancreatic amylase



Organic Compounds

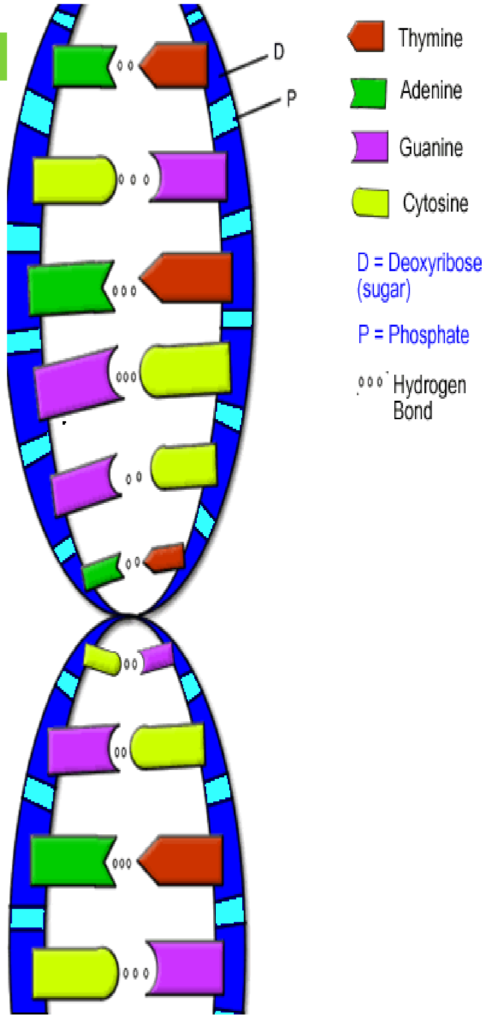
- **Nucleic Acids**
  - Composed of carbon, oxygen, hydrogen, nitrogen, and phosphorous.
  - Include two major classes of molecules- deoxyribonucleic acid (DNA) and ribonucleic acid (RNA).
    - DNA is found in the nucleus of the cell and constitutes the genetic material.
    - RNA is located **outside** the nucleus and is the "molecular slave" of DNA- carries out orders for protein synthesis issued by DNA.



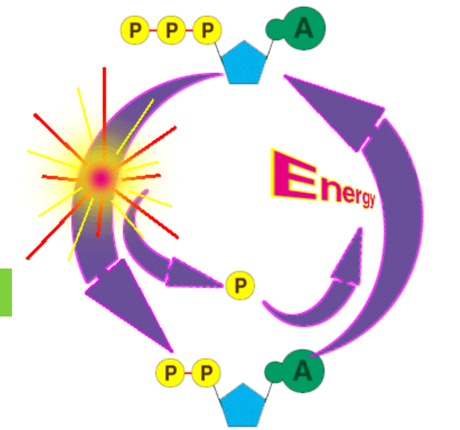
(c) Computer-generated image of a DNA molecule

Organic Compounds

- **Structural units of nucleic acids are nucleotides.**
  - Each nucleotide consists of: a nitrogen containing base, a pentose sugar, and a phosphate group.
  - Nitrogen containing bases: Adenine, Guanine, Cytosine, Thymine, and Uracil.
    - Adenine and Guanine are large 2 ring bases called purines.
    - Cytosine, Thymine, and Uracil are smaller single ring bases called pyrimidines.
    - These bases bond to form the double helix of DNA
      - G-C
      - A-T
    - RNA are single strands of nucleotides.
      - G-C
      - A-U



Organic Compounds



- **Adenosine Triphosphate (ATP)**
  - Primary energy-transferring molecule in cells which provides a form of energy that is immediately usable by body cells.
  - Structure: ATP is an adenine, ribose and 3 phosphate groups.
  - Without ATP, molecules cannot be made, cells cannot transport substances across their membrane boundaries, and life processes cease.