

Chapter 2 - Chemistry

How Matter is Organized

- Chemistry is the science of the structure and interactions of matter.
 - all living things consist of matter.
- Matter is anything that occupies space.
 - mass is the amount of matter in any object.
 - weight is the force of gravity acting on matter.
- In outer space, weight is close to zero, but mass remains the same as on Earth.

Chemical Elements

- Elements are substances that can not be split into simpler substances by ordinary means.
 - 112 elements (92 occur naturally)
 - 26 of naturally occurring elements are in the body
 - represented by chemical symbols (first 1-2 letters of name)
- 4 elements form 96 % of the body's mass
 - hydrogen, oxygen, carbon and nitrogen
- Trace elements are present in tiny amounts
 - such as copper, tin, selenium & zinc

Structure of Atoms

- Atoms are the smallest units of matter that retain the properties of an element
- Atoms consist of 3 types of subatomic particles
 - protons, neutrons and electrons
- Nucleus contains protons (p+) & neutrons (neutral charge)
- Electrons (e-) surround the nucleus as a cloud (electron shells are designated regions of the cloud)

Electron Shells

- Most likely region of the electron cloud in which to find electrons
- Each electron shell can hold only a limited number of electrons
 - first shell can hold only 2 electrons
 - 2nd shell can hold 8 electrons
 - 3rd shell can hold 18 electrons
 - higher shells (up to 7) hold many more electrons
- Number of electrons = number of protons
- Each atom is electrically neutral; charge = 0

Atomic Number & Mass Number

- Atomic number is number of protons in the nucleus. .
- Mass number is the sum of its protons and neutrons.

Isotopes

- Atoms of an element with different numbers of neutrons & different mass numbers
- All isotopes of an element have same properties
 - have same number of electrons (which determine its chemical properties)
- Only radioactive isotopes are unstable
 - decay over time to a more stable configuration
 - half-life is time required for half of the radioactive atoms in a sample to decay

Atomic Mass

- Mass is measured as dalton (atomic mass unit)
 - neutron has mass of 1.008 daltons
 - proton has mass of 1.007 daltons
 - electron has mass of 0.0005 dalton
- Atomic mass (atomic weight) is close to the mass number of its most abundant isotope.

Ions, Molecules, & Compounds

- Ions are formed by ionization
 - an atom that gave up or gained an electron
 - written with its chemical symbol and (+) or (-)
- Molecule
 - when atoms share electrons
 - if atoms are the same element = compound
 - written as molecular formula showing the number of atoms of each element (H₂O)

Chemical Bonds

- Bonds hold together the atoms in molecules and compounds
- An atom with a full outer electron shell is stable and unlikely to form a bond with another atom
- Octet rule states that biologically important elements interact to produce chemically stable arrangements of 8 electrons in the valence shell.
- Whether electrons are shared, donated or acquired determines the types of bonds formed

Ionic Bonds

- Positively and negatively charged ions attract each other to form an ionic bond
- In the body, ionic bonds are found mainly in teeth and bones
- An ionic compound that dissociates in water into + and - ions is called an electrolyte
 - the solution can conduct an electric current

The Ionic Bond in Sodium Chloride

- Sodium loses an electron to become Na⁺ (cation)
- Chlorine gains an electron to become Cl⁻ (anion)

- Na⁺ and Cl⁻ are attracted to each other to form the compound sodium chloride (NaCl)
-- table salt
- Ionic compounds generally exist as solids

Covalent Bonds

- Atoms share electrons to form covalent bonds
- Electrons spend most of the time between the 2 atomic nuclei
 - single bond = share 1 pair
 - double bond = share 2 pair
 - triple bond = share 3 pair
- Polar covalent bonds share electrons unequally between the atoms involved

Polar Covalent Bonds

- Unequal sharing of electrons between atoms.
- In a water molecule, oxygen attracts the hydrogen electrons more strongly
 - Oxygen has greater electronegativity as indicated by the negative Greek delta sign.

Hydrogen Bonds

- Polar covalent bonds between hydrogen and other atoms
- Only about 5% as strong as covalent bonds
- Useful in establishing links between molecules
- Large 3-D molecules are often held together by a large number of hydrogen bonds.

Chemical Reactions

- When new bonds form or old bonds are broken
- Metabolism is all the chemical reactions in the body
- Law of conservation of mass = total mass of reactants equals the total mass of the products

Energy and Chemical Reactions

- Chemical reactions involve energy changes
- Two principal forms of energy
 - potential energy = stored energy
 - kinetic energy = energy of motion
- Chemical energy is potential energy stored in the bond of molecules
 - digestion of food releases that chemical energy so that it can be converted to heat or mechanical energy
- Law of conservation of energy
 - energy can neither be created nor destroyed--just converted from one form to another

Energy Transfer in Chemical Reactions

- Forming new bonds releases energy & breaking old bonds requires energy
- Chemical reactions usually involve both
 - exergonic reactions release more energy
 - endergonic reactions absorb more energy than they release
- Human metabolism couples exergonic and endergonic reactions, so that the energy released from one reaction will drive the other.
 - Glucose breakdown releases energy used to build ATP molecules that store that energy for later use in other reactions

Activation Energy

- Atoms, ions & molecules are continuously moving & colliding
- Activation energy is the collision energy needed to break bonds & begin a reaction
- Increases in concentration & temperature, increase the probability of 2 particles colliding
 - more particles in a given space as concentration is raised
 - particles move more rapidly when temperature is raised

Catalysts or Enzymes

- Normal body temperatures and concentrations are too low to cause chemical reactions to occur
- Catalysts speed up chemical reactions by lowering the activation energy needed to get it started
- Catalysts orient the colliding particles properly so that they touch at the spots that make the reaction happen
- Catalyst molecules are unchanged and can be used repeatedly to speed up similar reactions.

Effectiveness of Catalysts

- Catalysts speed up chemical reactions by lowering the activation energy.

Synthesis Reactions--Anabolism

- Two or more atoms, ions or molecules combine to form new & larger molecules
- All the synthesis reactions in the body together are called anabolism
- Usually are endergonic because they absorb more energy than they release
- Example
 - combining amino acids to form a protein molecule

Decomposition Reactions--Catabolism

- Large molecules are split into smaller atoms, ions or molecules
- All decomposition reactions occurring together in the body are known as catabolism
- Usually are exergonic since they release more energy than they absorb

Exchange Reactions

- Substances exchange atoms
 - consist of both synthesis and decomposition reactions

- Example
 - $\text{HCl} + \text{NaHCO}_3$ gives rise to $\text{H}_2\text{CO}_3 + \text{NaCl}$
 - ions have been exchanged between substances

Reversible Reactions

- Chemical reactions can be reversible.
 - Reactants can become products or products can revert to the original reactants
- Indicated by the 2 arrows pointing in opposite directions between the reactants and the products
- $\text{AB} \rightleftharpoons \text{A} + \text{B}$

Oxidation-Reduction Reactions

- Oxidation is the loss of electrons from a molecule (decreases its potential energy)
 - acceptor of the electron is often oxygen
 - commonly oxidation reactions involve removing a hydrogen ion (H^+) and a hydride ion (H^-) from a molecule
 - equivalent to removing 2 hydrogen atoms = 2H
- Reduction is the gain of electrons by a molecule
 - increases its potential energy
- In the body, oxidation-reduction reactions are coupled & occur simultaneously

Inorganic Compounds & Solvents

- Most of the chemicals in the body are compounds
- Inorganic compounds
 - usually lack carbon & are structurally simple
 - water, salts, acids and bases
- Organic compounds
 - contain carbon & usually hydrogen
 - always have covalent bonds

Inorganic Acids, Bases & Salts

- Acids, bases and salts always dissociate into ions if they are dissolved in water
 - acids dissociate into H^+ and one or more anions
 - bases dissociate into OH^- and one or more cations
 - salts dissociate into anions and cations, none of which are either H^+ or OH^-
- Acid & bases react in the body to form salts
- Electrolytes are important salts in the body that carry electric current (in nerve or muscle)

Mixtures, Solutions, Colloids, & Suspensions

- Mixture is a combination of elements or compounds that are physically blended by not joined by bonds ---- air
 - Common liquid mixtures
 - solutions are solutes mixed in a solution
 - usually looks clear (sweat is water and dissolved salts)
 - colloid are solutes mixed in a solute
 - particles are larger so does not look clear (milk)
 - particles do not settle out of solution
 - suspension are solutes mixed in a solute
 - particles settle out of solution because of size (blood)
- Water
- Most important inorganic compound in living systems
 - Medium of nearly all chemical reactions
 - Polarity
 - uneven sharing of valence electrons
 - partial negative charge near oxygen atom and partial positive charge near hydrogen atoms
 - makes it an excellent solvent for ionic or polar substances
 - gives water molecules cohesion
 - allows water to moderate temperature changes

Water as a Solvent

- Most versatile solvent known
 - polar covalent bonds (hydrophilic versus hydrophobic)
 - its shape allows each water molecule to interact with 4 or more neighboring ions/molecules
 - oxygen attracts sodium
 - hydrogen attracts chloride
 - sodium & chloride separate as ionic bonds are broken
 - hydration spheres surround each ion and decrease possibility of bonds being reformed

- Water dissolves or suspends many substances

Water in Chemical Reactions

- Participates as a product or reactant in certain reactions in the body
 - hydrolysis reactions
 - digestion of food
 - dehydration synthesis reaction
 - two small molecules are joined to form a larger molecule releasing a water molecule

Heat Capacity of Water

- Heat capacity is high
 - can absorb a large amount of heat with only a small increase in its own temperature
- Heat of vaporization is also high
 - amount of heat needed to change from liquid to gas
 - evaporation of water from the skin removes large amount of heat

Water as a Lubricant

- Major component of lubricating fluids within the body
 - mucus in respiratory and digestive systems
 - synovial fluid in joints
 - serous fluids in chest and abdominal cavities
 - organs slide past one another

Concept of pH

- pH scale runs from 0 to 14 (concentration of H⁺ in moles/liter)
- pH of 7 is neutral (distilled water -- concentration of OH⁻ and H⁺ are equal)
- pH below 7 is acidic and above 7 is alkaline
- pH of 1 (10 times more H⁺ than pH of 2)

Buffer Systems of the Body

- Body fluids vary in pH but the range of each is limited and is maintained by a variety of buffering systems.
 - gastric juice 1.2 to 3.0; saliva 6.35 to 6.85; bile 7.6 to 8.6 and blood 7.35 to 7.45
- Buffers convert strong acids to weak ones which contribute fewer H⁺ ions & have less effect on pH
 - carbonic acid - bicarbonate buffer system
 - together they contribute H⁺ or OH⁻ ions as needed to keep the pH of the blood stable

Organic Compounds

- Always contain carbon and hydrogen
- Usually contain covalent bonds
- Usually large, unique molecules with complex functions
- Make up 40% of body mass

Carbon & Its Functional Groups

- Properties of carbon atoms
 - forms bonds with other carbon atoms produce large molecules
 - with many different shapes (rings, straight or branched chains)
 - do not dissolve in water
- Many functional groups can attach to carbon skeleton
 - esters, amino, carboxyl, phosphate groups (Table 2.5)
- Very large molecules called macromolecules (polymers if all monomer subunits are similar)

- Isomers have same molecular formulas but different structures (glucose & fructose are both C₆H₁₂O₆)
- STRUCTURAL FORMULA OF GLUCOSE

Carbohydrates

- Diverse group of substances formed from C, H, and O
 - ratio of one carbon atom for each water molecule (carbohydrates means “watered carbon”)
 - glucose is 6 carbon atoms and 6 water molecules (H₂O)
- Main function is source of energy for ATP formation
- Forms only 2-3 % of total body weight
 - glycogen is storage in liver and muscle tissue
 - sugar building blocks of DNA & RNA (deoxyribose & ribose sugars)
- Only plants produce starches or cellulose for energy storage

Diversity of Carbohydrates

- 3 sizes of carbohydrate molecules
 - monosaccharides
 - disaccharides
 - polysaccharides

Monosaccharides

- Called simple sugars
- Contain 3 to 7 carbon atoms
- We can absorb only 3 simple sugars without further digestion in our small intestine
 - glucose found syrup or honey
 - fructose found in fruit
 - galactose found in dairy products

Disaccharides

- Formed by combining 2 monosaccharides by dehydration synthesis (releases a water molecule)
 - sucrose = glucose & fructose
 - maltose = glucose & glucose
 - lactose = glucose & galactose (lactose intolerance)

Polysaccharides

- Contain 10 or 100's of monosaccharides joined by dehydration synthesis
- In animals
 - glycogen is a chain of hundreds of glucose molecules
 - found in liver & skeletal muscle
 - when blood sugar level drops, liver hydrolyzes glycogen to create and release glucose into the blood
- In plants
 - starch and cellulose are large carbohydrate molecules used for energy storage (rice, potatoes, grains)

Lipids = fats

- Formed from C, H and O
 - includes fats, phospholipids, steroids, eicosanoids, lipoproteins and some vitamins
- 18-25% of body weight
- Hydrophobic
 - fewer polar bonds because of fewer oxygen atoms
 - insoluble in polar solvents like water
- Combines with proteins for transport in blood
 - lipoproteins

Triglycerides

- Neutral fats composed of a single glycerol molecule and 3 fatty acid molecules
 - three-carbon glycerol molecule is the backbone
- Very concentrated form of energy
 - our bodies store triglycerides in fat cells if we eat extra food

Triglycerides

- 3 fatty acids & one glycerol molecule
- Fatty acids attached by dehydration synthesis

Saturation of Triglycerides

- Determined by the number of single or double covalent bonds
- Saturated fats contain single covalent bonds and are covered with hydrogen atoms----lard
- Monounsaturated are not completely covered with hydrogen----safflower oil, corn oil
- Polyunsaturated fats contain even less hydrogen atoms----olive and peanut oil

Chemical Nature of Phospholipids

Phospholipids

- Composition of phospholipid molecule
 - a polar head
 - a phosphate group (PO₄⁻³) & glycerol molecule
 - can form hydrogen bonds with water
 - 2 nonpolar fatty acid tails
 - interact only with lipids
 - amphipathic(molecules with polar & nonpolar parts)
- Composition of cell membrane
 - double layer of phospholipids with tails in center

Steroids

- Formed from 4 rings of carbon atoms joined together
- Common steroids
 - sex hormones, bile salts, vitamins & cholesterol
 - classified as sterols because have alcohol group attached to one or more of the rings
- Cholesterol found in animal cell membranes
 - starting material for synthesis of other steroids

Four Ring Structure of Steroids

Eicosanoids

- Lipid type derived from a fatty acid called arachidonic acid
 - prostaglandins = wide variety of functions
 - modify responses to hormones
 - contribute to inflammatory response
 - prevent stomach ulcers
 - dilate airways
 - regulate body temperature
 - influence formation of blood clots
 - leukotrienes = allergy & inflammatory responses

Proteins

- 12-18% of body weight
- Contain carbon, hydrogen, oxygen, and nitrogen
- Constructed from combinations of 20 amino acids.
 - dipeptides formed from 2 amino acids joined by a covalent bond called a peptide bond
 - polypeptides chains formed from 10 to 2000 amino acids.
- Levels of structural organization
 - primary, secondary and tertiary
 - shape of the protein influences its ability to form bonds

Amino Acid Structure

- Central carbon atom
- Amino group (NH₂)
- Carboxyl group (COOH)
- Side chains (R groups) vary between amino acids

Levels of Structural Organization

- Primary is unique sequence of amino acids
- Secondary is alpha helix or pleated sheet folding
- Tertiary is 3-dimensional shape of polypeptide chain
- Quaternary is relationship of multiple polypeptide chains

Protein Denaturation

- Function of a protein depends on its ability to recognize and bind to some other molecule
- Hostile environments such as heat, acid or salts will change a proteins 3-D shape and destroy its ability to function
 - raw egg white when cooked is vastly different

Enzymes

- Enzymes are protein molecules that act as catalysts
- Enzyme = apoenzyme + cofactor
 - Apoenzymes are the protein portion
 - Cofactors are nonprotein portion
 - may be metal ion (iron, zinc, magnesium or calcium)
 - may be organic molecule derived from a vitamin
- Enzymes usually end in suffix -ase and are named for the types of chemical reactions they catalyze

Enzyme Functions

- Bonds made or broken when atoms, ions or molecules collide
- Enzymes speed up reactions by properly orienting colliding molecules
- 1000 known enzymes speed up metabolic reactions to 10 billion times that in beaker
- Composed of protein portion (apoenzyme) & nonprotein portion (cofactor)
 - cofactors can be metal ions or vitamins

DNA Structure

- Huge molecules containing C, H, O, N and phosphorus
- Each gene of our genetic material is a piece of DNA that controls the synthesis of a specific protein
- A molecule of DNA is a chain of nucleotides
- Nucleotide = nitrogenous base (A-G-T-C) + pentose sugar + phosphate group

RNA Structure

- Differs from DNA
 - single stranded
 - ribose sugar not deoxyribose sugar
 - uracil nitrogenous base replaces thymine
- Types of RNA within the cell, each with a specific function
 - messenger RNA
 - ribosomal RNA
 - transfer RNA

Adenosine Triphosphate (ATP)

- Temporary molecular storage of energy as it is being transferred from exergonic catabolic reactions to cellular activities
 - muscle contraction, transport of substances across cell membranes, movement of structures within cells and movement of organelles
- Consists of 3 phosphate groups attached to adenine & 5-carbon sugar (ribose)

Formation & Usage of ATP

- Hydrolysis of ATP (removal of terminal phosphate group by enzyme -- ATPase)
 - releases energy
 - leaves ADP (adenosine diphosphate)
- Synthesis of ATP
 - enzyme ATP synthase catalyzes the addition of the terminal phosphate group to ADP
 - energy from 1 glucose molecule is used during both anaerobic and aerobic respiration to create 36 to 38 molecules of ATP