

**BENG 100 Frontiers of Biomedical Engineering**  
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**Chapter 2**

**SUMMARY**

This chapter reviewed biochemical concepts that are important in understanding the interaction between molecules with each other, molecules and their solvents, and molecules and the cell membrane.

- Atoms can form ionic or covalent bonds with one another.
- Hydrogen bonds and van der Waals interactions are weak bonds between molecules.
- Most chemical reactions in the body take place in an aqueous environment. The type of molecule - polar, nonpolar, acidic, basic - affects how it behaves in an aqueous environment.
- Hydrogen bonding is important in water chemistry as well as in the assembly of macromolecules, such as nucleic acids and proteins.
- Buffer systems in the blood help to maintain near neutral pH, which is critical to the function of many enzymes.
- The body maintains homeostasis through negative feedback mechanisms, such as the bicarbonate buffering system, that detect a change and act to reduce the magnitude of the change.
- Biomolecules contain various functional groups that confer different properties.
- Carbohydrates, nucleic acids, and proteins are polymers of small subunits.
- The cell is isolated from its extracellular environment by the phospholipid bilayer membrane. Phospholipids are amphiphilic molecules that make up the bilayer along with proteins and glycolipids.
- Diffusion is the movement of a solute from an area of high concentration to low concentration.
- Molecules can cross the membrane via passive or facilitated diffusion depending on their permeability.
- Active transport allows molecules to be transported against their concentration gradient by requiring energy input in the form of ATP.
- Diffusion of water is called osmosis. Movement of water through a selective membrane can generate osmotic pressure.

## KEY CONCEPTS AND DEFINITIONS

acid - a compound that can donate a proton ( $H^+$ ). The carboxyl and phosphate groups are the primary acidic groups in biological molecules.

acidosis – excess of acid in the body fluids, as may occur in kidney disease or diabetes

adenine – a compound that is one of four constituent bases of nucleic acid that is a purine derivative and hybridizes thymine in double stranded DNA

amino acid - monomeric building block of proteins, consisting of a carbon atom bound to a carboxyl group, an amino group, a hydrogen atom, and a distinctive side chain

amphiphilic – a molecule that has both hydrophobic and hydrophilic regions

anion – negatively charged ion, e.g.  $Cl^-$

active transport - the transport of molecules in an energetically unfavorable direction across a membrane coupled to the hydrolysis of ATP or other source of energy

ATP (adenosine 5'-triphosphate) - a nucleotide that is the most important molecule for capturing and transferring free energy in cells. Hydrolysis of each of the two high-energy phosphoanhydride bonds in ATP is accompanied by a large free-energy change ( $\Delta G$ ) of 7 kcal/mole

aquaporin – a water channel protein which allows water molecules to cross the cell membrane much more rapidly than through the phospholipid bilayer

base – a compound, usually containing nitrogen, that can accept a proton ( $H^+$ )

buffer – a solution of the acid (HA) and base (A) form of a compound that undergoes little change in pH when small quantities of strong acid or strong base are added

carbohydrate – A large group of organic compounds containing hydrogen and oxygen molecules in the ratio 2:1 that can be found in foods and living tissues including sugars, starch and cellulose and can be broken down to release energy

cation – positively charged ion, e.g.  $Na^+$

cell membrane – A semipermeable membrane surrounding the cytoplasm of the cell that regulates transport of material from the external environment into the cell and vice versa

complementary sequence – a sequence whose nucleotide bases match or hybridize (mirror images) with the original sequence

concentration gradient - difference in concentration between adjacent regions

condensation – the opposite of a hydrolysis reaction: a reaction that gives off a byproduct (usually water) during the reaction of two molecules to form one

conjugate acid – species formed by the addition of a proton ( $H^+$ ) to a base.  $CH_3COOH$  (aq) is the conjugate acid of  $CH_3COO^-$  (aq).

conjugate base - species formed by the loss of a proton ( $H^+$ ) of an acid.  $CH_3COO^-$  (aq) is

the conjugate base of  $\text{CH}_3\text{COOH}$  (aq).

covalent bond - stable chemical force that holds the atoms in molecules together by sharing of one or more pairs of electrons. Such a bond has strength of 50 - 200 kcal/mol

cytosine – A constituent of nucleic acid that is a pyrimidine derivative and pairs with guanine.

diffusion – net movement of molecules from high concentration to low concentration

disaccharide – A sugar that is formed by coupling together two monosaccharides (or simple sugars)

dissociation constant - the equilibrium constant for the decomposition of a complex ion into its components in solution. The smaller the value of  $K$ , the lesser the dissociation of the species in solution. This value varies with temperature, ionic strength, and the nature of the solvent

electrochemical gradient - a difference in chemical concentration and electric potential across a membrane

endothermic – referring to a chemical reaction that absorbs heat. Such a reaction has a positive change in enthalpy.

enthalpy change (" $H$ ") - heat; in a chemical reaction, the enthalpy of the reactants or products is equal to their total bond energies

entropy change (" $S$ ") – a measure of the degree of disorder or randomness in a system; the higher the entropy, the greater the disorder

enzyme – a protein that catalyzes a chemical reaction

equilibrium constant - ratio of forward and reverse rate constants for a reaction. For a binding reaction,  $A + B \rightleftharpoons AB$ , it equals the association constant,  $K_A$ ; the higher the  $K_A$ , the tighter the binding between A and B. The reciprocal of the  $K_A$  is the dissociation constant,  $K_D$ ; the higher the  $K_D$ , the weaker the binding between A and B.

exothermic – referring to a chemical reaction that releases heat. Such a reaction has a negative change in enthalpy.

facilitated diffusion – protein-aided transport of molecules across a membrane down its concentration gradient at a rate greater than that obtained by passive diffusion

flux - the rate of transfer of fluid, particles, or energy across a given surface

free-energy change (" $G$ ") - the difference in the free energy of the product molecules and of the reactants in a chemical reaction. A large negative value of " $G$ " indicates that a reaction has a strong tendency to occur; that is, at chemical equilibrium the concentration of products will be much greater than the concentration of reactants

fructose – A hexose sugar especially found in honey and fruits

functional groups – specific and variable chemical groups that give an organic compound its characteristic properties

galactose – A hexose sugar that is a constituent of lactose and many other polysaccharides

genetic information – Useful hereditary information that is carried by nucleic acids present in the gene

gene delivery – the process of transfer of foreign DNA into a cell

Gibbs free energy ( $G$ ) – a measure of the potential energy of a system, which is a function of the enthalpy ( $H$ ) and entropy ( $S$ )

glucose – A simple sugar that is an important energy source. It has the formula  $C_6H_{12}O_6$

glycocalyx - a carbohydrate coat covering the cell surface

glycolipid - a lipid consisting of two hydrocarbon chains linked to a polar head group containing carbohydrates

glycoprotein - a protein linked to oligosaccharides

guanine – A constituent of nucleic acid that belongs to a class called purines and hybridizes with cytosine in double stranded DNA

homeostasis – the tendency of physiological systems to maintain a stable internal environment

hybridization – the process of two single strands of DNA assembling into double-stranded DNA

hydrogen bond - a noncovalent bond between an electronegative atom (commonly oxygen or nitrogen) and a hydrogen atom covalently bonded to another electronegative atom. Particularly important in stabilizing the three-dimensional structure of proteins and formation of base pairs in nucleic acids

hydrolysis – the opposite of a condensation reaction: a reaction in which a covalent bond is cleaved with addition of an H from water to one product of the cleavage and of an OH from water to the other

hydrophilic – literally “water-loving:” compounds that have an affinity for water because of an ability to form hydrogen bonds

hydrophobic – literally “water-hating:” compounds that do not form hydrogen bonds and, therefore, do not dissolve easily in water

hydrophobic effect – The property of nonpolar molecules to self aggregate or cluster together in order to shield themselves from aqueous molecules.

hypertonic - referring to an external solution whose solute concentration is high enough to cause water to move out of cells due to osmosis

hypotonic - referring to an external solution whose solute concentration is low enough to cause water to move into cells due to osmosis

ionic bond - a noncovalent bond between a positively charged ion (cation) and negatively

charged ion (anion).

ion - an atom or group of atoms that carries a positive or negative electric charge as a result of having lost or gained one or more electrons, respectively.

isotonic - referring to a solution whose solute concentration is such that it causes no net movement of water in or out of cells

lactose – A disaccharide made of glucose and galactose units, usually found in milk

lipids – small biological molecules that do not dissolve in water including fatty acids and steroids

liposome - spherical phospholipid bilayer structure with an aqueous interior that forms in vitro from phospholipids and may contain proteins

macromolecule – large molecules formed by the repeated coupling of smaller units, called monomers

molecular complex – two or more molecules that are held together in an assembly by multiple weak non-covalent bonds, such as hydrogen bonds

monomer - any small molecule that can be linked with others of the same type to form a polymer. Examples include amino acids, nucleotides, and monosaccharides

monosaccharide - any simple sugar with the formula  $(CH_2O)_n$  where  $n = 3$  to  $7$

messenger RNA (mRNA) – a form of RNA in which genetic information transcribed from DNA is transferred to the ribosome

neutral – neither acidic nor basic:  $pH \sim 7$

nitrogenous base – nitrogen containing base that make up the nucleotides that form nucleic acids

noncovalent bond – any relatively weak chemical bond that does not involve an intimate sharing of electrons. Multiple noncovalent bonds often stabilize the conformation of macromolecules and mediate highly specific interactions between molecules.

nonpolar - referring to a molecule or structure that lacks any net electric charge or asymmetric distribution of positive and negative charges. Nonpolar molecules generally are insoluble in water.

nucleic acid – a polymer of nucleotides linked by phosphorous-containing bonds: DNA and RNA are the primary nucleic acids in cells

nucleotide - a nucleoside with one or more phosphate groups linked to the sugar moiety: DNA and RNA are polymers of nucleotides

osmosis - net movement of water across a semipermeable membrane from a solution of lesser to one of greater solute concentration. The membrane must be permeable to water but not to solute molecules

osmotic pressure - hydrostatic pressure that must be applied to the more concentrated

solution to stop the net flow of water across a semipermeable membrane separating solutions of different concentrations

passive diffusion - the process by which water and small uncharged molecules such as oxygen (O<sub>2</sub>) and carbon dioxide (CO<sub>2</sub>) pass through the plasma membrane

pH – a measure of the acidity or alkalinity of a solution defined as the negative logarithm of the hydrogen ion concentration in moles per liter:  $\text{pH} = -\log [\text{H}^+]$ . Neutrality is equivalent to a pH of 7; values below this are acidic and those above are alkaline

peptide - a small polymer usually containing fewer than 30 amino acids connected by peptide bonds

pentose – a five carbon sugar

phospholipid - the principal components of cell membranes, consisting of two hydrocarbon chains (usually fatty acids) joined to a polar head group containing phosphate

polar - referring to a molecule or structure with a net electric charge or asymmetric distribution of positive and negative charges. Polar molecules are usually soluble in water

polymer - any large molecule composed of multiple identical or similar units (monomers) linked by covalent bonds

polymerization - the chemical process of making a polymer from a collection of monomers

polypeptide – a linear organic polymer consisting of a large number of amino acid residues bonded together in a chain

polysaccharide – biological macromolecule composed of monosaccharide subunits

protein – biological macromolecule composed of amino acid subunits

protein folding – process by which a polypeptide (or collection of polypeptides) assumes its functional shape or conformation: the process occurs through attractive and repulsive interactions of the polypeptide subunits

proton – positively-charged subatomic particle, equivalent to a hydrogen atom without an electron, H<sup>+</sup>

purine - a class of nitrogenous compounds containing two fused heterocyclic rings. Two purines, adenine and guanine, commonly are found in DNA and RNA

pyrimidine – a class of nitrogenous compounds containing one heterocyclic ring; two pyrimidines, cytosine and thymine, commonly are found in DNA; in RNA, uracil replaces thymine

solute – substance that is dissolved to form a solution

steady-state - a stable condition that does not change over time or in which change in one direction is continually balanced by change in another

sucrose – A disaccharide made up of one glucose molecule and one fructose molecule

(C<sub>12</sub>H<sub>22</sub>O<sub>11</sub>)

thymine – A constituent of nucleic acid that belongs to a classes of nitrogenous bases called pyrimidine and hybridizes with adenine in double stranded DNA.

transcription – the process whereby genetic information contained represented as DNA nucleotides is copied into newly synthesized strands of RNA using the DNA as a template

translation – The process whereby a sequence of nucleotide triplets in mRNA gives rise to a specific sequence of amino acids during protein synthesis

triglycerides – a storage form of fat consisting of a glycerol molecule linked to three fatty acids

uracil – A constituent base of RNA; hybridizes with adenine

van der Waals interaction – a weak noncovalent attraction due to small, transient asymmetric electron distributions around atoms (dipoles).

## QUESTIONS

1. Describe the properties of acids and bases. It might be helpful to look in a chemistry book, to find information beyond that available in the chapter.
2. Why are polar molecules hydrophilic and nonpolar molecules hydrophobic?
3. If hydrogen bonds are much weaker than covalent bonds, why do you think hydrogen bonds are used to hold biomolecules together?
4. Does entropy increase or decrease during a polymerization reaction? Why?
5. Explain the difference between passive and active transport. Why is active transport necessary for some ions?
6. Normal saline solution (0.9 % NaCl by mass) is used for intravenous administration or for lubrication of dry eyes. Do you think that this solution isotonic, hypertonic, or hypotonic compared to the body fluids? Why?
7. If you are on a deserted island, why must you find water from a stream or well rather than drink the seawater? Explain your answer in terms of osmotic pressure.
8. How does hyperventilation—that is, very rapid deep breathing—disturb the HCO<sub>3</sub>/H<sub>2</sub>CO<sub>3</sub> equilibrium? Does it result in acidosis or alkalosis?
9. Do some research in the library or on the internet, using reliable sources. Cystic fibrosis is a genetic disease, what is the defect in cystic fibrosis patients and how does that defect manifest into the symptoms for the disease?