CHAPTER 2: CHEMICAL BASIS OF LIFE

I. INTRODUCTION

A. **Chemistry** = the study of matter.

B. **Matter** = anything that occupies space and has mass; (i.e. solids, liquids, gases)

II. STRUCTURE OF MATTER

A. Elements and Atoms

1. **Atom** =the smallest particle of an element;
   a. the least complex level of organization.
2. **Element** = a basic chemical substance composed of atoms.
3. Elements are represented by a **1 or 2 letter symbol** that are shown in the Periodic Table of the Elements;
4. 120 elements exist in nature, however only approximately 26 are naturally occurring in humans.
5. Learn the elements (and their chemical symbol).
6. The most abundant of the naturally occurring elements are carbon (C), Hydrogen (H), Oxygen (O) and Nitrogen (N) = **CHON**;

B. Atomic Structure

3 Subatomic Particles

1. **Proton** = a positively charged particle in the nucleus of an atom; Mass = 1.
2. **Neutron** = an electrically neutral particle in the nucleus of an atom; Mass = 1.
3. **Electron** = an electrically negative particle that revolves around the nucleus; Mass = 0.

SUBATOMIC PARTICLE SUMMARY TABLE (Keyed at the end of the outline)

SUBATOMIC PARTICLE	CHARGE	LOCATION	MASS (WEIGHT)

4. **Atoms are neutral in charge** - The number of protons is equal to the number of electrons.
5. The **Atomic Number** (A#) of an atom represents the number of protons in its nucleus.
   a. A# of H = 1
   b. A# of He = 2
   c. A# of O = 8.
6. The **Atomic Weight** (AW) of an atom is equal to the number of protons plus the number of neutrons in its nucleus.

II. STRUCTURE OF MATTER

C. **Isotopes** = atoms of an element that have the same A#'s but different AW's (i.e. same # of protons, different # of neutrons).

1. The nuclei of some isotopes are stable;
2. The nuclei of other isotopes are unstable and break apart to become more stable;

    a. When the nucleus of an atom breaks apart, it releases **radioactive energy**;
    b. Radioactive isotopes have many biological uses.

D. Molecules and Compounds

1. Molecules – combining of two or more atoms of the same element
    a. oxygen – O_2
    b. nitrogen – N_2

2. Compounds – combining of two or more atoms of different elements
    a. water – H_2O
    b. glucose – $C_6H_{12}O_6$

E. Bonding of Atoms

1. The electrons of an atom are arranged in orbits, shells, or **energy levels** around the central nucleus;

2. A characteristic number of electrons fill each shell:

    a. **2 electrons** fill the first shell (closest to nucleus);
    b. **8 electrons** fill the second shell;
    c. **8 electrons** fill the third shell.

Example 1: **Sodium (Na)**: Atomic Number = 11;
protons = 11;
electrons = 11.

Example 2: **Chlorine(Cl)**: Atomic Number= 17
protons= 17
electrons= 17

II. STRUCTURE OF MATTER

E. Bonding of Atoms

3. The way in which atoms react with one another (i.e. their chemical properties) is based on the electrons in their outermost shell = **VALENCE ELECTRONS**

   a. The outermost shell of an atom is called its valence shell.
   b. Na has _____ valance electrons;
   c. S has _____ valance electrons.

4. Summary/Overview:

   Example 1: Fluorine has an Atomic Number of 9. Draw an atom of fluorine. How and why will fluorine react?

   Example 2: Argon has an Atomic Number of 18. Draw an atom of argon. How and why will argon react?

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E. Bonding of Atoms

5. **Atoms form bonds with other atoms to fill their outermost or valence electron shell (energy level).**

   a. "Rule of Octets" = except for the first energy level (which contain 2 electrons), atoms react with other atoms so they will have 8 electrons in their valence shell.

6. **Ionic Bonds:**
   a. **Ions** = atoms that have lost or gained electrons to fill their valence shell.
   b. **anion** = a negatively charged ion (Cl^-);
   c. **cation** = a positively charged ion (Na^+).
   d. An attraction exists between oppositely charged ions and an ionic bond results.

   Na^+ (which is now the cation) has donated its outer electron to Cl^- (which now becomes the anion). Salts, such as table salt or **sodium chloride, are held together by ionic bond**.

7. **Covalent Bonds**:
   a. A covalent bond is formed by the **equal sharing** of electrons between atoms.
   b. a very strong bond
   c. Examples:
      1. H_2 (molecular hydrogen);
      2. O_2 (molecular oxygen);

8. **Polar Bonds**
   a. A covalent bond is formed by the **unequal sharing** of electrons between atoms.
   b. strong bond
   c. results in molecules that are **polar**
      1. one end of the molecule is slightly positive, one end of the molecule is slightly negative
   d. H_20 (water).

9. **Hydrogen Bonds:**
   a. A hydrogen bond is a weak bond formed between hydrogen atoms (that are covalently bonded to another atom) and another atom.
   b. Examples include interaction between **water molecules and DNA chains**.
   c. These bonds are **easily broken and put back together**.

CHEMICAL BOND SUMMARY TABLE (Keyed at the end of the outline)

TYPE OF BOND	DEFINITION	DESCRIPTION	EXAMPLE

F. Chemical Reactions

1. Definition: A chemical reaction occurs whenever chemical bonds are formed, rearranged or broken.
2. **Four Types**:

a. **Synthesis** = the building of a large molecule (polymer) from smaller building blocks (monomers);

- **constructive, anabolic** reactions;
- **Bonds are formed** which now hold chemical energy
- Water is usually removed from building blocks to form bond (**DEHYDRATION**);
  - Energy
  - ↓
- A + B ----------> A—B
  - ↓
  - H_20
- Example = the building of a large protein (polymer) from many smaller amino acids (monomer).

b. **Decomposition** = breaking a large molecule (polymer) down into its building blocks (monomers);

- **destructive, catabolic, "digestive"** reactions;
- **Bonds are broken** releasing chemical energy (**EXERGONIC**);
- Water is used to break bonds (**HYDROLYSIS**);
  - H_20
  - ↓
- A--B ----------> A + B
  - ↓
  - Energy
- Example = digesting a large protein we eat into its amino acid building blocks.

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II. STRUCTURE OF MATTER

F. Chemical Reactions

c. **Exchange Reactions** involve degradation followed by synthesis.

- A--B + C--D → A + B + C + D → A--C + B--D.

d. **Reversible Reactions =** products can be changed back to reactants

$A + B \leftrightarrow A—B$

Chemical Reaction Comparison Table (Keyed at the end of the outline)

	SYNTHESIS REACTIONS	**DEGRADATION REACTIONS**
GENERAL DESCRIPTION (Sentence)		
DESCRIPTIVE TERMS		
BOND FORMATION OR BREAKING?		
IS ENERGY REQUIRED OR RELEASED?		
HOW IS WATER INVOLVED? NAME THAT TERM.		
EXAMPLE IN HUMAN METABOLISM		

II. STRUCTURE OF MATTER

G. Acids, Bases and Salts

1. These ions are referred to as **electrolytes** (charged particles).
   a. Electrolytes must be maintained within a very narrow range in our blood and tissues (i.e. homeostasis);
   b. Needed for muscle contraction, nerve impulses, bone growth, et cetera;
   c. Examples include Na^+, K^+, Cl^-, Ca^+, PO_4^-; HCO_3^-, etc.

2. Acids dissociate (ionize) in water to form:
   a. a **hydrogen** cat**ion**, **H^+,** and
   b. an anion.
   c. Example = HCl (hydrochloric acid).

$$HCl \xrightarrow{H_2O} \mathbf{H^+} + Cl^-$$

3. Bases dissociate (ionize) in water to form:
   a a **hydroxyl** an**ion**, **OH^-**, and
   b. a cation.
   c. Example = NaOH (sodium hydroxide).

$$NaOH \xrightarrow{H_2O} Na^+ + \mathbf{OH^-}$$

4. Salts:
   a. Salts **dissociate (ionize) into ions** when dissolved in water.
      - an anion is formed and
      - a cation is formed.
      - Example = NaCl in water.

$$NaCl \xrightarrow{H_2O} Na^+ + Cl^-$$

II. STRUCTURE OF MATTER

H. Acid and Base Concentration:

1. The relative concentrations of hydrogen ions and hydroxyl ions determine the pH in our blood, fluids, and tissues.
2. pH in body = $[H^+]$ + $[OH^-]$.
3. pH = $-\log[H^+]$;
4. pH Scale ranges from 0 to 14

0 ----------7----------14

acid	**neutral**	**basic**
$[H^+] > [OH^-]$	$[H^+] = [OH^-]$	$[H^+] < [OH^-]$

5. Physiologic pH = 7.4
   a. pH < 7.4 = acidosis; lethal below 7.0;
   b. pH > 7.4 = alkalosis; lethal above 7.8.
   c. **Buffering Systems**

Definition: Buffers (are compounds added to solutions that) prevent abrupt change in pH.

- usually **weak** acids;
- function by donating H^+ when needed and by accepting H^+ when in excess;
- very important in biological systems!
- Example = the **carbonic acid** (H_2CO_3) buffering system.

when pH is rising

$$H_2CO_3 \leftrightarrow HCO_3^- + H^+$$

when pH is falling

carbonic acid (H+ donor)	bicarbonate ion (H+ acceptor)	hydrogen ion

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III. CHEMICAL CONSTITUENTS OF CELLS

A. **Inorganic Substances** are small compounds that do not contain the atoms C and H; Examples include oxygen, carbon dioxide (CO_2) water, salts, acids & bases.

1. **Water is** a polar molecule that demonstrates hydrogen bonding and therefore it possesses very unique characteristics.
   a. Water is an **excellent solvent** (universal?)
      - Many solutes are dissolved in our body's water (i.e. polar substances dissolve in polar water)
      - Many ionic compounds (i.e. NaCl) dissociate or break apart in water.

   b. Water **participates in many chemical reactions** (in our cells and fluids)
      - **Dehydration (synthesis)** is when water is removed from adjacent atoms (of molecules) to form a bond between them.
      - **Hydrolysis (degradation)** is when water is used to break bonds between molecules.

   c. Water is an **excellent temperature buffer.**
      - absorbs and releases heat very slowly

   d. Water provides an **excellent cooling mechanism.**
      - It requires a lot of heat to change water from a liquid to a gas (i.e. high heat of vaporization). If water does change forms and evaporate, it leaves a cool surface behind.

   e. Water serves as a **lubricant**
      - mucus;
      - internal organs;
      - joints.

   f. Water is the **most abundant component in cells** (about 70%).

2. **Oxygen** O_2
   a. gas that is transported in the blood
   b. used to release energy from nutrient molecules

3. **Carbon Dioxide** CO_2: a by-product of cellular respiration.

4. Inorganic salts. Many uses (See properties above)

III. CHEMICAL CONSTITUENTS OF CELLS

B. Organic Substances:

1. contains the atoms **carbon** (and hydrogen);

2. small molecules (monomers or building blocks) are covalently bonded together to form large **polymers** or **macromolecules**;

3. **Water** is usually involved in the formation and breakage of bonds between monomers;

   a. **Dehydration Synthesis** = removal of water to form a covalent bond between monomers;

   b. **Hydrolysis** = using water to break bonds between monomers.

4. The **four major classes** found in cells include:

   a. carbohydrates;

   b. lipids;

   c. proteins;

   d. nucleic acids.

III. CHEMICAL CONSTITUENTS OF CELLS

C. **CARBOHYDRATES** (sugars)

1. contains C, H, and O in a 1:2:1 ratio (usually);
   (Ex: glucose = $C_6H_{12}O_6$)

2. Monomers (building blocks) are **monosaccharides**;
   hexoses = simple 6-C sugars;

   a. **glucose**,
   b. fructose,
   c. galactose.

3. Polymers are formed by dehydration synthesis:

   a. **Disaccharides**: 2 monosaccharides covalently bonded together;

      1. maltose = glucose + glucose;
      2. lactose = glucose + galactose;
      3. sucrose = glucose + fructose

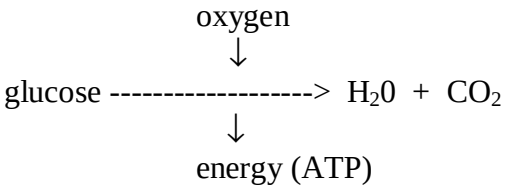
   b. **Polysaccharides: many** glucose molecules covalently bonded together;

      1. **starch** = plant storage carbohydrate;
      2. **glycogen** = animal storage carbohydrate; stored in liver and skeletal muscle.

   *Polymers are broken down by hydrolysis resulting in monosaccharides.

4. **Function = energy source / energy storage**!

   *How is the energy that is stored in carbohydrates released?
   *CELLULAR RESPIRATION OVERVIEW:



III. CHEMICAL CONSTITUENTS OF CELLS

D. LIPIDS

1. contain C, H, and O, but much less O than in carbohydrates;
2. types of lipids:

a. **Fats:**
- monomers (building blocks) = **triglycerides** (**glycerol + 3 fatty acids);**
- saturated vs. unsaturated fats:

1. **saturated fats**:
   a. have only single bonds between the carbons in their fatty acid chains;
   b. are solid at room temperature;
   c. are animal fats;
   d. include bacon grease, lard, butter;
   e. are nutritionally "BAD" fat;

2. **unsaturated fats**:
   a. have one or more double bond between the carbons in their fatty acid chains;
   b. are liquid at RT (oils);
   c. are plant fats;
   d. include corn and olive oil,
   e. are nutritionally "GOOD" fat;

- **Function = energy store/ energy source**

b. **Phospholipids:**
- triglyceride with the substitution of a polar phosphate group (PO_4^-) for one fatty acid chain;
- **Function = major cell membrane component**.

c. **Steroids:**
- four interconnected carbon rings;
- Example is cholesterol;
- Function = compose cell membranes; chemical messengers (**hormones**).

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III. CHEMICAL CONSTITUENTS OF CELLS

E. PROTEINS

1. Monomers = **amino acids**

   a. **Amino Acid Structure**

   amino group | side chain (or R group) | carboxyl group

   b. **Types of amino acids**
      - ❍ 20 different based on R-groups or side-chains

2. Polymers are formed by dehydration synthesis between the amino group of one amino acid and the carboxyl group of a 2nd amino acid.

   a. Bond formed = a **peptide bond**
   b. Length of amino acid chains may vary:
      - ❍ peptide = 2-100 aa's;
      - ❍ polypeptide = 100-thousands aa's without a function
      - ❍ protein = 100-thousands of aa's **with a specific function**

3. **Functions of Proteins**
   a. structure
      - keratin in hair, nails and skin;

   b. transport
      - hemoglobin;

   c. chemical messengers
      - hormones
      - neurotransmitters;

   d. movement
      - actin and myosin in muscle;

   c. defense
      - antibodies;

   e. catalysts
      - ENZYMES.

Biological catalysts, that increase the rate of chemical reactions without being consumed by the reaction.

III. CHEMICAL CONSTITUENTS OF CELLS

E. PROTEINS

4. **Denaturation of Proteins:** the loss of 3-dimensional conformation (shape) of a protein. This results in loss of function.

   a. Reasons for denaturation:

   - extreme pH values;
     - At what pH do our enzymes work best?
   - extreme temperature values;
     - At what temperature do our enzymes work best?
   - harsh chemicals (disrupt bonding);
   - high salt concentrations.
     - At what osmotic pressure do our enzymes work best?

5. **Protein Structure**
   a. **Primary** (1^o) = sequence of amino acids;
   b. **Secondary** (2^o) = twisting of amino acid chain; due to hydrogen bonding;
   c. **Tertiary** (3^o) = folding of the amino acid chain; due to ionic bonds, disulfide bridges, and hydrophobic interactions;
   d. **Quaternary** (4^o) = interactions between different amino acid chains (hemoglobin).

F. NUCLEIC ACIDS

1. Monomers = **nucleotides;**

   a. Nucleotide structure = 3 parts:

   - pentose sugar (5-C);
   - nitrogenous base;
     1. purine (double ring) or
     2. pyrimidine (single ring);
   - phosphate group.

2. Polymers are formed by bonding between the sugar of one nucleotide and the phosphate group of a second nucleotide = sugar/phosphate backbone;

III. CHEMICAL CONSTITUENTS OF CELLS

F. NUCLEIC ACIDS

3. Types of Nucleic Acids

a. DEOXYRIBONUCLEIC ACID = DNA

- Structure:
  1. Sugar = **deoxyribose**;
  2. Bases = **adenine (A), thymine (T), cytosine (C), guanine (G)**;
  3. **double stranded** (resembles ladder); strands held together by H-bonds between bases on opposite strands:
     a. A complements T (2 hydrogen bonds);
     b. C complements G (3 hydrogen bonds)
  4. **double helix** (ladder is twisted).
- Function = genetic material (i.e. genes, chromosomes).
  - DNA directs protein synthesis.
- **DNA contains all necessary information needed to sustain and reproduce life!**

b. Ribonucleic Acid = RNA

- Structure
  1. Sugar = **ribose**;
  2. Bases = A,G,C, and **uracil** (replaces thymine)
  3. **single stranded**.

4. Function = transport DNA code during protein synthesis.

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ORGANIC MOLECULE SUMMARY TABLE (key on page 19 of outline)

Organic Molecule				
Composed of what atoms?				
Building Blocks (monomers)				
Specific types & functions of monomers				
Specific types and functions of polymers				
Other				

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SUBATOMIC PARTICLE SUMMARY TABLE

SUBATOMIC PARTICLE	CHARGE	LOCATION	MASS (WEIGHT)
PROTON	POSITIVE	NUCLEUS	1 amu
NEUTRON	ZERO (NEUTRAL)	NUCLEUS	1 amu
ELECTRON	NEGATIVE	SHELLS OR ORBITALS AROUND NUCLEUS	0

CHEMICAL BOND SUMMARY TABLE

TYPE OF BOND	DEFINITION	DESCRIPTION	EXAMPLE
IONIC	when atoms lose or gain electrons becoming ions, and then oppositely charged ions are attracted to one another	bond is broken by water	salts, NaCl
COVALENT	when 1 or more pair(s) of electrons is/are shared equally by atoms	Very strong bond	the bonds holding together a molecule of CO_2
POLAR	when 1 or more pair(s) of electrons is/are shared unequally by atoms	Strong bond	the bonds holding together a molecule of H_2O
HYDROGEN	when a (slightly positive) hydrogen atom that is already covalently bonded to a molecule is attracted to a slightly negative atom.	Very weak bond; in molecules whose purpose is to easily break and then come back together	reactions between water molecules (i.e. ice to water to gas); DNA chains

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Chemical Reaction Comparison Table

	SYNTHESIS REACTIONS	DEGRADATION RXN'S
GENERAL DESCRIPTION	Synthesis involves the building of a large molecule (polymer) from smaller building blocks (monomer).	Degradation involves the breakdown of a polymer into individual monomers.
DESCRIPTIVE TERMS	building constructive anabolic	breakdown digestive decomposition catabolic
BOND FORMATION OR BREAKING?	Bonds are formed.	Bonds are broken.
IS ENERGY REQUIRED OR RELEASED?	Energy is required to form the bond.	Energy is released when the bond is broken.
HOW IS WATER INVOLVED? NAME THAT TERM.	Water is released when he bond is formed. Dehydration	Water is required to break the bond. Hydrolysis
EXAMPLE	Building a protein from individual amino acids; Building a triglyceride from glycerol and 3 fatty acids, etc	Breaking a protein into individual amino acids; Breaking starch down into monosaccharides, etc.

CHAPTER 2: CHEMICAL BASIS OF LIFE

ORGANIC MOLECULE SUMMARY TABLE

Organic Molecule	Carbohydrates (sugars)	Lipids (Fats)	Proteins	Nucleic Acids
Composed of what atoms?	C, H, 0	C, H, O	C, H, O, N, S	C, H, O, N, P
Building Blocks (monomers)	Monosaccharide or hexoses	Triglycerides: glycerol and 3 fatty acids	amino acids	nucleotides: pentose sugar, phosphate, nitrogen base
Specific types & functions of monomers	glucose, fructose, galactose. energy	TG: energy Phospholipid: cell membrane component Steroid: cell membrane component and chemical messenger (i.e. cholesterol)	20 different amino acids	N/A
Specific types and functions of polymers	Disaccharides: sucrose, lactose, maltose; energy _____ Polysaccharides Starch (plant); Glycogen (animal); energy storage.	N/A	proteins (>100 amino acids); Many functions: ENZYMES, antibodies, structure, transport, chemical messengers, storage	DNA: deoxy-ribonucleic acid; genetic material; RNA: ribonucleic acid; aids DNA in protein synthesis.
Other Information		Saturated (only single bonds between C's in FA chain) vs. Unsaturated (at least 1 double bond in FA chain)		DNA controls cellular activity by instructing our cells what proteins to make (i.e. Enzymes through protein synthesis).