

CHAPTER 2: THE CHEMICAL BASIS OF LIFE

OBJECTIVES

1. Define the terms *chemistry and matter*.
2. Define the terms *atom and element*.
3. Give the chemical symbol for the naturally occurring elements in humans.
4. List the four major elements that compose the human body.
5. Describe and distinguish between the three subatomic particles in terms of charge, weight, and location of each. Sketch a diagram to illustrate their relationship.
6. Distinguish between the atomic number and atomic weight of an atom of an element.
7. Discuss how isotopes of atoms of a particular element differ.
8. Given the atomic number of an atom, you should be able to determine the following:
 - a. the number of protons;
 - b. the number of electrons;
 - c. the electron configuration of the atom;
 - d. the number of valence electrons;
 - e. how that atom will react.
9. Explain how atoms react with one another.
10. Distinguish between ionic, covalent, and hydrogen bonds, and give an example of a molecule (or macromolecule) that demonstrates each.
11. Name the three types of chemical reactions.
12. Compare and contrast the major divisions (types of chemical reactions) of metabolism, in terms of a general descriptive sentence, additional descriptive terms, how energy is involved, whether bonds are formed or broken, and how water is involved. Also write a chemical reaction for each and give an example important in human metabolism.
13. List the four factors that affect the rate at which chemical reactions occur.

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OBJECTIVES

14. Distinguish between organic and inorganic compounds.
15. List five inorganic substances of importance to humans.
16. Discuss the unique structure of a water molecule and name the bonds that hold liquid water together.
17. List and discuss the characteristics of water.
18. List the major electrolytes released by inorganic salts when placed in water and explain how these electrolytes are needed for metabolic reactions.
19. Describe what happens to an acid and base when they are placed in water, and discuss the significance of these products in the human body.
20. Illustrate the pH scale, denoting acid, neutral, and basic (alkaline) pH values. Also denote the relationship between $[H^+]$ to $[OH^-]$ at each of the above pH's, and show approximately where on that scale the following substances would fall: acetic acid, distilled water, blood and ammonia.
21. Using the scale above, plot the pH values of the compounds you tested in lab.
22. Name the value of physiological pH.
23. Define the term *buffer*, and explain how the carbonic acid buffering system works in humans.
24. List the four major organic substances needed for human survival (i.e. proteins, carbohydrates, lipids and nucleic acids), name the building blocks that compose each, and give a general function for each.
25. Name the three types of atoms that compose sugars and lipids.
26. Name three monosaccharides and three disaccharides.
27. Name two polysaccharides, indicate whether each is a plant or animal carbohydrate, and name the tissue where the animal carbohydrate is stored.
28. Distinguish between the three types of lipids, in terms of structure and function.

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OBJECTIVES

29. Compare and contrast saturated and unsaturated fats.
30. Name the bond that is formed when two amino acids are joined.
31. Describe the levels of structural organization of a protein and explain the significance of a protein's conformation on its overall function.
32. Define the term *denaturation* and explain what conditions may cause a protein to become denatured.
33. List and discuss the many functions of proteins (Which is the most important?)
34. Discuss the structure of a nucleotide.
35. Name the type of chemical bond that holds the chains of a DNA molecule together.
36. List three differences between DNA and RNA.
37. Name the two types of nucleic acids, describe the structure of each, and give a general function for each molecule.

CHAPTER 2: CHEMISTRY

I. DEFINITIONS

- 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. **Atom** = the smallest particle of an element;
the least complex level of organization.
- B. **Element** = a basic chemical substance composed of atoms.
1. Elements are represented by a **1 or 2 letter symbol** that are shown in the Periodic Table of the Elements in Appendix A, page 986;
 2. 120 elements exist in nature, however only approximately 26 are naturally occurring in humans.
 3. Learn the elements (and their chemical symbol) listed in **Table 2.2, page 38**.
 4. The most abundant of the naturally occurring elements are carbon (C), Hydrogen (H), Oxygen (O) and Nitrogen (N) = **CHON**;
- C. **Composition of Atoms** = 3 Subatomic Particles See Fig 2.1 & Table 2.1, p 38.
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 (Key on page 36)

SUBATOMIC PARTICLE	CHARGE	LOCATION	MASS (WEIGHT)

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II. Structure of Matter

D. Atoms are neutral in charge

1. The number of protons is equal to the number of electrons.

E. The **Atomic Number** (A#) of an atom represents the number of protons in its nucleus.

1. A# of H = 1
2. A# of He = 2
3. A# of O = 8.

F. The **Atomic Weight** (AW) of an atom is equal to the number of protons plus the number of neutrons in its nucleus.

1. **Isotopes** = atoms of an element that have the same A#'s but different AW's (i.e. same # of protons, different # of neutrons).
 - a. The nucleus of some isotopes are stable;
 - b. The nucleus of other isotopes are unstable and break apart to become more stable;
 - m When the nucleus of an atom breaks apart, it releases **radioactive energy**;
 - m Radioactive isotopes have many biological uses.

See Clinical Application 2.1, page 40 & 41.

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II. Structure of Matter

G. Electron Configuration

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

See Fig 2.2 page 40.

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: **Sulfur (S)**: Atomic Number= 16
protons= 16
electrons= 16

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II. Structure of Matter

G. Electron Configuration

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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III. CHEMICAL BONDS

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

1. "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.

B. **Ionic Bonds:** See Fig 2.3, page 42.

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

Na^+ (the cation) donates its outer electron to Cl^- (the anion).

Table salt or **sodium chloride is held together by ionic bonds.**

C. **Covalent Bonds:** See Fig 2.4, page 42.

1. A covalent bond is formed by the sharing of electrons between atoms.
2. a very strong bond
3. Examples:
 - a. H_2 (molecular hydrogen);
 - b. O_2 (molecular oxygen);
 - c. H_2O (water).

D. **Hydrogen Bonds:** See Fig 2.5, page 44.

1. A hydrogen bond is a weak bond formed between hydrogen atoms (that are covalently bonded to another atom) and another atom.
2. Examples include **liquid water and DNA chains.**
3. These bonds are **easily broken and put back together.**

CHEMICAL BOND SUMMARY TABLE (Key on page 36)

TYPE OF BOND	DEFINITION	DESCRIPTION	EXAMPLE

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IV. CHEMICAL REACTIONS

A. Definition: A chemical reaction occurs whenever chemical bonds are formed, rearranged or broken.

B. **Three Types:**

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

a. **constructive, anabolic** reactions;

b. **Bonds are formed** which now hold chemical energy (**ENDERGONIC**);

c. Water is usually removed from building blocks to form bond (**DEHYDRATION**);

d.
$$A + B \xrightarrow[\text{H}_2\text{O}]{\text{Energy}} A-B.$$

e. Example = the building of a large protein (polymer) from many smaller amino acids (monomer).

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

a. **destructive, catabolic, "digestive"** reactions;

b. **Bonds are broken** releasing chemical energy (**EXERGONIC**);

c. Water is used to break bonds (**HYDROLYSIS**);

d.
$$A-B \xrightarrow[\text{Energy}]{\text{H}_2\text{O}} A + B$$

e. Example = digesting a large protein we eat into its amino acid building blocks.

3. **Exchange Reactions** involve both degradation and synthesis reactions;

a.
$$A-B + C-D \xrightarrow{\quad\quad\quad} A-C + B-D.$$

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IV. 4. Chemical Reaction Comparison Table (Key on page 37)

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

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IV. Chemical Reactions (continued)

C. Factors affecting the rate of chemical reactions:

1. **Particle size:** The smaller the particle, the faster the reaction will occur.
2. **Temperature:** The higher the temperature, the faster the reaction will occur (up to a point).
3. **Concentration:** The greater number of particles in a given space, the faster the reaction.
4. **Catalysts:**
 - a. **Definition:** A catalyst is something that speeds the rate of a reaction.
 - b. **Enzymes (special proteins) are biological catalysts.**

V. Types of Compounds in Living Matter

A. **Inorganic Compounds** are small compounds that do not contain the atoms C and H; Examples include carbon dioxide (CO₂) water, salts, acids & bases.

1. CO₂=by-product of cellular respiration.
2. **Water is** a polar molecule that demonstrates hydrogen bonding and therefore it possesses very unique characteristics.
 - a. Water is an **excellent solvent** (universal?)
 - m Many solutes are dissolved in our body's water.
 - m Many ionic compounds (i.e. NaCl) dissociate or break apart in water.
 - b. Water **participates in many chemical reactions.**
 - m **Dehydration (synthesis)** is when water is removed from adjacent atoms (of molecules) to form a bond between them.
 - m **Hydrolysis (degradation)** is when water is used to break bonds between molecules.

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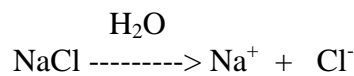
V. A. Inorganic Compounds (continued)

2. Water (continued)

- c. Water is an **excellent temperature buffer**.
 - m absorbs and releases heat very slowly
- d. Water provides an **excellent cooling mechanism**.
 - m requires a lot of heat to change from a liquid to a gas; high heat of vaporization.
- e. Water serves as a **lubricant**
 - m mucus;
 - m internal organs;
 - m joints.
- f. Water is the **most abundant component in cells** (about 70%).

3. Salts: See Fig 2.7, page 45.

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



- b. These ions are referred to as **electrolytes** (charged particles).
 - m Electrolytes must be maintained within a very narrow range in our blood and tissues (i.e. homeostasis);
 - m Needed for muscle contraction, nerve impulses, etc.;
 - m Examples include Na^+ , K^+ , Cl^- , Ca^{2+} , PO_4^{3-} ; HCO_3^- , etc.

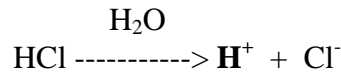
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V. A. Inorganic Compounds (continued)

4/5. Acids/Bases

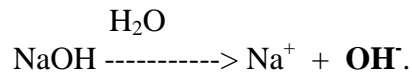
a. Acids dissociate (ionize) in water into:

- m a **hydrogen cation, H^+** , and
- m an anion.
- m Example = HCl (hydrochloric acid).



b. Bases dissociate (ionize) in water into:

- m a **hydroxyl anion, OH^-** , and
- m a cation.
- m Example = NaOH (sodium hydroxide).



c. **pH Scale:** See Fig 2.8, page 46.

- m The relative concentrations of hydrogen ions and hydroxyl ions determine the pH in our blood, fluids, and tissues.

$$pH \text{ in body} = [H^+] + [OH^-]$$

- m $pH = -\log[H^+]$;

- m pH Scale ranges from 0 to 14: See Fig 2.8, page 46.

$$0 \text{ ----- } 7 \text{ ----- } 14$$

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

- m Physiologic pH = 7.4

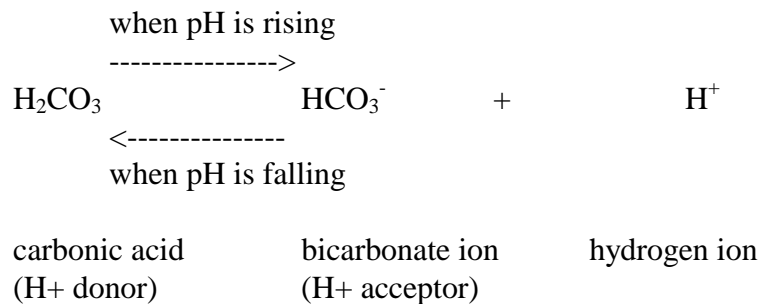
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V. A. 4/5. Acids/Bases (continued)

d. Buffering Systems

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

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



*Physiologic pH = 7.4.

*pH < 7.4 = acidosis; lethal below 7.0;

*pH > 7.4 = alkalosis; lethal above 7.8.

See Table 2.6, page 48 for Summary of the Inorganic Substances Common in Cells

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VI. ORGANIC COMPOUNDS

A. General Characteristics:

1. contain 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.

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VI. Organic Compounds (continued)

B. CARBOHYDRATES (sugars)

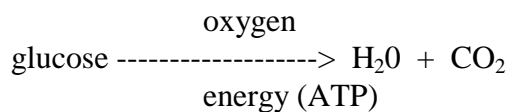
1. contain C, H, and O in a 1:2:1 ratio (usually);
(Ex: glucose = C₆H₁₂O₆)
2. Monomers (building blocks) = **monosaccharides**;
hexoses = simple 6-C sugars; See Fig 2.9, page 48.
 - a. **glucose**,
 - b. fructose,
 - c. galactose.
3. Polymers are formed by dehydration synthesis:
 - a. **disaccharides** = 2 monosaccharides covalently bonded together;
See Fig 2.10b, page 49.
 1. maltose = glucose + glucose;
 2. lactose = glucose + galactose;
 3. sucrose = glucose + fructose
 - b. **polysaccharides** = 100 to thousands of glucose molecules covalently bonded together; See Fig 2.10c, page 49.
 1. **starch** = plant storage carbohydrate; (24-30 glucose molecules);
 2. **glycogen** = animal storage carbohydrate; (12 glucose molecules); stored in liver and skeletal muscle.

*Polymers are broken down by hydrolysis resulting in monosaccharides.

4. **Function = energy storage!**

*How is the energy that is stored in carbohydrates released?

*CELLULAR RESPIRATION OVERVIEW:



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VI. Organic Compounds (continued)

C. LIPIDS

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

a. **Fats (See Fig 2.12, page 50):**

m monomers (building blocks) = **triglycerides (glycerol + 3 fatty acids);**

m saturated vs. unsaturated fats: See Fig 2.11, page 49.

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;

m **Function = energy source.**

b. **Phospholipids (See Fig 2.13, page 50)**

m triglyceride with the substitution of a phosphate group (PO_4^-) for one fatty acid chain;

m **Function = major cell membrane component.**

c. **Steroids (See Fig 2.14, page 50)**

m four interconnected carbon rings;

m Example is cholesterol;

m Function = compose cell membranes; chemical messengers (**hormones**).

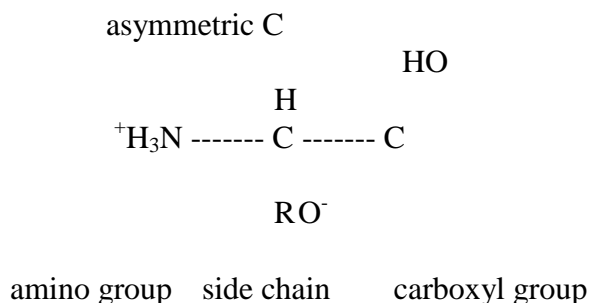
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VI. Organic Compounds (continued)

D. PROTEINS

1. Monomers = **amino acids**

a. **Amino Acid Structure** (See Fig 2.15a, page 51)



b. **Types of amino acids**

- m 20 different based on R-groups or side-chains
- m See Fig 2.15b, page 51 for some examples.

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

See Fig 2.16a, page 52.

a. Bond formed = a **peptide bond**

b. Length of amino acid chains may vary:

- m peptide = 2-9 aa's;
- m polypeptide = 10-100 aa's;
- m protein = over 100 aa's.

3. **Protein Structure** (See Fig 2.16-2.18 on page 52).

- 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;
- * A protein must be in its quaternary structure to be functional!!!!

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VI. Organic Compounds (continued)

D. Proteins (continued)

4. **Denaturation of Proteins** = the loss of 3 dimensional conformation of a protein; = loss of function.

a. Reasons for denaturation:

- m extreme pH values;
- m extreme temperature values;
- m harsh chemicals (disrupt bonding);
- m high salt concentrations.

5. **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;
- e. defense = antibodies;
- f. **catalysts = ENZYMES.**

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VI. Organic Compounds (continued)

E. NUCLEIC ACIDS

1. Monomers = **nucleotides**;

a. Nucleotide structure = 3 parts: See Fig 2.19, page 53.

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

See Fig 2.20, page 53.

3. **Types of Nucleic Acids**

a. **DEOXYRIBONUCLEIC ACID = DNA**

- m 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=T;
 - b. C=G.
 - 4. **double helix** (ladder is twisted).
- m Function = genetic material (i.e. genes, chromosomes).
- m **DNA contains all necessary information needed to sustain and reproduce life!**

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VI. Organic Compounds (continued)

E. NUCLEIC ACIDS

3. types of nucleic acids

b. **Ribonucleic Acid = RNA**

m Structure

1. Sugar = **ribose**;
2. Bases = A,G,C, and **uracil** (not thymine)
3. **single stranded.**

4. Function = transport DNA code during protein synthesis.

See Chart 2.8, page 53 for a summary of the four organic compounds in living things.

CHAPTER 2: CHEMICAL BASIS OF LIFE**ORGANIC MOLECULE SUMMARY TABLE** (key on page 38 of outline)

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

CHAPTER 2: CHEMICAL BASIS OF LIFE
SUBATOMIC PARTICLE SUMMARY TABLE (outline page 17)

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 (outline page 21)

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 are shared by atoms	strong bond	the bonds holding H ₂ O together (intra-), CO ₂
HYDROGEN	when a (slightly positive) hydrogen atom that is already covalently bonded to something else 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 (inter-; i.e. ice to water to gas); DNA chains

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Chemical Reaction Comparison Table (outline page 23)

	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 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? NAME THAT TERM.	Energy is required to form the bond. Endergonic	Energy is released when the bond is broken. Exergonic
HOW IS WATER INVOLVED? NAME THAT TERM.	Water is released when the 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.

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ORGANIC MOLECULE SUMMARY TABLE (outline page 32)

Organic Molecule	Carbohy- drates (sugars)	Lipids (Fats)	Proteins	Nucleic Acids
Composed of what atoms?	C, H, O	C, H, O	C, H, O, N, S	C, H, O, N, P
Building Blocks (monomers)	Monosaccha- rides 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, struc-ture, transport, chemical messengers, storage	DNA = deoxyribo=nucl eic acid; genetic material; RNA= ribonucleic acid; aids DNA in protein synthesis.
Other		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).