Chemistry of Life

- Basic chemistry
  - Atoms, molecules, isotopes, and bonds
- Water and living things
  - Properties of water, acid/bases, buffers
- Macromolecules of life
  - Carbohydrates
  - Lipids
  - Proteins
  - Nucleic acids

1

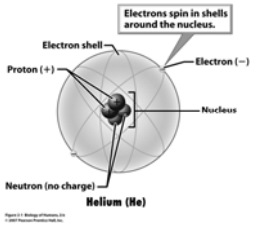
Basic Chemistry

- What is chemistry?
  - Branch of science concerned with the composition and properties of material substances
- Matter—anything that occupies space and has mass (AKA weight)
- 3 states of matter
  - Solid, liquid, gas
- All matter is composed of elements
  - Atoms—smallest unit of an element that still retains the chemical and physical properties of the element

2

Atoms Contain Protons, Neutrons, and Electrons

- Proton—positive charge, 1 atomic unit, in nucleus
- Neutron—neutral charge, 1 atomic unit, in nucleus
- Electron—negative charge, 0 atomic units
  - Electron cloud, orbital, valence shell
  - Inner shell can hold up to 2 e, others up to 8 e
- Atomic number = # of protons
- Atomic weight = # of protons + neutrons



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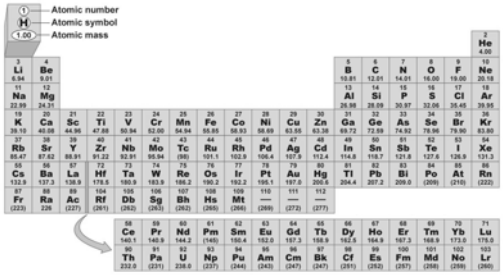

TABLE 2.1 Review of Subatomic Particles

Particle	Location	Charge	Mass
Proton	Nucleus	1 positive unit	1 atomic mass unit
Neutron	Nucleus	None	1 atomic mass unit
Electron	Outside the nucleus	1 negative unit	Negligible

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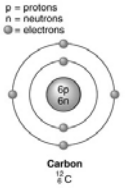
Common Elements in Living Things

Element	Atomic Symbol	Atomic Number	Atomic Weight	Comment
hydrogen	H	1	1	These elements make up most biological molecules.
carbon	C	6	12	
nitrogen	N	7	14	
oxygen	O	8	16	
phosphorus	P	15	31	
sulfur	S	16	32	
sodium	Na	11	23	These elements occur mainly as dissolved salts.
magnesium	Mg	12	24	
chlorine	Cl	17	35	
potassium	K	19	39	
calcium	Ca	20	40	

a.



b.

Isotopes and Radioisotopes

- Isotopes—same type of atom with varying numbers of neutrons
  - ^{12}C ^{13}C ^{14}C (radioactive)
- Radioactive isotopes—radiation emitting isotopes can be dangerous or useful
  - At higher doses it can kill cells, whole organisms, or cause cancer or other harmful effects
  - Used in medicine as a tracer and as a treatment
    - ^{131}I—used to check the condition of the thyroid gland as well as to kill cancerous cells

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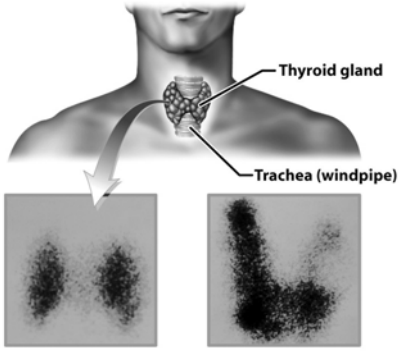

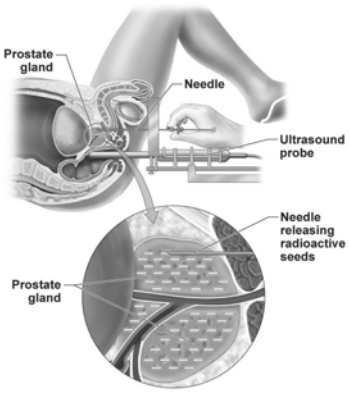

Elements Combine to Form Molecules and Compounds

- Molecule—bonding of same atoms to form a chemical unit

H_2	N_2	O_2
hydrogen gas	nitrogen gas	oxygen gas

- Compound—different atoms bond together

NaCl	H_2O	NaOH
salt	water	sodium hydroxide

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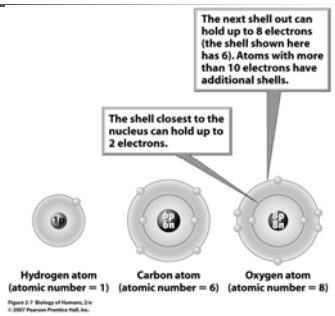
The element sodium is a solid metal.


Elemental sodium reacts explosively with water.


The element chlorine is a yellow gas.


When the elements sodium and chlorine join, they form table salt, a compound quite different from its elements.

Compounds are Held Together by Bonds



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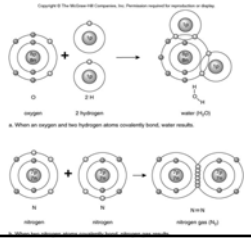
Chemical Bonds: Covalent Bonds

- Are the strongest bonds and form when two or more atoms share the electrons in their outer shells



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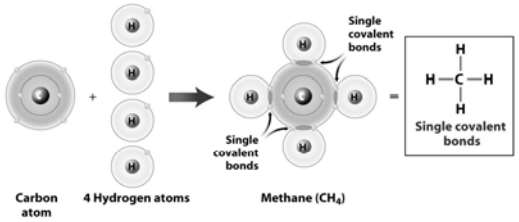

The molecule methane (CH_4) is formed by the sharing of electrons between one carbon atom and four hydrogen atoms. Because, in each case one pair of electrons is shared, the bonds formed are single covalent bonds.

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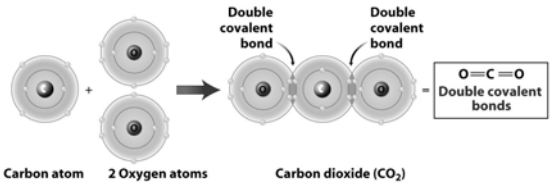

The oxygen atoms in a molecule of carbon dioxide (CO_2) form double covalent bonds with the carbon atom. In double bonds, two pairs of electrons are shared.

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Chemical Bonds: Ionic Bonds

- An **ion** is an atom or group of atoms with a positive or negative electrical charge
- **Ionic bonds**
  - Weaker than covalent bonds
  - Result from the attraction of oppositely charged ions, rather than shared electrons

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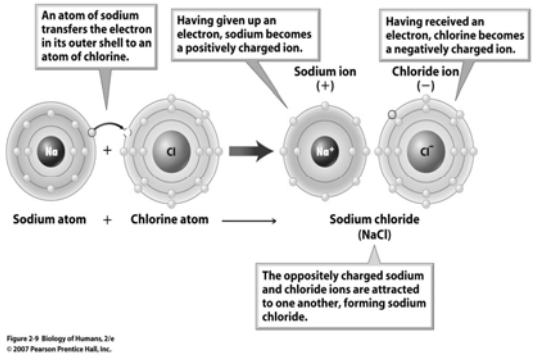

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Covalent versus Ionic Bonds Animation

Water and Living Things

- Water is the most abundant molecule in living things
  - 60-70% body weight
- Chemical and physical properties of water make life possible
- Water is a polar molecule and forms hydrogen bonds

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Polarity and Hydrogen Bonds

- When the electrons of a covalent bond are shared unequally, the bond is called polar and the resulting molecules are called **polar molecules**
  - Water is a polar molecule
- **Hydrogen bonds** are the attraction formed between a slightly positively charged hydrogen atom and another slightly negatively charged atom
  - Account for the unique properties of water and the geometric shape of many biological molecules
  - Weaker than either ionic or covalent bonds yet collectively are significant
    - Maintain the shape of proteins and DNA

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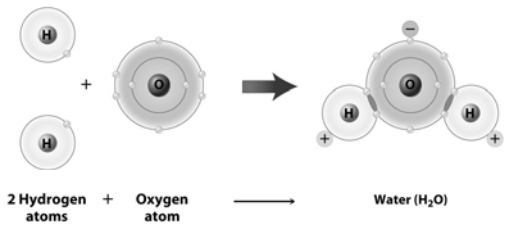

Water is formed when an oxygen atom covalently bonds (shares electrons) with two hydrogen atoms. As a result of unequal sharing of electrons, oxygen carries a slight negative charge and the hydrogen atoms a slight positive charge.

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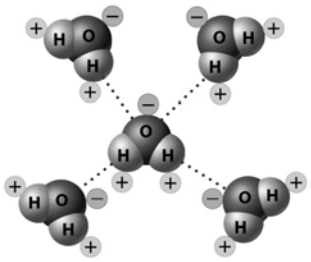

The hydrogen atoms from one water molecule are attracted to the oxygen atoms of other water molecules. This relatively weak attraction (shown by dotted lines) is called a hydrogen bond.

Figure 2-10b Biology of Humans, 2/e
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Hydrogen Bonding

Properties of Water

- Water is liquid at room temperature
- Temperature of liquid water rises and falls slowly
- Water has a high heat of vaporization
- Frozen water is less dense than liquid water
- Water molecules are cohesive
- Water is a solvent for polar and charged substances
  - Facilitates chemical reactions both outside and within our bodies
  - Serves as the body's main transport medium

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TABLE 2.2 Review of Chemical Bonds

Type	Basis for Attraction	Strength	Example
Covalent	Sharing of electrons between atoms; the sharing between atoms may be equal or unequal	Strongest	CH_4 (methane)
Ionic	Transfer of electrons between atoms creates oppositely charged ions that are attracted to one another	Strong	NaCl (table salt)
Hydrogen	Attraction between a hydrogen atom with a slight positive charge and another atom (often oxygen) with a slight negative charge	Weak	Between a hydrogen atom on one water molecule and an oxygen atom on another water molecule

Acids and Bases

- Acids—substances that dissociate in H_2O, releasing H^+

  $HCl \longrightarrow H^+ + Cl^-$ (dissociates in H_2O)

  (Acidic solutions—high H^+ concentration)
- Bases—substances that either take up H^+ or release OH^-

  $NaOH \longrightarrow Na^+ + OH^-$

  (Basic solutions—high OH^- concentration)

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pH Scale

- pH is defined as the negative logarithm of the concentration of the H+ ion in solution
  - Range from 0 to 14
- Used to indicate the acidity or basicity (alkalinity) of a solution
  - Higher the number, the more basic
  - Lower the number, the more acidic
  - pH of 7 is considered neutral

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- As we move toward a higher pH, each unit has 10 times the basicity of the previous unit
- As we move toward a lower pH, each unit has 10 times the acidity of the previous unit

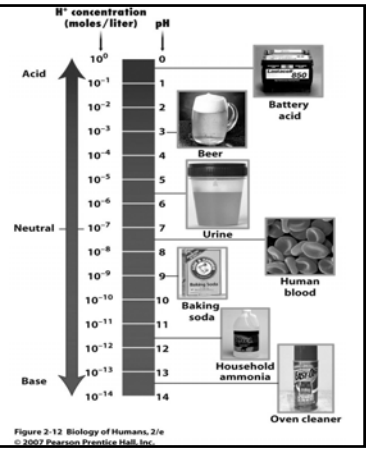

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TABLE 2.3 Review of the Characteristics of Acids and Bases

Characteristic	Acid	Base
Behavior in water	Releases H^+	Releases OH^-
pH	Less than 7	Greater than 7
Example	HCl (hydrochloric acid)	NaOH (sodium hydroxide)

Buffers

- Substances that prevent dramatic changes in pH
  - Many body fluids have the buffering capacity to maintain a constant internal environment
    - Carbonic acid – bicarbonate system

$$H_2O + CO_2 \longleftrightarrow H_2CO_3 \longleftrightarrow H^+ + HCO_3^-$$

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Molecules of Life are Macromolecules

- Macromolecule—a molecule that contains many subunits
  - Long chains called polymers
    - Repeating units called monomers
- Four categories unique to living things
  - Carbohydrates, lipids, proteins, nucleic acids

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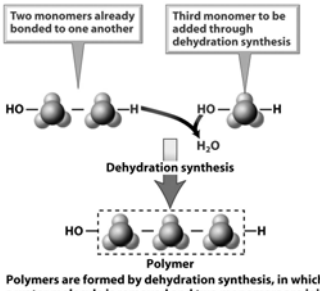
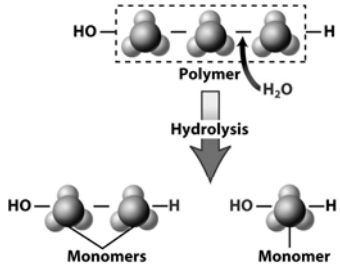
Polymer Formation: Dehydration Synthesis



Polymers are formed by dehydration synthesis, in which a water molecule is removed and two monomers are joined.

Polymer Breakdown: Hydrolysis



Polymers are broken down by hydrolysis, in which the addition of a water molecule disrupts the bonds between two monomers.

Macromolecules of Life: Carbohydrates

- Made up of C,H, and O
- **Serve as quick or short-term energy storage to cells**
- Simple carbohydrates
  - Monosaccharide—simple sugar made up of carbon atoms
    - glucose, fructose, and galactose
  - Disaccharide—made by joining only two monosaccharides together by a dehydration reaction

    maltose (glucose + glucose) sucrose (glucose + fructose)
- Complex carbohydrates or polysaccharides—made up of many glucose units
  - Starch—stored carbohydrates in plant cells
  - **Glycogen—stored carbohydrates in the liver and muscle**
  - Cellulose—found in plant cell walls, serves as dietary fiber in humans

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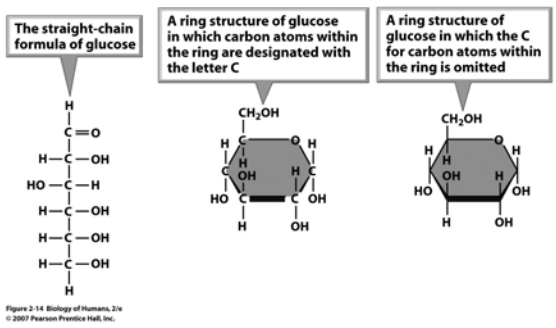
TABLE 2.4 Review of Some Common Carbohydrates

Carbohydrate	Molecular Formula	Source	Monomers
Monosaccharides			
Glucose	$C_6H_{12}O_6$	Blood, fruit, honey	
Fructose	$C_6H_{12}O_6$	Fruit, honey	
Galactose	$C_6H_{12}O_6$	From hydrolysis of lactose (milk sugar)	
Disaccharides			
Sucrose	$C_{12}H_{22}O_{11}$	Sugar cane, maple syrup	Glucose, fructose
Maltose	$C_{12}H_{22}O_{11}$	From hydrolysis of starch; ingredient in beer	Glucose
Lactose	$C_{12}H_{22}O_{11}$	Component of milk	Glucose, galactose
Polysaccharides			
Starch	*	Potatoes, corn, some grains	Glucose
Glycogen	*	Stored in muscle and liver cells	Glucose
Cellulose	*	Cell walls of plants	Glucose

*These complex carbohydrates consist of chains containing hundreds of glucose molecules joined to each other in long strings.



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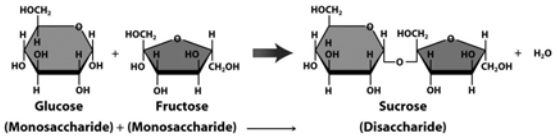

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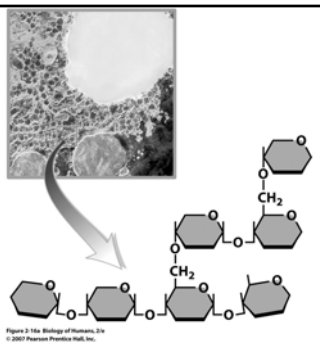
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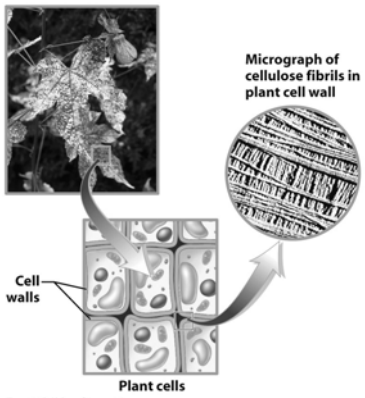
- Glycogen is the storage polysaccharide in animals
- Granules of glycogen are stored in cells of the liver



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Macromolecules of Life: Lipids

- **Lipids** are water-insoluble (or nonpolar) molecules made of C, H, and O
- Important functions include:
  - Store long-term energy
  - Protect vital organs
  - Form cell membranes
- Three types of lipids that are important for human health
  - Triglycerides – fats and oils
  - Phospholipids
  - Steroids

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Types of Lipids: Triglycerides

- A polymer made of one molecule of glycerol and three fatty acids
  - Fats and oils
- Classified depending on the presence or absence of double bonds between the carbon atoms in their fatty acids
  - Saturated fatty acids have only single covalent bonds
  - Unsaturated fatty acids have one or more double bonds between their carbon atoms

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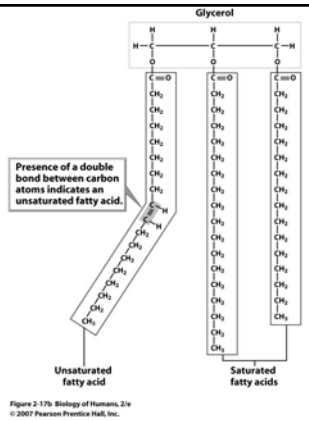
Triglyceride



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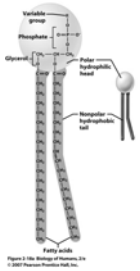
Types of Lipids: Phospholipids

- Molecule of glycerol bonded to two fatty acids and a negatively charged phosphate group
- Structure provides polar and nonpolar regions
  - Nonpolar or hydrophobic – water hating
  - Polar or hydrophilic – water loving
- Primary component of cell membranes



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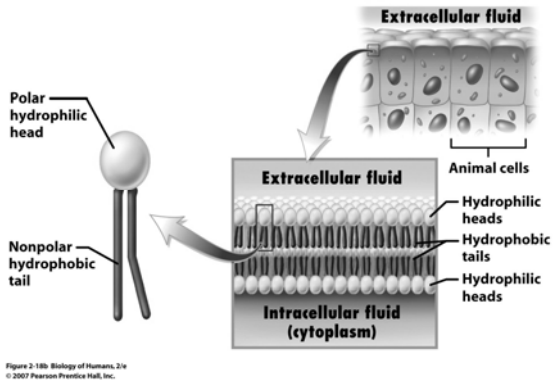

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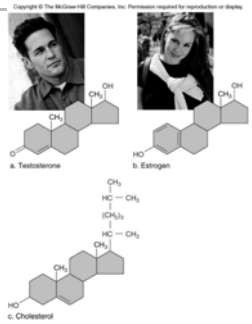
Types of Lipids: Steroids

- Steroid—type of lipid molecule having a complex of four carbon rings
  - Cholesterol, estrogen, progesterone, and testosterone
- Component of cell membranes



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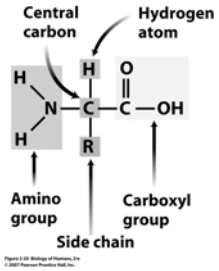
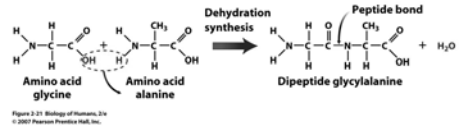
Macromolecules of Life: Proteins

- Consist of **Amino acids**
  - A central carbon atom bound to a hydrogen (H) atom, an amino group (NH_2), and a carboxyl group (COOH) in addition to a unique side chain called a radical (R)
- 20 amino acids

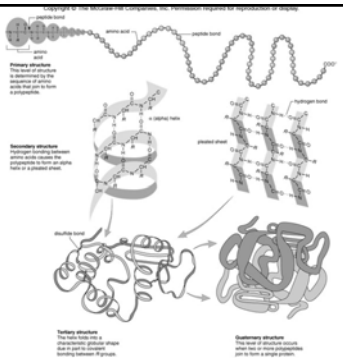


Macromolecules of Life: Proteins



- Chains of only a few amino acids are called **peptides**
- Chains of 10 or more are called **polypeptides**
- **Proteins** are polypeptide chains of at least 50 amino acids that provide structure, transport, and movement for the body

Levels of Protein Organization



Chemical changes in the environment of a protein can cause it to lose its structure or **denature** resulting in a loss of function

Levels of Protein Organization

- Primary structure—linear sequence of amino acids joined by peptide bonds
  - Polypeptide chain
- Secondary structure—occurs when polypeptide takes on a certain orientation in space
  - Hydrogen bonding
- Tertiary structure—final 3-dimensional shape
  - Covalent bonds between R groups
- Quaternary structure—consists of two or more polypeptide chains
  - Hemoglobin and most enzymes

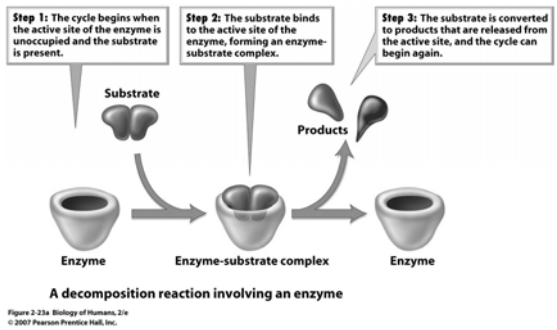
Proteins are the Body's Worker Molecules

- Muscle proteins enable all muscular movement
- Hemoglobin (Hb) carries oxygen
- Important in cell communication
  - Nerve and muscle cells
- Enzymes speed up chemical reactions
  - Digestion of food
- Machines that copy our genes and make new proteins
- Antibodies that help us fight disease
- Components of our hair, fingernail, skin, bones…
- It's structure is related to its function

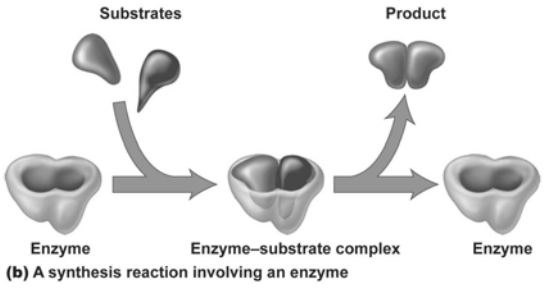
Enzymes

- A special group of proteins that serve as catalysts for chemical reactions
  - Speed them up 10,000 to 100,000 times
  - Are not consumed in the process
  - Particular substance an enzyme works on is called its substrate and is very specific

    E + S -> ES -> E + P
- Sometimes ***cofactors***, often called ***coenzymes***, bind at the **active site** to facilitate the reaction
- Enzyme deficiencies sometimes occur and affect our health
  - Lactose intolerance

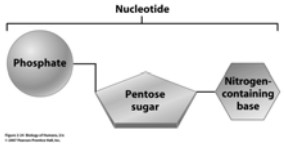


How Enzymes Work



Macromolecules of Life: Nucleic Acids

- Nucleotides are the building blocks of nucleic acids
  - Deoxyribonucleic acid (DNA) and ribonucleic acid (RNA)
- A nucleotide is made up of five-carbon sugar bonded to one of five nitrogen-containing bases and a phosphate group



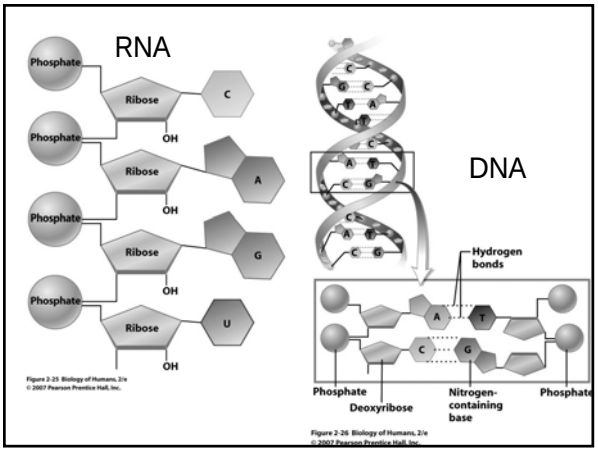
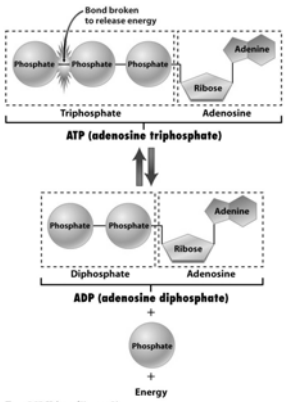


TABLE 2.5 Review of the Structural Differences between RNA and DNA

Characteristic	RNA	DNA
Sugar	Ribose	Deoxyribose
Bases	Adenine, guanine, cytosine, uracil	Adenine, guanine, cytosine, thymine
Number of strands	One	Two; twisted to form double helix

Adenosine Triphosphate (ATP)

- A special nucleotide capable of storing energy in its phosphate-to-phosphate bonds
- All energy from the breakdown of molecules such as glucose must be channeled through ATP before the body can use it
  - Energy currency of cells



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