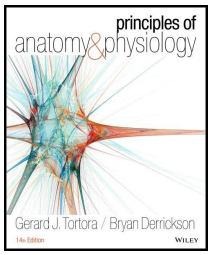


Principles of Anatomy and Physiology

14th Edition

CHAPTER 2
The Chemical Level of Organization

Introduction

The purpose of the chapter is to:

1. Introduce the language and fundamental concepts of chemistry
2. Discuss how matter is organized
3. Discuss how chemical bonds form and how chemical reactions occur
4. Compare and contrast organic and inorganic compounds

Basic Principles of Chemistry

1. Chemistry is the science of structure and interactions of matter
2. Matter is anything that has mass and takes up space
3. Mass is the amount of matter a substance contains, whereas weight is the force of gravity acting on a mass

Chemical Elements

Matter exists in 3 forms:

1. Solid
2. Liquid
3. Gas

All forms of matter are composed of chemical elements

Elements

Elements are given chemical symbols such as:

- O = oxygen
- C = carbon
- H = hydrogen
- N = nitrogen

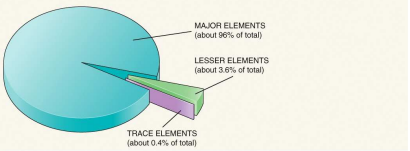
These elements make up the majority of our bodies

Trace Elements of the Human Body

TABLE 2.1 CONTINUED

Main Chemical Elements in the Body

CHEMICAL ELEMENT (SYMBOL)	% OF TOTAL BODY MASS	SIGNIFICANCE
TRACE ELEMENTS	(about 0.4)	Aluminum (Al), boron (B), chromium (Cr), cobalt (Co), copper (Cu), fluorine (F), iodine (I), manganese (Mn), molybdenum (Mo), selenium (Se), silicon (Si), tin (Sn), vanadium (V), and zinc (Zn).

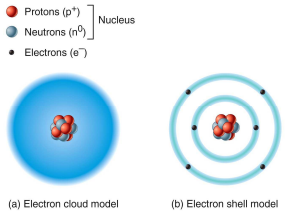


Atoms

Chemical elements are composed of units of matter of the same type called atoms

Atoms are the smallest units of matter that retain the properties and characteristics of an element

- Atoms are composed of protons, neutrons, and electrons



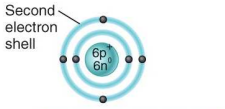
(a) Electron cloud model (b) Electron shell model

Atomic Number and Mass Number

Atomic number is the number of protons in the nucleus of an atom

Mass number is the number of protons and neutrons in an atom

- Isotopes



Carbon (C)
Atomic number = 6
Mass number = **12** or 13
Atomic mass = 12.01

Atomic Mass

Atomic mass assumes the mass of a:

- Neutron = 1.008 daltons
- Proton = 1.007 daltons
- Electron = 0.0005 daltons

The atomic mass/weight of an element is the average mass of all its naturally occurring isotopes

Ions, Molecules, and Compounds

Ion – an atom that has lost or gained an electron

Molecule – 2 or more atoms sharing electrons

Compound – a substance that can be broken down into 2 or more different elements

Chemical Bonding

Interactions Animation:

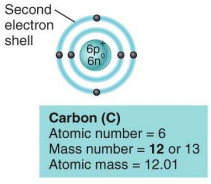
Chemical Bonds

You must be connected to the Internet and in Slideshow Mode to run this animation.

Chemical Bonds

A chemical bond occurs when atoms are held together by forces of attraction

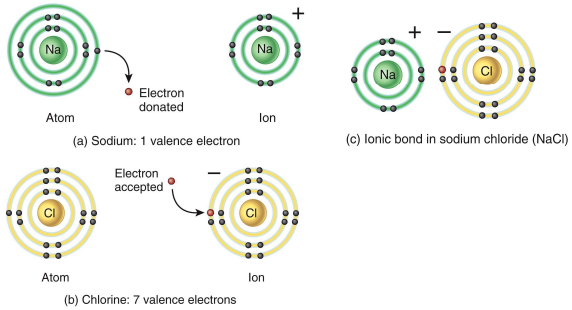
- The number of electrons in the valence shell determines the likelihood that an atom will form a chemical bond with another atom



Carbon (C)
Atomic number = 6
Mass number = **12** or 13
Atomic mass = 12.01

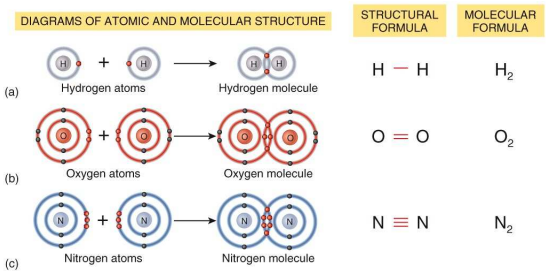
Ionic Bonds

Cations vs. Anions

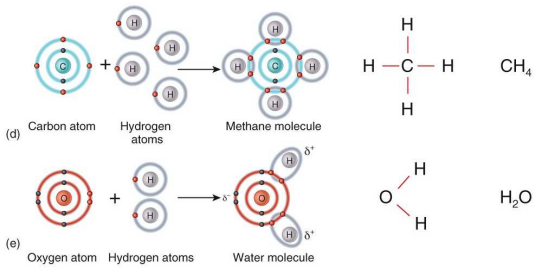


Covalent Bonds

Single, double, and triple bonds

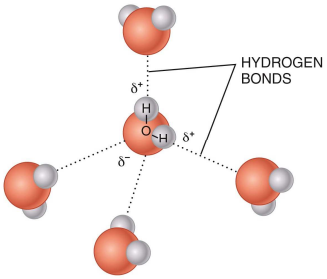


Covalent Bonds



Hydrogen Bonds

In a hydrogen bond, 2 other atoms associate with a hydrogen atom

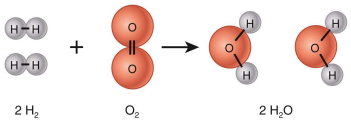


Chemical Reactions

A chemical reaction occurs when new bonds are formed or old bonds are broken

- Reactants – starting substances
- Products – ending substances
- Metabolism

Law of conservation of mass



Forms of Energy & Chemical Reactions

Energy is the capacity to do work

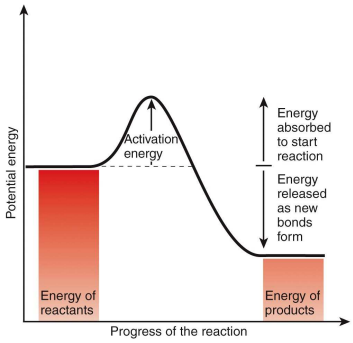
- Potential energy
- Kinetic energy
- Chemical energy

Law of conservation of energy

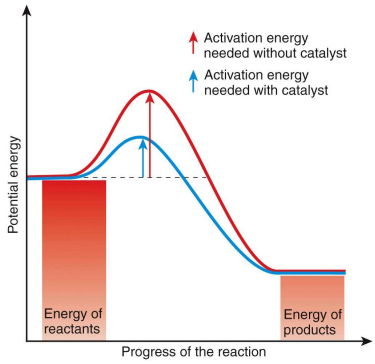
Energy Transfer

Exergonic vs. endergonic reactions

Activation energy



Catalysts



Types of Chemical Reactions

1. Synthesis
2. Decomposition
3. Exchange
4. Reversible
5. Oxidation-reduction

Inorganic vs. Organic Compounds

Inorganic compounds usually lack carbon and are simple molecules

- Water is the most important and abundant inorganic compound in all living things

Organic compounds always contain H, usually contain O, and always have covalent bonds

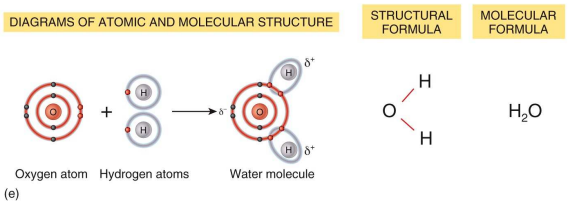
Properties of Water

Interactions Animation:

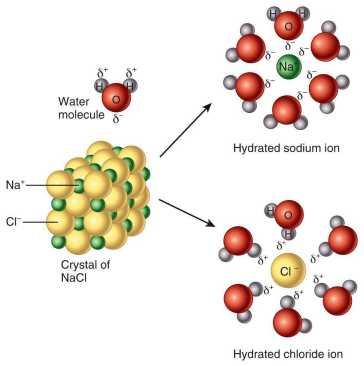
- Polarity and Solubility of Molecules

You must be connected to the Internet and in Slideshow Mode to run this animation.

Water as a Polar Molecule



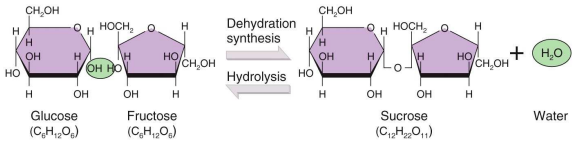
Water as a Solvent



Water in Chemical Reactions

Water is the ideal medium

- In a hydrolysis reaction, water is added to break bonds
- In a dehydration synthesis reaction, water is removed to make bonds



(a) Dehydration synthesis and hydrolysis of sucrose

Water's Thermal Properties

Water has a:

- High heat capacity
- High heat of vaporization

Water as a Lubricant

Water is a major component of our body fluids and helps reduce friction as membranes and organs slide over one another

Solutions, Colloids, and Suspensions

Mixture – a combination of elements or compounds that are physically blended together but not bonded together

3 types of mixtures:

1. Solution
2. Colloid
3. Suspension

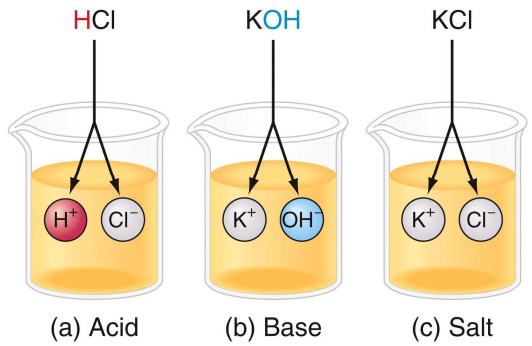
Percentage & Molarity

TABLE 2.3

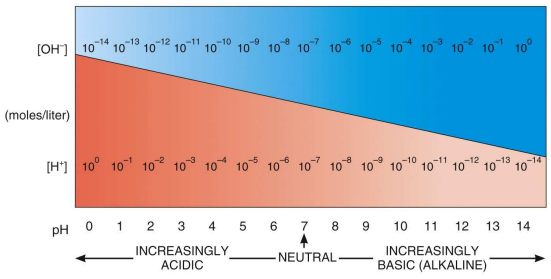
Percentage and Molarity

DEFINITION	EXAMPLE
Percentage (mass per volume) Number of grams of a substance per 100 milliliters (mL) of solution	To make a 10% NaCl solution, take 10 g of NaCl and add enough water to make a total of 100 mL of solution.
Molarity - moles (mol) per liter A 1 molar (1 M) solution = 1 mole of a solute in 1 liter of solution	To make a 1 molar (1 M) solution of NaCl, dissolve 1 mole of NaCl (58.44 g) in enough water to make a total of 1 liter of solution.

Acids, Bases, & Salts



pH



pH and Buffers

Interactions Animation:

- Acids and Bases

You must be connected to the Internet and in Slideshow Mode to run this animation.

Buffer Systems

Maintenance of body fluid homeostasis is critical

- Buffer systems help to regulate pH by converting strong acids or bases into weak acids or bases
- $H^+ + HCO_3^- \leftrightarrow H_2CO_3$

Carbon

Organic compounds always contain carbon

Many carbons can combine in a variety of shapes

Carbon compounds do not dissolve easily in water

Carbon compounds are a good source of energy

Functional Groups of Carbon

TABLE 2.5

Major Functional Groups of Organic Molecules

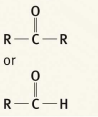
NAME AND STRUCTURAL FORMULA*	OCCURRENCE AND SIGNIFICANCE
Hydroxyl R—O—H	*Alcohols* contain an —OH group, which is polar and hydrophilic due to its electronegative O atom. Molecules with many —OH groups dissolve easily in water.
Sulfhydryl R—S—H	*Thiols* have an —SH group, which is polar and hydrophilic due to its electronegative S atom. Certain amino acids (for example, cysteine) contain —SH groups, which help stabilize the shape of proteins.

*R = variable group.

Functional Groups of Carbon

TABLE 2.5

Major Functional Groups of Organic Molecules

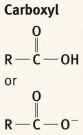
NAME AND STRUCTURAL FORMULA*	OCCURRENCE AND SIGNIFICANCE
Carbonyl 	*Ketones* contain a carbonyl group within the carbon skeleton. The carbonyl group is polar and hydrophilic due to its electronegative O atom. *Aldehydes* have a carbonyl group at the end of the carbon skeleton.

*R = variable group.

Functional Groups of Carbon

TABLE 2.5

Major Functional Groups of Organic Molecules

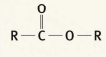
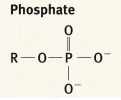
NAME AND STRUCTURAL FORMULA*	OCCURRENCE AND SIGNIFICANCE
Carboxyl 	*Carboxylic acids* contain a carboxyl group at the end of the carbon skeleton. All amino acids have a —COOH group at one end. The negatively charged form predominates at the pH of body cells and is hydrophilic.

*R = variable group.

Functional Groups of Carbon

TABLE 2.5

Major Functional Groups of Organic Molecules

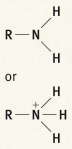
NAME AND STRUCTURAL FORMULA*	OCCURRENCE AND SIGNIFICANCE
Ester 	*Esters* predominate in dietary fats and oils and also occur in our body as triglycerides. Aspirin is an ester of salicylic acid, a pain-relieving molecule found in the bark of the willow tree.
Phosphate 	*Phosphates* contain a phosphate group ($—PO_4^{2-}$), which is very hydrophilic due to the dual negative charges. An important example is adenosine triphosphate (ATP), which transfers chemical energy between organic molecules during chemical reactions.

*R = variable group.

Functional Groups of Carbon

TABLE 2.5

Major Functional Groups of Organic Molecules

NAME AND STRUCTURAL FORMULA*	OCCURRENCE AND SIGNIFICANCE
Amino  	*Amines* have an —NH_2 group, which can act as a base and pick up a hydrogen ion, giving the amino group a positive charge. At the pH of body fluids, most amino groups have a charge of 1+. All amino acids have an amino group at one end.

*R = variable group.

Carbohydrates

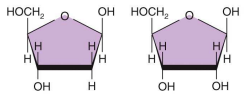
Carbohydrates provide most of the energy needed for life

TABLE 2.6

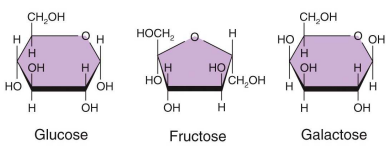
Major Carbohydrate Groups

TYPE OF CARBOHYDRATE	EXAMPLES
Monosaccharides (simple sugars that contain from 3 to 7 carbon atoms)	Glucose (the main blood sugar). Fructose (found in fruits). Galactose (in milk sugar). Deoxyribose (in DNA). Ribose (in RNA).
Disaccharides (simple sugars formed from the combination of two monosaccharides by dehydration synthesis)	Sucrose (table sugar) = glucose + fructose. Lactose (milk sugar) = glucose + galactose. Maltose = glucose + glucose.
Polysaccharides (from tens to hundreds of monosaccharides joined by dehydration synthesis)	Glycogen (stored form of carbohydrates in animals). Starch (stored form of carbohydrates in plants and main carbohydrates in food). Cellulose (part of cell walls in plants that cannot be digested by humans but aids movement of food through intestines).

Monosaccharides

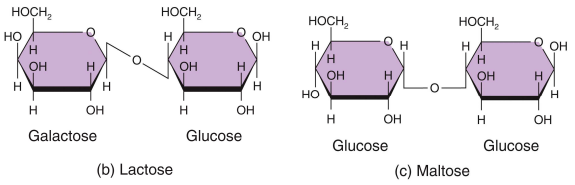


(a) Pentoses

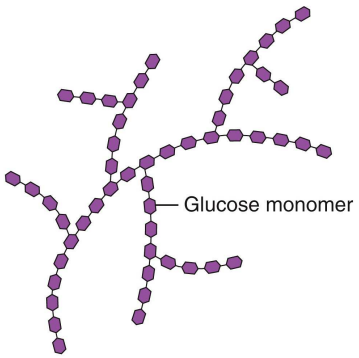


(b) Hexoses

Disaccharides



Polysaccharides



Lipids

TABLE 2.7
Types of Lipids in the Body

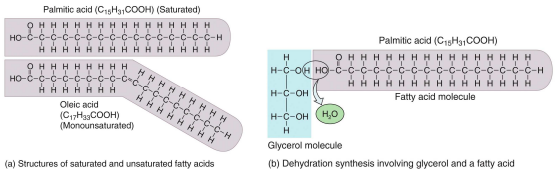
TYPE OF LIPID	FUNCTIONS
Fatty acids	Used to synthesize triglycerides and phospholipids or catabolized to generate adenosine triphosphate (ATP).
Triglycerides *(fats and oils)*	Protection, insulation, energy storage.
Phospholipids	Major lipid component of cell membranes.
Steroids	
Cholesterol	Minor component of all animal cell membranes; precursor of bile salts, vitamin D, and steroid hormones.
Bile salts	Needed for digestion and absorption of dietary lipids.
Vitamin D	Helps regulate calcium level in body; needed for bone growth and repair.
Adrenocortical hormones	Help regulate metabolism, resistance to stress, and salt and water balance.
Sex hormones	Stimulate reproductive functions and sexual characteristics.

TABLE 2.7
Types of Lipids in the Body

TYPE OF LIPID	FUNCTIONS
Eicosanoids *(prostaglandins and leukotrienes)*	Have diverse effects on modifying responses to hormones, blood clotting, inflammation, immunity, stomach acid secretion, airway diameter, lipid breakdown, and smooth muscle contraction.
Other lipids	
Carotenes	Needed for synthesis of vitamin A (used to make visual pigments in eye); function as antioxidants.
Vitamin E	Promotes wound healing, prevents tissue scarring, contributes to normal structure and function of nervous system, and functions as antioxidant.
Vitamin K	Required for synthesis of blood-clotting proteins.
Lipoproteins	Transport lipids in blood, carry triglycerides and cholesterol to tissues, and remove excess cholesterol from blood.

Fatty Acids

Fatty acids can be saturated or unsaturated

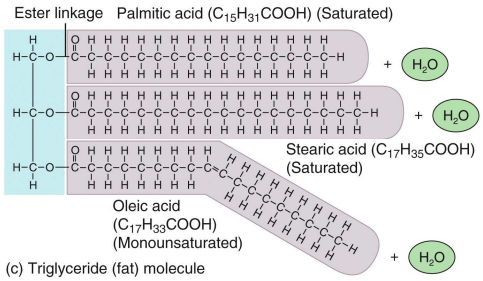


(a) Structures of saturated and unsaturated fatty acids

(b) Dehydration synthesis involving glycerol and a fatty acid

Triglycerides

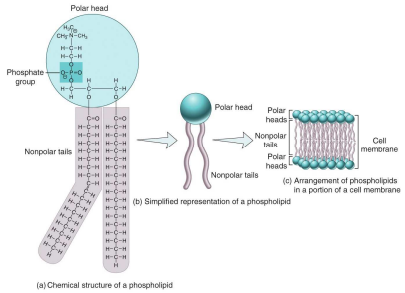
Triglycerides proved protection, insulation, and energy



(c) Triglyceride (fat) molecule

Phospholipids

Phospholipids are an important component of cell membranes

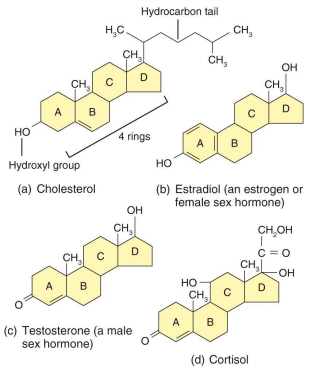


(a) Chemical structure of a phospholipid

(b) Simplified representation of a phospholipid

(c) Arrangement of phospholipids in a portion of a cell membrane

Steroids

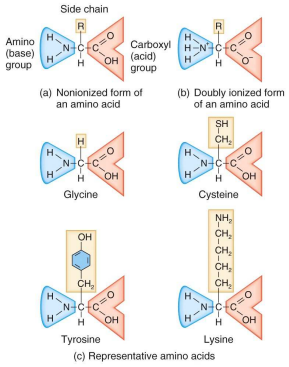


Proteins

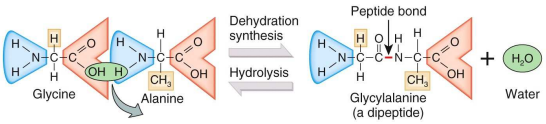
Proteins give structure to the body, regulate processes, provide protection, assist in muscle contraction, transport substances, and serve as enzymes

Amino Acids

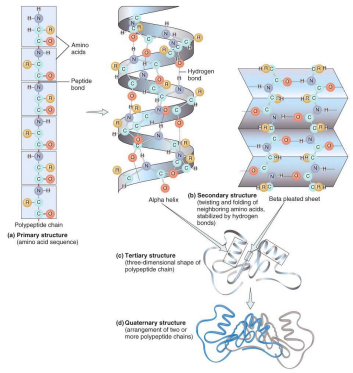
Proteins are formed by combining various amino acids



Polypeptides



Organization of Proteins



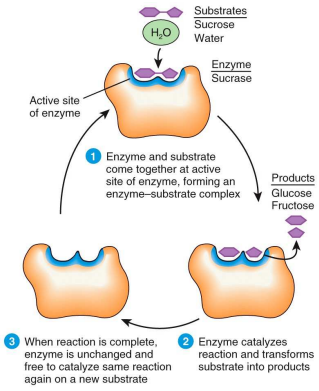
Enzymes

An enzyme is a catalyst in a living cell

Enzymes are:

- Highly specific
- Extremely efficient
- Subject to cellular controls

Enzymes



(a) Mechanism of enzyme action

Enzymes

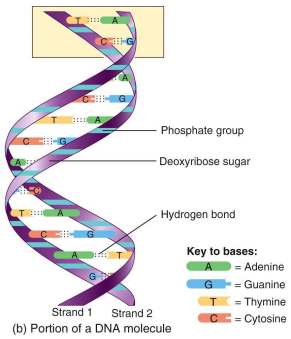
Interactions Animation:

- Enzyme Functions and ATP

You must be connected to the Internet and in Slideshow Mode to run this animation.

DNA & RNA

- DNA forms the genetic code in the nuclei of body cells and it regulates most of the cell's activities
- RNA guides protein formation



(b) Portion of a DNA molecule

DNA vs. RNA

TABLE 2.9

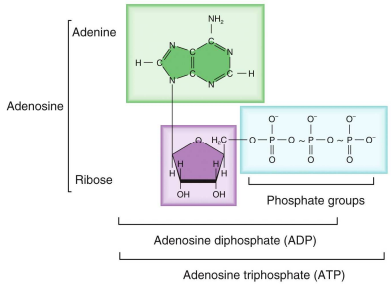
Comparison between DNA and RNA

FEATURE	DNA	RNA
Nitrogen ous bases	Adenine (A), cytosine (C), guanine (G), thymine (T)*.	Adenine (A), cytosine (C), guanine (G), uracil (U).
Sugar in nucleotides	Deoxyribose.	Ribose.
Number of strands	Two (double-helix, like a twisted ladder).	One.
Nitrogen ous base pairing (number of hydrogen bonds)	A with T (2), G with C (3).	A with U (2), G with C (3).
How is it copied?	Self-replicating.	Made by using DNA as a blueprint.
Function	Encodes information for making proteins.	Carries the genetic code and assists in making proteins.
Types	Nuclear, mitochondrial†.	Messenger RNA (mRNA), transfer RNA (tRNA), ribosomal RNA (rRNA)‡.

*Letters and words in red emphasize the differences between DNA and RNA.
†The nucleus and mitochondria are cellular organelles, which will be discussed in Chapter 3.
‡These RNAs participate in the process of protein synthesis, which will also be discussed in Chapter 3.

Adenosine Triphosphate (ATP)

ATP is the principal energy-storing molecule in the body



End of Chapter 2