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CORRECT ANSWERS ARE LOCATED IN THE 2ND HALF OF THIS DOC.

TRUE/FALSE - Write 'T' if the statement is true and 'F' if the statement is false.

1) Minerals are organic elements extracted from the soil by plants.
   - ◎ true
   - ◎ false

2) Molecules composed of two or more atoms are called compounds.
   - ◎ true
   - ◎ false

3) Hydrogen, deuterium, and tritium are three isotopes of hydrogen.
   - ◎ true
   - ◎ false

4) Potassium, sodium, and chlorine are trace elements.
   - ◎ true
   - ◎ false

5) Ionic bonds break apart in water more easily than covalent bonds do.
   - ◎ true
   - ◎ false

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6) A solution is a mixture of two or more substances that are physically blended but *not* chemically combined.
   - ◎ true
   - ◎ false

7) The pH of blood plasma is approximately 7.4, which is slightly acidic.
   - ◎ true
   - ◎ false

8) The high heat capacity of water makes it a very ineffective coolant.
   - ◎ true
   - ◎ false

9) In an exchange reaction, covalent bonds are broken and new covalent bonds are formed.
   - ◎ true
   - ◎ false

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10) Chemical reactions in which larger molecules are broken down into smaller ones are called catabolic reactions.
- ◎ true
- ◎ false

11) The opposite of a dehydration synthesis reaction is a hydrolysis reaction.
- ◎ true
- ◎ false

12) Unsaturated fatty acids have as much hydrogen as they can carry.
- ◎ true
- ◎ false

13) A dipeptide is a molecule with two peptide bonds.
- ◎ true
- ◎ false

14) All amino acids have both a carboxyl group and an amino group attached to a central carbon.
- ◎ true
- ◎ false

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15) ATP is the body's most important form of long-term energy storage.
- ◎ true
- ◎ false

16) A molecule that is oxidized gains electrons and energy.
- ◎ true
- ◎ false

17) Minerals are organic molecules that must be obtained through food.
- ◎ true
- ◎ false

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CHECK ALL THE APPLY. Choose all options that best completes the statement or answers the question.

18) Which of these is a cation? Check all that apply.

A) O_2
B) K+
C) Na+
D) Ca^{2+}
E) Cl^-

MULTIPLE CHOICE - Choose the one alternative that best completes the statement or answers the question.

19) The most abundant element in the human body, by weight, is _____.

A) nitrogen
B) hydrogen
C) carbon
D) oxygen
E) calcium

20) Sodium has an atomic number of 11 and an atomic mass of 23. Sodium has _____.

A) 12 neutrons and 11 protons
B) 12 protons and 11 neutrons TBEXAM.COM
C) 12 electrons and 11 neutrons
D) 12 protons and 11 electrons
E) 12 electrons and 11 protons

21) The chemical properties of an atom are determined by its _____.

A) protons
B) electrons
C) neutrons
D) protons and neutrons
E) particles

22) Na (atomic no. 11) reacts with Cl (atomic no. 17) to become stable. In the reaction, Na will _____, while Cl will _____.

A) accept one electron; give up one electron
B) give up one proton; accept one proton
C) share one electron with chlorine; share one electron with sodium
D) become an anion; become a cation
E) give up one electron; accept one electron

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23) Oxygen has an atomic number of 8 and an atomic mass of 16. How many valence electrons does it have?
A) 2
B) 4
C) 6
D) 8
E) 16

24) Oxygen has an atomic number of eight. When two oxygen atoms come together, they form a(n) _____ bond.
A) hydrogen
B) nonpolar covalent
C) polar covalent
D) ionic
E) Van der Waals

25) When table salt, sodium chloride (NaCl), is placed in water _____.
A) Na^+ and Cl^- form ionic bonds with each other
B) Na^+ and Cl^- form polar covalent bonds with each other
C) Na^+ and Cl^- form hydrogen bonds with water
D) ionic bonds between Na^+ and Cl^- are broken
E) Na^+ and Cl^- become separated by their Van der Waals forces

26) The bonding properties of an atom are determined by its _____.
A) electrons
B) protons
C) positrons
D) neutrons
E) photons

27) What type of bond attracts one water molecule to another?
A) An ionic bond
B) A peptide bond
C) A hydrogen bond
D) A covalent bond
E) A hydrolytic bond

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28) _____ account for 98.5% of the body's weight.
A) Carbon, oxygen, hydrogen, sodium, potassium, and chlorine
B) Carbon, oxygen, iron, sodium, potassium, and chlorine
C) Carbon, nitrogen, hydrogen, sodium, potassium, and chlorine
D) Carbon, oxygen, hydrogen, nitrogen, sodium, and potassium
E) Carbon, oxygen, hydrogen, nitrogen, calcium, and phosphorus

29) _____ differ from one another in their number of neutrons and atomic mass.
A) Cations
B) Anions
C) Isotopes
D) Electrolytes
E) Free radicals

30) When jumping into water you notice resistance. This resistance is caused by water's _____.
A) adhesiveness
B) cohesiveness
C) hydrophobic tension
D) hydrophilic tension
E) osmotic equilibrium

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31) Which of these is hydrophobic?
A) Glucose
B) K^+
C) Cl^-
D) Water
E) Fat

32) Blood contains NaCl, protein, and cells. The NaCl is in a(n) _____, the protein is in a(n) _____, and the cells are in a _____.
A) emulsion; solution; suspension
B) solvent; emulsion; colloid
C) colloid; suspension; solution
D) suspension; colloid; solution
E) solution; colloid; suspension

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33) Which of these is the most appropriate to express the number of molecules per volume?
A) Molarity
B) Volume
C) Percentage
D) Weight per volume
E) Milliequivalents per liter

34) A solution with pH 4 has _____ the H^+ concentration of a solution with pH 8.
A) ½
B) 2 times
C) 4 times
D) 10,000 times
E) 1/10,000

35) Which of these has the highest H^+ concentration?
A) Lemon juice, pH = 2.3
B) Red wine, pH = 3.2
C) Tomato juice, pH = 4.7
D) Saliva, pH = 6.6
E) Household ammonia, pH = 10.8

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36) In a workout your muscle cells produce lactate, yet you maintain a constant blood pH because _____.
A) metabolic acids are neutralized in muscle cells before released into the blood
B) metabolic bases are produced at the same rate by muscle cells to neutralize the acids
C) the respiratory system removes excess H^+ from the blood before the pH is lowered
D) the body contains chemicals called buffers that resist changes in pH
E) endothelial cells secrete excess H^+ to prevent a decrease in pH

37) A solution that resists a change in pH when an acid or base is added to it is a(n) _____.
A) buffer
B) catalyst
C) reducing agent
D) oxidizing agent
E) colloid

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38) A chemical reaction that removes electrons from an atom is called a(n) _____ reaction.
A) reduction
B) condensation
C) hydrolysis
D) anabolic
E) oxidation

39) The most relevant free energy in human physiology is the energy stored in _____.
A) electrolytes ionized in water
B) free radicals with an odd number of electrons
C) radioisotopes
D) the chemical bonds of organic molecules
E) Van der Waals forces

40) The breakdown of glycogen (an energy-storage compound) is an example of a(n) _____ reaction.
A) exergonic
B) endergonic
C) exchange
D) synthesis
E) equilibrium

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41) Potential energy stored in bonds is released as _____ energy.
A) electromagnetic
B) electrical
C) chemical
D) heat
E) kinetic

42) The breakdown of glucose to yield carbon dioxide, oxygen, and ATP can be described as _____.
A) anabolic and endergonic
B) catabolic and exergonic
C) anabolic and exergonic
D) catabolic and endergonic
E) anabolic and exothermic

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43) Which one of the following would *not* increase the rate of a reaction?
A) An increase in reactant concentrations
B) A rise in temperature
C) The presence of a catalyst
D) The presence of an enzyme
E) A decrease in reactant concentrations

44) Which of the following terms encompasses all of the other ones?
A) Catabolism
B) Anabolism
C) Metabolism
D) Oxidation reactions
E) Reduction reactions

45) The breakdown of starch by digestive enzymes into glucose molecules is a(n) _____ reaction.
A) synthesis
B) decomposition
C) exchange
D) anabolic
E) reduction

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46) Which of the following equations depicts an exchange reaction?
A) $AB \rightarrow A + B$
B) $A + B \rightarrow AB$
C) $AB + CD \rightarrow AC + BD$
D) $AB \rightarrow A^- + B^+$
E) $A + B \rightarrow AB \rightarrow C + D$

47) Which of these functional groups contains nitrogen?
A) Carboxyl group
B) Methyl group
C) Hydroxyl group
D) Amino group
E) Phosphate group

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48) Which of the following is *not* an organic compound?
A) $C_{16}H_{18}N_3ClS$
B) $Na_2HPO_3(H_2O)_5$
C) CH_4
D) $C_3H_7O_2N$

49) A _____ reaction breaks a _____ down into its monomers.
A) hydrolysis; polymer
B) dehydration synthesis; molecule
C) dehydration synthesis; polymer
D) polymer; molecule
E) condensation; reactant

50) The formula of an amino group is _____; the formula of a carboxyl group is _____.
A) -COOH; -OH
B) $-CH_3$; $-NH_2$
C) -OH; -SH
D) $-NH_2$; -COOH
E) -SH; $-H_2PO_4$

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51) Table sugar is a disaccharide called _____ and is made up of the monomer(s) _____.
A) maltose; glucose and sucrose
B) sucrose; glucose and fructose
C) lactose; glucose and galactose
D) glycogen; glucose and fructose
E) glucose; galactose and fructose

52) Which of the following is a disaccharide?
A) Galactose
B) Lactose
C) Glucose
D) Fructose
E) Amylose

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53) _____ is a monosaccharide, whereas _____ is a polysaccharide.
A) Fructose; sucrose
B) Galactose; maltose
C) Lactose; glycogen
D) Glucose; starch
E) Cellulose; glucose

54) In general, _____ have a 2:1 ratio of hydrogen to oxygen.
A) enzymes
B) proteins
C) lipids
D) carbohydrates
E) nucleic acids

55) Proteoglycans are composed of _____.
A) carbohydrates and fats
B) nucleic acids and fats
C) carbohydrates and proteins
D) proteins and fats
E) nucleic acids and proteins

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56) Triglycerides consist of a 3-carbon compound called _____ bound to three _____.
A) pyruvate; fatty acids
B) lactate; glycerols
C) eicosanoid; steroids
D) glycerol; fatty acids
E) sterol; fatty acids

57) _____ are major components of cell membranes, and are said to be _____.
A) Triglycerides; hydrophobic
B) Steroids; hydrophilic
C) Bile acids; fat-soluble
D) Eicosanoids; water-soluble
E) Phospholipids; amphiphilic

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58) Which of these molecules is hydrophobic?
A) Glucose
B) Cholesterol
C) Amino acid
D) Protein
E) Disaccharide

59) Proteins perform all of the following functions *except* _____.
A) catalyze metabolic reactions
B) give structural strength to cells and tissues
C) produce muscular and other forms of movement
D) regulate transport of solutes into and out of cells
E) store hereditary information

60) A drastic conformational change in a protein in response to extreme heat or pH is called _____.
A) contamination
B) denaturation
C) saturation
D) sedimentation
E) deconformation

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61) Proteins are _____ built from _____ different amino acids. 01_20_2015_CS-3282
A) monomers; 10
B) molecules; 10
C) polymers; 20
D) macromolecules; 40
E) peptides; 25

62) The folding and coiling of a protein into a globular shape is the _____ structure of the protein.
A) primary
B) secondary
C) tertiary
D) quaternary
E) denatured

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63) An enzyme is substrate-specific because of the shape of its _____.
A) active site
B) receptor
C) secondary structure
D) terminal amino acid
E) alpha chain

64) Lactose is the substrate of which enzyme?
A) Lactase
B) Amylase
C) Galactase
D) Protease
E) Sucrase

65) All enzymes are _____.
A) cofactors
B) proteins
C) lipids
D) carbohydrates
E) nucleic acids

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66) Nucleic acids are _____ of _____.
A) monomers; monosaccharides
B) monomers; ATP
C) polymers; nucleotides
D) polymers; cAMP
E) polymers; DNA

67) ATP_____ endergonic and exergonic reactions.
A) opposes
B) decomposes
C) reduces
D) links
E) dehydrates

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68) An atom with 12 electrons, 13 neutrons, and 11 protons is a(n) _____.
A) anion
B) cation
C) free radical
D) both an anion and a free radical
E) both a cation and a free radical

69) The concentration of a solution may be expressed by all of the following *except* _____.
A) weight per volume
B) percentage
C) molarity
D) pH

70) The vibration of an ear drum is an example of _____ energy.
A) kinetic
B) potential
C) elastic
D) radiant

71) In the following reaction, what is(are) the product(s)? $CO_2 + H_2O$ ---> H_2CO_3
A) H_2CO_3
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B) CO_2 and H_2O
C) CO_2 and H_2CO_3
D) H_2O and H_2CO_3

72) Which of the following will increase the rate of a chemical reaction?
A) An increase in reactant concentration
B) An increase in product concentration
C) A decreased temperature
D) Enzyme inhibition

73) Carbon is very versatile in forming bonds with other atoms because it has _____ valence electrons.
A) four
B) two
C) eight
D) six

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74) Amylase is a digestive enzyme that breaks starches down into sugars through _____ reactions.
A) hydrolysis
B) dehydration synthesis
C) anabolic
D) endergonic

75) Which of the following is ***not*** a nucleotide?
A) RNA
B) GTP
C) ATP
D) cAMP

76) Metabolism is the sum of _____ and _____.
A) inhalation; exhalation
B) growth; differentiation
C) anabolism; catabolism
D) positive; negative feedback
E) responsiveness; movement

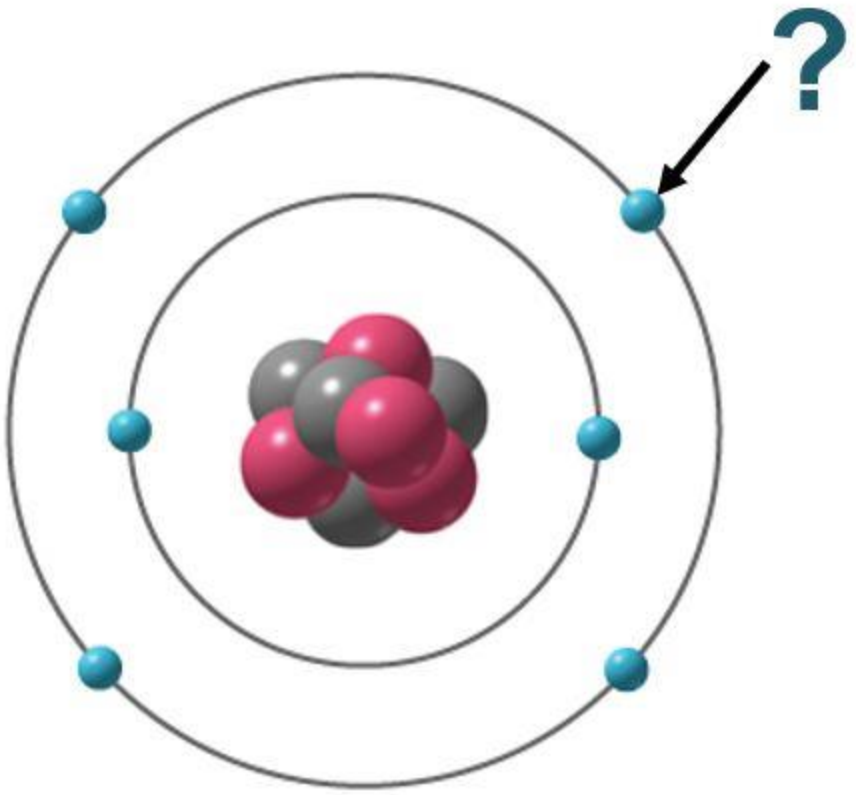
77) Minerals do which of the following?TBEXAM.COM
A) Contribute to the structure of bones and teeth
B) Act as fully functional enzymes
C) Store energy within the body
D) Act as the monomers of nucleic acids
E) Form the nuclei of atoms

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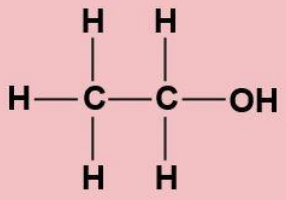
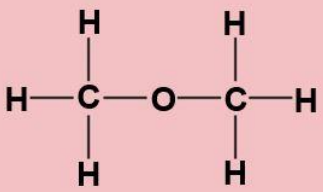
78)
What is indicated by the arrow?

A) Electron
B) Proton
C) Neutron
D) Anion
E) Prion

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	Structural formulae	Condensed structural formulae	Molecular formulae
Ethanol		CH_3CH_2OH	C_2H_6O
Ethyl ether		1	2

79)

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What is the correct condensed structural formula for ethyl ether? (What goes in the box labeled 1?)

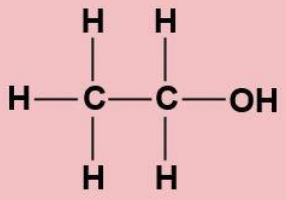
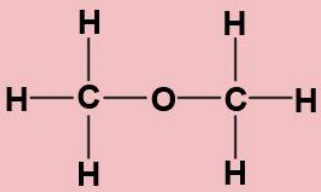
A) CH_3OCH_3
B) CH_3O
C) CH_3CH_3OH
D) C_2H_6O
E) CH_2CH_2OH

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	Structural formulae	Condensed structural formulae	Molecular formulae
Ethanol		CH_3CH_2OH	C_2H_6O
Ethyl ether		1	2

80)

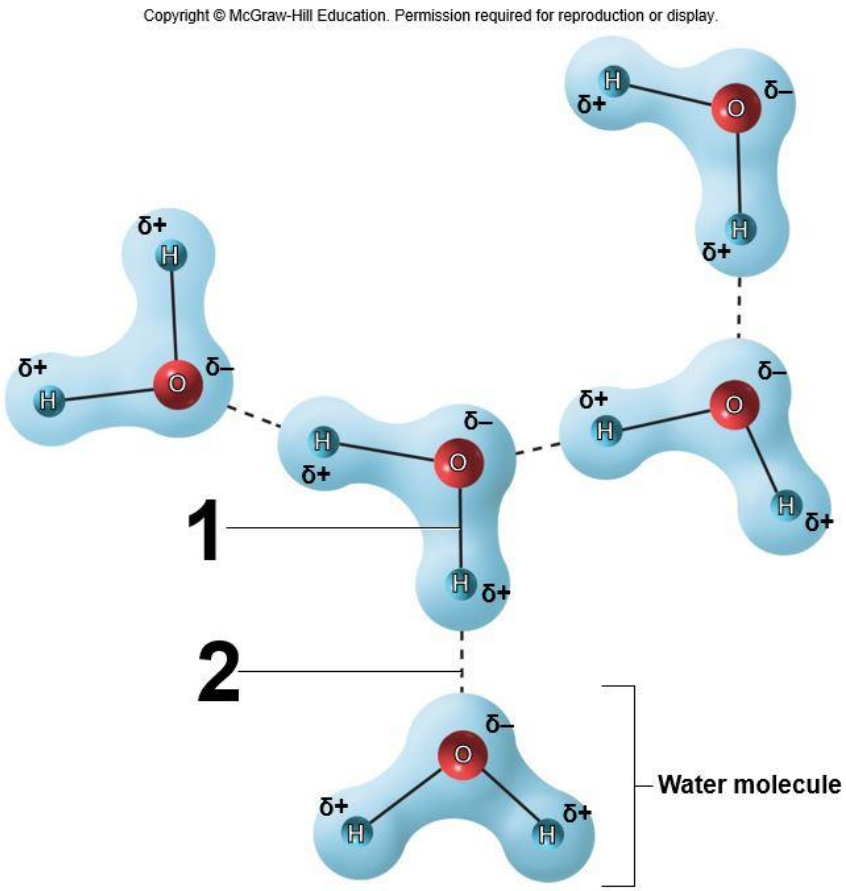
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What is the correct molecular formula for ethyl ether? (What goes in the box labeled 2?)

A) C_2H_6O
B) C_2H_3O
C) CH_3O
D) C_3H_6O
E) C_3H_3O

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81)

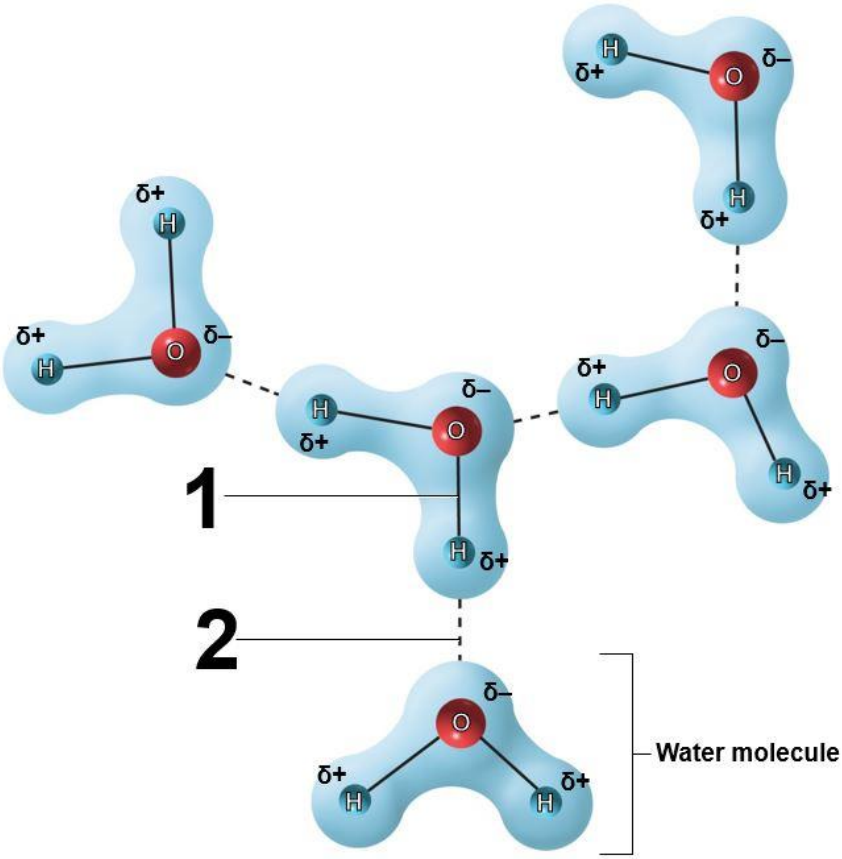
What type of bond is labeled 1?

A) Covalent
B) Hydrogen
C) Ionic
D) Disulfide
E) Van der Waals

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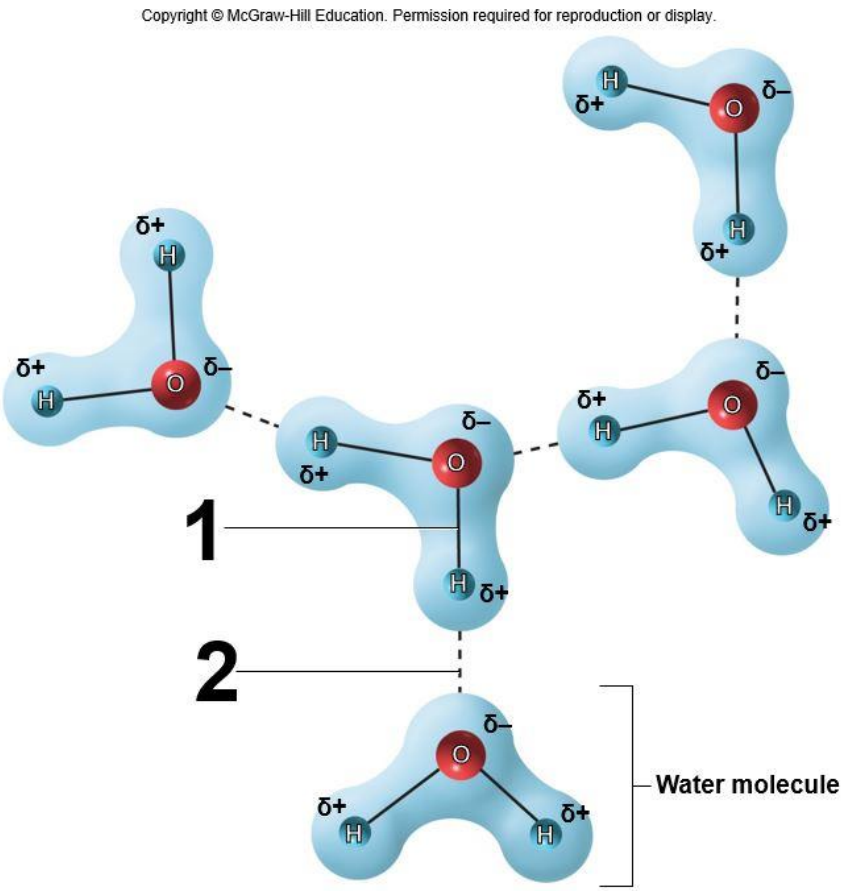
82)

What type of bond is labeled 1?

A) Single polar covalent bond
B) Double polar covalent bond
C) Single nonpolar covalent bond
D) Double nonpolar covalent bond
E) Triple covalent bond

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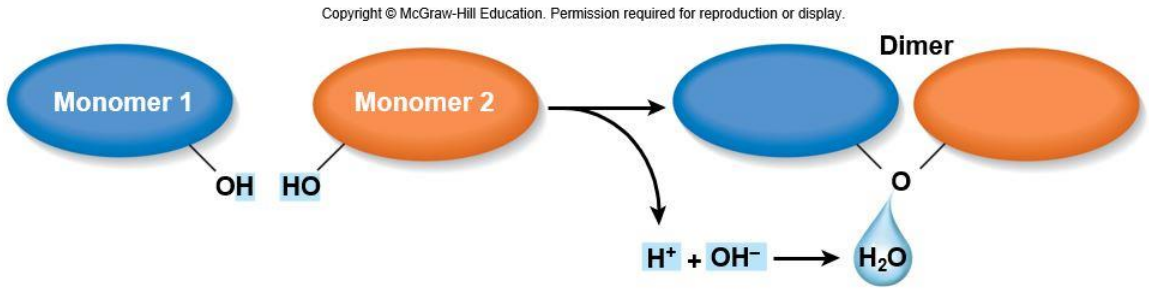
83)

What type of bond is labeled 2?

A) Hydrogen
B) Polar covalent
C) Nonpolar covalent bond
D) Ionic
E) Disulfide

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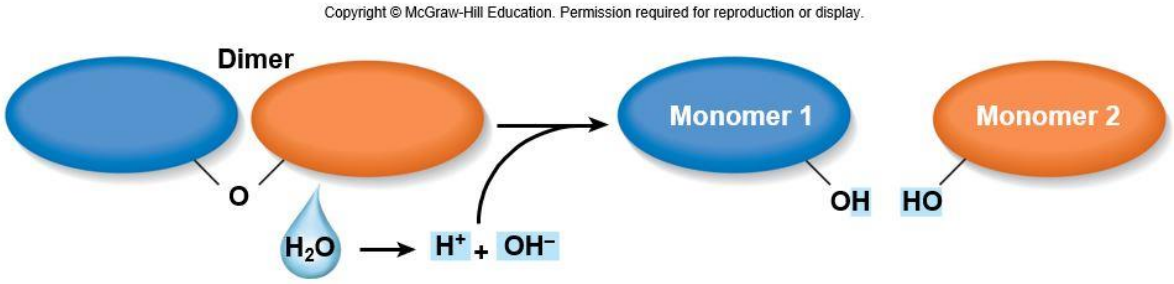
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84)

What type of reaction is shown here?

A) Dehydration synthesis reaction
B) Hydrolysis reaction
C) Exergonic reaction
D) Catabolic reaction
E) Oxidation reaction



85)

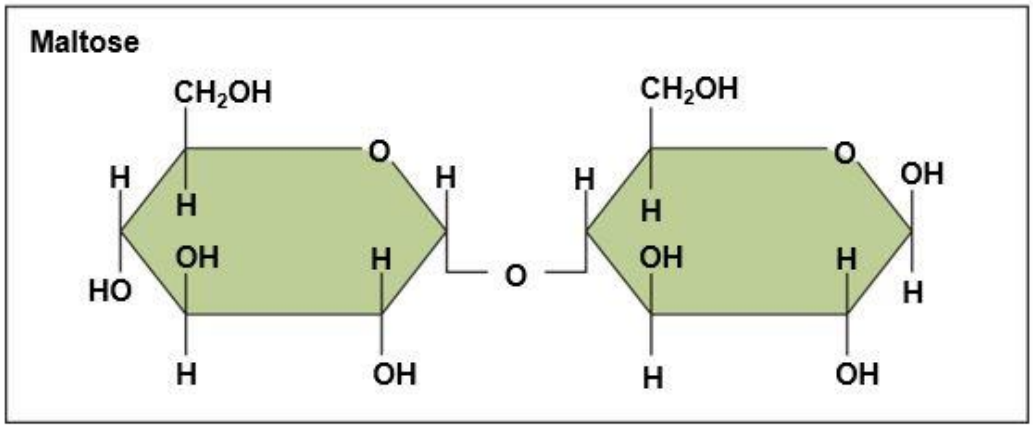
What type of reaction is shown here?

A) Hydrolysis reaction
B) Dehydration synthesis reaction
C) Endergonic reaction
D) Anabolic reaction
E) Reduction reaction

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86)

What type of molecule is maltose?

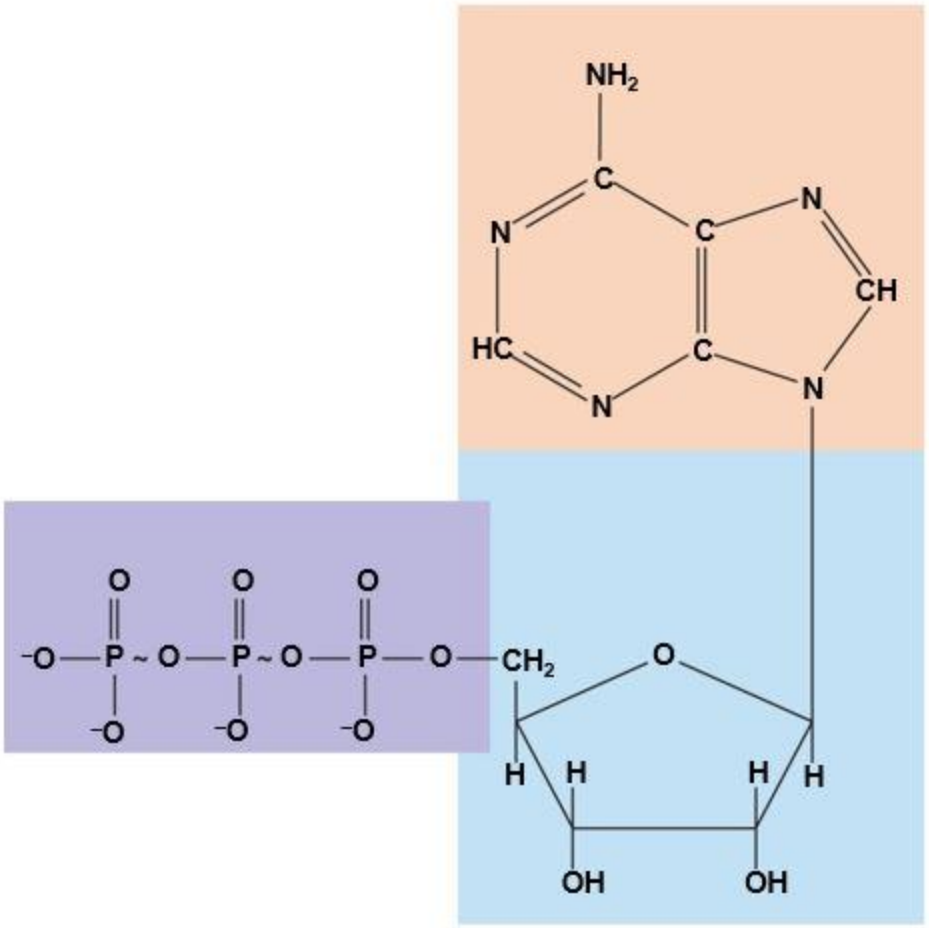
A) Disaccharide
B) Monosaccharide
C) Polysaccharide
D) Polypeptide
E) Oligopeptide
F) Triglyceride

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87)

What molecule is shown here?

A) ATP
B) cAMP
C) Lecithin
D) Glucose
E) Cholesterol

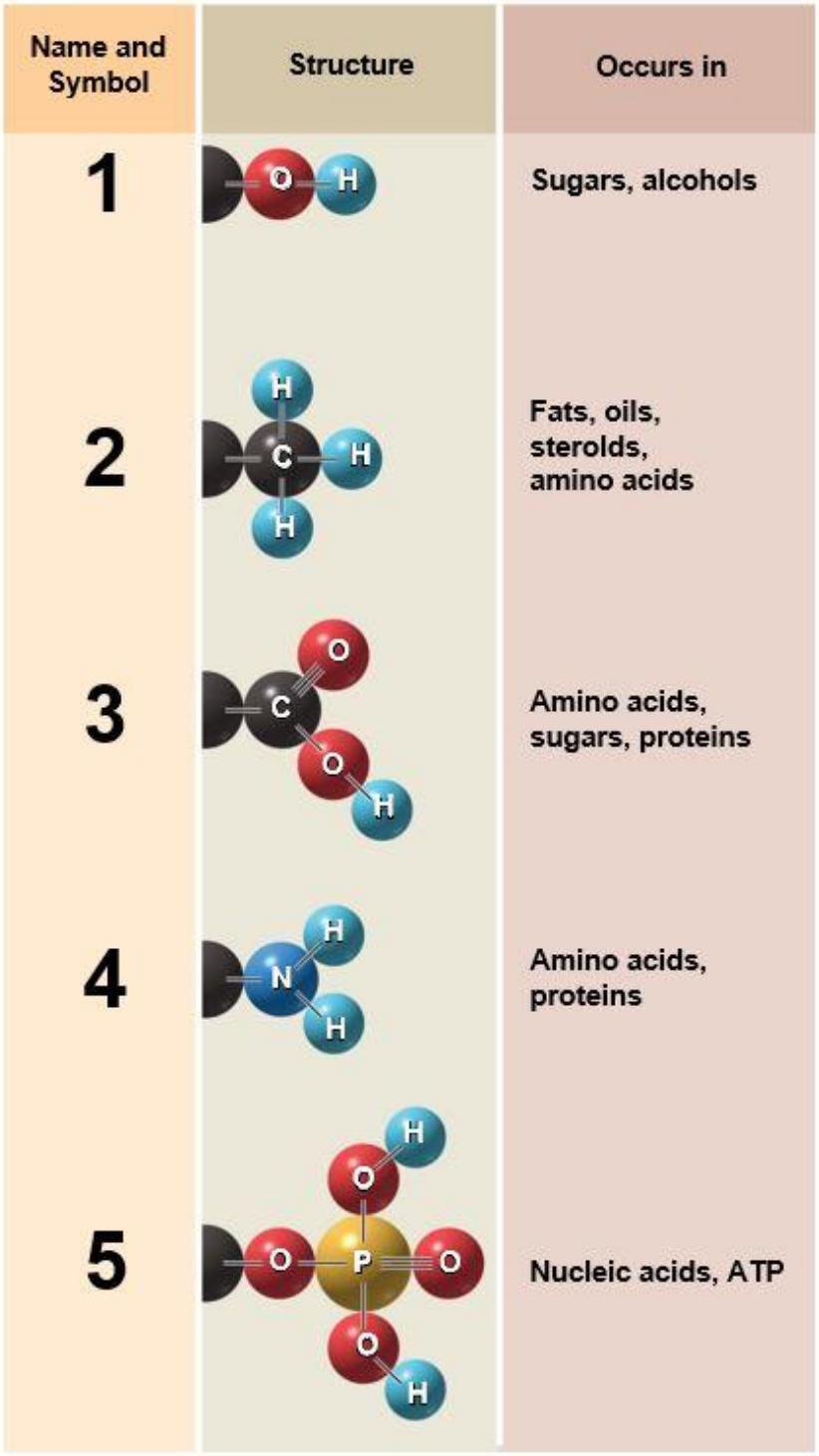
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SECTION BREAK. Answer all the part questions.

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88)

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88.1) Which functional group is labeled 1?
A) Hydroxyl
B) Methyl
C) Carboxyl
D) Amino
E) Phosphate

88.2) Which functional group is labeled 2?
A) Hydroxyl
B) Methyl
C) Carboxyl
D) Amino
E) Phosphate

88.3) Which functional group is labeled 3?
A) Hydroxyl
B) Methyl
C) Carboxyl
D) Amino
E) Phosphate

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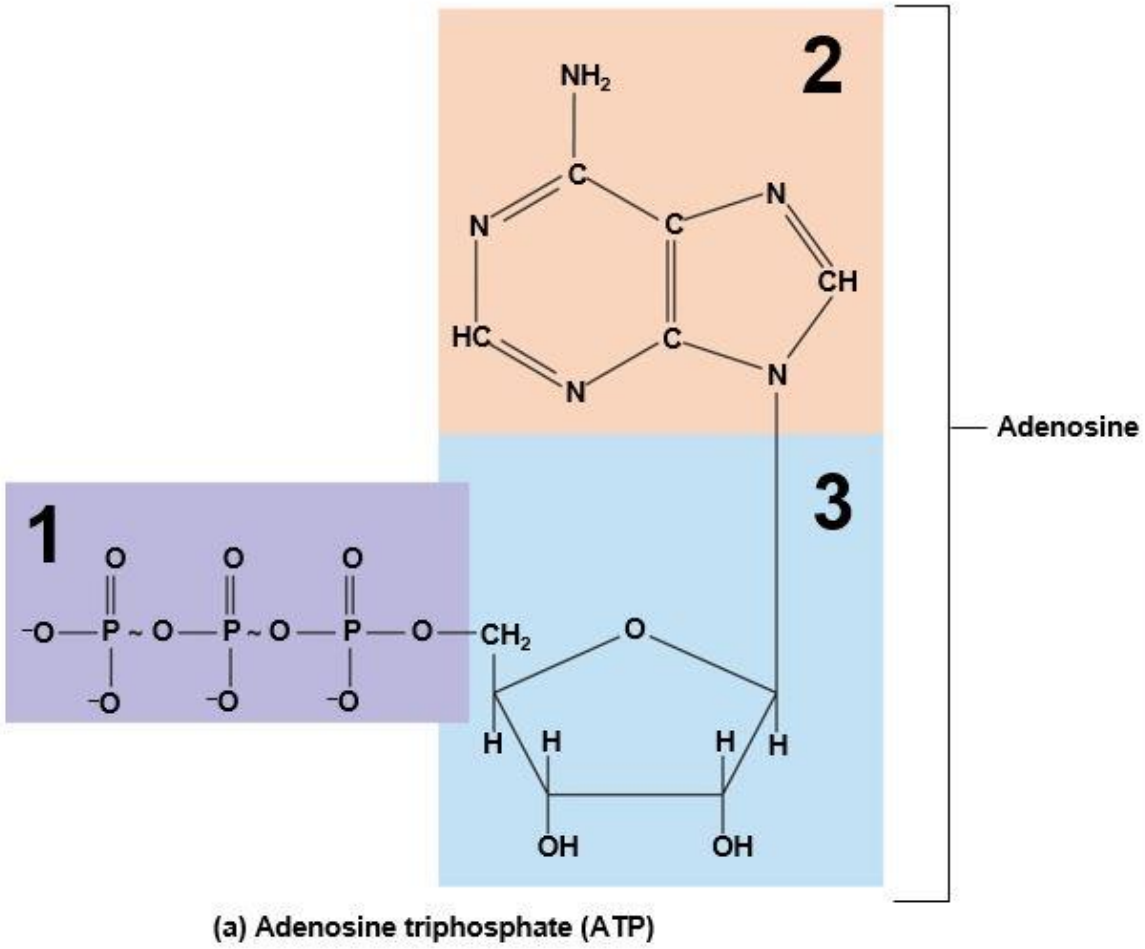
88.4) Which functional group is labeled 4?
A) Hydroxyl
B) Methyl
C) Carboxyl
D) Amino
E) Phosphate

88.5) Which functional group is labeled 5?
A) Hydroxyl
B) Methyl
C) Carboxyl
D) Amino
E) Phosphate

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(a) Adenosine triphosphate (ATP)

89)

89.1) Identify the structural component of ATP labeled 1.

A) Triphosphate
B) Adenine
C) Ribose
D) Adenosine
E) cAMP

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89.2) Identify the structural component of ATP labeled 2.
A) Triphosphate
B) Adenine
C) Ribose
D) Adenosine
E) cAMP

89.3) Identify the structural component of ATP labeled 3.
A) Triphosphate
B) Adenine
C) Ribose
D) Adenosine
E) cAMP

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Answer Key

Test name: Chapter 02

1) FALSE
2) FALSE
3) TRUE
4) FALSE
5) TRUE
6) TRUE
7) FALSE
8) FALSE
9) TRUE
10) TRUE
11) TRUE
12) FALSE
13) FALSE
14) TRUE
15) FALSE
16) FALSE
17) FALSE

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Minerals are inorganic elements extracted from the soil by plants and passed up the food chain to humans.

18) [B, C, D]
19) D
20) A
21) B
22) E
23) C
24) B
25) D
26) A
27) C
28) E
29) C
30) B
31) E
32) E
33) A
34) D

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35) A
36) D
37) A
38) E
39) D
40) A
41) C
42) B
43) E
44) C
45) B
46) C
47) D
48) B
49) A
50) D
51) B
52) B
53) D
54) D
55) C
56) D
57) E
58) B
59) E
60) B
61) C
62) C
63) A
64) A
65) B
66) C
67) D
68) A
69) D
70) A
71) A
72) A
73) A
74) A

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75) A
76) C
77) A
78) A
79) A
80) A
81) A
82) A
83) A
84) A
85) A
86) A
87) A
88) Section Break
88.1) A
88.2) B
88.3) C
88.4) D
88.5) E
89) Section Break
89.1) A
89.2) B
89.3) C

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Saladin 9e Extended Chapter Outline

Chapter 2 The Chemistry of Life

I. Atoms, Ions, and Molecules

A. A chemical element is the simplest form of matter to have unique chemical properties.

1. Each element is identified by an *atomic number*.

2. The elements are represented by one- or two-letter symbols based on their English or sometimes Latin names.

3. There are 91 naturally occurring elements.

a. Twenty-four elements play normal physiological roles in the human body.

i. Six elements account for 98.5% of the body's weight: oxygen, carbon, hydrogen, nitrogen, calcium, and phosphorus.

ii. Another 6 elements make up 0.8%: sulfur, potassium, sodium, chlorine, magnesium, and iron.

iii. The remaining 12 elements are known as trace elements and make up 0.7% of the body's weight.

b. Other elements that do not have physiological roles can contaminate and disrupt the body's functions, such as the heavy metals.

4. Minerals are inorganic elements extracted from soil and passed up the food chain to humans.

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a. Minerals constitute 4% of the body's weight. Nearly 3/4 is calcium and phosphorous, and the rest is made up of chlorine, magnesium, potassium, sodium, and sulfur.

b. Minerals contribute to body structures.

i. Bones and teeth are composed, in part, of crystals of minerals.

ii. Minerals such as phosphorus and sulfur are major components of nucleic acids, ATP, proteins, and cell membranes.

c. Minerals also enable enzyme function.

d. Mineral salts, or electrolytes, are vital to nerve and muscle function.

B. The Greek philosopher Democritus, in the fifth century BCE, was the first to use the term *atom* for particles so small that they were indivisible. John Dalton, in 1803, proposed an atomic theory of matter, and Niels Bohr, in 1913, proposed a model of structure.

1. The nucleus of an atom is composed of protons and neutrons.

a. Protons have a positive electrical charge, whereas neutrons have no charge.

b. The *atomic mass* of protons and neutrons is 1 amu (*atomic mass unit*); the atomic mass of an element is the total of its protons and neutrons.

2. Electrons surround the nucleus in concentric clouds.

a. Electrons have a negative electrical charge.

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b. The atomic mass of electrons is negligible and therefore not considered in an element's atomic mass.

c. The number of electrons is equal to the number of protons, so an atom is electrically neutral.

3. Electrons swarm about the nucleus in regions called *electron shells* or *energy levels.*

a. Shells hold a limited number of electrons; the one closest to the nucleus contains a maximum of 2, the next a maximum of 8, and the third a maximum of 18.

b. The known elements do not exceed seven electron shells, but the elements involved in physiology do not exceed four.

4. The electrons of the outermost shell are called valence electrons.

a. The valence electrons determine chemical bonding properties of an element.

b. An atom tends to bond with other atoms that will fill its outer shell and produce a stable number of valence electrons.

C. All elements have varieties called isotopes, which differ from one another in the number of neutrons the atom contains.

Insight 2.1 Medical History: Radiation and Madame Curie

1. Hydrogen, which normally has a single proton, has two isotopes: *deuterium* with one proton and one neutron, and *tritium* with one proton and two neutrons.

2. The *atomic weight* of an element is the sum of the mixture of isotopes of that element that occurs in nature. The atomic weight of carbon is 12.011.

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3. Some isotopes are unstable and *decay* (break down) into stable isotopes, giving off radiation. These are called radioisotopes, and the process of decay is called radioactivity.

4. Some forms of radiation are harmless, such as light and radio waves, but high-energy radiation, or ionizing radiation, destroys molecules and tissues.

5. In high doses, ionizing radiation is fatal; in low doses, it can be *mutagenic* (causing DNA mutations) or *carcinogenic* (triggering cancerous changes in cells).

a. Examples of radiation include ultraviolet rays, X-rays, and three kinds of additional radiation caused by decay: *alpha particles, beta particles,* and *gamma rays.*

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i. An alpha particle is composed of two protons and two neutrons and does not penetrate deeply; however, alpha particle emitters are dangerous if they enter the body.

ii. A beta particle is a free electron and also does not penetrate deeply, but can be dangerous if emitted inside the body.

iii. Gamma rays have high energy, are deeply penetrating, and can be dangerous even if emitted outside the body.

6. The physical half-life of an isotope is the time required for 50% of its atoms to decay.

a. Nuclear plants produce hundreds of radioisotopes that will be radioactive beyond the life of any disposal container.

7. The biological half-life of an isotope is the time required for half of it to disappear from the body.

a. The biological half-life depends on both physical decay and physiological clearing.

b. Cesium-137 has a physical half-life of 30 years but a biological half-life of 17 days.

8. Intensity of ionizing radiation is measured in *sieverts (Sv);* a dosage of 5 Sv or more is usually fatal.

a. Americans receive about 2.4 millisieverts (mSv) per year in *background radiation* and another 0.6 mSv from artificial sources, including medical X-rays, radiation therapy, color televisions, smoke detectors, etc.

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b. A limit of 50 mSv per year is considered acceptable occupational exposure.

D. Ions are charged particles with unequal numbers of protons and electrons.

1. *Ionization* occurs when an element gives up electrons or gains electrons in its outer shell.

2. An anion has a negative charge; a cation has a positive charge.

a. In sodium chloride, NaCl, sodium has 1 electron in its outer shell, which it gives up. Chlorine has 7 electrons in its outer shell, and gaining an electron from sodium fills its outer shell.

b. Some elements, such as iron, have two or more ionized forms; for example, ferrous (Fe^{2+}) and ferric (Fe^{3+}).

c. Molecules may also be ions; for example, phosphate (PO_4^{3-}) and bicarbonate (HCO_3^-).

3. Physiologically, ions with opposite charges tend to follow each other through the body. When sodium is excreted in the urine, chlorine tends to follow it.

4. Electrolytes are salts that ionize in water, forming solutions that can conduct electricity.

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a. Electrolytes are important for their chemical reactivity, osmotic effects, and electrical effects.

b. Electrolyte balance is one of the most important considerations in patient care.

5. Free radicals are chemical particles with an odd number of electrons, such as the *superoxide anion,* O_2^-•.

a. Free radicals are produced by some metabolic reactions, by radiation, and by chemicals such as nitrites.

b. Free radicals have short lives because they are unstable and combine with other molecules, creating free-radical chain reactions and damaging tissues.

c. Antioxidants are chemicals that neutralize free radicals, such as the enzyme *superoxide dismutase.* Dietary antioxidants include vitamins C and E, β-carotene, and selenium.

E. Molecules are chemical particles composed of two or more atoms united by a chemical bond.

1. Molecules composed of two or more different elements are called compounds. O_2 is a molecule but not a compound; CO_2 is a compound.

2. Molecules can be represented by a *molecular formula* or by a *structural formula*.

a. Molecules with the same molecular formula but different arrangements of atoms are called isomers.

b. Structural formulas differentiate isomers.

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3. The molecular weight of a compound is the sum of the atomic weights of its atoms.

4. Chemical bonds hold molecules together and include *ionic bonds, covalent bonds, hydrogen bonds,* and *van der Waals forces.*

a. An ionic bond is the attraction of a cation to an anion, as in NaCl.

i. Ionic bonds can be formed by more than two ions, as in $CaCl_2$.

b. Ionic bonds are weak and easily dissociate in the presence of more attractive molecules, such as in water.

c. A covalent bond forms by the sharing of electrons between two atoms.

i. A *single covalent bond* is the sharing of a single pair of electrons; a *double covalent bond* is the sharing of two pairs of electrons.

ii. When shared electrons spend approximately equal time around each nucleus, the result is a *nonpolar covalent bond.*

iii. When shared electrons spend more time around one nucleus, they form a *polar covalent bond* that results in a small charge difference between different regions of the molecule. This is represented as δ– and δ+.

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5. A hydrogen bond is a weak attraction between a slightly positive hydrogen atom in one molecule and a slightly negative oxygen or nitrogen atom in another.

a. Water molecules form hydrogen bonds with each other.

b. Hydrogen bonds may form between different regions of a single large molecule, as in protein and DNA molecules.

c. Hydrogen bonds are extremely important in physiology.

6. Van der Waals forces are weak, brief attractions between neutral atoms caused by random fluctuations in electron orbits.

a. Van der Waals attractions are at work when plastic wrap clings, spiders walk across ceilings, etc.

b. Van der Waals attraction also plays a role in protein folding and binding.

II. Water and Mixtures

A. A mixture consists of substances that are physically blended but not chemically combined.

B. Most mixtures in the body consist of chemicals dissolved in water.

1. Water constitutes 50% to 75% of our body weight.

2. Two aspects of its structure are important: Its atoms are joined by polar covalent bonds, and the molecule is V-shaped with a 105° bond angle.

a. The molecules are therefore polar and form hydrogen bonds.

b. This polarity gives water properties that account for its ability to support life: *solvency, cohesion, adhesion, chemical reactivity,* and *thermal stability.*

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3. *Solvency* is the ability to dissolve other chemicals; water is sometimes called the *universal solvent.*

a. Substances that dissolve in water, such as sugar, are said to by hydrophilic.

b. Substances that do not dissolve in water, such as fats, are said to be hydrophobic.

c. To be soluble in water, a molecule must be polarized or charged.

i. When sodium chloride is dissolved in water, water molecules form a *hydration sphere* around each ion.

ii. The hydration spheres help keep the ions separated and dissolved.

4. *Adhesion* is the tendency of one substance to cling to another; *cohesion* is the tendency of a substance to cling to itself.

a. Water adheres to other substances, such as tissues of the body, and forms a lubricating film.

b. Water is also very cohesive and can form a surface film held together by *surface tension.*

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5. Water participates in many chemical reactions because of its ability to ionize other chemicals and also because of its ability to become ionized itself.

6. Water has a high heat capacity, meaning that it can absorb energy without changing state.

a. Water's high heat capacity gives it *thermal stability,* which helps stabilize the body's internal temperature.

b. Water is also an effective coolant because it carries away so much heat energy when it evaporates.

C. Mixtures of substances in water can be classified as *solutions, colloids, and suspensions.*

1. A solution consists of particles of matter called a solute mixed with a more abundant substance, usually water, called a solvent.

a. Solute particles are under 1 nm in size.

b. Such small particles do not scatter light noticeably.

c. Solute particles will pass through most selectively permeable membranes.

d. The solute does not separate from the solvent when the solution is allowed to stand.

2. A colloid is a mixture of larger particles in a solvent, such as albumin in blood plasma.

a. Colloid particles range from 1 to 100 nm in size.

b. Particles this large scatter light, so colloids are usually cloudy.

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c. The particles are too large to pass through most selectively permeable membranes.

d. The particles do remain permanently mixed, however, and do not separate from the solvent.

3. A suspension has large particles mixed in a solvent, such as red blood cells in blood plasma.

a. Suspended particles exceed 100 nm in size.

b. The suspension is cloudy or opaque.

c. The particles are too large to pass through selectively permeable membranes.

d. The particles do not remain permanently mixed, so suspensions separate upon standing.

4. An emulsion is a suspension of one liquid in another, such as an oil and vinegar salad dressing and breast milk.

5. Blood is an example of a mixture that fits in more than one category; it is a solution, a colloid, and a suspension.

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D. Concentration is a measure of the amount of solute in a given volume of solution.

1. Weight per volume is a simple way to express concentration and is given in grams per liter of solution (g/L).

a. For biological purposes, milligrams per deciliter (mg/dL) is more often used.

2. Percentages are also used, but whether the percentage refers to weight or volume must be specified, e.g. 5% w/v (weight per volume), 70% v/v (volume per volume).

3. For physiological purposes, molarity is used.

a. Each molecule has a characteristic molecular weight, such as 180 for glucose and 342 for sucrose.

b. The molecular weight of a substance expressed in grams is termed 1 *mole* of that substance.

c. A mole of any substance contains the same number of molecules as a mole of any other substance, namely Avogadro's number (6.023×10^{23} molecules).

d. Molarity is the number of moles of a solute per liter of solution; a *one-molar* (1.0 M) solution of glucose contains 180 grams of glucose per liter.

i. In physiological solutions, clinicians and researchers usually work with *millimolar (mM)* and *micromolar (μM)* solutions.

4. Electrolyte concentrations are measured in terms of *equivalents (Eq)*.

a. One Eq of an electrolyte is defined as the amount that would electrically neutralize 1 mole of hydrogen ions (H^+) or hydroxide ions (OH^-).

b. Body fluids typically have low concentrations of electrolytes, so milliequivalents per liter (mEq/L) is more often used.

c. A relationship exists between molarity and equivalents, and it is based on the valence of the ion: A solution of 1 mM Na^+ is equal to 1mEq/L, whereas a solution of 1 mM Ca^{2+} is equal to 2 mEq/L.

E. An acid is any *proton donor,* that is, a molecule that releases H^+ in water. A base is a proton acceptor. (p. 51)

1. Acidity is expressed in terms of pH, which is derived from the molarity of H^+.

a. The pH scale is logarithmic, so that a change of one whole number on the scale represents a 10-fold change in H^+ concentration.

b. Slight disturbances of pH can disrupt physiological functions; larger deviations can even lead to death.

c. Buffers are chemical solutions that resist changes in pH.

Insight 2.2 Clinical Application: pH and Drug Action

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III. Energy and Chemical Reactions

A. Energy is the capacity to do work. Work is the action of moving something, whether it is a muscle or a molecule.

1. Energy can be classified as *potential energy* or *kinetic energy*.

a. Potential energy is energy an object contains because of its position or internal state, but that is not doing work at the time.

b. Kinetic energy is the energy of motion, energy that is doing work.

c. Ions in greater concentration on one side of a membrane have potential energy. When the ions flow through to the other side, their kinetic energy is used to create an electrical signal.

2. *Chemical energy* is potential energy stored in the bonds of molecules.

3. *Heat* is the kinetic energy of molecular motion.

4. *Electromagnetic energy* is the kinetic energy of moving "packets" of energy called *photons.*

5. *Electrical energy* is both potential, as charged particles at a battery terminal, and kinetic, as when those particles begin to move and produce an electrical current.

6. Free energy is the potential energy available in a system to do work.

a. In human physiology, the most relevant free energy is stored in chemical bonds.

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B. A chemical reaction is a process in which a covalent or ionic bond is formed or broken.

1. The course of a chemical reaction is symbolized by a chemical equation, with *reactants* on the left side and *products* on the right side.

2. Chemical reactions can be classified as *decomposition, synthesis,* or *exchange reactions.*

a. In decomposition reactions, a large molecule breaks down into two or more smaller ones, such as when starch is broken down into glucose.

b. In synthesis reactions, two or more small molecules combine to form a larger one, such as when the body synthesizes proteins.

c. In exchange reactions, two molecules exchange atoms or groups of atoms. Such a reaction would occur when sodium bicarbonate from the pancreas neutralizes hydrochloric acid in the stomach; sodium exchanges bicarbonate for chlorine.

3. Reversible reactions can go in either direction under different circumstances.

a. The direction in which a reversible reaction goes is determined by the relative abundance of substances on each side of the equation, and thus is an example of the law of mass action.

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b. Reversible reactions exist in a state of equilibrium, in which the ratio of products to reactants is stable.

C. The rate of a reaction depends on the nature of the reactants and the frequency and force of collisions between molecules.

1. Reaction rates increase when the reactants are more concentrated and thus collide more frequently.

2. Reaction rates increase when the temperature rises because the molecules tend to move more rapidly and collide with greater force and frequency.

3. Reaction rates are increased by catalysts, substances that temporarily bind to reactants and hold them in a favorable position to react with each other.

D. All the chemical reactions that take place in the body are collectively termed metabolism, which can be subclassified as *catabolism* and *anabolism.*

1. Catabolism consists of energy-releasing decomposition reactions; such reactions are called *exergonic* reactions.

2. Anabolism consists of energy-storing synthesis reactions, such as the production of protein or fat. Such reactions require an input of energy and are called *endergonic* reactions.

E. Oxidation is any reaction in which a molecule gives up electrons and releases energy.

1. A molecule is *oxidized* (gives up electrons), and the molecule that takes electrons from it is called an *oxidizing agent* (electron acceptor).

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2. Oxygen is often involved as the electron acceptor, but many oxidation reactions do not require oxygen, such as fermentation.

F. Reduction is a chemical reaction in which a molecule gains electrons and energy.

1. A molecule that accepts electrons is said to be *reduced,* and the molecule that donates electrons is called a *reducing agent* (electron donor).

2. A reduction reaction may involve more than transfer of electrons. In some cases, the electrons are transferred in the form of hydrogen atoms. The fact that protons are also involved is immaterial.

IV. Organic Compounds

A. *Organic chemistry* is the study of compounds of carbon.

1. Organic molecules are broadly classified as *carbohydrates, lipids, proteins,* and *nucleic acids.*

2. Carbon is a versatile atom with four valence electrons, able to form up to four covalent bonds.

3. Carbon atoms readily combine with each other to form carbon backbones in the form of long chains, branched molecules, and rings.

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4. Carbon backbones can carry a variety of functional groups—small clusters of atoms that determine properties of an organic molecule, such as carboxyl, phosphate, hydroxyl, methyl, and amino groups.

B. Some organic molecules are gigantic *macromolecules* with large molecular weights.

1. A polymer is a molecule consisting of a long chain made up of monomers—identical or similar subunits linked together.

a. Starch is a polymer of about 3,000 glucose monomers.

2. *Polymerization,* the joining together of monomers as a polymer, is achieved by means of dehydration synthesis (condensation).

a. In dehydration synthesis, a hydroxyl (–OH) group is removed from one monomer and a hydrogen (–H) from another, producing water as a by-product.

b. The two monomers are joined by a covalent bond into a *dimer;* the dimer is then expanded with further rounds of dehydration synthesis.

3. The opposite of dehydration synthesis is hydrolysis.

a. In hydrolysis, water is ionized into H^+ and OH^-.

b. A covalent bond between monomers is broken, with H^+ being added to one monomer and OH^- being added to the other one.

i. All digestion is accomplished by hydrolysis.

C. A carbohydrate is a hydrophilic organic molecule with the general formula $(CH_2O)_n$, where *n* is the number of carbon atoms.

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1. The most familiar carbohydrates are the sugars and starches.

2. The root word *sacchar-* and the suffix *-ose* both mean sugar or sweet.

3. The simplest carbohydrates are the monosaccharides, including glucose, fructose, and galactose.

a. Glucose is the “blood sugar” that provides energy to our cells.

4. Disaccharides are sugars composed of two monosaccharides, such as sucrose, lactose, and maltose.

5. Polysaccharides are long chains of glucose; examples important to human physiology are glycogen, starch, and cellulose.

a. Glycogen is a branched, energy-storage polysaccharide produced by cells of the liver, muscles, brain, uterus, and vagina; it is produced after a meal and broken down between meals.

b. Starch is the energy-storage polysaccharide made by plants; they produce it when sunlight and nutrients are available and draw from it at night and in winter.

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c. Cellulose is a structural polysaccharide made by plants; it cannot be broken down in the human body but is important as fiber in the diet.

6. Carbohydrates are a source of energy that can be quickly mobilized, but have other functions as well.

a. Carbohydrates are ultimately converted to glucose, which provides energy to most of our cells.

b. Carbohydrates also have other functions when conjugated with proteins and lipids.

i. Glycolipids and glycoproteins are components of cell membranes; glycoproteins are a major component of mucus, a protective substance.

ii. Proteoglycans are a type of conjugated molecule in which the carbohydrate is dominant and the protein forms a smaller component; proteoglycans have many roles in the body as gelatinous fillers, lubricants, and cushions in the joints.

iii. In conjugated molecules, each type of component is called a moiety; proteoglycans have a protein moiety and a carbohydrate moiety.

D. Lipids are hydrophobic molecules usually composed only of carbon, hydrogen, and oxygen, with a high ratio of hydrogen to oxygen.

1. Lipids are less oxidized than carbohydrates, and therefore have more calories per gram.

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2. A fatty acid is a chain of usually 4 to 24 carbon atoms with a carboxyl group at one end and a methyl group at the other.

a. A saturated fatty acid, such as palmitic acid, has as much hydrogen as it can carry.

b. An unsaturated fatty acid, such a linoleic acid, has some carbons joined by double covalent bonds—and is thus not “saturated” with hydrogen.

c. Polyunsaturated fatty acids have many double bonds.

d. Most fatty acids can be synthesized in the body, but the essential fatty acids cannot and must be obtained from food.

3. A triglyceride is a molecule consisting of three fatty acids bonded to glycerol, a three-carbon alcohol; each bond is formed by dehydration synthesis.

a. Once bonded to glycerol, a fatty acid is no longer an acid, so triglycerides are called neutral fats.

b. Oils are generally, but not always, liquid at room temperature, whereas fats are solid.

c. Animal fats are usually made of saturated fatty acids; most plant triglycerides are polyunsaturated.

Insight 2.3 Clinical Application: *Trans* Fats and Cardiovascular Health

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d. The primary function of fat is energy storage; it also serves as thermal insulation and cushions vital organs.

4. Phospholipids are similar to neutral fats, but in place of one fatty acid, they have a phosphate group, which is linked to other functional groups.

a. Lecithin is a common phospholipid that has *choline* as a functional group.

b. The two fatty acid "tails" are hydrophobic, but the phosphate "head" is hydrophilic, giving phospholipid molecules an amphipathic nature.

c. The most important function of phospholipids is as a structural component of cell membranes.

5. Eicosanoids are 20-carbon compounds derived from a fatty acid called *arachidonic acid*.

a. Eicosanoids have a hormonelike function.

b. Prostaglandins are eicosanoids that have a 5-carbon ring structure; they act as signals in many processes, including inflammation, blood clotting, labor contractions, etc.

6. A steroid is a lipid with 17 of its carbon atoms arranged in four rings.

a. Cholesterol is the "parent" steroid from which all others are synthesized, including cortisol, progesterone, estrogens, testosterone, and bile acids.

Insight 2.4 Clinical Application: "Good" and "Bad" Cholesterol

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b. Cholesterol is synthesized only by animals and is a natural product of the body.

c. The body produces 85% of its cholesterol; only about 15% comes from the diet.

d. Cholesterol is critical to cell membranes and proper nervous system function.

E. Proteins are the most versatile molecules in the body.

1. A protein is a polymer of amino acids.

a. An amino acid has a central carbon atom with an amino ($–NH_2$) and a carboxyl group (–COOH) bound to it.

b. Amino acids also have a *radical* (R group) attached to the central carbon; this R group may be a single hydrogen or a complex ring of carbon.

c. There are 20 amino acids involved in proteins of the human body.

2. A peptide is any molecule composed of two or more amino acids joined by peptide bonds.

a. Chains of fewer than 10 or 15 amino acids are called oligopeptides; chains larger than that are called polypeptides.

b. A protein is a polypeptide of 50 or more amino acids.

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c. The average protein has a molecular weight of 30,000 amu, and the range is from 4,000 to hundreds of thousands of amu.

3. Proteins have complex coiled and folded structures and even slight changes in their conformation can destroy function.

4. Proteins have three to four levels of complexity, from primary through quaternary structure.

a. Primary structure is the protein's amino acid sequence.

b. Secondary structure is a coiled or folded shape held together by hydrogen bonds.

i. Common secondary structures include the alpha (α) helix and the beta (β) pleated sheet.

ii. Many proteins have multiple alpha-helical and beta-pleated regions joined by short segments.

c. Tertiary structure is formed by further bending and folding resulting from the association of hydrophobic R groups with each other to avoid water, while hydrophilic R groups are attracted to water.

i. Van der Waals forces play a role in stabilizing tertiary structure.

ii. Two types of proteins with tertiary structure include *globular proteins* such as enzymes and antibodies, and *fibrous proteins* that provide strength to skin, hair, and tendons.

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iii. Tertiary structure may also include disulfide bridges in which two sulfur-containing amino acids associate with one another by forming a bond between their sulfur groups. Insulin is a molecule held together by disulfide bridges.

d. Quaternary structure is the association of two or more polypeptide chains by noncovalent forces, such as ionic bonds and hydrophilic–hydrophobic interactions.

i. Hemoglobin contains four polypeptide chains: two alpha chains and two beta chains.

e. Proteins can change conformation reversibly, and this property is important to processes such as muscle contraction and enzyme function.

f. Denaturation is usually an irreversible conformational change, such as occurs when cooking an egg.

g. *Conjugated proteins* have a non-amino acid moiety called a prosthetic group.

i. The iron-containing ring called *heme* in hemoglobin is a prosthetic group.

h. Proteins have a variety of functions in the body.

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i. Structure; for example, keratin in nails, hair, and skin.

ii. Communication; for example, receptors on the surface of cells that bind a hormone as a ligand.

iii. Membrane transport; such as channels and transport proteins in cell membranes.

iv. Catalysis; metabolic pathways are controlled by enzymes, which act as catalysts.

v. Recognition and protection; some proteins serve to recognize and fight invaders, others bring about blood clotting to stop bleeding.

vi. Movement; for example, motor proteins that bring about everything from intracellular transport to the act of running.

vii. Cell adhesion; proteins bind cells to each other.

F. Enzymes are proteins that function as biological catalysts, permitting biochemical reactions to occur rapidly at body temperatures.

1. Some enzyme names are arbitrary; others reflect the enzyme's substrate or its action.
2. Enzymes lower the activation energy of reactions; they do so by releasing energy in small steps rather than all at once.

Insight 2.5 Clinical Application: Blood Enzymes as Disease Markers

3. Enzyme structure is related to its action in a metabolic process.

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a. A substrate molecule approaches the active site of its enzyme; this site has a conformation that allows amino acid side groups to bind functional groups on the substrate.

b. The substrate is bound, forming an enzyme–substrate complex; enzymes have selectivity and are intended to bind to only one substrate, for example, the enzyme sucrase will bind to only sucrose.

c. The enzyme breaks the bond holding substrate components together, for example, sucrase breaks sucrose by hydrolysis, releasing its components, glucose and fructose (reaction products); the enzyme remains unchanged.

d. Factors that change the shape of an enzyme tend to alter or destroy its ability to bind its substrate; temperature and pH are notable examples.

4. Many enzymes require cofactors (nonprotein partners) in order to function.

a. Cofactors include iron, copper, zinc, magnesium, or calcium ions; these affect an enzyme's conformation.

b. Coenzymes are organic cofactors usually derived from water-soluble vitamins; for example, NAD^+ is derived from niacin and shuttles electrons from one pathway to another in ATP production.

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5. A metabolic pathway is a chain of reactions with each step catalyzed by a different enzyme.

G. Nucleotides are organic compounds consisting of a carbon–nitrogen ring called a *nitrogenous base,* a monosaccharide, and one or more phosphate groups.

1. Adenosine triphosphate (ATP) is one of the best-known nucleotides and is the body's most important energy-transfer molecule.

a. The second and third phosphate groups of ATP are high-energy covalent bonds.

b. Enzymes called adenosine triphosphatases (ATPases) hydrolyze the third phosphate bond, producing ADP and an inorganic phosphate group, plus 7.3 kcals of energy per mole of ATP broken down.

c. The free phosphate groups are often added to enzymes to activate them, a process called phosphorylation, which is carried out by kinases.

2. The energy for ATP synthesis comes from glucose oxidation.

a. The first stage is glycolysis, the splitting of glucose into *pyruvic acid.*

b. If oxygen is unavailable, pyruvic acid is then converted to lactic acid through anaerobic fermentation.

c. If oxygen is abundant, a more efficient pathway of aerobic respiration occurs, breaking down pyruvic acid into carbon dioxide and water.

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3. Other nucleotides include guanosine triphosphate (GTP) and cyclic adenosine monophosphate (cAMP), also known as a "second messenger."

4. Nucleic acids are polymers of nucleotides.

a. DNA is the largest nucleic acid, typically 100 million to 1 billion nucleotides in length.

b. RNA comes in three forms, which range from 70 to 10,000 nucleotides in length.

c. DNA and RNA play roles in genetics and protein synthesis.

Insight 2.6 Clinical Application: Anabolic–Androgenic Steroids

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