ESSENTIAL CELL BIOLOGY, FOURTH EDITION
CHAPTER 2: CHEMICAL COMPONENTS OF CELLS

Chemical Bonds

2-1 Select the answer that *best* completes the following statement: Chemical reactions in living systems occur in an ____________ environment, within a narrow range of temperatures.

(a) optimal
(b) organic
(c) extracellular
(d) aqueous

2-2 Indicate whether the statements below are *true* or *false*. If a statement is false, explain why it is false.

A. The chemistry of life is carried out and coordinated primarily by the action of small molecules.
B. Carbon-based compounds make up the vast majority of molecules found in cells.
C. The chemical reactions in living systems are loosely regulated, allowing for a wide range of products and more rapid evolution.

2-3 Which subatomic particles contribute to the atomic number for any given element?

(a) protons
(b) protons and neutrons
(c) neutrons
(d) protons and electrons

2-4 Which subatomic particles contribute to the atomic mass for any given element?

(a) protons
(b) protons and neutrons
(c) neutrons
(d) protons and electrons

2-5 Which subatomic particles can vary between isotopes of the same element, without changing the observed chemical properties?

(a) electrons
(b) protons and neutrons
(c) neutrons
(d) neutrons and electrons

2-6 Figure Q2-6 depicts the structure of carbon. Use the information in the diagram to choose the correct atomic number and atomic weight, respectively, for an atom of carbon.

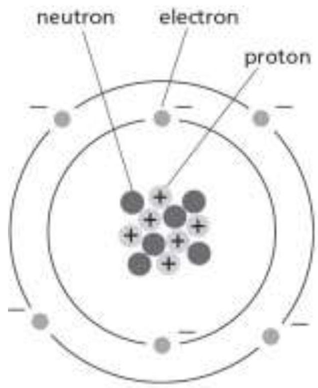

Figure Q2-6

(a) 6, 12
(b) 12, 12
(c) 6, 18
(d) 12, 6

2-7 Carbon 14 is an unstable isotope of carbon that decays very slowly. Compared to the common, stable carbon 12 isotope, carbon 14 has two additional _______________.
(a) electrons.
(b) neutrons.
(c) protons.
(d) ions.

2-8 If the isotope ^{32}S has 16 protons and 16 neutrons, how many protons, neutrons, and electrons will the isotope ^{35}S have, respectively?
(a) 16, 20, 15
(b) 16, 19, 15
(c) 16, 19, 16
(d) 16, 19, 17

2-9 A. If 0.5 mole of glucose weighs 90 g, what is the molecular mass of glucose?
B. What is the concentration, in grams per liter (g/L), of a 0.25 M solution of glucose?
C. How many molecules are there in 1 mole of glucose?

2-10 Which of the following elements is *least* abundant in living organisms?
(a) sulfur
(b) carbon
(c) oxygen
(d) nitrogen

2-11 You explain to a friend what you have learned about Avogadro's number. Your friend thinks the number is so large that he doubts there is even a mole of living cells on the Earth. You have recently heard that there are about 50 trillion (5×10^{13}) human cells in each adult human body and that each human contains more bacterial cells (in the digestive system) than human cells, so you bet your friend $5 that there is more than a mole of cells on Earth. The human population is approximately 7 billion (7×10^9). What calculation can you show your friend to convince him you are right?

2-12 Avogadro's number, calculated from the atomic weight of hydrogen, tells us how many atoms or molecules are in a mole. The resulting base for all calculations of moles and molarity (how many molecules are present when you weigh out a substance or measure from a stock solution) is the following:

1 g of hydrogen atoms = 6×10^{23} hydrogen atoms = 1 mole of hydrogen

Sulfur has a molecular weight of 32. How many moles and atoms are there in 120 grams of sulfur?

(a) 3.75 and 6×10^{23}
(b) 32 and 6×10^{23}
(c) 1.75 and 1.05×10^{24}
(d) 3.75 and 2.25×10^{24}

2-13 The first task you are assigned in your summer laboratory job is to prepare a concentrated NaOH stock solution. The molecular weight of NaOH is 40. How many grams of solid NaOH will you need to weigh out to obtain a 500 mL solution that has a concentration of 10 M?

(a) 800 g
(b) 200 g
(c) 400 g
(d) 160 g

2-14 You have a concentrated stock solution of 10 M NaOH and want to use it to produce a 150 mL solution of 3 M NaOH. What volume of water and stock solutions will you measure out to make this new solution?

(a) 135 mL of water, 15 mL of NaOH stock
(b) 115 mL of water, 35 mL of NaOH stock
(c) 100 mL of water, 50 mL of NaOH stock
(d) 105 mL of water, 45 mL of NaOH stock

2-15 Indicate whether the statements below are *true* or *false*. If a statement is false, explain why it is false.

A. Electron shells fill discrete regions around the nucleus of the atom and limit the number of electrons that can occupy a specific orbit.
B. H, C, O, and N are the most common elements in biological molecules because they are the most stable.
C. Some atoms are more stable when they lose one or two electrons, even though this means they will have a net positive charge.

2-16 A covalent bond between two atoms is formed as a result of the _______________.

(a) sharing of electrons.
(b) loss of electrons from both atoms.

(c) loss of a proton from one atom.
(d) transfer of electrons from one atom to the other.

2-17 An ionic bond between two atoms is formed as a result of the _______________.

(a) sharing of electrons.
(b) loss of electrons from both atoms.
(c) loss of a proton from one atom.
(d) transfer of electrons from one atom to the other.

2-18 For each of the following sentences, fill in the blanks with the best word or phrase selected from the list below. Not all words or phrases will be used; each word or phrase should be used only once.

Whereas ionic bonds form a(n) ___________________, covalent bonds between atoms form a(n) ___________________. These covalent bonds have a characteristic bond ___________________ and become stronger and more rigid when two electrons are shared in a(n) ___________________. Equal sharing of electrons yields a(n) ___________________ covalent bond. If one atom participating in the bond has a stronger affinity for the electron, this produces a partial negative charge on one atom and a partial positive charge on the other. These ___________________ covalent bonds should not be confused with the weaker ___________________ bonds that are critical for the three-dimensional structure of biological molecules and for interactions between these molecules.

charge	length	polar
covalent	molecule	salt
double bond	noncovalent	single bond
ionic	nonpolar	weight

2-19 Indicate whether the statements below are *true* or *false*. If a statement is false, explain why it is false.

A. Electrons are constantly moving around the nucleus of the atom, but they can move only in discrete regions.
B. There is no limit to the number of electrons that can occupy the fourth electron shell.
C. Atoms with unfilled outer electron shells are especially stable and are therefore less reactive.

2-20 Table Q2-20 indicates the electrons in the first four atomic electron shells for selected elements. On the basis of the information in the chart and what you know about atomic structure, which elements are chemically inert?

atomic number		energy level (electron shell)			
	element	I	II	III	IV
1	Hydrogen	●			
2	Helium	○○			
6	Carbon	○○	●●●●		
7	Nitrogen	○○	●●●●●		
8	Oxygen	○○	●●●●●●		
10	Neon	○○	○○○○○○○○		
11	Sodium	○○	○○○○○○○○	●	
12	Magnesium	○○	○○○○○○○○	●●	
15	Phosphorus	○○	○○○○○○○○	●●●●●	
16	Sulfur	○○	○○○○○○○○	●●●●●●	
17	Chlorine	○○	○○○○○○○○	●●●●●●●	
18	Argon	○○	○○○○○○○○	○○○○○○○○	
19	Potassium	○○	○○○○○○○○	○○○○○○○○	●
20	Calcium	○○	○○○○○○○○	○○○○○○○○	●●

Table Q2-20

(a) carbon, sulfur
(b) helium, neon
(c) sodium, potassium
(d) magnesium, calcium

2-21 Table Q2-21 indicates the electrons in the first four atomic electron shells for selected elements. On the basis of the information in the chart and what you know about atomic structure, which elements will form ions with a net charge of +1 in solution?

atomic number		energy level (electron shell)			
	element	I	II	III	IV
1	Hydrogen	●			
2	Helium	○○			
6	Carbon	○○	●●●●		
7	Nitrogen	○○	●●●●●		
8	Oxygen	○○	●●●●●●		
10	Neon	○○	○○○○○○○○		
11	Sodium	○○	○○○○○○○○	●	
12	Magnesium	○○	○○○○○○○○	●●	
15	Phosphorus	○○	○○○○○○○○	●●●●●	
16	Sulfur	○○	○○○○○○○○	●●●●●●	
17	Chlorine	○○	○○○○○○○○	●●●●●●●	
18	Argon	○○	○○○○○○○○	○○○○○○○○	
19	Potassium	○○	○○○○○○○○	○○○○○○○○	●
20	Calcium	○○	○○○○○○○○	○○○○○○○○	●●

Table Q2-21

(a) carbon, sulfur
(b) helium, neon
(c) sodium, potassium
(d) magnesium, calcium

2-22 Table Q2-22 indicates the electrons in the first four atomic electron shells for selected elements. On the basis of the information in the chart and what you know about atomic structure, which elements will form ions with a net charge of +2 in solution?

atomic number ↓		energy level (electron shell)			
	element	I	II	III	IV
1	Hydrogen	●			
2	Helium	○○			
6	Carbon	○○	●●●●		
7	Nitrogen	○○	●●●●●		
8	Oxygen	○○	●●●●●●		
10	Neon	○○	○○○○○○○○		
11	Sodium	○○	○○○○○○○○	●	
12	Magnesium	○○	○○○○○○○○	●●	
15	Phosphorus	○○	○○○○○○○○	●●●●●	
16	Sulfur	○○	○○○○○○○○	●●●●●●	
17	Chlorine	○○	○○○○○○○○	●●●●●●●	
18	Argon	○○	○○○○○○○○	○○○○○○○○	
19	Potassium	○○	○○○○○○○○	○○○○○○○○	●
20	Calcium	○○	○○○○○○○○	○○○○○○○○	●●

Table Q2-22

(a) carbon, sulfur
(b) helium, neon
(c) sodium, potassium
(d) magnesium, calcium

2-23 Table Q2-23 indicates the electrons in the first four atomic electron shells for selected elements. On the basis of the information in the chart and what you know about atomic structure, which elements form stable but reactive diatomic gases?

atomic number ↓		energy level (electron shell)			
	element	I	II	III	IV
1	Hydrogen	●			
2	Helium	○○			
6	Carbon	○○	●●●●		
7	Nitrogen	○○	●●●●●		
8	Oxygen	○○	●●●●●●		
10	Neon	○○	○○○○○○○○		
11	Sodium	○○	○○○○○○○○	●	
12	Magnesium	○○	○○○○○○○○	●●	
15	Phosphorus	○○	○○○○○○○○	●●●●●	
16	Sulfur	○○	○○○○○○○○	●●●●●●	
17	Chlorine	○○	○○○○○○○○	●●●●●●●	
18	Argon	○○	○○○○○○○○	○○○○○○○○	
19	Potassium	○○	○○○○○○○○	○○○○○○○○	●
20	Calcium	○○	○○○○○○○○	○○○○○○○○	●●

Table Q2-23

(a) nitrogen, oxygen
(b) helium, neon
(c) sodium, potassium
(d) magnesium, calcium

2-24 Indicate whether the statements below are *true* or *false*. If a statement is false, explain why it is false.

A. There are four elements that constitute 99% of all the atoms found in the human body.
B. Copper, zinc, and manganese are among 11 nonessential trace elements that contribute less than 0.1% of all the atoms in the human body.
C. Approximately 0.9% of the atoms in the human body come from seven essential elements—Na, Mg, K, Ca, P, S, and Cl—all of which form stable ions in aqueous solution.

2-25 Which of the following factors *do not* influence the length of a covalent bond?

(a) the tendency of atoms to fill the outer electron shells
(b) the attractive forces between negatively charged electrons and positively charged nuclei
(c) the repulsive forces between the positively charged nuclei
(d) the minimization of repulsive forces between the two nuclei by the cloud of shared electrons

2-26 Double covalent bonds are both shorter and stronger than single covalent bonds, but they also limit the geometry of the molecule because they ____________________.

(a) create a new arrangement of electron shells.
(b) change the reactivity of the bonded atoms.
(c) limit the rotation of the bonded atoms.
(d) prevent additional bonds from being formed with the bonded atoms.

2-27 Polar covalent bonds are formed when the electrons in the bond are not shared equally between the two nuclei. Which one of these molecules contains polar bonds?

(a) molecular oxygen
(b) methane
(c) propane
(d) water

2-28 A. In which scientific unit is the strength of a chemical bond usually expressed?

B. If 0.5 kilocalories of energy are required to break 6×10^{23} bonds of a particular type, what is the strength of this bond?

2-29 Oxygen, hydrogen, carbon, and nitrogen atoms are enriched in the cells and tissues of living organisms. The covalent bond geometries for these atoms influence their biomolecular structures. Match the elements on the left with the bond geometries illustrated on the right. Some elements assume more than one bond geometry.

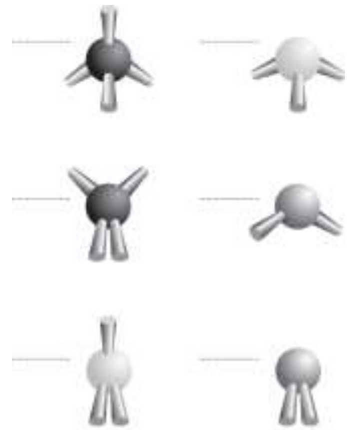

Figure Q2-29

A. oxygen
B. carbon
C. nitrogen

2-30 Which combination of answers best completes the following statement: When atoms are held together by ____________ ___________, they are typically referred to as __________.
(a) hydrogen bonds, molecules.
(b) ionic interactions, salts.
(c) ionic interactions, molecules.
(d) double bonds, nonpolar.

2-31 Although covalent bonds are 10–100 times stronger than noncovalent interactions, many biological processes depend upon the number and type of noncovalent interactions between molecules. Which of the noncovalent interactions below will contribute most to the strong and specific binding of two molecules, such as a pair of proteins?
(a) electrostatic attractions
(b) hydrogen bonds
(c) hydrophobic interactions
(d) Van der Waals attractions

2-32 Which of the following expressions accurately describes the calculation of pH?
(a) $pH = -\log_{10}[H^+]$
(b) $pH = \log_{10}[H^+]$
(c) $pH = -\log_2[H^+]$
(d) $pH = -\log_{10}[OH^-]$

2-33 The pH of an aqueous solution is an indication of the concentration of available protons. However, you should not expect to find lone protons in solution; rather, the proton is added to a water molecule to form a(n) _______________ ion.
(a) hydroxide
(b) ammonium
(c) chloride
(d) hydronium

2-34 The relative strengths of covalent bonds and van der Waals interactions remain the same when tested in a vacuum or in water. However, this is not true of hydrogen bonds or ionic bonds, whose bond strengths are lowered considerably in the presence of water. Explain these observations.

2-35 Indicate whether the statements below are *true* or *false*. If a statement is false, explain why it is false.

A. Any covalently bonded H atom can participate in a hydrogen bond if it comes in close proximity with an oxygen atom that forms part of a water molecule.

B. Protons are constantly moving between water molecules, which means there is an overall equilibrium between hydroxyl ions and hydronium ions in aqueous solutions.

C. A strong base is defined as a molecule that can readily remove protons from water.

2-36 Larger molecules have hydrogen-bonding networks that contribute to specific, high-affinity binding. Smaller molecules such as urea can also form these networks. How many hydrogen bonds can urea (Figure Q2-36) form if dissolved in water?

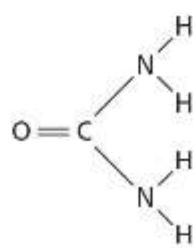

Figure Q2-36

(a) 6
(b) 5
(c) 3
(d) 4

2-37 A. Sketch three different ways in which three water molecules could be held together by hydrogen-bonding.

B. On a sketch of a single water molecule, indicate the distribution of positive and negative charge (using the symbols δ^+ and δ^-).

C. How many hydrogen bonds can a hydrogen atom in a water molecule form? How many hydrogen bonds can the oxygen atom in a water molecule form?

2-38 A. What is the pH of pure water?

B. What concentration of hydronium ions does a solution of pH 8 contain?

C. Complete the following reaction:

$CH_3COOH + H_2O \leftrightarrow$ __________.

D. Will the reaction in (C) occur more readily (be driven to the right) if the pH of the solution is high?

2-39 Aromatic carbon compounds such as benzene are planar and very stable. Double-bond character extends around the entire ring, which is why it is often drawn as a hexagon with a circle inside. This characteristic is caused by electron __________.

(a) resonance.
(b) pairing.
(c) partial charge.
(d) stacking.

2-40 The amino acid histidine is often found in enzymes. Depending on the pH of its environment, sometimes histidine is neutral and at other times it acquires a proton and becomes positively charged. Consider an enzyme with a histidine side chain that is known to have an important role in the function of the enzyme. It is not clear whether this histidine is required in its protonated or its unprotonated state. To answer this question, you measure enzyme activity over a range of pH, with the results shown in Figure Q2-40. Which form of histidine is necessary for the active enzyme?

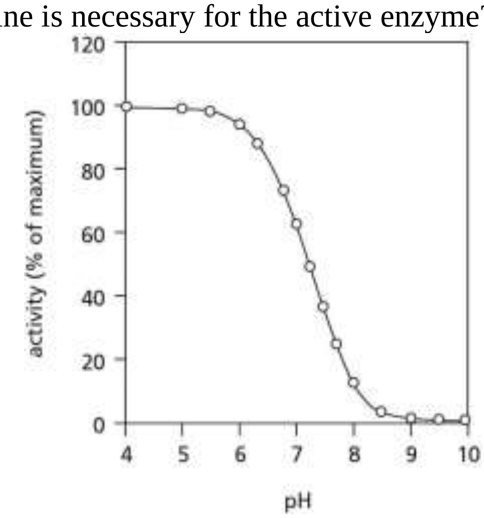

Figure Q2-40

2-41 Silicon is an element that, like carbon, has four vacancies in its outer electron shell and therefore has the same bonding chemistry as carbon. Silicon is not found to any significant degree in the molecules found in living systems, however. Does this difference arise because elemental carbon is more abundant than silicon? What other explanations are there for the preferential selection of carbon over silicon as the basis for the molecules of life?

2-42 Selenium (Se) is an element required in the human body in trace amounts. Selenium is obtained through the diet and levels of selenium found in food depend greatly on the soil where it is grown. Once ingested and absorbed as selenate, it can become incorporated into a small number of polypeptides. These selenoproteins are formed when selenium replaces an element that is found in two of the twenty “standard” amino acids. Using your knowledge of atomic structure, the periodic table in Figure 2–7, and the structure of amino acids found in Panel 2–5, deduce which two amino acids may be converted to "seleno" amino acids and used to make selenoproteins.

Small Molecules in Cells

2-43 Indicate whether the molecules below are inorganic (I) or organic (O).

A. glucose
B. ethanol
C. sodium chloride
D. water
E. cholesterol
F. adenosine
G. calcium
H. glycine
I. oxygen
J. iron
K. phospholipid

2-44 Which of the following monomer building blocks is necessary to assemble selectively permeable boundaries around and inside cells?

(a) sugars
(b) fatty acids
(c) amino acids
(d) nucleotides

2-45 The variety and arrangement of chemical groups on monomer subunits contribute to the conformation, reactivity, and surface of the macromolecule into which they become incorporated. What type of chemical group is circled on the nucleotide shown in Figure Q2-45?

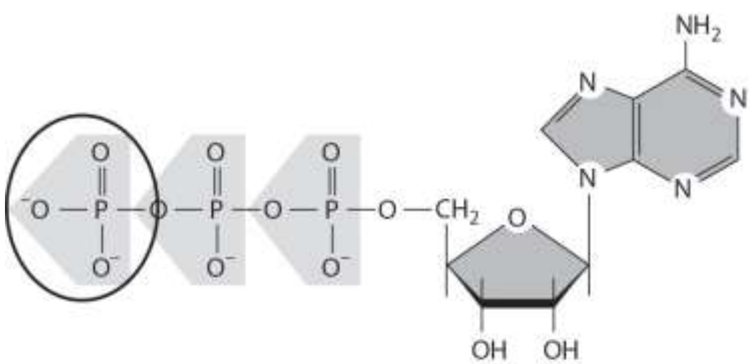

Figure Q2-45

(a) pyrophosphate
(b) phosphoryl
(c) carbonyl
(d) carboxyl

2-46 The amino acids glutamine and glutamic acid are shown in Figure Q2-46. They differ only in the structure of their side chains (circled). At pH 7, glutamic acid can participate in molecular interactions that are not possible for glutamine. What types of interactions are these?

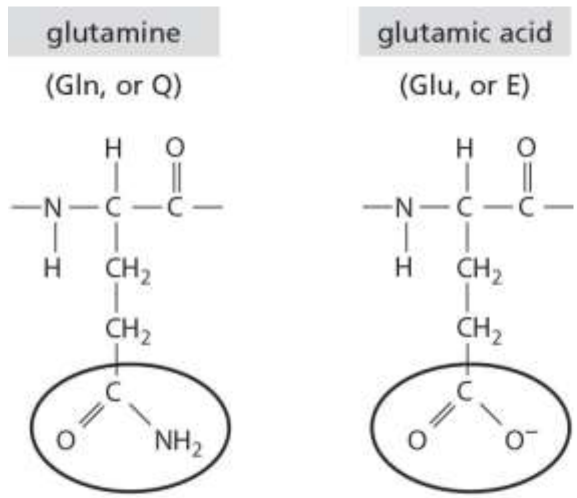

Figure Q2-46

(a) ionic bonds
(b) hydrogen bonds
(c) van der Waals interactions
(d) covalent bonds

2-47 Cells require one particular monosaccharide as a starting material to synthesize nucleotide building blocks. Which of the monosaccharides below fills this important role?

(a) glucose
(b) fructose
(c) ribulose
(d) ribose

2-48 Oligosaccharides are short sugar polymers that can become covalently linked to proteins and lipids through condensation reactions. These modified proteins and lipids are called glycoproteins and glycolipids, respectively. Within a protein, which of the amino acids (shown in Figure Q2-48) is the most probable target for this type of modification?

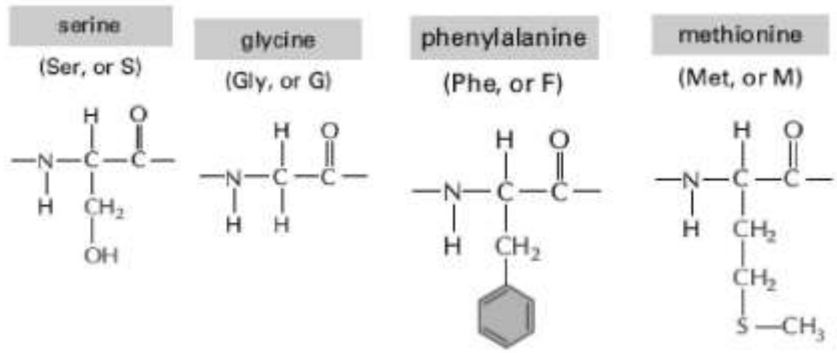

Figure Q2-48

(a) serine
(b) glycine
(c) phenylalanine
(d) methionine

2-49 Which of the following are examples of isomers?
(a) glucose and galactose
(b) alanine and glycine
(c) adenine and guanine
(d) glycogen and cellulose

2-50 A. How many carbon atoms does the molecule represented in Figure Q2-50 have?
B. How many hydrogen atoms does it have?
C. What type of molecule is it?

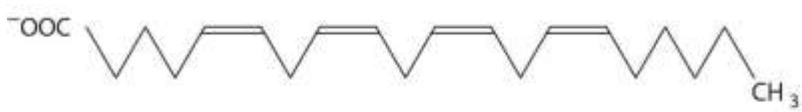

Figure Q2-50

2-51 Most types of molecules in the cell have asymmetric (chiral) carbons. Consequently there is the potential to have two different molecules that look much the same but are mirror images of each other and therefore not equivalent. These special types of isomer are called stereoisomers. Which of the four carbons circled in Figure Q2-51 is the asymmetric carbon that determines whether the amino acid (threonine in this case) is a D or an L stereoisomer?

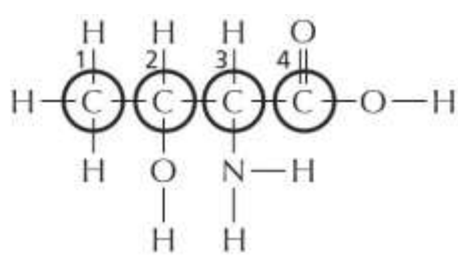

Figure Q2-51

(a) 1
(b) 2
(c) 3
(d) 4

2-52 Indicate whether the statements below are *true* or *false*. If a statement is false, explain why it is false.

A. A disaccharide consists of a sugar covalently linked to another molecule such as an amino acid or a nucleotide.

B. The hydroxyl groups on monosaccharides are reaction hot spots and can be replaced by other functional groups to produce derivatives of the original sugar.

C. The presence of double bonds in the hydrocarbon tail of a fatty acid does not greatly influence its structure.

2-53 On the phospholipid molecule in Figure Q2-53, label each numbered line with the correct term selected from the list below.

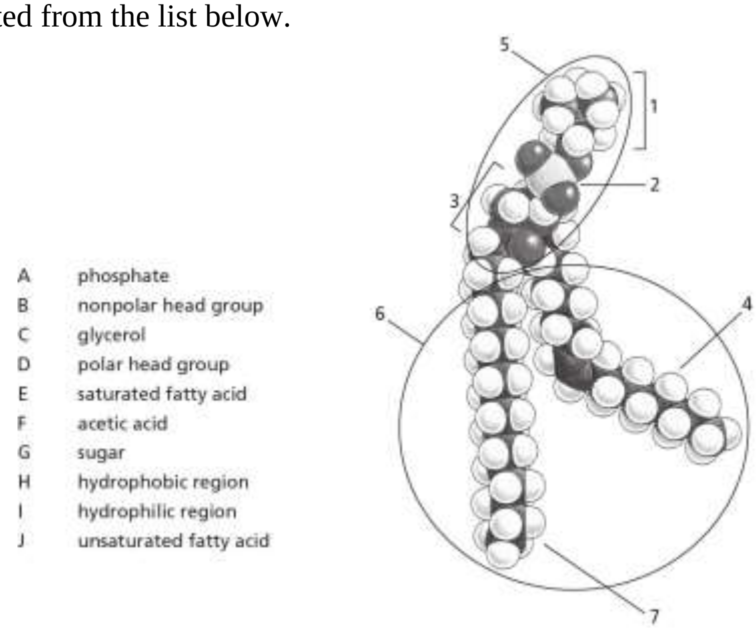

Figure Q2-53

2-54 Many types of cells have stores of lipids in their cytoplasm, usually seen as fat droplets. What is the lipid most commonly found in these droplets?

(a) cholesterol
(b) palmitic acid
(c) isoprene
(d) triacylglycerol

2-55 Choose the answer that best fits the following statement: Cholesterol is an essential component of biological membranes. Although it is much smaller than the typical

phospholipids and glycolipids in the membrane, it is a(n) __________________ molecule, having both hydrophilic and hydrophobic regions.
(a) polar
(b) oxygen-containing
(c) hydrophobic
(d) amphipathic

2-56 For each of the following sentences, fill in the blanks with the best word or phrase selected from the list below. Not all words or phrases will be used; each word or phrase should be used only once.

Proteins are _______________ built from amino acids, which each have an amino group and a ______________ group attached to the central ________________. There are twenty possible ________________ that differ in structure and are generally referred to as "R." In solutions of neutral pH, amino acids are ________________, carrying both a positive and negative charge. When a protein is made, amino acids are linked together through ________________, which are formed by condensation reactions between the carboxyl end of the last amino acid and the ____________________ end of the next amino acid to be added to the growing chain.

amino	ionized	polypeptides
α-carbon	length	protein
carbon	noncovalent	R group
carboxyl	peptide bonds	side chains
hydroxide		

2-57 DNA and RNA are different types of nucleic acid polymer. Which of the following is true of DNA but *not* true of RNA?
(a) It contains uracil.
(b) It contains thymine.
(c) It is single-stranded.
(d) It has 5′-to-3′ directionality.

2-58 Match each term related to the structure of nucleic acids (A–I) with one of the descriptions provided.
A. base
B. glycosidic bond
C. nucleoside
D. nucleotide
E. phosphoanhydride bond
F. phosphoester bond
G. ribose
H. phosphodiester bond
I. deoxyribose

____ the linkage between two nucleotides

____ the linkage between the 5′ sugar hydroxyl and a phosphate group
____ the nitrogen-containing aromatic ring
____ five-carbon sugar found in DNA
____ sugar unit linked to a base
____ linkage between the sugar and the base
____ linkages between phosphate groups
____ sugar linked to a base and a phosphate
____ five-carbon sugar found in RNA

2-59 A. Write out the sequence of amino acids in the following peptide, using the full names of the amino acids.
Pro-Val-Thr-Gly-Lys-Cys-Glu
B. Write the same sequence with the single-letter code for amino acids.
C. According to the conventional way of writing the sequence of a peptide or a protein, which is the C-terminal amino acid and which is the N-terminal amino acid in the above peptide?

2-60 The cell is able to harvest energy from various processes in order to generate ATP molecules. These ATPs represent a form of stored energy that can be used later to drive other important processes. Explain how the cell can convert the chemical energy stored in ATP to generate mechanical energy, for example changing the shape of a protein.

Macromolecules in Cells

2-61 Both DNA and RNA are synthesized by covalently linking a nucleoside triphosphate to the previous nucleotide, constantly adding to a growing chain. In the case of DNA, the new strand becomes part of a stable helix. The two strands are complementary in sequence and antiparallel in directionality. What is the principal force that holds these two strands together?
(a) ionic interactions
(b) hydrogen bonds
(c) covalent bonds
(d) van der Waals interactions

2-62 Each nucleotide in DNA and RNA has an aromatic base. What is the principal force that keeps the bases in a polymer from interacting with water?
(a) hydrophobic interactions
(b) hydrogen bonds
(c) covalent bonds
(d) van der Waals interactions

2-63 Because there are four different monomer building blocks that can be used to assemble RNA polymers, the number of possible sequence combinations that can be created for an RNA molecule made of 100 nucleotides is _______.
(a) 100^4
(b) 4^{100}

(c) 4 × 100
(d) 100/4

2-64 There are 20^{100} different possible sequence combinations for a protein chain with 100 amino acids. In addition to the amino acid sequence of the protein, what other factors *increase* the potential for diversity in these macromolecules?
(a) free rotation around single bonds during synthesis
(b) noncovalent interactions sampled as protein folds
(c) the directionality of amino acids being added
(d) the planar nature of the peptide bond

2-65 Indicate whether the statements below are *true* or *false*. If a statement is false, explain why it is false.
A. "Nonpolar interactions" is simply another way of saying "van der Waals attractions."
B. Condensation reactions occur in the synthesis of all the macromolecules found in cells.
C. All proteins and RNAs pass through many unstable conformations as they are folded, finally settling on one single, preferred conformation.

2-66 Macromolecules in the cell can often interact transiently as a result of noncovalent interactions. These weak interactions also produce stable, highly specific interactions between molecules. Which of the factors below is the most significant in determining whether the interaction will be transient or stable?
(a) the size of each molecule
(b) the concentration of each molecule
(c) the rate of synthesis
(d) surface complementarity between molecules

2-67 As a protein is made, the polypeptide is in an extended conformation, with every amino acid exposed to the aqueous environment. Although both polar and charged side chains can mix readily with water, this is not the case for nonpolar side chains. Explain how hydrophobic interactions may play a role in the early stages of protein folding, and have an influence on the final protein conformation.

2-68 You are trying to make a synthetic copy of a particular protein but accidentally join the amino acids together in exactly the reverse order. One of your classmates says the two proteins must be identical, and bets you $20 that your synthetic protein will have exactly the same biological activity as the original. After having read this chapter, you have no hesitation in staking your $20 that it won't. What particular feature of a polypeptide chain makes you sure your $20 is safe and that the project must be done again.

2-69 A protein chain folds into its stable and unique three-dimensional structure, or conformation, by making many noncovalent bonds between different parts of the chain. Such noncovalent bonds are also critical for interactions with other proteins and cellular molecules. From the list provided, choose the class(es) of amino acids that are most important for the interactions detailed below.

A. forming ionic bonds with negatively charged DNA
B. forming hydrogen bonds to aid solubility in water
C. binding to another water-soluble protein
D. localizing an “integral membrane” protein that spans a lipid bilayer
E. tightly packing the hydrophobic interior core of a globular protein

acidic	nonpolar
basic	uncharged polar

2-70 It is now a routine task to determine the exact order in which individual subunits have been linked together in polynucleotides (DNA) and polypeptides (proteins). However, it remains difficult to determine the arrangement of monomers in a polysaccharide. Explain why this is the case.

2-71 Your lab director requests that you add new growth medium to the mammalian cell cultures before heading home from the lab on a Friday night. Unfortunately, you need to make fresh medium because all the premixed bottles of medium have been used. One of the ingredients you know you need to add is a mix of the essential amino acids (those that cannot be made by the cells, but are needed in proteins). On the shelf of dry chemicals you find the amino acids you need, and you mix them into your medium, along with all the other necessary nutrients, and replace the old medium with your new medium. On Sunday, you come in to the lab just to check on your cells and find that the cells have not grown. You are sure you made the medium correctly, but on checking you see that somebody wrote a note on the dry mixture of amino acids you used: “Note: this mixture contains only D-amino acids.”

A. What is the meaning of the note and how does it explain the lack of cell growth in your culture?
B. Are there any organisms that could grow using this mixture? Justify your answer.

2-72 Eukaryotic cells have their DNA molecules inside their nuclei. However, to package all the DNA into such a small volume requires the cell to use specialized proteins called histones. Histones have amino acid sequences enriched for lysines and arginines.

A. What problem might a cell face in trying to package DNA into a small volume without histones, and how do these special packaging proteins alleviate the problem?
B. Lysine side chains are substrates for enzymes called acetylases. A diagram of an acetylated lysine side chain is shown in Figure Q2-72. How do you think the acetylation of lysines in histone proteins will affect the ability of a histone to perform its role (refer to your answer in part A)?

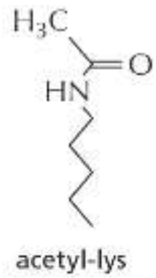

Figure Q2-72

ANSWERS

2-1 (d)

2-2 A. False. Although small molecules are important in many processes, the chemical reactions in living systems are regulated by the coordinated action of large polymeric molecules.

B. True.

C. False. The chemical reactions in living systems are very tightly controlled, ensuring that events occur at the proper time and at the proper location inside the cell.

2-3 (a)

2-4 (b)

2-5 (c)

2-6 (a)

2-7 (b)

2-8 (c)

2-9 A. 180 daltons. A mole of a substance has a mass equivalent to its molecular weight expressed in grams.

B. 45 g/L

C. 6×10^{23} molecules

2-10 (a) Sulfur is the least abundant element among the choices given.

2-11 Avogadro's number, or 6×10^{23}, is the number of atoms (or units) in a mole. If you multiply the number of people on Earth by the number of cells in the human body, then double it to account for the bacteria, you will calculate: $(7 \times 10^9) \times (1 \times 10^{14}) = 7 \times 10^{23}$. Thus, even when only considering the human population and the associated microbial populations, you can estimate more than a mole of living cells on Earth. You win $5.

2-12 (d)

2-13 (b)

2-14 (d)

2-15 A. True.

B. False. H, C, N, and O are the most common elements in biological molecules because their outer shells are unfilled, making them highly reactive.

C. True.

2-16 (a)

2-17 (d)

2-18 Whereas ionic bonds form a **salt**, covalent bonds between atoms form a **molecule**. These covalent bonds have a characteristic bond **length** and become stronger and more rigid when two electrons are shared in a **double bond**. Equal sharing of electrons yields a **nonpolar** covalent bond. If one atom participating in the bond has a stronger affinity for the electron, this produces a partial negative charge on one atom and a partial positive charge on the other. These **polar** covalent bonds should not be confused with the weaker **noncovalent** bonds that are critical for the three-dimensional structure of biological molecules and for interactions between these molecules.

2-19 A. True.
B. False. The fourth electron shell has the capacity to hold 18 electrons.
C. False. Atoms that have their outer electron shells filled are the most stable and least reactive. Atoms with unfilled outer shells are more reactive because they tend to share or transfer electrons to fill and therefore stabilize the outer shell.

2-20 (b)

2-21 (c)

2-22 (d)

2-23 (a) An oxygen atom with six outer electrons needs two more to attain a stable outer shell. This can be achieved by forming two covalent bonds with a second oxygen, as shown on the right. Similarly, a nitrogen atom needs three more electrons and makes three covalent bonds with another nitrogen atom.

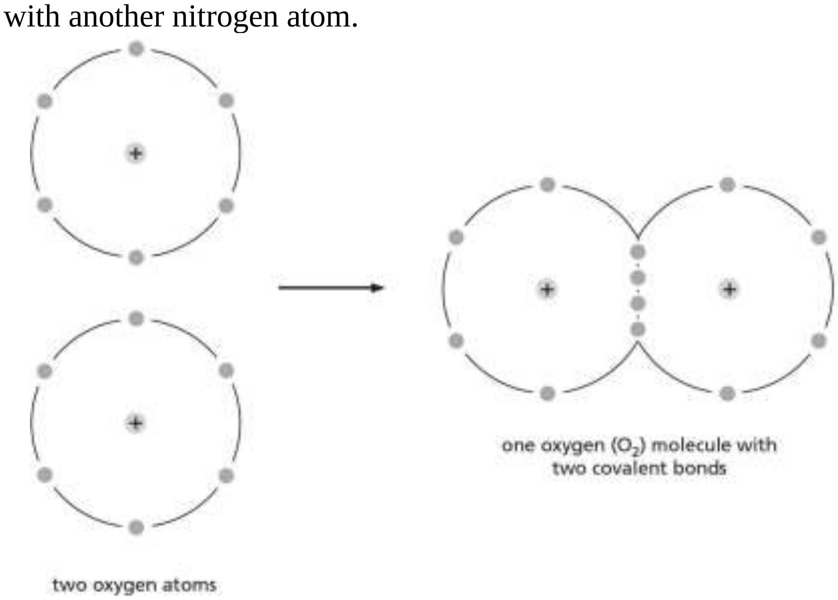

Figure A2-23

2-24 A. True.
B. False. Cu, Zn, and Mn are essential trace elements in the human body.
C. False. Na, Mg, K, Ca, and Cl form ions in aqueous solution, but P and S form covalent bonds in order to fill their outer electron shells.

2-25 (a)

2-26 (c)

2-27 (d)

2-28 A. kilocalories per mole (*or* kilojoules per mole)
B. 0.5 kcal/mole

2-29

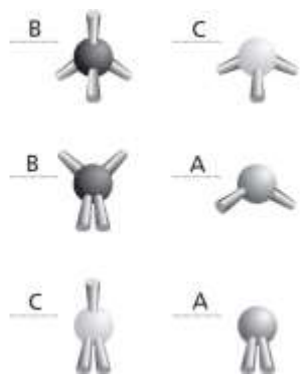

Figure A2-29

2-30 (b)

2-31 (a)

2-32 (a)

2-33 (d)

2-34 We estimate bond strengths by measuring the amount of energy needed to break them. As explained in Panel 2–7 (p.78–79), in an aqueous solution, water can form hydrogen bonds with any polar molecules that are capably of forming hydrogen bonds with each other. This formation of bonds with water takes away from the net energy that would be gained from the molecules forming hydrogen bonds with each other, as they would in a vacuum. Similarly, water forms favorable electrostatic interactions with ions, thereby greatly weakening the ionic bonds that form between positive and negative ions in a vacuum (see Panel 2–7). Thus, for example, solid table salt (NaCl) readily dissociates in water, producing separate Na^+ and Cl^- ions as it dissolves. In contrast, covalent bonds and van der Waals attractions have an intrinsic bond strength that is independent of the aqueous environment, because changes in water molecule associations are not involved in the formation of these two types of bonds.

2-35 A. False. Hydrogen atoms that are covalently bonded to carbon atoms do not participate in hydrogen bonds because these hydrogens have almost no net positive charge.
B. True.
C. True.

2-36 (a) Urea can form at least six hydrogen bonds in water: two from the oxygen atom and one from each hydrogen atom.

2-37
A. See Figure A2-37A.
B. See Figure A2-37B.
C. Hydrogen can form one; oxygen two.

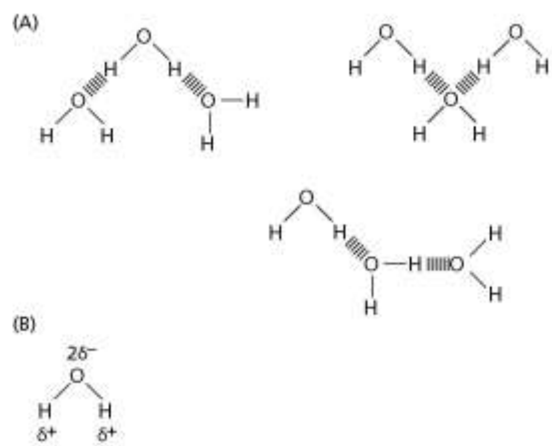

Figure A2-37

2-38 A. pH 7
B. 10^{-8} M
C. $CH_3COO^- + H_3O^+$
D. Yes. If the pH is high, then the concentration of hydronium ions will be low. Therefore the rightward reaction, which produces hydronium ions, will be favored.

2-39 (a)

2-40 Assuming that the change in enzyme activity is due to the change in the protonation state of histidine, the enzyme must require histidine in the protonated, charged state. The enzyme is active only at low, acidic pH, where the proton (or hydronium ion) concentration is high; thus, the loss of a proton from histidine will be disfavored so that histidine is likely to be protonated.

2-41 On the basis of Figure 2–4 in your textbook, silicon is actually more abundant in the Earth's crust than carbon, so this is not likely to be the reason that carbon was used preferentially. Carbon might have been the element of choice in living systems because it is lighter than silicon and forms shorter covalent bonds with other elements. Shorter bonds are typically stronger and more stable.

2-42 Sulfur is the only element found exclusively in two of the twenty amino acids. This element is located directly above selenium in the periodic table, indicating that these elements have the same number of electrons in their outer shell and both prefer to form bonds with other atoms to fill their outer orbital. If selenium instead of sulfur is incorporated into cysteine or methionine, the altered "seleno" amino acids will be produced (selenocysteine and selenomethionine). We can expect that this substitution will alter the nature of the proteins in which these amino acids are incorporated because selenium is a larger atom than sulfur.

2-43 Indicate whether the molecules below are inorganic (I) or organic (O).

A. O
B. O
C. I
D. I
E. O
F. O
G. I
H. O
I. I
J. I
K. O

2-44 (b)

2-45 (b)

2-46 (a)

2-47 (d)

2-48 (a)

2-49 (a) Glucose and galactose are both six-carbon sugars and thus both have the formula $C_6H_{12}O_6$. They are therefore isomers of each other. Adenine and guanine are bases containing different numbers of nitrogen and oxygen atoms. Glycogen and cellulose are different polymers of glucose. Alanine and glycine are amino acids with quite different side chains: a methyl group and a hydrogen atom, respectively.

2-50 A. 20 carbon atoms
B. 31 hydrogen atoms

C. A fatty acid (Figure A2-50 is arachidonic acid, an essential fatty acid required by most mammals)

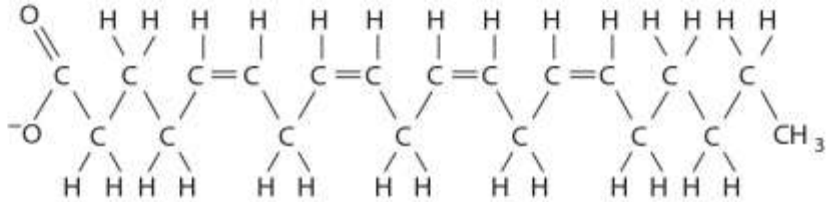

Figure A2-50

2-51 (c) Two of the carbon atoms of threonine are asymmetric (numbered 2 and 3 in Figure Q2-51) but by convention it is the α-carbon (number 3) that determines whether the amino acid is the D or L isomer.

2-52 A. False. A disaccharide consists of two sugar molecules that undergo a condensation reaction to form a covalent bond (known as a glycosidic linkage).
B. True.
C. False. The presence of a double bond in the hydrocarbon chain of a fatty acid causes a kink in the chain, decreasing its flexibility and packing with neighboring hydrocarbon chains.

2-53 1—D; 2—A; 3—C; 4—J; 5—I; 6—H; 7—E

2-54 (d)

2-55 (d)

2-56 Proteins are **polypeptides** built from amino acids, which each have an amino group and a **carboxyl** group attached to the central **α-carbon**. There are twenty possible **side chains** that differ in structure and are generally referred to as "R." In solutions of neutral pH, amino acids are **ionized**, carrying both a positive and negative charge. When a protein is made, amino acids are linked together through **peptide bonds**, which are formed by condensation reactions between the carboxyl end of the last amino acid and the **amino** end of the next amino acid to be added to the growing chain.

2-57 (b)

2-58 H—the linkage between two nucleotides
F—the linkage between the 5′ sugar hydroxyl and a phosphate group
A—the nitrogen-containing aromatic ring
I—five-carbon sugar found in DNA
C—sugar unit linked to a base
B—linkage between the sugar and the base
E—linkages between phosphate groups
D—sugar linked to a base and a phosphate
G—five-carbon sugar found in RNA

2-59 A. proline-valine-threonine-glycine-lysine-cysteine-glutamic acid (*or* glutamate)
B. PVTGKCE
C. C-terminal is glutamic acid (*or* glutamate); N-terminal is proline

2-60 The terminal phosphate group is typically hydrolyzed and the energy released from this chemical bond is often "reinvested" to generate a new bond that links the phosphate group to a protein. This addition of a phosphate group can cause a change in the protein's conformation. This conformational change is usually associated with change in function or transient interactions with other macromolecules, generating a domino effect within the cell.

2-61 (b)

2-62 (a)

2-63 (b)

2-64 (a)

2-65 A. False. Van der Waals attractions describe the general attractive forces between all atoms. The contact distance between any two nonbonded atoms is the sum of the van der Waals radii. Nonpolar interactions are based on the exclusion of hydrophobic molecules from a hydrophilic environment.
B. True.
C. True.

2-66 (d)

2-67 One reason that nonpolar groups are excluded from an aqueous environment is that a hydrophobic surface would organize water into a highly structured network of hydrogen bonds, which is energetically unfavorable. So, you would expect that nonpolar amino acids would group together early, forming "hydrophobic pockets," while the polar and charged side chains remain at the interface of the surrounding solution. In the final, folded protein, most of the nonpolar amino acids will remain buried inside the protein. This fold is more stable because nonpolar atoms are prevented from contact with water and remain in contact with each other.

2-68 As a peptide bond has a distinct chemical polarity, a polypeptide chain also has a distinct polarity (see Figure A2-68). The reversed protein chain cannot make the same noncovalent interactions during folding and thus will not adopt the same three-dimensional structure as the original protein. The activities of these two proteins will definitely be different, because the activity of a protein depends on its three-dimensional structure. It is unlikely that the reverse chain will fold into any well-defined, and hence functionally useful, structure at all, because it has not passed the stringent selective pressures imposed during evolution.

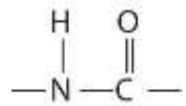

Figure A2-68

2-69 A. basic
B. uncharged polar
C. uncharged polar, basic, and acidic
D. nonpolar
E. nonpolar

2-70 Nucleotides and amino acids have an intrinsic directionality, and the mechanism by which monomers are added into a growing polymer is always the same. This yields a linear polymer with the same directionality as the monomers. Polysaccharides are produced by linking monosaccharides together. The monosaccharides can be either added directly or modified to produce various derivatives before addition. Beyond this, there are multiple sites on each monosaccharide where addition can occur, producing highly complex, branched polymers.

2-71 A. The note indicates that the mixture contains only one of the two possible stereoisomers (L or D). Because mammalian cells use only the L stereoisomer, the D-amino acid mixture could not be used and therefore it is as though no amino acids were added at all.
B. Not unless L-amino acids were also mixed in. Certain types of bacteria use D-amino acids to produce their cell walls, but they would still require L-amino acids for the rest of the proteins they make.

2-72 A. DNA is a nucleic acid polymer in which each monomer has a negatively charged phosphate group. The negative charges will naturally repel each other, so in order to wrap the high density of negative charges into a small space, positively charged molecules must be present. Histones accomplish this because they are rich in lysines and arginines, which are positively charged in solution at pH 7.
B. A histone with acetylated lysine residues will not be as good at packaging the DNA. The addition of the acetyl group to the terminal amino on the lysine side chain lowers the histone's net positive charge, which makes it less effective at buffering the negative charges on the DNA backbone.