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CHAPTER

2

The Chemistry of the Cell

2-1. (a) Its valence of four allows a carbon atom to form multiple covalent bonds, with other carbon atoms as well as non-carbon atoms, most notably oxygen, hydrogen, nitrogen, and sulfur, thereby generating a great diversity of molecules with a wide variety of properties.

(b) The high bond energy of the carbon-carbon bond ensures the stability of molecules that contain two or more carbon atoms. Specifically, the bond energy of carbon-carbon bonds is well above that of the most energetic portion of visible light (measured in kilocalories/mole; see Figure 2-3 on p. 24 of the textbook), thereby ensuring that carbon-carbon (and other covalent bonds in biological molecules) cannot be broken upon exposure to visible light. (Note, however, that this is not true of ultraviolet radiation because any radiation with a wavelength of about 344 nm or less has enough energy to break carbon-carbon bonds.)

(c) The ability of a carbon atom to bond to two or more carbon atoms enables the generation of long chains of carbon atoms as well as ring structures, which are essential features of many biological molecules.

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(d) The ability of carbon atoms to bond to hydrogen, nitrogen, and sulfur atoms increases the diversity of carbon-containing molecules in terms of not only the atom components but also the functional group (such as methyl, amino, and sulfhydryl groups) components, which differ from one another in properties such as charge and asymmetric electron distribution, thereby enabling such molecules to play quite different roles in cellular reactions.

(e) The presence of asymmetric carbon atoms results in further structural diversity in the form of stereoisomers, which often differ from one another not only in their structural configuration but also in their biochemical properties.

2-2. (a) T; living organisms are essentially aqueous solutions containing many kinds of molecules, most of which are polar and hence readily soluble in water.

(b) T; oxygen is the ultimate electron acceptor in cellular respiration, resulting in water as the product.

(c) F; the density of ice is less than that of water, thereby ensuring that ice will float on the surface of a body of water, where it will melt readily if the temperature of the surrounding air rises above the freezing point.

(d) T; this property explains the high specific heat and high heat of vaporization and hence the capacity of water to "buffer" cells and organisms against temperature changes.

(e) T; this property of water allows light to penetrate readily, such that submerged photosynthetic organisms (or parts of organisms) can receive sunlight.

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(f) X; the lack of odor or taste is probably not a strategic advantage to most organisms.

(g) T; high specific heat means that a large amount of heat is required to increase the temperature, which effectively "buffers" cells and organisms against temperature changes in response to changes in the temperature of the environment.

(h) T; high heat of vaporization means that a large amount of heat is required to convert water from a liquid to a gas, which means that organisms can be effectively cooled by evaporation of perspiration or other forms of water from the skin or other surfaces of the organism.

2-3. (a) Oxygen, nitrogen, and carbon are the elements that most readily form strong multiple bonds. Hydrogen can form only a single bond, never multiple bonds.

(b) Water has a higher specific heat than most other liquids because of extensive hydrogen bonding between water molecules. During heating, much of the absorbed energy is used to disrupt hydrogen bonds rather than to raise the temperature.

(c) Hydrophobic oil droplets in water coalesce not because of an intrinsic attraction of oil molecules to each other, but because they have no affinity for polar molecules and therefore are not soluble in water.

(d) A hydrogen bond, unlike a covalent bond, does not involve the sharing of electrons. In a hydrogen bond, a partially positively charged hydrogen atom is attracted to a nearby partially negatively charged atom, typically an oxygen or a nitrogen.

(e) Biological membranes are called selectively permeable because only certain molecules can pass through easily. Small nonpolar molecules pass through membranes unassisted, whereas large polar molecules and ions require protein transporters to pass through the membranes.

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2-4. Due to its lack of polar atoms (for example, oxygen and nitrogen) and its symmetrical structure, benzene is highly nonpolar. Therefore, only nonpolar molecules such as lipids will readily dissolve in benzene. Slightly more polar molecules such as fatty acids and cholesterol will have low solubility in benzene. Polar molecules such as sugars, hydrophilic amino acids, and water will be insoluble in benzene.

2-5. Several answers are possible in theory. You could encase the drug in a lipid-soluble vesicle (liposome) that will easily be absorbed by the cell. You could attach functional groups to the drug that have known transporters in the cell membrane; the transporters will take up molecules containing these groups. You could block the polar functional groups by attaching nonpolar groups, which will be removed by known cellular enzymes once inside the cell. Perhaps you have thought of a reasonable strategy that could someday be applied!

2-6. (a) An amphipathic molecule has one or more hydrophilic regions and one or more hydrophobic regions; such polar molecules are important membrane constituents because the interior of the membrane is hydrophobic, but the milieu on either side of the membrane is aqueous and hence hydrophilic.

(b) A lipid monolayer would have one hydrophobic side and one hydrophilic side, but both sides of the membrane must interact with an aqueous environment. This means that both sides must be hydrophilic for the membrane to be a stable structure.

(c) Selective permeability means that some specific ions and molecules can move across a given membrane at reasonable rates, whereas others cannot. This, in turn, means that the membrane has transport proteins for some ions and molecules, but not others.

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(d) Although membranes are very impermeable to ions, K^+ ions (as well as other specific ions) can move across a membrane via transport proteins (usually ion channels) specific for that particular ion.

(e) Short sequences of hydrophobic amino acids (usually 20–30 amino acids per sequence) are likely the segments of the protein that span the membrane. For more details, see the discussion of integral membrane proteins in Chapter 7.

2-7. It is this asymmetry that renders water a polar molecule; most of the desirable properties of water as a solvent depend on this polarity.

2-8. (a) In propane, there are two carbon-carbon bonds and eight carbon-hydrogen bonds. The total bond energy is $(2 \times 83) + (8 \times 99) = 958$ kcal/mol.

(b) There are 27 hydrogen bonds in the nine GC base pairs and 12 in the six AT base pairs, for a total of 39, resulting in a total energy of $39 \times 5 = 195$ kcal/mol. This is approximately equal to the bond energy of 2.3 carbon-carbon covalent bonds.

(c) The gene contains 600 GC base pairs (1800 hydrogen bonds) and 400 AT base pairs (800 hydrogen bonds), for a total of 2600 hydrogen bonds and a total bond energy of 13,000 kcal/mol. This would be the equivalent of about 157 carbon-carbon covalent bonds, which represents a formidable force holding the two strands together.

2-9. (a) TMV virions self-assemble spontaneously without the input of energy or information, which means that all of the information necessary to direct their assembly must be already present in the RNA and/or proteins.

(b) The strain-specific assembly of TMV virions in vivo is determined by the RNA, not the coat protein.

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(c) The information necessary to direct self-assembly of TMV virions appears to reside in the coat protein monomers.

(d) The self-assembly of TMV virions is specific for TMV RNA.

(e) The most stable configuration of TMV virions involves a 3:1 ratio of nucleotides to coat protein monomers, which is therefore the product formed upon self-assembly, regardless of the starting ratio of nucleotides to monomers.

2-10. You would first determine whether the macromolecule is made of a series of monomeric subunits, like macromolecules on Earth. If so, you would then determine the number of different kinds of monomers and their arrangement. A repetitive pattern consisting of one or two different monomers would suggest a structural macromolecule. A seemingly random pattern consisting of several different monomers would suggest an informational macromolecule.

2-11. (a) Yes, infectious TMV particles were likely formed in this experiment. When the TMV protein was mixed with TMV RNA, significant numbers of lesions (over 10) were found on leaves after 24 or 96 hours. Both TMV protein and TMV RNA are required since control reactions with only one or the other did not cause significant lesion formation.

(b) Yes, RNA is required. Two of the reaction conditions suggest this. First, TMV protein alone did not form lesions. Second, when the TMV RNA was treated with RNase (an enzyme that degrades RNA) prior to mixing with TMV protein, no lesions formed.

(c) Yes, the source of the RNA needs to be TMV because when the TMV protein was mixed with RNA isolated from turnip yellow mosaic virus (TYMV), no lesions formed.

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