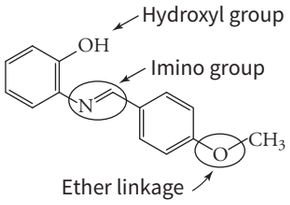
Solutions

Chapter 1

1. **a.** carboxylic acid; **b.** amine; **c.** ester; **d.** alcohol.

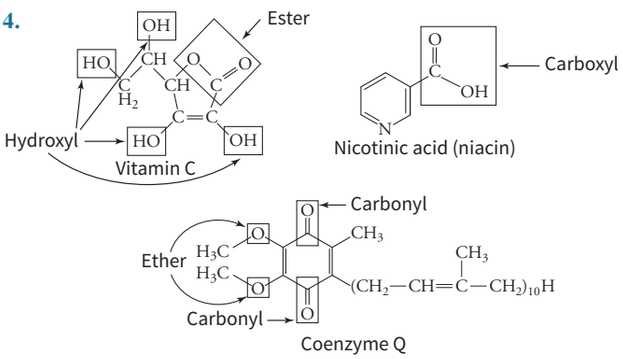
2. **a.** ether; **b.** phosphoric acid ester; **c.** thiol; **d.** ketone.

3.



[From Li, S.-Y., Wang, X.-B., and Kong, L.-Y. *Eur. J. Med. Chem.* **71,** 36–45 (2014).]

4.



5. Amino acids, monosaccharides, nucleotides, and lipids are the four types of biological small molecules. Amino acids, monosaccharides, and nucleotides can form polymers of proteins, polysaccharides, and nucleic acids, respectively.

6. **a.** *N*-acetylglucosamine is a monosaccharide. **b.** CMP is a nucleotide. **c.** Homocysteine is an amino acid. **d.** Cholesteryl ester is a lipid.

7. **a.** C and H plus some O; **b.** C, H, and O; **c.** C, H, O, and N plus small amounts of S.

8. It is a lipid (it is actually lecithin). It is mostly C and H, with relatively little O and only one N and one P. It has too little O to be a carbohydrate, too little N to be a protein, and too little P to be a nucleic acid.

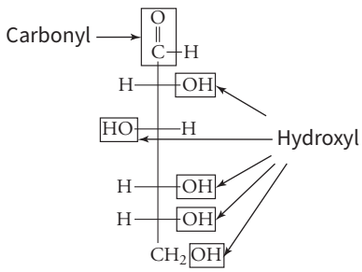
9. You should measure the nitrogen content, since this would indicate the presence of protein (neither lipids nor carbohydrates contain appreciable amounts of nitrogen).

10. You could add the compound that contains the most nitrogen, compound B, which is melamine. [Melamine is a substance that in the past was added to some pet foods and milk products from China so that they would appear to contain more protein. Melamine is toxic to pets and children.] Compound C is an amino acid, so it would already be present in protein-containing food.

11. A diet high in protein results in a high urea concentration, since urea is the body's method of ridding itself of extra nitrogen. Nitrogen is found in proteins but is not found in significant amounts in lipids or carbohydrates. A low-protein diet provides the patient with just enough protein for tissue repair and growth. In the absence of excess protein consumption, urea production decreases, and this puts less strain on the patient's weakened kidneys.

12. Asn has an amido group and Cys has a sulfhydryl group.

13.



14. **a.** Fructose has the same molecular formula, $C_6H_{12}O_6$, as glucose. **b.** Fructose is a ketone, whereas glucose is an aldehyde.

15. Uracil has a carbonyl functional group, whereas cytosine has an amino functional group.

16. Nucleotides consist of a five-carbon sugar, a nitrogenous ring, and one or more phosphoryl groups linked covalently together.

17. As described in the text, palmitate and cholesterol are highly nonpolar and are therefore insoluble in water. Both are highly aliphatic. Alanine is water soluble because its amino group and carboxylate group are ionized, which render the molecule "saltlike." Glucose is also water soluble because its aldehyde group and many hydroxyl groups are able to form hydrogen bonds with water.

18. Glucose has several hydroxyl groups and is a polar molecule. As such, it will have difficulty crossing the nonpolar membrane. The 2,4-dinitrophenol molecule consists of a substituted benzene ring and has greater nonpolar character. Of the two molecules, the 2,4-dinitrophenol will traverse the membrane more easily.

19. DNA forms a more regular structure because DNA consists of only four different nucleotides, whereas proteins are made up of as many as 20 different amino acids. In addition, the 20 amino acids have much more individual variation in their structures than do the four nucleotides. Both of these factors result in a more regular structure for DNA. The cellular role of DNA relies on the *sequence* of the nucleotides that make up the DNA, not on the overall shape of the DNA molecule itself. On the other hand, proteins fold into unique shapes, as illustrated by endothelin in Figure 1.4. The ability of proteins to fold into a wide variety of shapes means that proteins can also serve a wide variety of biochemical roles in the cell. According to Table 1.2, the major roles of proteins in the cell are to carry out metabolic reactions and to support cellular structures.

20. Polysaccharides serve as fuel-storage molecules and can also serve as structural support for the cell.

21. Pancreatic amylase is unable to digest the glycosidic bonds that link the glucose residues in cellulose. Figure 1.6 shows the structural differences between starch and cellulose. Pancreatic amylase binds to starch prior to catalyzing the hydrolysis of the glycosidic bond; thus the enzyme and the starch must have shapes that are complementary. The enzyme would be unable to bind to the cellulose, whose structure is much different from that of starch.

22. Cellulose cannot be digested by mammals and therefore the energy yield is 0 kilocalories per gram. Although both starch and glycogen

are polymers of glucose, the glucose residues are linked differently in the two molecules, and pancreatic amylase is unable to hydrolyze the glycosidic bonds in cellulose (see Solution 21). Cellulose provides no energy to the diet but is an important component of the diet as fiber.

23. A positive entropy change indicates that the system has become more disordered; a negative entropy change indicates that the system has become more ordered. **a.** negative; **b.** positive; **c.** positive; **d.** positive; **e.** negative.

24. **a.** decrease; **b.** increase.

25. The polymeric molecule is more ordered and thus has less entropy. A mixture of constituent monomers has a large number of different arrangements (like the balls scattered on a pool table) and thus has greater entropy.

26. Entropy increases as the reactants (7 molecules) are converted to products (12 molecules).

27. The dissolution of ammonium nitrate in water is a highly endothermic process, as indicated by the positive value of ΔH. This means that when ammonium nitrate dissolves in water, the system absorbs heat from the surroundings and the surroundings become cold. The plastic bag containing the ammonium nitrate becomes cold and can be used as a cold pack to treat an injury.

28. The dissolution of calcium chloride in water is a highly exothermic process, as indicated by the negative value of ΔH. This means that when calcium chloride dissolves in water, the system loses heat to the surroundings and the surroundings become warm. The plastic bag holding the calcium chloride solution becomes warm and can be used as a hot pack by the camper at cold temperatures.

29. The dissolution of urea in water is an endothermic process and has a positive ΔH value. In order for the process to be spontaneous, the process must also have a positive ΔS value in order for the free energy change of the process to be negative. Solutions have a higher degree of entropy than the solvent and solute alone.

30. First, calculate ΔH and ΔS, as described in Sample Calculation 1.1:

$$\Delta H = H_B - H_A$$
$$\Delta H = 60 \text{ kJ} \cdot \text{mol}^{-1} - 54 \text{ kJ} \cdot \text{mol}^{-1}$$
$$\Delta H = 6 \text{ kJ} \cdot \text{mol}^{-1}$$
$$\Delta S = S_B - S_A$$
$$\Delta S = 43 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1} - 22 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$$
$$\Delta S = 21 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$$

a. $\Delta G = (6000 \text{ J} \cdot \text{mol}^{-1}) - (4 + 273 \text{ K})(21 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1})$
$\Delta G = 180 \text{ J} \cdot \text{mol}^{-1}$
The reaction is not favorable at 4°C.
b. $\Delta G = (6000 \text{ J} \cdot \text{mol}^{-1}) - (37 + 273 \text{ K})(21 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1})$
$\Delta G = -510 \text{ J} \cdot \text{mol}^{-1}$
The reaction is favorable at 37°C.

31. $0 > 15{,}000 \text{ J} \cdot \text{mol}^{-1} - (T)(51 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1})$
$-15{,}000 > -(T)(51 \text{ K}^{-1})$
$15{,}000 < (T)(51 \text{ K}^{-1})$
$294 \text{ K} < T$
The reaction is favorable at temperatures of 21°C and higher.

32. Process **a** is always spontaneous; processes **b** and **c** are likely to be spontaneous, depending on the temperature, and process **d** is never spontaneous.

33. $0 > -14.3 \text{ kJ} \cdot \text{mol}^{-1} - (273 + 25 \text{ K})(\Delta S)$
$14.3 \text{ kJ} \cdot \text{mol}^{-1} > -(273 + 25 \text{ K})(\Delta S)$
$-48 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1} > \Delta S$
ΔS could be any positive value, or it could have a negative value smaller than $-48 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$.

34. $-63 \text{ kJ} \cdot \text{mol}^{-1} = \Delta H - (273 + 25 \text{ K})(190 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1})$
$\Delta H = -63 \text{ kJ} \cdot \text{mol}^{-1} + 56.6 \text{ kJ} \cdot \text{mol}^{-1}$
$\Delta H = -6.4 \text{ kJ} \cdot \text{mol}^{-1}$
The reaction releases heat to the surroundings.

35. **a.** Entropy decreases when the antibody–protein complex binds because the value of ΔS is negative.
b. $\Delta G = \Delta H - T\Delta S$
$\Delta G = -87{,}900 \text{ J} \cdot \text{mol}^{-1} - (298 \text{ K})(-118 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1})$
$\Delta G = -52.7 \text{ kJ} \cdot \text{mol}^{-1}$
The negative value of ΔG indicates that the complex forms spontaneously.
c. The second antibody binds to cytochrome *c* more readily than the first because the change in free energy of binding is a more negative value. [From Raman, C. S., Allen, M. J., and Nall, B. T. *Biochemistry* **34,** 5831–5838 (1995).]

36. **a.** The reaction releases heat to the surroundings because the value of ΔH is negative.
b. $\Delta G = \Delta H - T\Delta S$
$-17{,}200 \text{ J} \cdot \text{mol}^{-1} = -9500 \text{ J} \cdot \text{mol}^{-1} - (310 \text{ K})(\Delta S)$
$\Delta S = 25 \text{ J} \cdot \text{K}^{-1} \cdot \text{mol}^{-1}$
The positive value of ΔS indicates that the reaction proceeds with an increase in entropy.
c. The ΔH term makes a greater contribution to the ΔG value. This indicates that the reaction is spontaneous largely because the reaction is exothermic.

37. **a.** The conversion of glucose to glucose-6-phosphate is not favorable because the ΔG value for the reaction is positive, indicating an endergonic process.
b. If the two reactions are coupled, the overall reaction is the sum of the two individual reactions. The ΔG value is the sum of the ΔG values for the two individual reactions.

$$\text{ATP} + \text{glucose} \rightarrow \text{ADP} + \text{glucose-6-phosphate}$$
$$\Delta G = -16.7 \text{ kJ} \cdot \text{mol}^{-1}$$

Coupling the conversion of glucose to glucose-6-phosphate with the hydrolysis of ATP converts an unfavorable reaction to a favorable reaction. The ΔG value of the coupled reaction is negative, which indicates that the reaction as written is favorable.

38. **a.** The reaction is not favorable because the ΔG value for the reaction is positive, indicating an endergonic process.
b.

$\text{GAP} + P_i + \text{NAD}^+ \rightarrow \text{1,3BPG} + \text{NADH}$	$\Delta G = +6.7 \text{ kJ} \cdot \text{mol}^{-1}$
$\text{1,3BPG} + \text{ADP} \rightarrow \text{3PG} + \text{ATP}$	$\Delta G = -18.8 \text{ kJ} \cdot \text{mol}^{-1}$
$\text{GAP} + P_i + \text{NAD}^+ + \text{ADP} \rightarrow \text{3PG} + \text{NADH} + \text{ATP}$	$\Delta G = -12.1 \text{ kJ} \cdot \text{mol}^{-1}$

The coupled reaction is spontaneous because the ΔG value is negative.

39. C (most oxidized), A, B (most reduced)

40. **a.** reduction; **b.** oxidation.

41. **a.** oxidized; **b.** oxidized; **c.** oxidized; **d.** reduced.

42. **a.** oxidizing agent; **b.** oxidizing agent; **c.** oxidizing agent; **d.** reducing agent.

43. **a.** Palmitate's carbon atoms, which have the formula —CH_2—, are more reduced than CO_2, so their reoxidation to CO_2 releases free energy.

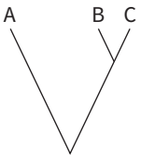
b. Because the —CH_2— groups of palmitate are more reduced than those of glucose (—HCOH—), their conversion to the fully oxidized CO_2 would be even more thermodynamically favorable (have a larger negative value of ΔG) than the conversion of glucose carbons to CO_2. Therefore, palmitate carbons provide more free energy than glucose carbons.

44. The complete oxidation of stearate to CO_2 yields more energy because 17 of the 18 carbons of stearate are fully reduced. The conversion of these carbons to CO_2 provides more free energy than some of the carbons of α-linolenate, which participate in double bonds and are therefore already partially oxidized.

45. Morphological differences, which are useful for classifying large organisms, are not useful for bacteria, which often look alike. Furthermore, microscopic organisms do not leave an easily interpreted imprint in the fossil record, as vertebrates do. Thus, molecular information is often the only means for tracing the evolutionary history of bacteria.

46. It is difficult to envision how a single engulfment event could have given rise to a stable and heritable association of the eukaryotic host and the bacterial dependent within a single generation. It is much more likely that natural selection gradually promoted the interdependence of the cells. Over many generations, genetic information supporting the association would have become widespread.

47.



48. a. H15 and H7 are closely related, as are H4 and H14.

b. H4 and H14 are most closely related to H3.

Chapter 2

1. The water molecule is not perfectly tetrahedral because the electrons in the nonbonding orbitals repel the electrons in the bonding orbitals more than the bonding electrons repel each other. The angle between the bonding orbitals is therefore slightly less than 109°.

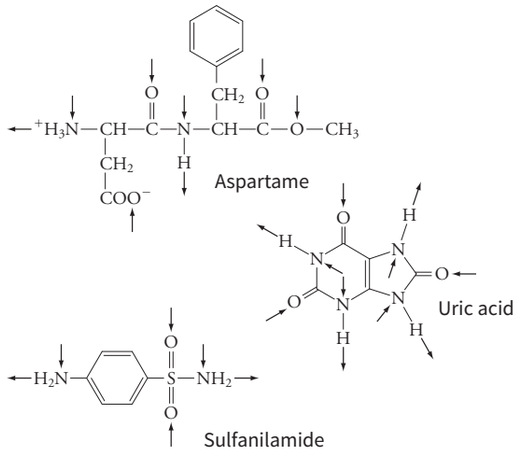
2. Because the partial negative charges are arranged symmetrically (and the shape of the molecule is linear), the molecule as a whole is not polar.

$$\overset{\delta^-}{O}=\overset{\delta^+}{C}=\overset{\delta^-}{O}$$

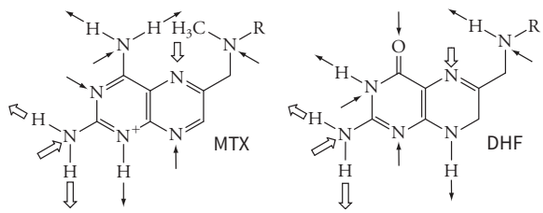
3. Water has the higher boiling point because, although each molecule has the same geometry and can form hydrogen bonds with its neighbors, the hydrogen bonds formed between water molecules are stronger than those formed between H_2S molecules. The electronegativity difference between H and O is greater than that between H and S and results in greater differences in the partial charges on the atoms in the water molecule.

4. Water has the highest melting point because each water molecule forms hydrogen bonds with four neighboring water molecules, and hydrogen bonds are among the strongest intermolecular forces. Ammonia is also capable of forming hydrogen bonds, but they are not as strong (due to the smaller electronegativity difference between hydrogen and nitrogen). Methane cannot form hydrogen bonds; the molecules are attracted to their neighbors only via weak London dispersion forces.

5. The arrows point toward hydrogen acceptors and away from hydrogen donors:

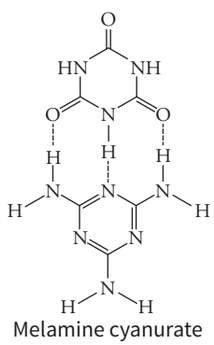


6. Arrows point toward hydrogen acceptors and away from hydrogen donors. [From Kubiny, H., in *3D QSAR in Drug Design: Volume 1: Theory Methods and Application,* Springer Science & Business Media (1993).]



7. Identical hydrogen bonding patterns in the two molecules are shown as open arrows in Solution 6.

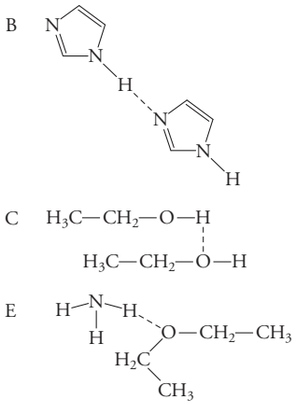
8. [From Puschner, P., Poppenga, R. H., Lowenstine, L. J., Filigenzi, M. S., and Pesavento, P. A. *J. Vet. Diagn. Invest.* **19,** 616–624 (2007).]



9. a. H < C < S < N < O < F

b. The greater an atom's electronegativity, the more polar its bond with H and the greater its ability to act as a hydrogen bond acceptor. Thus, N, O, and F, which have relatively high electronegativities, can act as hydrogen bond acceptors, whereas C and S, whose electronegativities are only slightly greater than hydrogen's, cannot.

10. Compound A does not form hydrogen bonds (the molecule has a hydrogen bond acceptor but no hydrogen bond donor). Compounds B and C form hydrogen bonds as shown because each molecule contains at least one hydrogen bond donor and a hydrogen bond acceptor. The molecules in D do not form hydrogen bonds with each other because ethyl chloride lacks both a hydrogen bond donor and a hydrogen bond acceptor. The molecules in E do because ammonia has a hydrogen bond donor and diethyl ether has a hydrogen bond acceptor:



11. **a.** van der Waals forces (dipole–dipole interactions); **b.** hydrogen bonding; **c.** van der Waals forces (London dispersion forces); **d.** ionic interactions.

12. **a.** hydrogen bonding; **b.** ionic interactions; **c.** van der Waals forces (London dispersion forces).

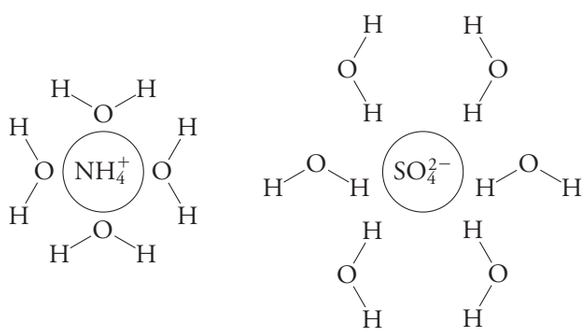
13. Solubility in water decreases as the number of carbons in the alcohol increases. The hydroxyl group of the alcohol is able to form hydrogen bonds with water, but water cannot interact favorably with the hydrocarbon chain. Increasing the length of the chain increases the number of potentially unfavorable interactions of the alcohol with water and solubility decreases as a result.

14. Solubility in water and dielectric constants are correlated; low molecular weight alcohols are miscible with water and have a high dielectric constant; high molecular weight alcohols are not very soluble in water and have a low dielectric constant.

15. Aquatic organisms that live in the pond are able to survive the winter. Since the water at the bottom of the pond remains in the liquid form instead of freezing, the organisms are able to move around. The ice on top of the pond also serves as an insulating layer from the cold winter air.

16. Water is unique in that its liquid form is more dense than its solid form. The weight of the skater puts pressure on the thin blade of the ice skate. The ice melts under the blade because of this increased pressure. A higher pressure favors the liquid form of water over the solid form because the liquid form is more dense and takes up less volume.

17. The positively charged ammonium ion is surrounded by a shell of water molecules that are oriented so that the partially negatively charged oxygen atoms interact with the positive charge on the ammonium ion. Similarly, the negatively charged sulfate ion is hydrated with water molecules oriented so that the partially positively charged hydrogen atoms interact with the negative charge on the sulfate anion. (Not shown in the diagram is the fact that the ammonium ions outnumber the sulfate ions by a 2:1 ratio. Also note that the exact number of water molecules shown is unimportant.)



18. Methanol, which has the highest dielectric constant, would be the best solvent for the cationic NH_4^+. The polarity of the alcohols, which all contain a primary —OH group, varies with the size of the hydrocarbon portion. 1-Butanol, with the largest hydrophobic group, is the least polar and therefore has the lowest dielectric constant.

19. Structure A depicts a polar compound, while structure B depicts an ionic compound similar to a salt like sodium chloride. This is more consistent with glycine's physical properties as a white crystalline solid with a high melting point. While structure A could be water soluble because of its ability to form hydrogen bonds, the high solubility of glycine in water is more consistent with an ionic compound whose positively and negatively charged groups are hydrated in aqueous solution by water molecules.

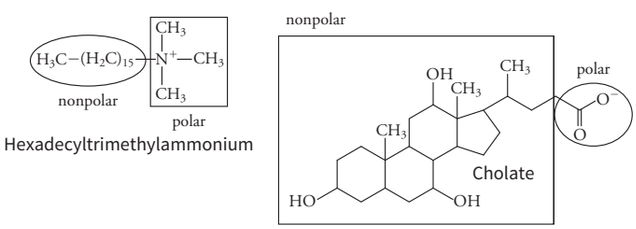
20. **a.** Surface tension is defined as the force that must be applied to surface molecules in a liquid so that they may experience the same forces as the molecules in the interior of the liquid. Water's surface tension is greater than ethanol's because the strength and number of water's intermolecular forces (hydrogen bonds) are both greater. Ethanol's —OH group also forms hydrogen bonds, but the hydrocarbon portion of the molecule cannot interact favorably with water, and weaker London dispersion forces form instead.

b. The kinetic energy of the water molecules increases when temperature increases. Intermolecular forces are weaker in strength as a consequence of the increased molecular motion. Because surface tension increases when the strength of intermolecular forces increases as described in part (a), surface tension decreases when temperature increases.

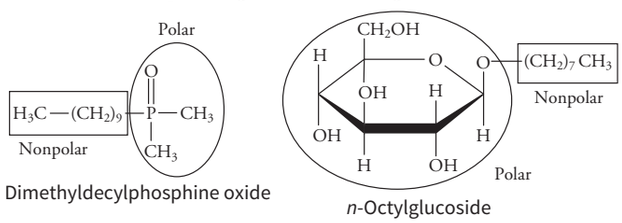
21. The waxed car is a hydrophobic surface. To minimize its interaction with the hydrophobic molecules (wax), each water drop minimizes its surface area by becoming a sphere (the geometrical shape with the lowest possible ratio of surface to volume). Water does not bead on glass, because the glass presents a hydrophilic surface with which the water molecules can interact. This allows the water to spread out.

22. The paper clip, although composed of a metal with a greater density than water, floats due to the strong hydrogen bonding that occurs among water molecules on the surface of the liquid. Soap disrupts these strong intermolecular forces and as a result the paper clip sinks to the bottom of the container.

23. Polar and nonpolar regions of the detergents are indicated.



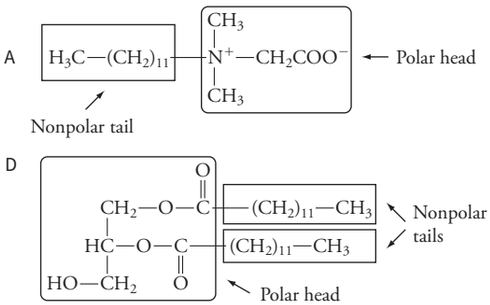
24. Polar and nonpolar regions of the detergents are indicated.



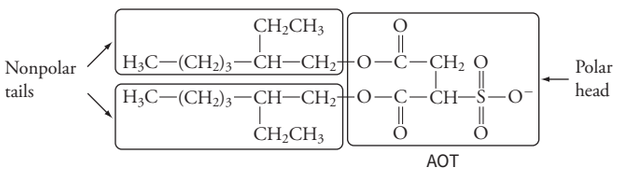
25. Compounds A and D are amphiphilic, compound B is nonpolar, and compounds C and E are polar.

26. Compound A has a polar head and a nonpolar tail as indicated and can form a micelle (see Fig. 2.9). Compound D has a polar head

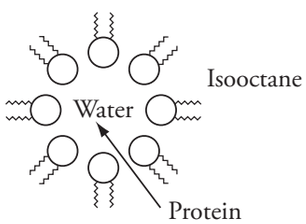
and two nonpolar tails as indicated and can form a bilayer (see Fig. 2.10). Compounds B, C, and E form neither micelles nor bilayers.



27. a. In the nonpolar solvent, AOT's polar head group faces the interior of the micelle, and its nonpolar tails face the solvent.



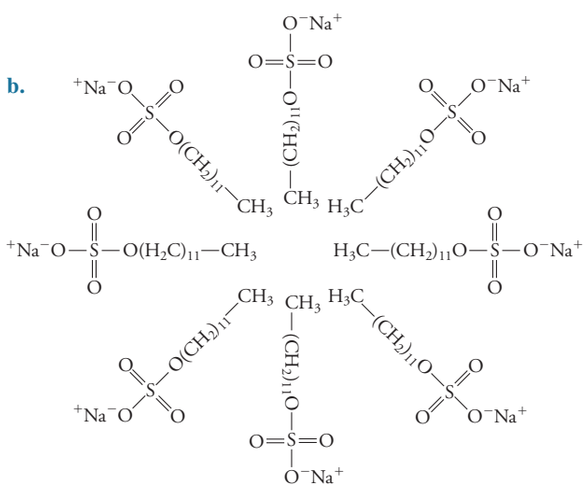
b. The protein, which contains numerous polar groups, interacts with the polar AOT groups in the micelle interior.



28.

a. Nonpolar tail → $H_3C-(CH_2)_{11}-O-S(=O)(=O)-O^-Na^+$ ← Polar head

b.



c. The hydrophobic grease moves into the hydrophobic core of the water-soluble soap micelle. The "dissolved" grease can then be washed away with the micelle.

29. a. The nonpolar core of the lipid bilayer helps prevent the passage of water since the polar water molecules cannot easily penetrate the hydrophobic core of the bilayer. **b.** Most human cells are surrounded by a fluid containing about 150 mM Na^+ and slightly less Cl^- (see Fig. 2.12). A solution containing 150 mM NaCl mimics the extracellular fluid and therefore helps maintain the isolated cells in near-normal conditions. If the cells were placed in pure water, water would tend to enter the cells by osmosis; this might cause the cells to burst.

30. In reverse osmosis, water moves from an area of low concentration (high solute concentration) to an area of high concentration (low solute concentration). This movement is opposite that described for osmosis in Problem 29. This is a non-spontaneous process that requires an input of energy in order to proceed, unlike osmosis, which occurs spontaneously without input of energy.

31. a. CO_2 is nonpolar and would be able to cross a bilayer. **b.** Glucose is polar and would not be able to pass through a bilayer because the presence of the hydroxyl groups means glucose is highly hydrated and would not be able to pass through the nonpolar tails of the molecules forming the bilayer. **c.** DNP is nonpolar and would be able to cross a bilayer. **d.** Calcium ions are charged and are, like glucose, highly hydrated and would not be able to cross a lipid bilayer.

32. Vesicles consist of a lipid bilayer that closes up to enclose an aqueous compartment. The polar drug readily dissolves in this aqueous compartment. Delivery to the cell is accomplished when the vesicle membrane fuses with the cell membrane, releasing the drug into the cytosol.

33. Substances present at high concentration move to an area of low concentration spontaneously, or "down" a concentration gradient in a process that increases their entropy. The export of Na^+ ions from the cell requires that the sodium ions be transported from an area of low concentration to an area of high concentration. The same is true for potassium transport. Thus, these processes are not spontaneous, and an input of cellular energy is required to accomplish the transport.

34. The amount of Na^+ (atomic weight 23 g · mol^{-1}) lost in 15 minutes, assuming a fluid loss rate of 2 L per hour and a sweat Na^+ concentration of 50 mM (Box 2.B), is

$$0.25\text{ h} \times \frac{2\text{ L}}{\text{h}} \times \frac{0.05\text{ mol}}{\text{L}} \times \frac{23\text{ g}}{\text{mol}} \times \frac{1000\text{ mg Na}^+}{\text{g Na}^+} \times \frac{1\text{ oz chips}}{200\text{ mg Na}^+} = 2.9\text{ oz chips}$$

It would take 2.9 ounces of potato chips (about a handful) to replace the lost sodium ions.

35. a. In a high-solute medium, the cytoplasm loses water and therefore its volume decreases. **b.** In a low-solute medium, the cytoplasm gains water and therefore its volume increases.

36. *E. coli* accumulates water when grown in a low-salt medium. However, regulation of water content only would cause a large increase in cytoplasmic volume. To avoid this large increase in volume, *E. coli* also exports K^+ ions. The opposite occurs when *E. coli* is grown in a high-salt medium: The cytoplasmic water content is decreased, but cytoplasmic osmolarity increases as *E. coli* imports K^+ ions. [From Record, M.T., et al., *Trends Biochem. Sci.* **23**, 143–148 (1998).]

37. Since the molecular mass of H_2O is 18.0 g · mol^{-1}, a given volume (for example, 1 L or 1000 g) has a molar concentration of 1000 g · L^{-1} ÷ 18.0 g · mol^{-1} = 55.5 M. By definition, a liter of water at pH 7.0 has

a hydrogen ion concentration of 1.0×10^{-7} M. Therefore the ratio of $[H_2O]$ to $[H^+]$ is 55.5 M/$(1.0 \times 10^{-7}$ M) = 5.55×10^8.

38. $[H^+] = [OH^-] = 1.47 \times 10^{-14}$

$[H^+] = \sqrt{1.47 \times 10^{-14}}$

$[H^+] = 1.21 \times 10^{-7}$ M

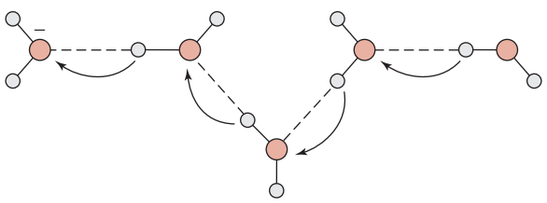
$pH = -\log(1.21 \times 10^{-7}\text{ M})$

$pH = 6.92$

39. The HCl is a strong acid and dissociates completely. This means that the concentration of hydrogen ions contributed by the HCl is 1.0×10^{-9} M. But the concentration of the hydrogen ions contributed by the dissociation of water is 100-fold greater than this: 1.0×10^{-7} M. The concentration of the hydrogen ions contributed by the HCl is negligible in comparison. Therefore, the pH of the solution is equal to 7.0.

40. The pH of this solution is 7.0 (see Solution 39).The concentration of hydroxide ions contributed by the dissociation of water is 100-fold greater than that contributed by the dissociation of the dilute NaOH.

41.



42.

	Acid, base, or neutral?	pH	$[H^+]$ (M)	$[OH^-]$ (M)
Blood	base	7.42	3.8×10^{-8}	2.6×10^{-7}
Saliva	neutral	7.00	1.0×10^{-7}	1.0×10^{-7}
Urine	acid	6.80	1.6×10^{-7}	6.3×10^{-8}
Gastric juice	acid	2.10	7.9×10^{-3}	1.3×10^{-12}

43. The stomach contents have a low pH due to the contribution of gastric juice (pH 1.5–3.0). When the partially digested material enters the small intestine, the addition of pancreatic juice (pH 7.8–8.0) neutralizes the acid and increases the pH.

44. The carbonate ions accept protons from water and form hydroxide ions (as shown in the equation below), resulting in basic urine.

$$CO_3^{2-}(aq) + H_2O(l) \rightarrow HCO_3^-(aq) + OH^-(aq)$$

45. **a.** $C_2O_4^{2-}$ **b.** SO_3^{2-} **c.** HPO_4^{2-} **d.** CO_3^{2-} **e.** AsO_4^{3-} **f.** PO_4^{3-} **g.** O_2^{2-}

46. **a.** $H_2C_2O_4$ **b.** H_2SO_3 **c.** H_3PO_4 **d.** H_2CO_3 **e.** $H_2AsO_4^-$ **f.** $H_2PO_4^-$ **g.** H_2O_2

47. **a.** The final concentration of HNO_3 is $\frac{(0.020\text{ L})(1.0\text{ M})}{0.520\text{ L}} =$ 0.038 M. Since HNO_3 is a strong acid and dissociates completely, the added $[H^+]$ is equal to $[HNO_3]$. (The existing hydrogen ion concentration in the water itself, 1.0×10^{-7} M, can be ignored because it is much smaller than the hydrogen ion concentration contributed by the nitric acid.)

$$pH = -\log[H^+]$$
$$pH = -\log(0.038)$$
$$pH = 1.4$$

b. The final concentration of KOH is $\frac{(0.015\text{ L})(1.0\text{ M})}{0.515\text{ L}} = 0.029$ M

Since KOH dissociates completely, the added $[OH^-]$ is equal to the [KOH]. (The existing hydroxide ion concentration in the water itself, 1.0×10^{-7} M, can be ignored because it is much smaller than the hydroxide ion concentration contributed by the KOH.)

$$K_w = 1.0 \times 10^{-14} = [H^+][OH^-]$$
$$[H^+] = \frac{1.0 \times 10^{-14}}{[OH^-]}$$
$$[H^+] = \frac{1.0 \times 10^{-14}}{(0.029\text{ M})}$$
$$[H^+] = 3.4 \times 10^{-13}\text{ M}$$
$$pH = -\log[H^+]$$
$$pH = -\log(3.4 \times 10^{-13})$$
$$pH = 12.5$$

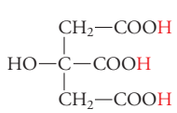
48. **a.** The final concentration of HCl is (0.0015 L)(3 mol/L) ÷ 1 L = 0.0045 M. Since HCl is a strong acid and dissociates completely, the added $[H^+]$ is equal to [HCl]. (The existing hydrogen ion concentration in the water itself, 1.0×10^{-7} M, can be ignored because it is much smaller than the hydrogen ion concentration contributed by the hydrochloric acid.)

$$pH = -\log[H^+]$$
$$pH = -\log(0.0045)$$
$$pH = 2.3$$

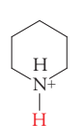
b. The final concentration of NaOH is (0.0015 L)(3 mol/L) ÷ 1 L = 0.0045 M. Since NaOH dissociates completely, the added $[OH^-]$ is equal to the [NaOH]. (The existing hydroxide ion concentration in the water itself, 1.0×10^{-7} M, can be ignored because it is much smaller than the hydroxide ion concentration contributed by the NaOH.)

$$K_w = 1.0 \times 10^{-14} = [H^+][OH^-]$$
$$[H^+] = \frac{1.0 \times 10^{-14}}{[OH^-]}$$
$$[H^+] = \frac{1.0 \times 10^{-14}}{(0.0045\text{ M})}$$
$$[H^+] = 2.2 \times 10^{-12}\text{ M}$$
$$pH = -\log[H^+]$$
$$pH = -\log(2.2 \times 10^{-12})$$
$$pH = 11.6$$

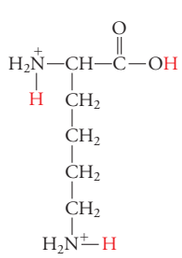
49.



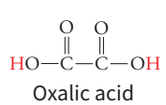
Citric acid



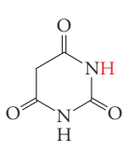
Piperidine



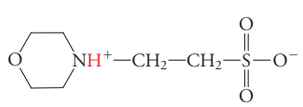
Lysine



Oxalic acid



Barbituric acid



4-Morphine ethanesulfonic acid (MES)

50. Convert all the data to either K_a or pK values to evaluate (pK = –logK_a). The greater the K_a value, the stronger the acid—that is, the greater the tendency for the proton to be donated. (The lower the pK value, the stronger the acid.) From strongest to weakest acid: E, D, B, A, C. Note that the stronger the acid, the weaker its conjugate base. For example, citric acid is a stronger acid than citrate, and succinic acid is a stronger acid than succinate.

	Acid	K_a	pK
A	citrate	1.74×10^{-5}	4.76
B	succinic acid	6.17×10^{-5}	4.21
C	succinate	2.29×10^{-6}	5.64
D	formic acid	1.78×10^{-4}	3.75
E	citric acid	7.41×10^{-4}	3.13

51. Calculate the final concentrations of the weak acid ($H_2PO_4^-$) and conjugate base (HPO_4^{2-}). Note that K^+ is a spectator ion.

$$[H_2PO_4^-] = \frac{(0.025\ \text{L})(2.0\ \text{M})}{0.200\ \text{L}} = 0.25\ \text{M}$$

$$[HPO_4^{2-}] = \frac{(0.050\ \text{L})(2.0\ \text{M})}{0.200\ \text{L}} = 0.50\ \text{M}$$

Next, substitute these values into the Henderson–Hasselbalch equation using the pK values in Table 2.4:

$$\text{pH} = \text{p}K + \log\frac{[\text{A}^-]}{[\text{HA}]}$$

$$\text{pH} = 6.82 + \log(0.50\ \text{M})/(0.25\ \text{M})$$

$$\text{pH} = 6.82 + 0.30$$

$$\text{pH} = 7.12$$

52. Use the pK value in Table 2.4 and the Henderson–Hasselbalch equation to calculate the ratio of the concentrations of imidazole (A^-) and the imidazolium ion (HA):

$$\text{pH} = \text{p}K + \log\frac{[\text{A}^-]}{[\text{HA}]}$$

$$\log\frac{[\text{A}^-]}{[\text{HA}]} = \text{pH} - \text{p}K$$

$$\frac{[\text{A}^-]}{[\text{HA}]} = 10^{(\text{pH}-\text{p}K)}$$

$$\frac{[\text{A}^-]}{[\text{HA}]} = 10^{(7.4-7.0)}$$

$$\frac{[\text{A}^-]}{[\text{HA}]} = \frac{2.5}{1}$$

53. The final volume is 500 mL + 10 mL + 20 mL = 0.53 L

$$[\text{boric acid}] = [\text{HA}] = \frac{(0.01\ \text{L})(0.05\ \text{M})}{0.53\ \text{L}} = 9.4 \times 10^{-4}\ \text{M}$$

$$[\text{borate}] = [\text{A}^-] = \frac{(0.02\ \text{L})(0.02\ \text{M})}{0.53\ \text{L}} = 7.5 \times 10^{-4}\ \text{M}$$

$$\text{pH} = \text{p}K + \log\frac{[\text{A}^-]}{[\text{HA}]}$$

$$= 9.24 + \log\frac{7.5 \times 10^{-4}}{9.4 \times 10^{-4}}$$

$$= 9.24 - 0.10 = 9.14$$

54.

$$\text{pH} = \text{p}K + \log\frac{[\text{A}^-]}{[\text{HA}]}$$

$$\log\frac{[\text{A}^-]}{[\text{HA}]} = \text{pH} - \text{p}K = 5.0 - 4.76 = 0.24$$

$$\frac{[\text{A}^-]}{[\text{HA}]} = 1.74 \text{ or } [\text{A}^-] = 1.74\ [\text{HA}]$$

$$[\text{A}^-] = 1.74[\text{HA}] = 1.74(0.05\ \text{M} - [\text{A}^-])$$

$$[\text{A}^-] = 0.087 - 1.74[\text{A}^-]$$

$$2.74[\text{A}^-] = 0.087\ \text{M}$$

$$[\text{A}^-] = 0.032\ \text{M or } 32\ \text{mM}$$

55. First, determine the ratio of $[A^-]$ to [HA]:

$$\text{pH} = \text{p}K + \log\frac{[\text{A}^-]}{[\text{HA}]}$$

$$\log\frac{[\text{A}^-]}{[\text{HA}]} = \text{pH} - \text{p}K$$

$$\frac{[\text{A}^-]}{[\text{HA}]} = 10^{(\text{pH}-\text{p}K)}$$

Substitute the values for the desired pH (5.0) and the pK (4.76):

$$\frac{[\text{A}^-]}{[\text{HA}]} = 10^{(5.0-4.76)} = 10^{0.24} = 1.74$$

Calculate the number of moles of acetate (A^-) already present:

$$(0.50\ \text{L})(0.20\ \text{mol} \cdot \text{L}^{-1}) = 0.10\ \text{moles acetate}$$

Calculate the moles of acetic acid needed, based on the calculated ratio:

$$\frac{[\text{A}^-]}{[\text{HA}]} = 1.74$$

$$[\text{HA}] = \frac{0.10\ \text{moles}}{1.74}$$

$$[\text{HA}] = 0.057\ \text{moles}$$

Finally, calculate the volume of glacial acetic acid needed:

$$\frac{0.057\ \text{moles}}{17.4\ \text{mol} \cdot \text{L}^{-1}} = 0.0033\ \text{L, or } 3.3\ \text{mL}$$

The addition of 3.3 mL to a 500-mL solution dilutes the solution by less than 1%, which doesn't introduce significant error.

56. Adding NaOH to the acetic acid will convert some of the acetic acid (HA) to acetate (A^-):

$$\text{NaOH} + \text{CH}_3\text{COOH} \rightarrow \text{Na}^+ + \text{CH}_3\text{COO}^- + \text{H}_2\text{O}$$

For every mole of NaOH added, one mole of CH_3COOH will be consumed, and one mole of CH_3COO^- will be generated. If x is the number of moles of NaOH added, then x will also be the number of moles of A^- generated.

Calculate the initial amount of acetic acid:

The initial amount of acetic acid is 0.10 mol (see Solution 55), so the final amount of acetic acid will be 0.10 mol – x.

$$\frac{[\text{A}^-]}{[\text{HA}]} = 1.74 = \frac{x}{0.10\ \text{mol} - x}$$

$$x = 1.74(0.10\ \text{mol} - x) = 0.174\ \text{mol} - 1.74\,x$$

$$2.74\,x = 0.174\ \text{mol}$$

$$x = 0.174\ \text{mol}/2.74 = 0.0635\ \text{mol}$$

Calculate the mass of NaOH to add:

$$0.0635\ \text{mol} \times 40.0\ \text{g} \cdot \text{mol}^{-1} = 2.54\ \text{g}$$

57. a.

$$H_2CO_3 \rightarrow H^+ + HCO_3^-$$
$$HCO_3^- \rightarrow H^+ + CO_3^{2-}$$

b. The pK of the first dissociation is closer to the pH; therefore the weak acid present in blood is H_2CO_3 and the conjugate base is HCO_3^-.

c.

$$\text{pH} = \text{p}K + \log\frac{[HCO_3^-]}{[H_2CO_3]}$$

$$7.40 = 6.35 + \log\frac{24 \times 10^{-3}\,\text{M}}{[H_2CO_3]}$$

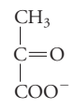
$$1.05 = \log\frac{24 \times 10^{-3}\,\text{M}}{[H_2CO_3]}$$

$$11.2 = \frac{24 \times 10^{-3}\,\text{M}}{[H_2CO_3]}$$

$$[H_2CO_3] = 2.1 \times 10^{-3}\,\text{M} = 2.1\,\text{mM}$$

58. The pK of the fluorinated compound would be lower (it is 9.0); that is, the compound becomes less basic and more acidic. This occurs because the F atom, which is highly electronegative, pulls on the nitrogen's electrons, loosening its hold on the proton.

59. a.



Pyruvate

b. Pyruvate predominates in the cell at pH 7.4. The pK values for carboxylic acid groups are typically in the 2–3 range; therefore, the carboxylate group will be unprotonated at physiological pH.

60.

pH 2 $^+H_3N{-}CH_2{-}COOH$

pH 7 $^+H_3N{-}CH_2{-}COO^-$

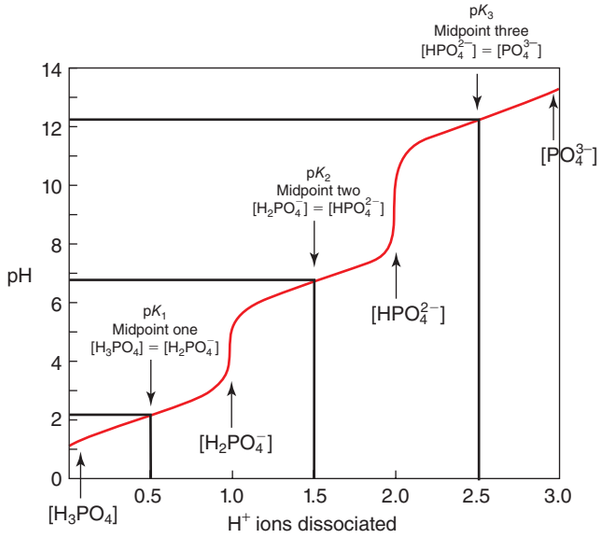
pH 10 $H_2N{-}CH_2{-}COO^-$

The carboxylic acid group has a pK of 2.35, and the amino group has a pK of 9.78. The Henderson–Hasselbalch equation can be used to calculate the exact percentage of protonated/unprotonated forms of each functional group, but that really isn't necessary. Instead, the pK values for each group should be compared to the pH. At pH = 2, the pH is below both pK values, so both functional groups are mostly protonated. At pH = 7, the pH is well above the pK for the carboxylic acid group but below the pK for the amino group. Therefore the carboxylic acid group is unprotonated and the amino group is protonated. At pH = 10, the pH is above the pK values of both functional groups. Thus, both groups are mostly unprotonated.

61. a. 10 mM glycinamide buffer, because its pK is closer to the desired pH. **b.** 20 mM Tris buffer, because the higher the concentration of the buffering species, the more acid or base it can neutralize. **c.** Neither. Both a weak acid and a conjugate base are required buffer constituents. Neither the weak acid alone (boric acid) nor the conjugate base alone (sodium borate) can serve as an effective buffer.

62. a. 10 mM acetic acid buffer, because its pK is closer to the desired pH. **b.** 20 mM acetic acid buffer, because the higher concentration of buffer species will allow it to neutralize a greater amount of acid or base. **c.** Neither. Both a weak acid and a conjugate base are required buffer constituents. Neither the weak acid alone (acetic acid) nor the conjugate base alone (sodium acetate) can serve as an effective buffer.

63. a. The three ionizable protons of phosphoric acid have pK values of 2.15, 6.82, and 12.38 (Table 2.4). The pK values are the midpoints of the titration curve:



b.

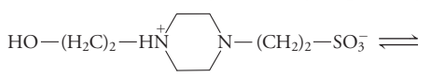
$$H_3PO_4 \rightarrow H^+ + H_2PO_4^-$$
$$H_2PO_4^- \rightarrow H^+ + HPO_4^{2-}$$
$$HPO_4^{2-} \rightarrow H^+ + PO_4^{3-}$$

c. The dissociation of the second proton has a pK of 6.82, which is closest to the pH of blood. Therefore the weak acid present in blood is $H_2PO_4^-$ and the weak base is HPO_4^{2-}.

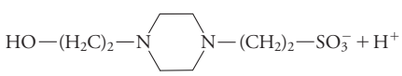
d. The dissociation of the third proton has a pK of 12.38. Therefore, a buffer solution at pH 11 would consist of the weak acid HPO_4^{2-} and its conjugate base, PO_4^{3-} (supplied as the sodium salts Na_2HPO_4 and Na_3PO_4).

64. The aspirin is more likely to be absorbed in the stomach at pH 2. At this pH, the carboxylate group is mostly protonated and uncharged. This allows the aspirin to pass more easily through the nonpolar lipid bilayer. At the pH of the small intestine, the carboxylate group is mostly in the ionized form and will be negatively charged. Charged species are more polar than uncharged species (and are likely to be hydrated) and will have difficulty traversing a lipid bilayer.

65. a.



Weak acid (HA)



Conjugate base (A)

b. The pK for HEPES is 7.55; therefore, its effective buffering range is 6.55–8.55.

c.

$$1.0\,\text{L} \times \frac{0.10\,\text{mole}}{\text{L}} \times \frac{260.3\,\text{g}}{\text{mol}} = 26\,\text{g}$$

Weigh 26 g of the HEPES salt and add to a beaker. Dissolve in slightly less than 1.0 liter of water (leave "room" for the HCl solution that will be added in the next step).

d. At the final pH,

$$\frac{[A^-]}{[HA]} = 10^{(\text{pH}-\text{p}K)} = 10^{(8.0-7.55)} = 10^{0.45} = 2.82$$

For each mole of HCl added, x, one mole of HEPES salt (A^-) will be converted to a mole of HEPES acid (HA). The starting amount of A^- is (1.0 L)(0.10 mol · L^{-1}) = 0.10 moles. After the HCl is added, the amount of A^- will be 0.10 moles – x, and the amount of HA will be x. Consequently,

$$\frac{[A^-]}{[HA]} = 2.82 = \frac{0.10 \text{ mole} - x}{x}$$

$$2.82x = 0.10 \text{ mol} - x$$

$$3.82x = 0.10 \text{ mol}$$

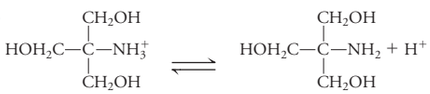
$$x = 0.10 \text{ mol}/3.82 = 0.0262 \text{ mol}$$

Calculate how much 6.0 M HCl to add:

$$\frac{0.0262 \text{ mol}}{6.0 \text{ mol} \cdot L^{-1}} = 0.0044 \text{ L, or } 4.4 \text{ mL}$$

To make the buffer, dissolve 26 g of HEPES salt [see part c] in less than 1.0 L. Add 4.4 mL of 6.0 M HCl, then add water to bring the final volume to 1.0 L.

66. a.



Weak acid (HA) Conjugate base (A^-)

b. The pK of Tris is 8.30; therefore, its effective buffering range is 7.30–9.30.

c. Rearranging the Henderson–Hasselbalch equation gives

$$\frac{[A^-]}{[HA]} = 10^{(pH-pK)} = 10^{(8.2-8.3)} = 10^{-0.1} = 0.79$$

Since $[A^-] + [HA] = 0.10$ M, $[A^-] = 0.10 \text{ M} - [HA]$, and $\dfrac{(0.10 \text{ M} - [HA])}{[HA]} = 0.79$

$$0.79\,[HA] = 0.10 \text{ M} - [HA]$$

$$1.79\,[HA] = 0.10 \text{ M}$$

$$[HA] = \frac{0.10 \text{ M}}{1.79} = 0.056 \text{ M} = 56 \text{ mM}$$

$[A^-] + [HA] = 0.10 \text{ M} = 100 \text{ mM}$, so $[A^-] = 44$ mM

d. When HCl is added, an equivalent amount of Tris base (A^-) is converted to Tris acid (HA).

Let x = moles of H^+ added = (0.0015 L)(3.0 mol · L^{-1}) = 0.0045 moles = 4.5 mmol.

The final amount of A^- is 44 mmol – 4.5 mmol = 39.5 mmol.

The final amount of HA is 56 mmol + 4.5 mmol = 60.5 mmol.

Use the Henderson–Hasselbalch equation to calculate the new pH:

$$pH = pK + \log\frac{[A^-]}{[HA]}$$

$$pH = 8.3 + \log\frac{39.5 \text{ mmol} \div 1001.5 \text{ mL}}{60.5 \text{ mmol} \div 1001.5 \text{ mL}}$$

$$pH = 8.3 + (-0.2)$$

$$pH = 8.1$$

The buffer is effective: The pH decreases about 0.1 unit (from 8.2 to 8.1) with the addition of the strong acid. In comparison, the addition of the same amount of acid to water, which is not buffered, results in a pH change from approximately 7.0 to 2.3 (see Problem 48a).

e. When NaOH is added, an equivalent amount of Tris acid (HA) is converted to Tris base (A^-). Let x = moles of OH^- added = (0.0015 L)(3.0 mol · L^{-1}) = 0.0045 moles = 4.5 mmol.

The final amount of A^- is 44 mmol + 4.5 mmol = 48.5 mmol.

The final amount of HA is 56 mmol – 4.5 mmol = 51.5 mmol.

Use the Henderson–Hasselbalch equation to calculate the new pH:

$$pH = pK + \log\frac{[A^-]}{[HA]}$$

$$pH = 8.3 + \log\frac{48.5 \text{ mmol} \div 1001.5 \text{ mL}}{51.5 \text{ mmol} \div 1001.5 \text{ mL}}$$

$$pH = 8.3 + (-0.026)$$

$$pH = 8.27$$

The buffer is effective: The pH increases only 0.07 unit (from 8.2 to 8.27) with the addition of the strong base. In comparison, the addition of the same amount of base to water, which is not buffered, results in a pH change from approximately 7.0 to 11.6 (see Problem 48b).

67.

$$pH = pK + \log\frac{[A^-]}{[HA]}$$

$$\log\frac{[A^-]}{[HA]} = pH - pK$$

$$\frac{[A^-]}{[HA]} = 10^{(pH-pK)}$$

$$\frac{[A^-]}{[HA]} = 10^{(6.5-7.0)} = 10^{-0.5} = 0.316$$

Since the starting solution contains (0.5 L)(0.01 mol · L^{-1}) = 0.005 mole of imidazole (A^-), the amount of imidazolium chloride (HA) needed is 0.005 mol/0.316 = 0.016 moles. The stock imidazolium chloride is 1 M, so the volume of imidazolium chloride to be added is

$$\frac{0.016 \text{ mol}}{1.0 \text{ mol} \cdot L^{-1}} = 0.016 \text{ L or16 mL}$$

68. a. First, calculate the ratio of $[A^-]$ to [HA]. Rearranging the Henderson–Hasselbalch equation gives

$$\frac{[A^-]}{[HA]} = 10^{(pH-pK)} = 10^{(2.0-8.3)} = 10^{-6.3} = 5 \times 10^{-7}$$

Virtually all of the Tris is in the weak acid form. Therefore, the concentration of the weak acid, HA, is 0.10 M and the concentration of the conjugate base, A^-, is 5.0×10^{-8} M.

b. The added HCl dissociates completely, so the amount of H^+ added is (0.0015 L)(3.0 mol · L^{-1}) = 0.0045 mol. In an effective buffer, the acid would convert some of the conjugate Tris base to weak acid. But the concentration of conjugate base is already negligible. Therefore, the moles of additional H^+ should be added to the concentration of hydrogen ions already present (1.0×10^{-2} M), for a total concentration of 0.0145 M.

$$pH = -\log[H^+] = \log(0.0145 \text{ M}) = 1.84$$

The buffer has not functioned effectively. There was not enough conjugate base to react with the additional hydrogen ions added. The result is a decrease in pH from 2.0 to 1.84.

c. When NaOH is added, an equivalent amount of Tris acid (HA) is converted to Tris base (A^-). Let x = moles of OH^- added = (0.0015 L)(3.0 mol · L^{-1}) = 0.0045 moles = 4.5 mmol.

The final amount of A^- is 5.0×10^{-8} mol + 4.5 mmol = 4.5 mmol.

The final amount of HA is 100 mmol – 4.5 mmol = 95.5 mmol.

The new pH is determined by substituting the new concentrations of H^- and HA into the Henderson–Hasselbalch equation:

$$pH = pK + \log\frac{[A^-]}{[HA]}$$

$$pH = 8.3 + \log\frac{(4.5 \text{ mmol} \div 1001.5 \text{ mL})}{(95.5 \text{ mmol} \div 1001.5 \text{ mL})}$$

$$pH = 8.3 + (-1.3) = 7.0$$

Tris is not an effective buffer at pH 2.0, a pH more than 6 units lower than its pK value. Virtually all of the Tris is in the weak acid form at this pH. If acid is added, there is not enough base to absorb the excess added hydrogen ions, and the pH decreases. If base is added, some of the weak acid is converted to the conjugate base and the pH approaches the value of the pK.

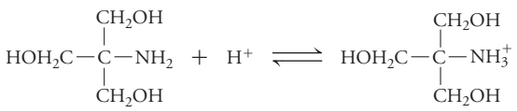
69. $H^+(aq) + HCO_3^-(aq) \rightleftharpoons H_2CO_3(aq) \rightleftharpoons H_2O(l) + CO_2(aq)$

Failure to eliminate CO_2 in the lungs would cause a buildup of $CO_2(aq)$. This would shift the equilibrium of the above equations to the left. The increase in $CO_2(aq)$ would lead to the increased production of carbonic acid, which would in turn dissociate to form additional hydrogen ions, causing acidosis.

70. a. Mechanical hyperventilation removes CO_2 from the patient's lungs. Carbonic acid in the blood would produce more water and CO_2 to make up for the loss of CO_2. This in turn would cause additional hydrogen ions and bicarbonate ions to form more carbonic acid. The loss of hydrogen ions would result in an increased pH, bringing the patient's pH back to normal.

b. The additional bicarbonate would combine with hydrogen ions to form carbonic acid. The additional carbonic acid would dissociate to form water and carbon dioxide. This helps alleviate the acidosis because the bicarbonate combines with excess hydrogen ions, thus decreasing the hydrogen ion concentration and increasing the pH. However, it is not acceptable for use in patients with ALI because of the increased production of aqueous CO_2 in the blood. The CO_2 produced would need to be exhaled in the lungs, which would be difficult in patients with ALI.

c. Tris becomes protonated to form its conjugate acid. This removes H^+ from circulation and brings the pH back to normal. The protonated form of Tris is excreted in the urine. This method of acidosis treatment does not involve exhalation of CO_2 and is therefore an acceptable treatment for patients with ALI.



[From Kallet, R. H., et al., *Am. J. Respir. Crit. Care Med.* **161,** 1149–1153 (2000).]

71. During hyperventilation, too much CO_2 (which is equivalent to H^+ in the form of carbonic acid) is given off, resulting in respiratory alkalosis. By repeatedly inhaling the expired air, the individual can recover some of this CO_2 and restore acid–base balance.

72. The ratio of bicarbonate to carbonic acid in the patient's blood can be determined using the Henderson–Hasselbalch equation:

$$\text{pH} = \text{p}K + \log\frac{[\text{A}^-]}{[\text{HA}]}$$

$$7.55 = 6.35 + \log\frac{[HCO_3^-]}{[H_2CO_3]}$$

$$10^{1.2} = \frac{[HCO_3^-]}{[H_2CO_3]}$$

$$\frac{[HCO_3^-]}{[H_2CO_3]} = \frac{15.8}{1}$$

Similarly, the ratio of bicarbonate to carbonic acid in a normal person's blood can be determined:

$$\text{pH} = \text{p}K + \log\frac{[\text{A}^-]}{[\text{HA}]}$$

$$7.4 = 6.35 + \log\frac{[HCO_3^-]}{[H_2CO_3]}$$

$$10^{1.05} = \frac{[HCO_3^-]}{[H_2CO_3]}$$

$$\frac{[HCO_3^-]}{[H_2CO_3]} = \frac{11.2}{1}$$

In order to serve as an effective buffer (*i.e.*, absorb both added H^+ and OH^-), both a conjugate base and a weak acid must be present. In the patient, the ratio of conjugate base to weak acid does not lie within an effective buffering range. The bicarbonate concentration (conjugate base) is too high relative to the carbonic acid (weak acid) concentration; thus the relative amount of weak acid is insufficient. [Krause, D. S., Wolf, B. A., and Shaw, L. M., *Ther. Drug Monit.* **14,** 441–451 (1992).]

73. Ammonia and ammonium ions are in equilibrium, as represented by the following equation:

$$NH_4^+ \rightleftharpoons H^+ + NH_3$$

Carbonic acid and bicarbonate ions are in equilibrium, as represented by the following equation:

$$H_2CO_3 \rightleftharpoons H^+ + HCO_3^-$$

Phosphate ions are in equilibrium, according to the following equation:

$$H_2PO_4^- \rightleftharpoons H^+ + HPO_4^{2-}$$

In metabolic acidosis, the concentration of protons increases, so the equilibrium shifts to form $H_2PO_4^-$, carbonic acid, and ammonium ions. In order to bring the pH back to normal, the kidney excretes $H_2PO_4^-$ and ammonium ions, and bicarbonate ions are reabsorbed. The result is a decrease in the concentration of protons and an increase in blood pH.

74. The relevant equations are shown in Solution 73. In metabolic alkalosis there is an excess of hydroxide ions, which react with protons to form water. This causes the equilibria to shift to form HPO_4^{2-}, NH_3, and HCO_3^-. In order to bring the pH back to normal, the kidney reabsorbs NH_4^+ and $H_2PO_4^-$ and excretes HCO_3^-.

75. The concentrations of both Na^+ and Cl^- are greater outside the cell than inside (see Fig. 2.12). Therefore the movement of these ions into the cell is thermodynamically favorable. Na^+ movement into the cell drives the exit of H^+ via an exchange protein in the plasma membrane (the favorable movement of Na^+ into the cell "pays for" the unfavorable movement of H^+ out of the cell). Similarly, the movement of Cl^- into the cell drives the movement of HCO_3^- out of the cell through another exchange protein.

76. Acetoacetate and 3-hydroxybutyrate are acids (they are ionized at physiological pH). The accumulation of the ketone bodies therefore causes metabolic acidosis. The body attempts to compensate by increasing the breathing rate in order to eliminate more CO_2.

77. The cell-surface carbonic anhydrase can catalyze the conversion of $H^+ + HCO_3^-$ to CO_2, which can then diffuse into the cell (the ionic H^+ and HCO_3^- cannot cross the hydrophobic lipid bilayer on their own). Inside the cell, carbonic anhydrase converts the CO_2 back to $H^+ + HCO_3^-$.

78. The lungs can compensate for metabolic acidosis through an increase in the breathing rate in order to eliminate more CO_2. The kidneys can compensate for respiratory acidosis by increasing the breakdown of glutamine to produce NH_3 (excreted in urine as NH_4^+, see Solution 73); however, this mechanism requires the synthesis of enzymes, which takes several hours at least.

Chapter 3

1. The heat treatment destroys the polysaccharide capsule of the wild-type *Pneumococcus*, but the DNA survives the heat treatment. The DNA then "invades" the mutant *Pneumococcus* and supplies the genes encoding the enzymes needed for capsule synthesis that the mutant lacks. The mutant is now able to synthesize a capsule and has the capacity to cause disease, which results in the death of the mice and the appearance of encapsulated *Pneumococcus* in the mouse tissue.

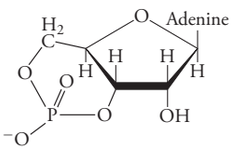
2. These experiments showed that the transforming factor was neither a protein nor RNA.

3. Some of the labeled "parent" DNA appears in the progeny, but none of the labeled protein appears in the progeny. This indicates that the bacteriophage DNA is involved in the production of progeny bacteriophages, but bacteriophage protein is not required.

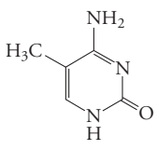
4. The triple-helical model is not consistent with the hydrophobic effect, which suggests that the nonpolar nitrogenous bases would reside in the center of the DNA structure and the hydrophilic phosphates would reside on the surface. The triple-helical model also assumes that the phosphate groups are protonated and form stabilizing hydrogen bonds in the DNA interior. But the p*K* value for phosphate is well below 7, so the phosphate groups would not be protonated at physiological pH. In the absence of hydrogen bonds, there are no additional forces that would hold the strands of the triple helix together.

5. Thymine (5-methyl uracil) contains a methyl group attached to C5 of the pyrimidine ring of uracil.

6.

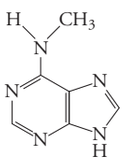


7.



5-Methylcytosine

8. a.



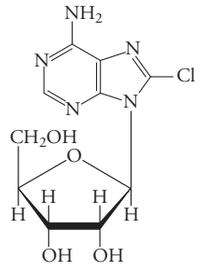
N^6-Methyladenine

b. The N^6-DNA methyltransferase might be a good drug target. If methylation of certain adenine residues is required for virulence, then it is possible that inhibition of the bacterial transferase enzyme might prevent adenine methylation and thus prevent disease caused by pathogenic bacteria.

9. The base 5-chlorouracil is a substitute for thymine (5-methyluracil).

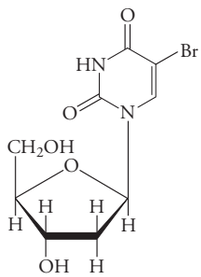
10. A chlorine is substituted for a hydrogen in 5-chorouracil, which closely resembles thymine (see Solution 9). Therefore, the culture containing 5-chlorouracil will incorporate this base in place of thymine as the DNA replicates. The 5-chlorouracil has a greater mass than thymine, so DNA isolated from this culture will have a greater mass than DNA isolated from the control culture.

11. [From Jordheim, L. P., Durantel, D., Zoulim, F., and Dumontet, C. *Nat. Rev. Drug Discov.* **12,** 447–464 (2013).]



8-Chloroadenosine

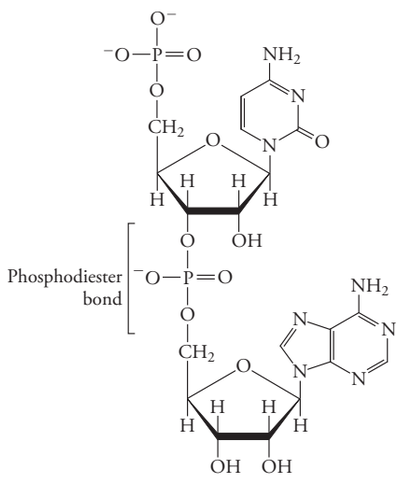
12. The compound is a thymidine analog. [From Maity, J. and Stromberg, R., *Molecules* **18,** 12740–12750 (2013).]



5-Bromo-2′-deoxyuridine

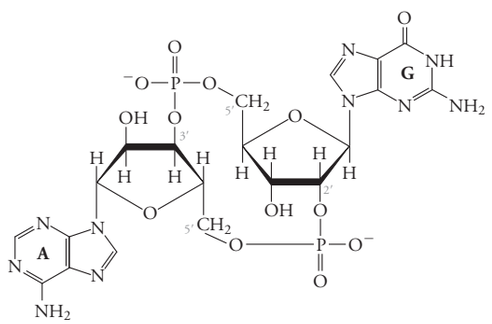
13. a. A diphosphate bridge links the ribose groups in each dinucleotide. This linkage is a variation of the monophosphate bridge (phosphodiester linkage) in DNA and RNA. **b.** The adenosine group in CoA bears a phosphoryl group on C3′.

14.

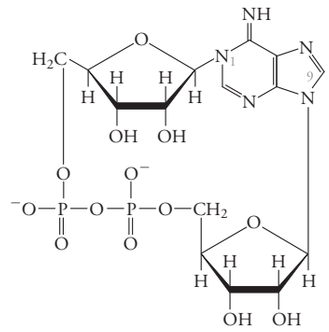


If the dinucleotide were DNA, it would lack OH groups at each ribose C2′ position.

15.



16.



17. The organism must also contain 19% A (since [A] = [T] according to Chargaff's rules) and 62% C + G (or 31% C and 31% G, since [C] = [G]). Each cell is a diploid, containing 60,000 kb or 6×10^7 bases. Therefore,

$$[A] = [T] = (0.19)(6 \times 10^7 \text{ bases}) = 1.14 \times 10^7 \text{ bases}$$
$$[C] = [G] = (0.31)(6 \times 10^7 \text{ bases}) = 1.86 \times 10^7 \text{ bases}$$

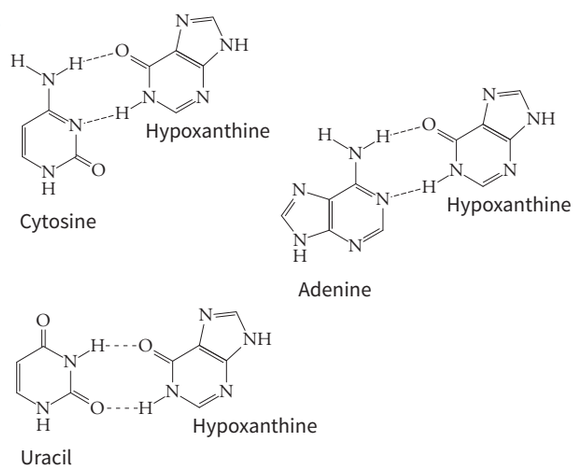
18. a. Using Chargaff's rules (see Solution 17), the number of C residues must also be 24,182. Subtracting (2 × 24,182) from 97,004 yields 48,640 (A + T) residues. Dividing this number by 2 yields 24,320 residues each of A and T. **b.** GenBank reports only the sequence of a single strand of DNA, since the sequence of the complementary strand can easily be deduced using Watson–Crick base-pairing.

19. The total amount of purines (A + G) in DNA must equal the total amount of pyrimidines (C + T) because each base pair in the double-stranded DNA molecule consists of a purine and a pyrimidine. This is not true for RNA, which is single-stranded.

20. The genome contains 28.7% T, 21.5% G, 29.3% A, and 20.6% C. Chargaff's rules do not apply because the viral genome is composed of single-stranded DNA.

21. It is a G:C base pair.

22.



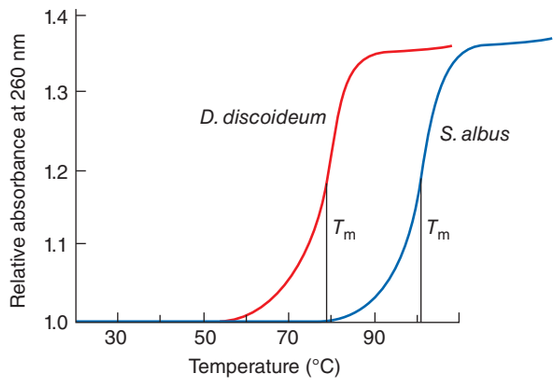
23. The statement is false because the greater stability of GC-rich DNA is due to the stronger stacking interactions involving G:C base pairs and does not depend on the number of hydrogen bonds in the base pairs.

24. It is certainly the case that hydrogen bonds hold A:T and G:C base pairs together and that these interactions are very favorable. But upon denaturation of the DNA, each nitrogenous base has the opportunity to form equally favorable hydrogen bonds with water. Therefore, forces other than hydrogen bonds must contribute to the overall stability of the DNA molecule.

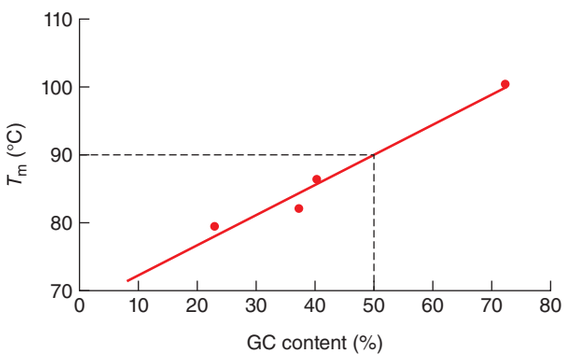
25. The sugar–phosphate backbone is on the outside of the molecule. The polar sugar groups can form hydrogen bonds with the surrounding water molecules. The negatively charged phosphate groups interact favorably with positively charged ions. The nonpolar nitrogenous bases are found on the inside of the molecule and interact favorably via stacking interactions. In this way, contact with the aqueous solution is minimized, as described by the hydrophobic effect.

26. a. Proteins are more likely to bind to the major groove, which can easily accommodate proteins. The larger surface area of the major groove allows multiple favorable interactions between the DNA and protein. **b.** The positively charged side chains of the Lys and Arg residues form ion pairs with the negatively charged phosphate groups on the DNA backbone. These are strong interactions, so the histones have a high affinity for DNA.

27. a. The T_m is approximately 72°C. **b.** The melting curves are shown below.



28. a. The DNA contains 50% G + C, so its melting point would be approximately 90°C. **b.** The DNA would need to be cooled gradually to 65–70°C (20–25°C below its melting temperature).



29. The DNA from the organisms that thrive in hot environments would contain more G and C than DNA from species living in a more temperate environment. The higher GC content increases the stability of DNA at high temperatures.

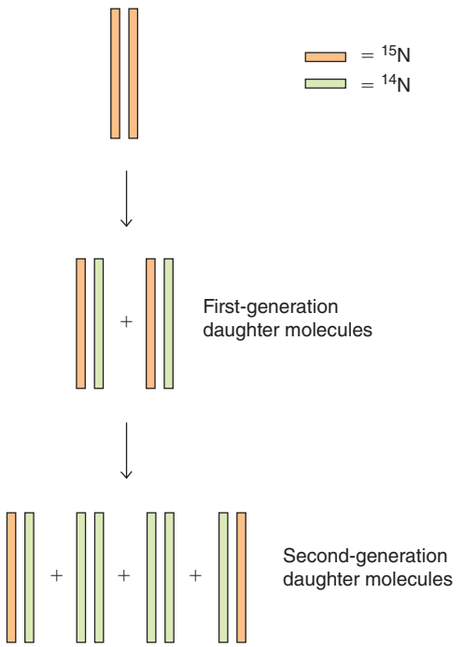
30. The positively charged sodium ions can form ion pairs with the negatively charged phosphate groups on the DNA backbone and "shield" the negative charges from one another. This increases the overall stability of DNA and makes it more difficult to melt.

31. a. You should increase the temperature to melt out imperfect matches between the probe and the DNA. **b.** You should decrease the temperature to increase the chances that the two strands will align, despite the mismatch.

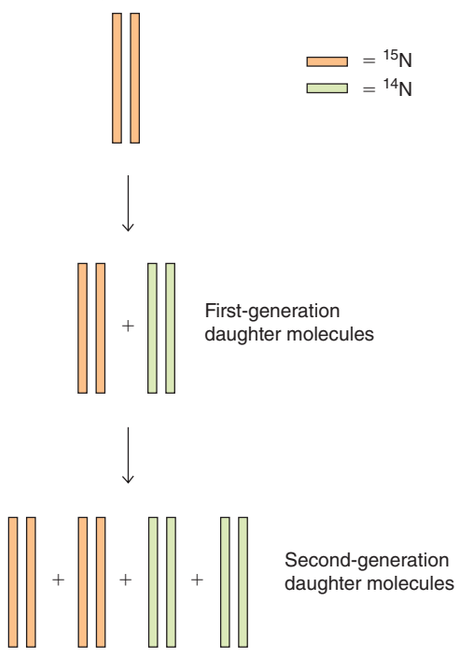
32. Heating denatures the target DNA (separates its two strands) so that a single-stranded probe can more easily form sequence-specific hydrogen bonds with it.

33. a. An inherited characteristic could be determined by more than one gene. **b.** Some sequences of DNA encode RNA molecules that are not translated into protein (for example, rRNA and tRNA). **c.** Some genes are not transcribed during a cell's lifetime. This can occur if the gene is expressed only under certain environmental conditions or in certain specialized cells in a multicellular organism.

34. a. The DNA isolated after one generation is a homogeneous sample of DNA with a density intermediate between DNA containing all ^{14}N and all ^{15}N. **b.** The DNA isolated after the second generation is heterogeneous. Half of the DNA has the same density as the first generation; half of the DNA consists of all ^{14}N DNA and has a lower density.



c. A hypothetical scheme for conservative DNA replication is shown below. The DNA isolated after both the first and the second generations is heterogeneous. Half of the DNA has the same high density as the original DNA (all ^{15}N); half of the DNA consists of all ^{14}N DNA and has a lower density.



35. a. 3′-TGTGGTACCACGTAGACTGA-5′
b. 5′-ACACCAUGGUGCAUCUGACU-3′

36. a. The top strand is the coding strand and the bottom strand is the noncoding strand. **b.** Only coding strands are published because the mRNA sequence is identical to the sequence of the coding strand, with the exception that U replaces T in the mRNA.

37. a. A poly-Phe polypeptide was produced. **b.** Poly A produces poly-Lys; poly C yields poly-Pro; and poly G yields poly-Gly.

38. a. The cell-free system produces polypeptides consisting of alternating Val and Cys residues. Some of the polypeptides begin with Val; others begin with Cys, depending on which reading frame is used. **b.** The production of this peptide does not allow one to unambiguously assign the GUG and UGU codons. Additional experimental data are required to make this assignment.

39. The number of possible sequences of four different nucleotides taken n at a time is 4^n; here n is the number of nucleotides in the sequence. **a.** $4^1 = 4$ **b.** $4^2 = 16$ **c.** $4^3 = 64$ **d.** $4^4 = 256$. At least three nucleotides are necessary to code for 20 amino acids.

40. There are 216 codons possible: $6^3 = 216$. [From Malyshev, D. A., Dhami, K., Lavergne, T., Chen, T., Dai, N., Foster, J. M., Corrêa Jr., I. R., and Romesberg, F. E., *Nature* **509,** 385–388 (2014).]

41. a. First reading frame:

AGG TCT TCA GGG AAT GCC TGG CGA GAG GGG AGC
Arg - Ser - Ser - Gly - Asn - Ala - Trp - Arg - Glu - Gly - Ser-

AGC TGG TAT CGC TGG GCC CAA AGG C
Ser - Trp - Tyr - Arg - Trp - Ala - Gln - Arg

Second reading frame:

A GGT CTT CAG GGA ATG CCT GGC GAG AGG GGA GCA
- Gly - Leu - Gln - Gly - Met - Pro - Gly - Glu - Arg - Gly - Ala-

GCT GGT ATC GCT GGG CCC AAA GGC
Ala - Gly - Ile - Ala - Gly - Pro - Lys - Gly

Third reading frame:

AG GTC TTC AGG GAA TGC CTG GCG AGA GGG GAG CAG
--Val - Phe - Arg - Glu - Cys - Leu - Ala - Arg - Gly - Glu - Gln-

CTG GTA TCG CTG GGC CCA AAG GC
Leu - Val - Ser - Leu - Gly - Pro - Lys-

b. The second reading frame, which produces a protein in which every third amino acid is Gly, is the correct reading frame.

42. a. Asparagine has two codons, AAU and AAC (see Table 3.3). An A→G mutation at the second position could generate a codon for serine (AGU or AGC). **b.** The CGA codon codes for the amino acid arginine; the mutation (C→T in the DNA) converts the codon to a Stop codon. When the mRNA for the gene is translated, protein synthesis terminates prematurely and the truncated protein is nonfunctional.

43. The genetic code (shown in Table 3.3) is redundant. Since there are 64 different possibilities for 3-base codons and only 20 amino acids, most amino acids have more than one codon. If a mutation happens to occur in the third position (3′ end), the mutation might not alter the protein sequence. For example, GUU, GUC, GUA, and GUG all code for valine. A mutation in the third position of a valine codon would still result in the selection of valine and would have no effect on the amino acid sequence of the protein.

44. The same segment of DNA can encode two different proteins if each strand is a coding strand.

45. First, identify the translation start site, the Met residue whose codon is AUG in the mRNA (see Table 3.3) or ATG in the DNA. Translation stops at the DNA sequence TAA, which corresponds to