2

CHEMICAL FOUNDATIONS

REVIEW THE CONCEPTS

1. Less energy is required to form noncovalent bonds than covalent bonds, and the bonds that stick the gecko's feet to the smooth surface need to be formed and broken many times as the animal moves. Since van der Waals interactions are so weak, there must be many points of contact (a large surface area) yielding multiple van der Waals interactions between the septae and the smooth surface.

2. a. These are likely to be hydrophilic amino acids, and in particular, negatively charged amino acids (aspartate and glutamate), which would have an affinity for K^+ via ionic bonds.

   b. Like the phospholipid bilayer itself, this portion of the protein is likely to be amphipathic, with hydrophobic amino acids in contact with the fatty acyl chains and hydrophilic amino acids in contact with the hydrophilic heads.

   c, d. Since both the cytosol and extracellular space are aqueous environments, hydrophilic amino acids would contact these fluids.

3. At pH = 7.0, the net charge is –1 because of the negative charge on the carboxyl residue of glutamate (E). After phosphorylation by a tyrosine kinase, two additional negative charges (because of attachment of phosphate residues to tyrosines (Y)) would be added. Thus, the net charge would be –3. The most likely source of phosphate is ATP since the attachment of inorganic phosphate (P_i) to tyrosine is energetically highly unfavorable, but when coupled to the hydrolysis of the high-energy phosphoanhydride bond of ATP, the overall reaction is energetically favorable.

4. Disulfide bonds are formed between two cysteine residue side chains. The formation of disulfide bonds increases the order and therefore decreases the entropy (S becomes more negative).

5. Stereoisomers are compounds that have the same molecular formula but are mirror images of each other. Many organic molecules can exist as stereoisomers because of two different possible orientations around an asymmetric carbon atom (e.g., amino acids). Because stereoisomers differ in their three-dimensional orientation and because biological molecules interact with one another based on precise molecular complementarity, stereoisomers often react with different molecules, or react differently with the same molecules. Therefore, they may have very distinct physiological effects in the cell.

6. The compound is guanosine triphosphate (GTP). Although the guanine base is found in both DNA and RNA, the sugar is a ribose sugar because of the 2′ hydroxyl group. Therefore, GTP is a component of RNA only. GTP is an important intracellular signaling molecule.

7. At least three properties contribute to this structural diversity. First, monosaccharides can be joined to one another at any of several hydroxyl groups. Second, the C-1 linkage can have either an α or a β configuration. Third, extensive branching of carbohydrate chains is possible.

8. What is the pH of 1 L of water? In all aqueous solutions, water spontaneously dissociates into hydrogen and hydroxide ions according to the equilibrium reaction $H_2O \rightleftharpoons H^+ + OH^-$. The ionization constant for aqueous solutions at 25°C is $K_w = [H^+][OH^-] = 1 \times 10^{-14}\ M^2$. In a solution of pure water, the production of one H^+ ion will always be accompanied by the production of one OH^- ion. In other words, $[H^+] = [OH^-]$.

$$K_w = [H^+][OH^-] = [H^+]^2 = 1 \times 10^{-14}\ M^2$$
$$[H^+] = 1 \times 10^{-7}\ M$$
$$pH = -\log_{10}[H^+] = -\log_{10}(1 \times 10^{-7}) = 7$$

What is the pH after 0.008 moles NaOH are added? NaOH (sodium hydroxide) is a strong base. This means all the added NaOH ionizes to increase the $[OH^-]$ concentration to 0.008 M.

$$[H^+] = K_w/[OH^-] = (1 \times 10^{-14}\ M^2)/(0.008\ M) = 1.25 \times 10^{-12}\ M$$
$$pH = -\log_{10}[H^+] = -\log_{10}(1.25 \times 10^{-12}) = 11.903$$

What is the pH of the solution of 50 mM MOPS? MOPS is a weak acid. As such, upon dissolving in water it will undergo partial dissociation yielding equal concentrations of hydrogen ions and MOPS conjugate base according to the equilibrium reaction:

$$\text{MOPS(weak acid form)} = H^+ + \text{MOPS(conjugate base form)}$$

The extent to which this reaction goes forward determines the relative strength of the MOPS weak acid and is given by its acid dissociation equilibrium constant:

$$K_a = ([H^+][\text{MOPS(conjugate base form)}])/[\text{MOPS(weak acid form)}]$$
$$pK_a = -\log_{10}K_a = 7.20$$

If the relative concentrations are known for the weak acid and conjugate base forms of a dissolved weak acid at equilibrium in water, then the solution pH can be determined according to the equation:

$$pH = pK_a + \log_{10}([\text{conjugate base}]/[\text{weak acid}])$$

Therefore,

$$pH = 7.20 + \log_{10}(0.39/0.61) = 7.01$$

What is the pH after 0.008 moles NaOH are added to the MOPS buffer solution? Rather than simply increase the total $[OH^-]$ by 0.008 moles, addition of the strong base shifts the equilibrium of the dissolved MOPS such that [MOPS(weak acid)] *decreases* by 0.008 M and [MOPS(conjugate base)] *increases* by 0.008 M.

Before addition of 0.008 moles NaOH:

$$[\text{MOPS(weak acid)}] = 0.61(0.050\ \text{M}) = 0.0305\ \text{M}$$
$$[\text{MOPS(conjugate base)}] = 0.39(0.050\ \text{M}) = 0.0195\ \text{M}$$

After addition of 0.008 moles NaOH:

$$[\text{MOPS(weak acid)}] = 0.0305\ \text{M} - 0.008\ \text{M} = 0.0225\ \text{M}$$
$$[\text{MOPS(conjugate base)}] = 0.0195\ \text{M} + 0.008\ \text{M} = 0.0275\ \text{M}$$

The final pH after addition of 0.008 moles NaOH to 50 mM MOPS at pH 7.01 is, therefore:

$$pH = 7.20 + \log_{10}(0.0275/0.0225) = 7.29$$

9. In the acidic pH of a lysosome, ammonia is converted to ammonium ion. Ammonium ion is unable to traverse the membrane because of its positive charge and is trapped within the lysosome. The accumulation of ammonium ion decreases the concentration of protons within lysosomes and therefore elevates lysosomal pH. At neutral pH, ammonia has little, if any, tendency to protonate to ammonium ion and thus has no effect on cytosolic pH.

10. $K_{eq} = [LR]/[L][R]$

Since 90% of L binds R, the concentration of LR at equilibrium is $0.9(1 \times 10^{-3}\text{M}) = 9 \times 10^{-4}\ \text{M}$. The concentration of free L at equilibrium is the 10% of L that remains

unbound, 1×10^{-4} M. The concentration of R at equilibrium is $(5 \times 10^{-2}\ \text{M}) - (9 \times 10^{-4}\ \text{M}) = 4.91 \times 10^{-2}$ M. Therefore, $[LR]/[L][R] = 9 \times 10^{-4}\ \text{M} / ((1 \times 10^{-4}\ \text{M})(4.91 \times 10^{-2}\ \text{M})) = 183.3\ \text{M}^{-1}$.

The equilibrium constant is unaffected by the presence of an enzyme.

$$K_d = 1/K_{eq} = 5.\ 4 \times 10^{-3}\ \text{M}.$$

11. $\Delta G = \Delta G^{o\prime} + \text{RTln [products]/[reactants]}$

    For this reaction, $\Delta G = -1000$ cal/mol + [1.987 cal/(degree · mol) × (298 degrees) × ln (0.01 M/(0.01 M × 0.01 M))].

    $$\Delta G = -1000 \text{ cal/mol} + 2727 \text{ cal/mol} = 1727 \text{ cal/mol}$$

    To make this reaction energetically favorable, one could increase the concentration of reactants relative to products such that the term RTln [products]/[reactants] becomes smaller than 1000 cal/mol. One might also couple this reaction to an energetically favorable reaction.

12. The presence of one or more carbon-carbon double bonds is indicative of an unsaturated or polyunsaturated fatty acid. The term saturated refers to the fact that all carbons, except the carbonyl carbon, have four single bonds. In a cis unsaturated fatty acid, the carbon atoms flanking the double bond are on the same side, thus introducing a kink in the otherwise flexible straight chain. There is no such kink in a trans unsaturated fatty acyl chain.

13. Glutamate is the amino acid that undergoes γ-carboxylation, resulting in the formation of a host of blood clotting factors. Warfarin inhibits γ-carboxylation of glutamate. Thus, blood clotting is severely compromised. Patients prone to forming clots (thrombi) in blood vessels might be prescribed warfarin in order to prevent an embolism, which would result if the clot dislodged and blocked another vessel elsewhere in the body. Patients at risk for heart disease due to blockages in the coronary arteries are also often prescribed this drug.

ANALYZE THE DATA

1. Biomolecules are relatively easy to synthesize from inorganic starting materials, which suggests that living and nonliving matter are not fundamentally different. Living matter is subject to the same laws of physics and chemistry that govern nonliving matter. The fact that biomolecules can be produced through nonliving, chemical processes suggests that life itself could have evolved by similar means. Biochemistry attempts to describe the mechanisms that give rise to living systems from the perspective of the molecules that make up living things. We can often gain considerable insight into the properties of a living thing by studying the structure and chemistry of its molecules.

2. When a weak acid is in aqueous solution of pH at or near its value of pK_a, the weak acid will quickly establish an equilibrium with its conjugate base form and together the two will act to resist additional changes to the solution pH. Solutions in which weak acid/conjugate base pairs function to inhibit pH changes are called "buffers." Buffers are at their most efficient when the concentrations of the weak acid and conjugate base forms are equal, as would be the case when precisely one half the amino acid concentration of sodium hydroxide has been added (0.05 M OH^-), and at this point the solution pH should equal the pK_a of that weak acid group. At a low pH like 1.8, the buffering species on the amino acid must be a relatively strong type of weak acid like a carboxylic acid. Additional buffer points at pH 6 and 9.3 indicate that there are two additional chemical groups on the dissolved amino acid that can behave as buffers at the appropriate OH^- concentrations. The pK_a of 9.3 likely corresponds to the amino group present on every amino acid. The ability of this amino acid to behave like a buffer at three different values of solution pH indicates that the amino acid side chain also has weak acid properties. Its apparent pK_a value of 6.0 identifies this amino acid as histidine due to the fact that its imidazole side chain functions as a buffer at this pH.