Chapter 2

Solutions to Questions

1. Describe the properties of acids and bases. It might be helpful to look in a chemistry book, to find information beyond that available in the chapter.

Answer:

The word acid comes from the Greek word acidus, meaning sour, for its sour taste when dissolved in water. In chemistry it has the generic formula HA and can be considered a substance that when dissolved in water gives a pH lower than 7. An acid can be described by the Arrhenius definition (increases hydronium or H_3O concentration), the Brønsted-Lowry definition (proton donor), or finally, the Lewis definition (an electrophile or electron pair acceptor). Strong acids, like HCl, almost completely dissociate in water while weak acids, like HNO_3, only partly dissociate in water. All acids are generally sour, produce a stinging feeling when touched, and corrode most metals. Conversely, bases have the generic formula B- and can be considered a substance that when dissolved in water gives a pH higher than 7. A base is also defined in the same three fashions and can be described as reducing hydronium concentration, being a proton acceptor, or finally being a nucleophile and an electron pair donor. An alkali is a special example of a base, where in an aqueous environment, hydroxide ions, -OH, are donated. This is because the ion combines with the hydronium ion to make two molecules of water. Unlike acids, bases taste bitter, feel soapy when touched, and are caustic on organic material.

2. Why are polar molecules hydrophilic and nonpolar molecules hydrophobic?

Answer:

Water is a polar molecule. A hydrophilic molecule can transiently bond with water through hydrogen bonding and become soluble in water. On the other hand, hydrophobic molecules are repelled from a mass of water and do not dissolve in it. This follows the general chemistry notion of "like dissolves like", where polar compounds dissolve in polar compounds and non-polar compounds dissolve in non-polar compounds.

3. If hydrogen bonds are much weaker than covalent bonds, why do you think hydrogen bonds are used to hold biomolecules together?

Answer:

Biomolecules are not held together by a single hydrogen bond, but rather a large series of these. Hydrogen bonding between parts of the same biomolecule cause it to fold into a specific shape, which helps determine the molecule's physiological role. For example, it plays an important role in determining the three-dimensional structures adopted by proteins and nucleic bases. The double helical structure of DNA and the tertiary structure of a protein are largely determined by hydrogen bonds. In both these examples, while the energy required to break a single hydrogen bond is small, the energy required to break all of the hydrogen bonds holding the structure together is large. In the absence of biological reactions, the molecules stay together and hold their functional structure. However, these bonds are used to hold biomolecules together because specifically designed reaction mechanisms, frequently involving enzymes, exist that can easily break or form hydrogen bonds in a serial fashion that involves breaking only one bond at a time. To visualize this description, DNA for example, can be thought as a zipper that is zipped and unzipped: tugging on the sides of the zipper will accomplish nothing but moving the fixed zipper head up and down easily separates the strands.

4. Does entropy increase or decrease during a polymerization reaction? Why?

Answer:

Generally speaking, entropy decreases during polymerization because monomers must be ordered into polymers, causing a decrease in the number of possible microscopic configurations of the system and thus decreasing the amount of disorder.

5. Explain the difference between passive and active transport. Why is active transport necessary for some ions?

Answer:

In active transport biomolecules require energy to move against an electrochemical gradient, generally in the form of ATP. On the other hand, passive transport moves with the electrochemical gradient and depends only on the permeability of the cell membrane. Some ions require active transport because the function of the membrane highly depends on maintaining and replenishing an electrochemical gradient. In the sodium-potassium pump, for example, cells must keep a low concentration of sodium ions and high levels of potassium ions within the cell; conversely maintaining high concentrations of sodium and low *concentrations of potassium outside the cell. Ions must be moved against their electrochemical gradient to create a progressively stronger driving force that is vital in allowing electrical signals in the form of action potentials to nerves and muscles.*

6. Normal saline solution (0.9% NaCl by mass) is used for intravenous administration or for lubrication of dry eyes. Do you think that this solution isotonic, hypertonic, or hypotonic compared to the body fluids? Why?

Answer:
Normal saline solution is isotonic compared to body fluids to avoid changes in osmolality in the body. This is because hypotonic or hypertonic solutions will inevitably drive water in or out of the cell.

7. If you are on a deserted island, why must you find water from a stream or well rather than drink the seawater? Explain your answer in terms of osmotic pressure.

Answer:
Seawater has such a high salt content that it increases the salinity of my extracellular fluids and makes it hypertonic. When my extracellular fluids become hypertonic, there is a higher concentration of solute outside the cell that creates an osmotic pressure on my cells' permeable membrane. As a result, water flows out of my cells and into my extracellular fluids, which in turn dehydrates my tissues and causes me to have more thirst.

8. How does hyperventilation—that is, very rapid deep breathing—disturb the HCO/H_2CO_3 equilibrium? Does it result in acidosis or alkalosis?

Answer:
Hyperventilation produces respiratory alkalosis by decreasing the amount of CO_2 found in the blood, shifting the body's pH, and causing the body to become more alkaline or basic. In response the kidneys decrease the amount of HCO_3- in an attempt to restore normal pH.

9. Do some research in the library or on the internet, using reliable sources. Cystic fibrosis is a genetic disease, what is the defect in cystic fibrosis patients and how does that defect manifest into the symptoms for the disease?

Answer:

Cystic fibrosis is a hereditary disease that affects the whole body and is characterized by: difficulty breathing, thick mucus, lung infections, sinus infections, poor growth, diarrhea, and infertility. The disease is caused by malfunction in both copies of the gene called the cystic fibrosis transmembrane conductance regulator, CFTR, and is therefore an autosomal recessive disease. The way CF causes malfunction in human cells is not perfectly understood. However, it is thought that the CFTR protein failure creates problems in sodium and chloride uptake into the cells, creating thick and dehydrated mucus. In terms of osmotic pressure, this means that cystic fibrosis leads to a hypertonic extracellular fluid that dehydrates the body's cells. Cystic fibrosis patients have thick mucus that effectively blocks the narrow passages that allow normal secretions in the body. CF can be diagnosed prior to birth by a genetic testing or in early childhood by a sweat test. There is currently no cure for cystic fibrosis and lung transplantation is often necessary for severe cases.

Solutions to Problems

1. Write the condensation reactions involved in the synthesis of a disaccharide from two monosaccharides, a dipeptide from two amino acids, and dinucleotide from two nucleotides.

Answer:

1 monosaccharide + 1 monosaccharide = 1 disaccharide + 1 H_2O

1 glucose + 1 glucose= 1 maltose + 1 water

$C_6H_{12}O_6 + C_6H_{12}O_6 = C_{12}H_{22}O_{11} + 1\ H_2O$

1 amino acid + 1 amino acid = 1 dipeptide + 1 H_2O

$1\ NH_2HCRCOOH + 1\ NH_2HCRCOOH = 1\ NH_2HCRCONHHCRCOOH + 1\ H_2O$

1 nucleotide + 1 nucleotide = 1 dinucleotide + 1 H_2O

1 N + 1 N = 1 NpN + 1 H_2O

2. For each of the following compounds, classify it as an acid or a base: a) NH_3, b) H_3PO_4, c) LiOH, d) HCOOH (formic acid), e) H_2SO_4, f) HF, g) $Ba(OH)_2$.

Answer:

a. NH_3 *base*

b. $H_3P\ O_4$ *acid*

c. *LiOH base*

d. *H_2SO_4 acid*

e. *HF acid*

f. *$Ba(OH)_2$ base*

3. For the following substances: draw the chemical structure, determine whether the substance is polar or non-polar. If it is polar, indicate the partial negative and positive charges on the appropriate atoms.
   a) Carbon Dioxide (CO_2)
   b) Carbon tetrachloride (CCl_4)
   c) Hydrochloric acid (HCl)
   d) Ammonia (NH_3)
   e) Oxygen (O_2)

Answer:

a. *O=C=O, non-polar*

b. *CCl_4, non-polar*

c. *HCl, ionic: hydrogen ion +, Chlorine ion –*

d. *NH_3, polar: nitrogen + dipole, hydrogens – dipole*

e. *O=O, non-polar*

4. Tyrosine, serine, and threonine are amino acids which can be modified by phosphorylation (addition of phosphate group). As you will see, this is an important mechanism for turning enzymes on or off. (a) Find the chemical structures for tyrosine, serine, and threonine and draw them (see appendix). For each of the structures: (b) Identify each functional group in the molecule. (c) Determine whether the molecule can undergo hydrogen bonding? Mark the partial charges on the appropriate atoms.

Answer:

5. Identify the acid and conjugate base in each reaction. Calculate the pK_a for each acid. List them in order from the strongest to weakest acid. The acid-ionization constants, K_a, at 25°C are listed for each.

   a) $HC_2H_3O_2 + H_2O \leftrightarrow H_3O^+ + C_2H_3O_2^-$ acetic acid, $K_a = 1.7 \times 10^{-5}$

   b) $HC_7H_5O_2 + H_2O \leftrightarrow H_3O^+ + C_7H_5O_2^-$ benzoic acid, $K_a = 6.3 \times 10^{-5}$

   c) $HC_6H_4NO_2 + H_2O \leftrightarrow H_3O^+ + C_6H_4NO_2^-$ nicotinic acid, $K_a = 1.4 \times 10^{-5}$

Answer:

a. $HC_2H_3O_2 / C_2H_3O_2^-$ *pKa = 4.77*

b. $HC_7H_5O_2 / C_7H_5O_2^-$ *pKa = 4.20*

c. $HC_6H_4NO_2 / C_6H_4NO_2^-$ *pKa = 4.85*

$HC_7H_5O_2 > HC_2H_3O_2 > HC_6H_4NO_2$

6. Calculate the $[H^+]$ of stomach acid and blood. Which has a higher $[H^+]$? What generalization can you make regarding the relationship between $[H^+]$ and pH?

Answer:

Gastric Acid: 2-3 pH

Blood: 7.4 pH

$[H^+]_{Stomach\ acid} = 1x10^{-2.5} = 3.162 \times 10^{-3}\ [H^+]$

$[H^+]_{Blood} = 1x10^{-7.4} = 3.981 \times 10^{-8}\ [H^+]$

Therefore, the higher the [H⁺], the lower the pH and vice versa.

7. A solution contains 0.45 M hydrofluoric acid (HF; $K_a = 6.8 \times 10^{-4}$). Write the dissociation reaction. Determine the degree of ionization and the pH of the solution.

Answer: *$HF \leftrightarrow H^+ + F^-$*

*Degree of Ionization: % Ionization = [sqrt(K_a*conc.) / conc.] * 100%*

*% Ionization = [sqrt($6.8x10^{-4}$ * 0.45M) / 0.45M] * 100% =* ***3.89%***

Calculating pH:

$K_a = [H^+][F^-] / [HF] = x^2 / (0.45 - x)$

$6.8x10^{-4} = x^2 / (0.45 - x)$

Assuming x is very small the denominator becomes only 0.45 and so;

	HF	F^-	H^+
[original]	0.45	0	0
Change in conc.	-x	+x	+x
[equilib.]	0.45 – x	x	x

*$6.8x10^{-4} = x^2 / 0.45$ → x =sqrt(0.45*$6.8x10^{-4}$) = 0.0175 = $[H^+]$*

pH = -log($[H^+]$) = -log(0.0175) = ***1.76 = pH***

8. The pH of a 0.1 M acetic acid solution is 2.885. What is the dissociation constant of acetic acid?

Answer: *$[H^+] = 10^{-2.885}$ = 0.001303 M; $K_a = (0.001303)^2 / (0.1 - 0.001303)$ =* ***$1.72x10^{-5}$***

9. What is the pH of a buffer solution that is 0.20 M proprionic acid ($HC_3H_4O_2$) and 0.1 M sodium proprionate ($NaC_3H_4O_2$)? The K_A of proprionic acid is 1.3×10^{-5}.

Answer:

$$HC_3H_4O_{2(aq)} + H_2O_{(l)} \rightleftharpoons H_3O^+_{(aq)} + C_3H_4O_2^-{}_{(aq)}$$

$HC_3H_4O_2$	H_2O	H_3O^+	$C_3H_4O_2^-$
0.20 M	—	—	0.10 M
$-x$		$+x$	$+x$
$0.20 - x$	—	x	$0.10 + x$

$$K_a = \frac{[H_3O^+][C_3H_4O_2^-]}{[HC_3H_4O_2]} = \frac{x(0.10 + x)}{0.20 - x} = 1.3 \times 10^{-5}$$

$x = 2.599 \times 10^{-5}$

$= -1.0 \times 10^{-1}$ → extraneous

$pH = -\log[H_3O^+]$

$pH = -\log(2.599 \times 10^{-5})$

$\boxed{pH = 4.585}$

10. Carbohydrates in foods are a source of energy. The combustion of glucose ($C_6H_{12}O_6$) is shown below.

    $C_6H_{12}O_6(s) \quad + \quad 6O_2(g) \quad \rightarrow \quad 6CO_2(g) \quad + \quad 6H_2O(l)$

    a. Calculate the standard enthalpy of the reaction. HINT: Use heats of formation from Appendix B, Table B.2.
    b. Is this an exothermic or endothermic process? How much heat (kcal) is generated for each gram of glucose that is burned?
    c. Calculate the value of $\Delta G°$ at 37°C if $\Delta S°$ is 212 J/(K-mol). Is this a favorable reaction?

    [Note: 1 cal = 4.184 J]

Answer:

$C_6H_{12}O_6(s) \quad + \quad 6O_2(g) \quad \rightarrow \quad 6CO_2(g) \quad + \quad 6H_2O(l)$

a. ΔH�� = (6ΔHƒû$_{H_2O}$+ 6ΔHƒû$_{CO_2}$) - (ΔHƒû$_{C_6H_{12}O_6}$ + 6ΔHƒû$_{O_2}$)

$\Delta H° = [6(-285.8)] + 6(-393.5)] - [(-1274.5) + 6(0)]$

$\Delta H° = -2801.3$ kJ/mol

b. The release of energy is indicated through the negative sign of the standard enthalpy of the reaction. The reaction is thus exothermic.

$$\frac{-2801.3\ \text{kJ}}{1\ \text{mol}}\left(\frac{1\ \text{mol}\ C_6H_{12}O_6}{180.2\ \text{g}\ C_6H_{12}O_6}\right)=15.55\ \text{kJ/g}\ C_6H_{12}O_6$$

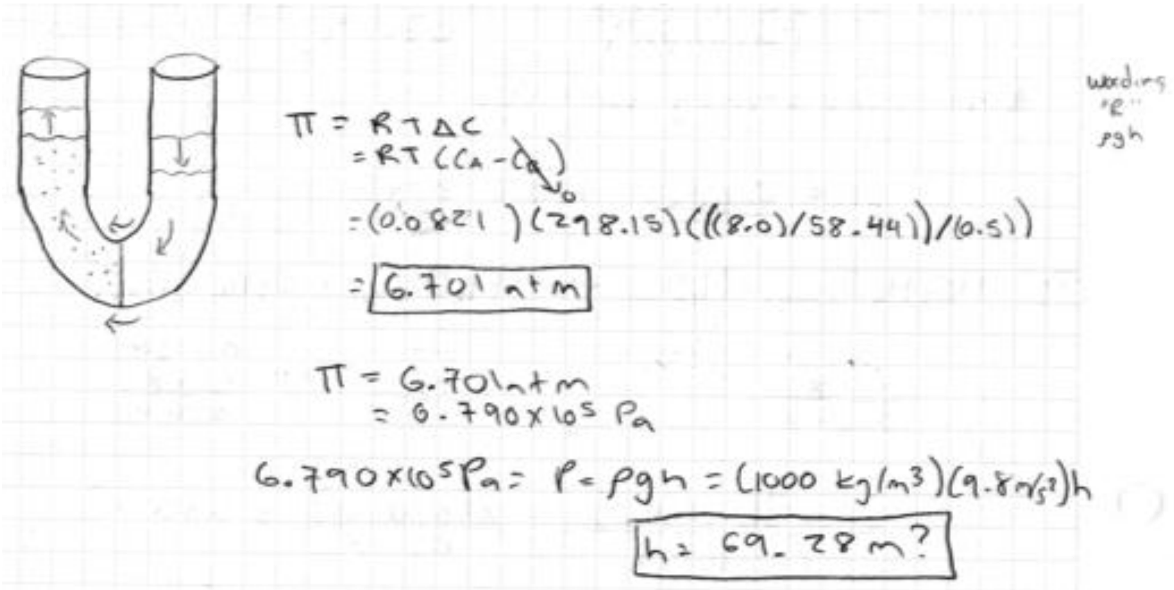
c. $\Delta G^\circ = \Delta H^\circ - T\Delta S^\circ$

$\Delta G^\circ = (-2801.3) - (310.15)(0.212) = -2867.1$ *kJ/mol*

Yes, it is a favorable reaction (-ΔG).

11. A U-tube apparatus (as in Box 2.6) is separated by a membrane permeable to water but not sodium chloride (NaCl). If 8 g of NaCl is dissolved in 0.5L of water and placed on one side of a semipermeable membrane with pure water on the other side of the membrane. Draw a diagram of the beaker. Which direction will the water flow? If the temperature of the water is constant at 25°C, what is the osmotic pressure? If compartment A and B begin with equal volumes, what will be the difference in the height of the fluid columns at equilibrium?

Answer:



12. The first step in glycolysis (breakdown of sugar) is to convert glucose to glucose-6-phosphate. Calculate the equilibrium constant for the reaction at 25°C. Is this reaction favorable or not? If it is not favorable, what can drive the reaction to proceed as written?

Glucose + Phosphate → Glucose-6-phosphate + H_2O $\Delta G° = 3.3$ kcal/mol

Answer:

$\Delta G° = -RT \ln(K)$

$K = e^{\frac{\Delta G°}{-RT}}$ $\Delta G > 0$ ∴ nonspontaneous process

$3.3 \text{ kcal} \left(\frac{4184 \text{ J}}{1 \text{ kcal}}\right) = 13{,}807.2 \text{ J}$

$K = e^{\frac{13807.2}{-(8.31447)(298.15)}} = \boxed{3.811 \times 10^{-3}}$

The reaction can occur by coupling it to another reaction that has a great amount of free energy.

13. In vitro experiments are conducted at pH =7.4 to simulate physiological conditions. A phosphate buffer system is often used.

    $H_2PO_4^-$ → HPO_4^{2-} + H^+ $pK_A = 7.2$

    a) What must be the ratio of the concentrations of HPO_4^{2-} to $H_2PO_4^-$ ions?

    b) What mass of NaH_2PO_4 must be added to 500.0 mL of 0.10 M Na_2HPO_4 (aq) in the preparation of the buffered solution?

Answer:

a. $K_a = [HPO_4^{2-}][H^+] / [H_2PO_4^-]$; $[H^+] = [HPO_4^{2-}] = 10^{-7.4} = 3.98x10^{-8}$;

$K_a = 10^{-7.2} = 6.31x10^{-8} = (3.98x10^{-8})^2 / [H_2PO_4^-]$; $[H_2PO_4^-] = 2.51x10^{-8}$

$[HPO_4^{2-}] / [H_2PO_4^-] = 3.98 / 2.51 = \mathbf{1.59}$

b. Assume Na_2HPO_4 *completely dissociates into 0.1M* Na^+ *and 0.1M* HPO_4^{2-}

$pH = pK_a + \log([A^-]/[HA])$; → $[HA] = [A^-] / 10^{\wedge}(pH - pK_a)$

[HA] = 0.1M / 10^(7.4 – 7.2) = 0.063 mol/L; multiply by the volume of liquid present and molecular weight of NaH_2PO_4 *→ 0.063 mol/L * (0.5L) * 119.98 g/mol =* ***3.79g***

(Alternatively, start from the ratio calculated in part (a) above to find $[H_2PO_4^-]$*)*

14. Estimate the flux ($mg/cm^2/sec$) by diffusion of a steroid through a lipid bilayer membrane. Assume the diffusion coefficient for steroid in the lipid bilayer is 10^{-6} cm^2/sec, and that the concentration is 1 ng/mL on the outside of the membrane and 0 on the inside.

Answer:

$$J = -D\frac{dC}{dx}$$

$$= -(1\times10^{-6})\left(\frac{1\times10^{-6}-0}{3\times10^{-7}}\right)$$

$$= -3.333\times10^{-6}\ \text{mg/cm/sec}$$

$$\frac{1\,\text{ng}}{1\,\text{mL}} = \frac{1\times10^{-9}\,\text{g}}{1\,\text{mL}} = \frac{1\times10^{-6}\,\text{mg}}{1\,\text{mL}}$$

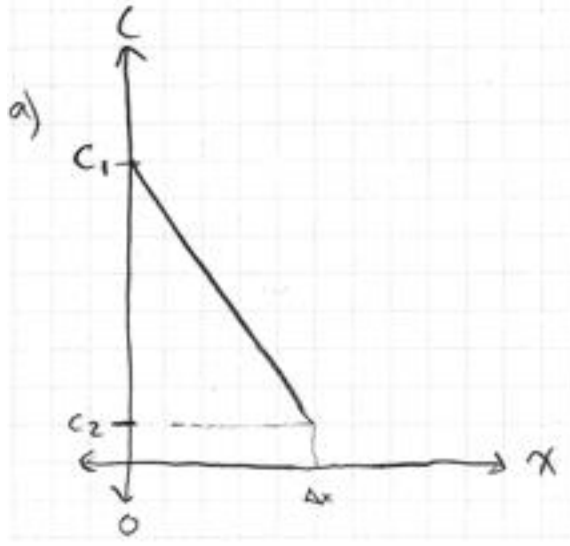
$$3\,\text{nm} = 3\times10^{-7}\,\text{cm}$$

15. For the membrane of thickness Δx shown in the Box 2.5:

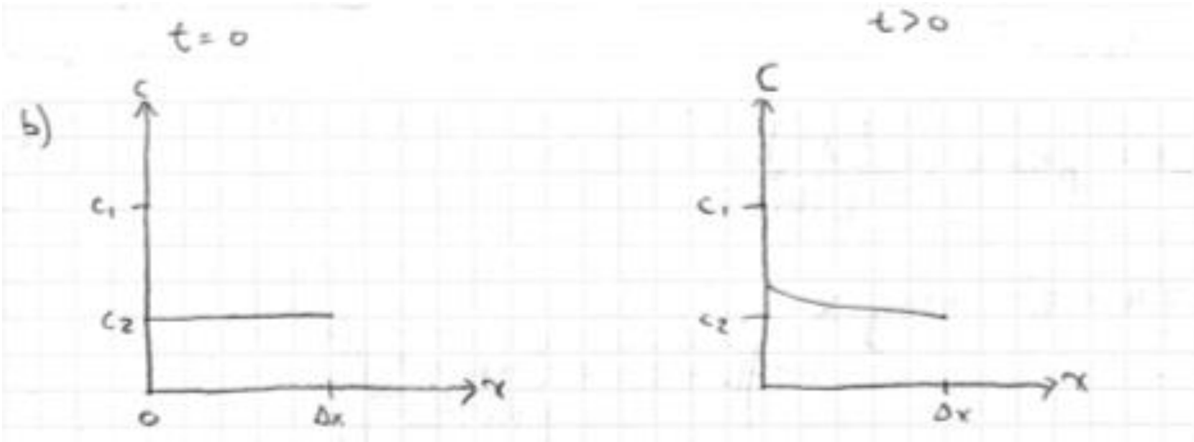
a) Draw a graph of the concentration of solute as a function of x at steady-state.

b) Estimate the concentration profiles that you expect during the approach to steady state. That is, assume that the membrane is initially saturated with solute at concentration, C_2, and then the concentration on the left boundary (at x=0) is suddenly increased to C_1. Sketch the concentration profile immediately after the increase to C_1. Sketch the concentration profile a little later, but before steady state is achieved.

Answer:



$$C = \left(\frac{C_2 - C_1}{\Delta x}\right)x + C_1$$



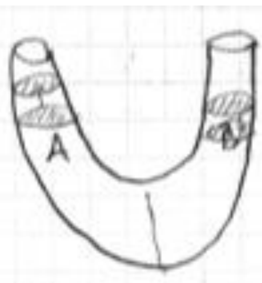
16. A solution of 1 M glucose is separated by a selectively permeable membrane from a solution of 0.2 M fructose and 0.7 M sucrose. The membrane is not permeable to any of the sugar molecules. Indicate which side of the membrane is initially hypertonic, which is hypotonic, and the direction of water movement.

Answer:

The glucose side is hypertonic and the fructose and sucrose side is hypotonic. Water will move out of the 1.0 M glucose solution and into the 0.2 M fructose and 0.7 M sucrose solution.

17. Consider a U-shaped tube (as illustrated in Box 2.6) in which the arms of the U-tube are separated by a membrane that is permeable to water and glucose but not sucrose. The left side (side A) is filled with a solution of 2.0 M sucrose and 1.0 M glucose. The right side (side B) is filled with 1.0 M sucrose and 2.0 M glucose.
    a. What changes would you observe, as the system moves toward equilibrium?
    b. During the period from initial filling to equilibrium, which molecule(s) will show net movement through the membrane?

Answer:



a) the height of the solution in A will increase

b) Glucose and H_2O will show net movement to A.

18. One of the components in the head of "strike-anywhere" matches is tetraphosphorus trisulfide, P_4S_3. The combustion is shown below.

a) Calculate the standard enthalpy of the reaction.

b) Draw a graphical representation of the standard enthalpy change for this reaction.

c) Is this an exothermic or endothermic process? Explain your answer.

$P_4S_3(s) + 8O_2(g) \rightarrow P_4O_{10}(s) + 3SO_2(g)$

$\Delta H°_f\,(P_4S_3) = -155$ kJ/mol

$\Delta H°_f\,(O_2) = 0$ kJ/mol

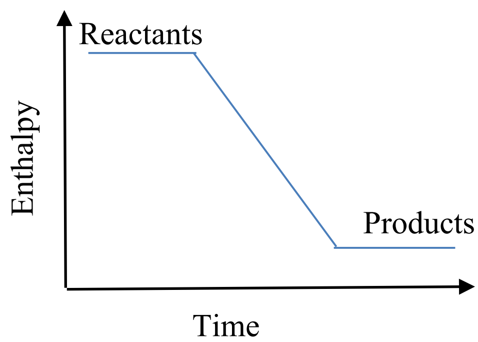
$\Delta H°_f\,(P_4O_{10}) = -2942$ kJ/mol

$\Delta H°_f\,(SO_2) = -296.8$ kJ/mol

Answer:

a. $\Delta H°_{rxn} = \Delta H°_{prod} - \Delta H°_{react}$ = *(-2942 kJ/mol + 3*-296.8kJ/mol) – (-155kJ/mol + 8(0))*
= ***-3677.4 kJ/mol***

b.



c. *The process is exothermic because the enthalpy change is negative, meaning that energy is released as the reaction proceeds.*

19. The decomposition of calcium carbonate is shown below along with the standard enthalpy and entropy values.

a) Calculate the $\Delta H°_f$ for the reaction.

b) Calculate the ΔS for the reaction.

c) What is the standard Gibb's free energy change expression for the reaction?

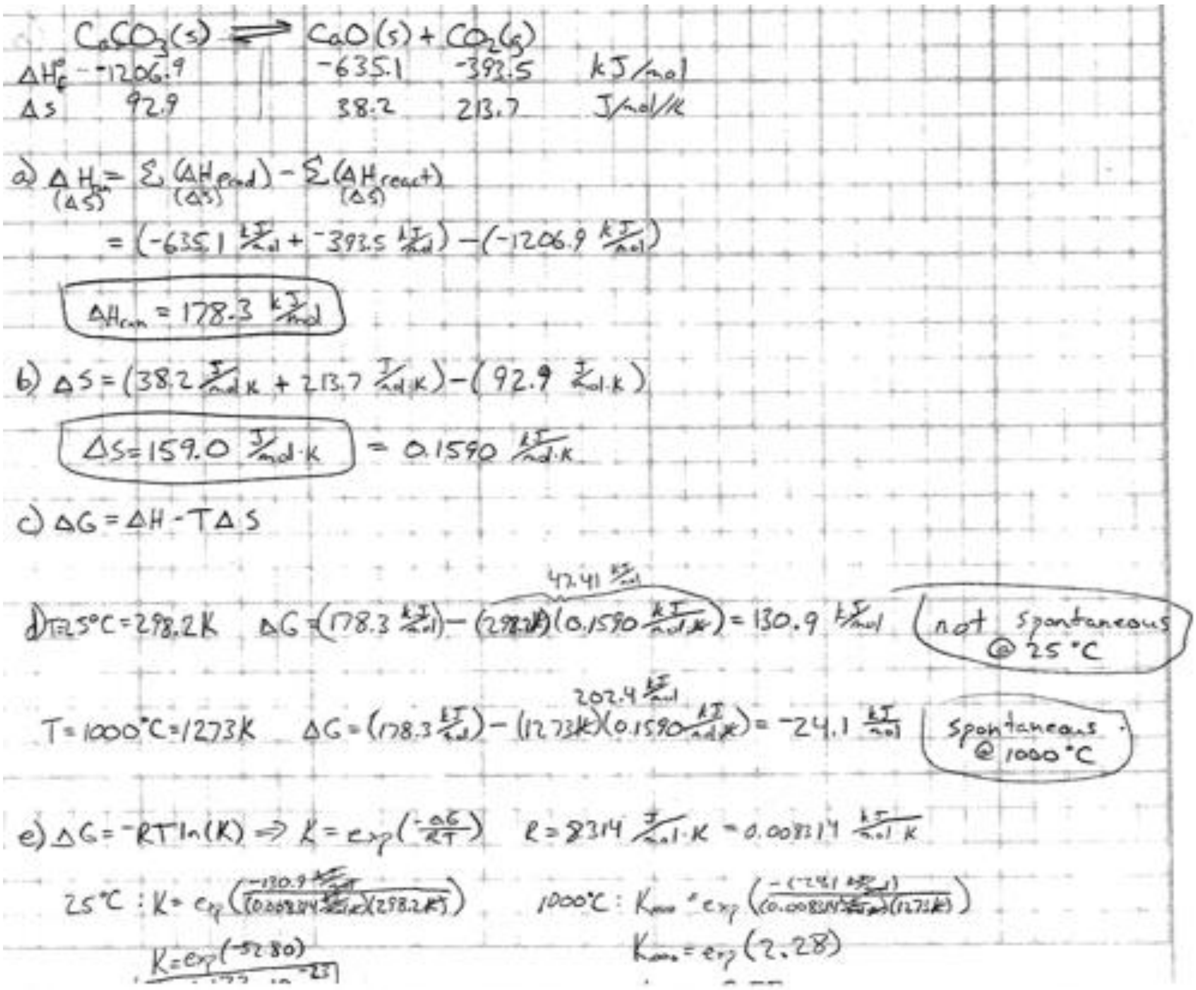
d) Is the reaction spontaneous at 25 °C? Is the reaction spontaneous at 1000 °C? Explain your answers.

e) Calculate the equilibrium constant at 25 °C and 1000 °C.

$$CaCO_3(s) \rightarrow CaO(s) + CO_2(g)$$

	$CaCO_3(s)$	$CaO(s)$	$CO_2(g)$
ΔH°_f (kJ/mol)	-1206.9	-635.1	-393.5
ΔS (kJ/mol)	92.9	38.2	213.7

Answer:



20. The reaction in which urea is formed from NH_3 and CO_2 is shown below. The standard free-energy change ΔG at 25 °C is -13.6 kJ/mol.

$$2NH_3(g) + CO_2(g) \Leftrightarrow NH_2CONH_2(aq) + H_2O(l)$$

a) Write an expression for the equilibrium constant, K, in terms of the molar concentrations of the reactants and products.

b) Write an expression for the equilibrium constant, *K*, as a function of $\Delta G°$ and temperature.

c) Determine the value of the equilibrium constant, *K*, for this reaction at 25 °C.

Answer:

$2NH_3(g) + CO_2(g) \rightleftharpoons NH_2CONH_2(aq) + H_2O(\ell)$

$\Delta G° = -13.6\ kJ/mol$

a) $K = \dfrac{[NH_2CONH_2][H_2O]}{[NH_3]^2[CO_2]}$

b) $K = \exp\left\{\dfrac{-\Delta G}{RT}\right\}$

c) $T = 25\ °C = 298.2\ K$ $\quad R = 0.008314\ \frac{kJ}{mol \cdot K}$

$K_{298.2} = \exp\left\{\dfrac{-(-13.6\ \frac{kJ}{mol})}{(0.008314\ \frac{kJ}{mol \cdot K})(298.2\ K)}\right\} = \exp(5.49)$

$K_{298} = 242$

21. Acetic acid, CH_3COOH, is a typical weak acid. It is an ingredient in vinegar.
    a) Acetic acid partially ionizes in water. Write a balanced chemical reaction for the dissociation of acetic acid into its conjugate base and hydrogen ion.
    b) Write an expression for the equilibrium constant for acetic acid.
    c) The equilibrium concentrations are $[CH_3COOH] = 0.15$ M and $[CH_3COO^-] = 1.63$ mM. What is the equilibrium constant of ionization, K_A?
    d) Calculate the pK_A of acetic acid.

Answer:

a) $HAc \rightleftharpoons H^+ + Ac^-$

b) $K_a = \frac{[H^+][Ac^-]}{[HAc]}$

c) $[H^+] = [Ac^-] = 1.63\ mM = 0.00163M$

$[HAc] = 0.150M$

$$K_a = \frac{[H^+][Ac^-]}{[HA_c]} = \frac{(0.00163M)^2}{(0.150M)} = \boxed{2.89\times10^{-8}\ M} \quad 1.77\times10^{-5}$$

d) $pK_a = pH - \log\frac{[Ac^-]}{[HA]}$ $\quad pH = -\log(0.00163) = 2.79$

$$pK_a = 2.79 - \log\left(\frac{(0.00163)}{(0.150)}\right) = 2.79 - (-1.96) = 4.75$$

22. A solution initially contains 42 mM formic acid ($HCHO_2$, $pK_A = 3.76$).
    a) Formic acid is a weak acid and partially ionizes in water. Write a balanced chemical reaction for its dissociation.
    b) Determine the conjugate base and H+ concentration at equilibrium
    c) Calculate the percentage of ionization.

Answer:

a) $HCHO_2 \rightleftharpoons H^+ + CHO_2^-$ $pK_a = 3.76 = -\log K_a$

b) $K_a = \frac{[H^+][CHO_2^-]}{[HCHO_2]}$ $[H^+] = [CHO_2^-] = x$ $[HCHO_2] = 42\,mM - x$

$[HCHO_2]_0 = 42\,mM$

$K_a = 10^{\wedge}(-pK_a) = 1.74\times10^{-4}\,M = 0.174\,mM$

$K_a = \frac{x^2}{42\,mM - x}$

$x^2 = (42\,mM)K_a - K_a x$

$x^2 + K_a x - (42\,mM)K_a = 0$

$x = \frac{-K_a \pm \sqrt{K_a^2 - 4(42\,mM)K_a}}{2} = \frac{-(0.174\,mM) \pm \sqrt{(0.174\,mM)^2 - 4(42\,mM)(0.174\,mM)}}{2}$

$= \frac{-(0.174\,mM) \pm \sqrt{(0.0303\,mM^2) - (29\,mM^2)}}{2} = \frac{-(0.174\,mM) \pm \sqrt{29\,mM^2}}{2}$

$x = \frac{-(0.174\,mM) \pm 5.4\,mM}{2} = 2.6\,mM$

$[H^+] = [CHO_2^-] = 2.6\,mM$

c) $\%\ ionization = \frac{[CHO_2^-]}{[HCHO_2]} \times 100\% = \frac{(2.6\,mM)}{(42\,mM)} \times 100\%$

$\%\ ionization = 6.2\%$

23. For the dissociation reaction of a weak acid shown below, begin with defining the K_a and show all the steps for the derivation of the Henderson-Hasselbalch equation.

$$HA \Leftrightarrow H^+ + A^-$$

The Henderson Hasselbalch equation for the blood bicarbonate system is shown as follows:

$$pH = 6.1 + \frac{[HCO_3^-]}{[H_2CO_3]}$$

a) Calculate the $[HCO_3^-]/[H_2CO_3]$ ratio for a blood pH of 5.8

b) Is this patient experiencing acidosis or alkalosis? Why?

c) What can the body due to restore the blood pH to normal?

Answer:

H-H Derivation: $HA \underset{k_r}{\overset{k_f}{\leftrightarrow}} H^+ + A^-$

Forward Rate = $k_f[HA]$; *Reverse Rate* = $k_r[H^+][A^-]$

At equilibrium, these rates are equal: $k_f[HA] = k_r[H^+][A^-]$ *which can be rearranged to* $k_f / k_r = [H^+][A^-] / [HA] = K_a$ *which is defined as a new variable, the acid dissociation constant*

$K_a = [H^+][A^-] / [HA]$ *rearranging yields* → $1/[H^+] = 1/K_a * [A^-]/[HA]$ *taking the log of both sides and recalling properties of logarithms* → $-\log([H^+]) = -\log(K_a) + \log([A^-]/[HA])$

$-\log([H^+])$ *is defined as pH and likewise,* $-\log(K_a)$ *is defined as* pK_a, *yielding:*

$pH = pK_a + \log([A^-]/[HA])$ *which is the Henderson-Hasselbalch Equation.*

a. $pH = pK_a + \log([HCO_3-]/[H_2CO_3])$ → $[HCO_3-]/[H_2CO_3] = 10\text{^}(pH - pK_a)$
   $[HCO_3-]/[H_2CO_3] = 10\text{^}(-0.3) =$ ***0.5012***

b. *If their blood pH is 5.8, they are experiencing acidosis. Normal blood pH is about 7.4, and a value of 5.8 is much lower and therefore more acidic.*

c. *The body can restore pH balance through control of respiration and excretion. Because* CO_2 *is rapidly cleared from the body as soon as it is produced, increasing respiration will increase the rate at which* H_2CO_3 *is removed from the blood, thereby decreasing its acidic effect. The kidneys are able to filter and excrete* H^+ *ions and the anions produced from strong acids as well as produce more* HCO_3^- *to buffer the blood.*