## Multiple Choice Questions

*Questions 1–5 refer to the following 0.2 M solutions: $NaCl$, $NaHSO_4$, $NaHCO_3$, $Na_2CO_3$, $NH_4Cl$.*

1. *Which solution will have the lowest $[OH^-]$?*

   A) $Na_2CO_3$

   B) $NaHCO_3$

   C) $NaCl$

   D) $NaHSO_4$

   E) $NH_4Cl$

2. *Which solution will be the strongest base?*

   A) $Na_2CO_3$

   B) $NaHCO_3$

   C) $NaCl$

   D) $NaHSO_4$

   E) $NH_4Cl$

3. *Which aqueous solutions are acidic?*

   A) $Na_2CO_3$ and $NaHCO_3$

   B) $NaCl$ and $NH_4Cl$

   C) $NaHSO_4$ and $NH_4Cl$

   D) $NaHSO_4$ and $NaHCO_3$

   E) $NaHSO_4$, $NaHCO_3$, and $NH_4Cl$

4. *What is the order of increasing pH (lowest pH first) of the solutions?*

   A) $Na_2CO_3 < NaHCO_3 < NaCl < NH_4Cl$

   B) $NaCl < Na_2CO_3 < NaHCO_3 < NH_4Cl$

   C) $NH_4Cl < NaHCO_3 < NaCl < Na_2CO_3$

   D) $NH_4Cl < NaCl < NaHCO_3 < Na_2CO_3$

   E) $Na_2CO_3 < NaCl < NaHCO_3 < NH_4Cl$

5. *Which solution will have the highest concentration of $Na^+$ ions?*

   A) $Na_2CO_3$

   B) $NaHCO_3$

   C) $NaCl$

   D) $NaHSO_4$

   E) *All are equal.*

6. *According to the Brønsted–Lowry definition, an acid is a substance that*

   A) *increases the hydrogen ion concentration in water.*

   B) *can react with water to form* $H^+$ *ions.*

   C) *can accept an electron pair to form a covalent bond.*

   D) *can donate a proton to a base.*

   E) *can react with water to form hydronium ions.*

7. *Which pair of chemical species is NOT a conjugate acid–base pair?*

   A) $H_2CO_3$ *and* $CO_3^{2-}$

   B) $OH^-$ *and* $H_2O$

   C) $HPO_4^{2-}$ *and* $PO_4^{3-}$

   D) $NH_3$ *and* $NH_4^+$

   E) $CH_3NH_2$ *and* $CH_3NH^-$

8. *Which oxide when mixed in equal molar amounts with water forms a solution with the lowest pH?*

   A) $CaO$

   B) $CO_2$

   C) $SO_2$

   D) $SO_3$

   E) $P_2O_5$

9. *Aqueous solutions of equal molar concentrations of these salts are listed in order of increasing pH.*
   $NaBr < NaIO_3 < NaF < NaC_2H_3O_2 < Na_2SO_3$

   *Which acid is the weakest?*

   A) $HBr$

   B) $HIO_3$

   C) $HF$

   D) $CH_3COOH$

   E) $NaHSO_3$

10. *The net ionic equation for the addition of 10.0 mL of 0.10 M sulfurous acid to 10.0 mL of 0.10 M aqueous sodium hydroxide is*

    A) $H_2SO_3 + 2OH^- \rightleftharpoons 2H_2O + SO_3^{2-}$

    B) $H_2SO_4 + OH^- \rightleftharpoons H_2O + HSO_4^-$

    C) $H_2SO_3 + OH^- \rightleftharpoons H_2O + HSO_3^-$

    D) $H^+ + OH^- \rightleftharpoons H_2O$

    E) $HSO_3^- + NaOH \rightarrow NaSO_3^- + H_2O$

11. *Identify the acid anhydride of chlorous acid, $HClO_2$.*

    A) $Cl_2O$

    B) $ClO$

    C) $ClO_2$

    D) $Cl_2O_3$

    E) $Cl_2O_5$

12. *The acid dissociation constants for the diprotic acid, malonic acid, $H_2C_3H_2O_4$, are $K_{a_1} = 1.5 \times 10^{-3}$ and $K_{a_2} = 2.0 \times 10^{-6}$.*

    *Which of the following represents the $K_b$ for $HC_3H_2O_4^-$?*

    A) $K_w \times K_{a_1}$

    B) $K_w \times K_{a_2}$

    C) $K_w \times K_{a_1}$

    D) $K_w \times K_{a_2}$

    E) $K_{a_1} \times K_{a_2}$

13. *Percentage ionization is defined as the number of moles of weak acid that ionizes expressed as a percentage of the original concentration: % ionization $= (x/I)(100)$. Calculate the percentage ionization of a 0.10 M solution of hydroazoic acid, $HN_3$.$K_a = 1.9 \times 10^{-5}$.*

    A) $1.9 \times 10^{-3}$

    B) *1.9*

    C) *0.19*

    D) *1.4*

    E) *0.14*

### Free Response Questions

1. *Sulfurous acid, $H_2SO_3$, is a diprotic acid. $K_{a_1} = 1.7 \times 10^{-2}$; $K_{a_2} = 6.4 \times 10^{-8}$*

    a. *Write an ionic equation for the aqueous ionization that corresponds to $K_{a_1}$.*

    *Write an ionic equation for the aqueous ionization that corresponds to $K_{a_2}$.*

    *Identify the conjugate acid–base pairs in each of your two equations.*

    b. *Identify any amphoteric species, other than water, in your equations.*

    c. *Assume the amphoteric species you identified in Part b is a base. Write an ionic equation for its aqueous ionization and calculate the corresponding $K_b$.*

    d. *Is an aqueous solution of $NaHSO_3$ acidic or basic? Explain your reasoning.*

    e. *Calculate the pH of a 0.50 M solution of $Na_2SO_3$.*

6. *D. A Brønsted–Lowry acid is a proton donor. An Arrhenius acid increases* $[H^+]$ *when dissolved in water.*

7. *A. An acid–base conjugate pair consists of two chemical species that differ in formula by an* $H^+$*. The species of the pair with the more positive charge (and hence the extra H) is the acid.*

8. *D. A lower pH implies a stronger acid. Nonmetal oxides tend to be acidic (acid anhydrides) while metal oxides tend to be basic (base anhydrides). When comparing oxides having different central atoms, the more electronegative atom forms the strongest acid. Sulfur is the most electronegative atom represented. When comparing oxides having the same central atom, the one with the greater number of oxygen atoms is more acidic.*

9. *E. A higher pH implies a stronger base. The strongest base,* $Na_2SO_3$*, has the weakest conjugate acid,* $NaHSO_3$*. The sodium ions are neutral because* $Na^+$ *is the cation of the strong base, NaOH.*

10. *C. Sulfurous acid,* $H_2SO_3$*, is a weak acid and should not be confused with sulfuric acid,* $H_2SO_4$*, a strong acid. Sodium hydroxide is a strong electrolyte, so the sodium ion is a spectator ion. Only one millimole each of the acid and base is present, so only one of the two ionizable protons on sulfurous acid will react.*

11. *D. The oxidation number of chlorine in* $HClO_2$ *is* $+3$*. The acid anhydride of an acid is generally the nonmetal oxide with the same oxidation number of the nonmetal.*

12. *C. The chemical reactions are:*

    1. $H_2C_3H_2O_4 + H_2O \rightleftharpoons HC_3H_2O_4^- + H_3O^+$

       $K_{a_1} = [HC_3H_2O_4^-][H_3O^+]/[H_2C_3H_2O_4]$

    2. $HC_3H_2O_4^- + H_2O \rightleftharpoons C_3H_2O_4^{2-} + H_3O^+$

       $K_{a_2} = [C_3H_2O_4^{2-}][H_3O^+]/[HC_3H_2O_4^-]$

    3. $HC_3H_2O_4^- + H_2O \rightleftharpoons H_2C_3H_2O_4 + OH^-$

       $K_b = [H_2C_3H_2O_4][OH^-]/[HC_3H_2O_4^-]$

    4. $H_2O + H_2O \rightleftharpoons H_3O^+ + OH^-$

       $k_w = [H_3O^+][OH^-]$

    *The relationship between* $K_a$ *and* $K_b$ *is* $K_b = K_w/K_a$*. Which* $K_a$ *is the correct one to use in this case?*

    *Substituting* $K_b = K_w/K_{a_1}$*, we get the correct solution:*

    $[H_2C_3H_2O_4][OH^-]/[HC_3H_2O_4^-] = [\cancel{H_3O^+}][OH^-]/$

    $([HC_3H_2O_4^-][\cancel{H_3O^+}]/[H_2C_3H_2O_4])$

    *Alternatively, Reaction 3 includes the same conjugate pair as Reaction 1, so* $K_b = K_w/K_{a_1}$ *is correct.*

13. D. $K_a = x^2/I$ *and % ionization* $= (x/I)(100)$, *where x is the moles per liter ionized and I is the initial concentration.*

$1.9 \times 10^{-5} = x^2/0.10$

$x = 1.4 \times 10^{-3}$

*% ionization* $= (1.4 \times 10^{-3}/0.10)(100) = 1.4$

## Free Response Answers

1. a. $\underset{\text{acid}}{H_2SO_3(aq)} + \underset{\text{base}}{H_2O(l)} = \underset{\text{acid}}{H_3O^+(aq)} + \underset{\text{base}}{HSO_3^-(aq)}$

$\underset{\text{acid}}{HSO_3^-(aq)} + \underset{\text{base}}{H_2O(l)} = \underset{\text{acid}}{H_3O^+(aq)} + \underset{\text{base}}{SO_3^{2-}(aq)}$

b. $HSO_3^-(aq)$

c. $HSO_3^-(aq) + H_2O(l) = OH^-(aq) + H_2SO_3(aq)$

$K_b = K_w/K_{a_1} = 1.0 \times 10^{-14}/1.7 \times 10^{-2} = 5.9 \times 10^{-13}$

d. $HSO_3^-(aq)$ *forms an acidic solution because its* $K_a$ *is much greater than its* $K_b$.

$K_{a_2} = 6.4 \times 10^{-8} > K_b = 5.9 \times 10^{-13}$

e. $K_b = K_w/K_{a_2} = 1.00 \times 10^{-14}/6.4 \times 10^{-8} = 1.56 \times 10^{-7}$

$K_b = y^2/I$

$1.56 \times 10^{-7} = y^2/0.50$

$y = 2.8 \times 10^{-4} = [OH^-]$

$pOH = -log\,[OH^-] = -log\,(2.8 \times 10^{-4}) = 3.55$

$pH = 14.00 - pOH = 14.00 - 3.55 = 10.45$

2. a. *Most anions, except those of strong acids, act as weak bases because their negative charges attract protons from water molecules, leaving hydroxide ions in solution.*

$X^{3-} + H_2O \rightarrow HX^{2-} + OH^-$

b. $Na_3X = pH\ 10.7$; $Na_2Y = pH\ 8.5$; *and* $NaZ = pH\ 7.0$.
*Generally, the anion with the most negative charge will be the most basic because it has the greatest tendency to attract a proton from a water molecule.*

c. *Because HZ has a neutral anion, it is most likely a strong acid that ionizes completely in water:*

$HZ \rightarrow H^+ + Z^-$

*A 0.01 M solution of HZ will produce a 0.01 M solution of* $H^+$.
$pH = -\log[H^+] = -\log(0.01) = 2.0$.

## Multiple Choice Answers and Explanations

1. *D. Sulfate ion is a neutral ion of the strong acid, sulfuric acid. Sodium hydrogen sulfate contains the second ionizable proton of sulfuric acid, so it is also relatively strong.*
2. *A. Carbonate ion has a 2– charge, the greatest negative-charged anion represented. It will have the greatest tendency to attract a positive proton.*
3. *C. Sodium ion and chloride ion are both neutral species in solution. Hydrogen sulfate ion and ammonium ion are both acids in solution.*
4. *D. A lower pH implies a stronger acid. In general, cations (except for the cations of strong bases) tend to be acidic and anions (except for the anions of strong acids) tend to be basic. The more positive the charge, the more acidic the cation, and the more negative the charge, the more basic the anion. Sodium ion is the neutral ion of the strong base, NaOH, and chloride ion is the neutral ion of the strong acid, HCl, so sodium chloride is neutral. Ammonium ion is slightly acidic, and hydrogen carbonate is the ion found in baking soda. Carbonate ion, because of its 2– charge, is a stronger base than is hydrogen carbonate.*
5. *A. All are strong electrolytes, but sodium carbonate provides two moles of sodium ion per mole. The others provide only one each.*