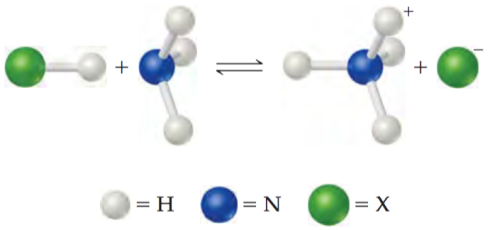
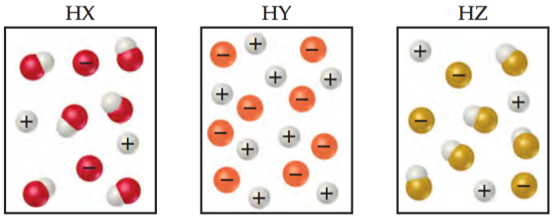
Acid-Base Equilibria
Problem Set

16.1 **(a)** Identify the Brønsted–Lowry acid and base in the reaction



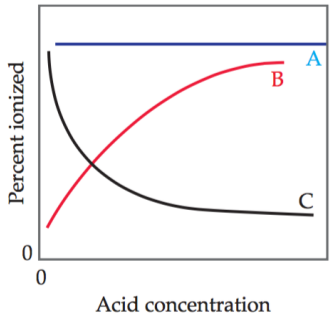
(b) Identify the Lewis acid and base in the reaction. [Sections 16.2 and 16.11]

16.3 The following diagrams represent aqueous solutions of three acids, HX, HY, and HZ. The water molecules have been omitted for clarity, and the hydrated proton is represented as H^+ rather than H_3O^+. **(a)** Which of the acids is a strong acid? Explain. **(b)** Which acid would have the smallest acid-dissociation constant, K_a? **(c)** Which solution would have the highest pH? [Sections 16.5 and 16.6]



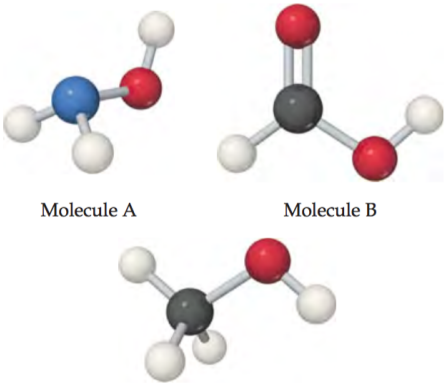
16.4 In which of the following cases is the approximation that the equilibrium concentration of $H^+(aq)$ is small relative to the initial concentration of HA likely to be most valid: **(a)** initial [HA] = 0.100 *M* and $K_a = 1.0 \times 10^{-6}$, **(b)** initial [HA] = 0.100 *M* and $K_a = 1.0 \times 10^{-4}$, **(c)** initial [HA] = 1.00 *M* and $K_a = 1.0 \times 10^{-6}$? [Section 16.6]

16.6 **(a)** Which of these three lines represents the effect of concentration on the percent ionization of a weak acid? **(b)** Explain in qualitative terms why the curve you chose has the shape it does. [Section 16.6]

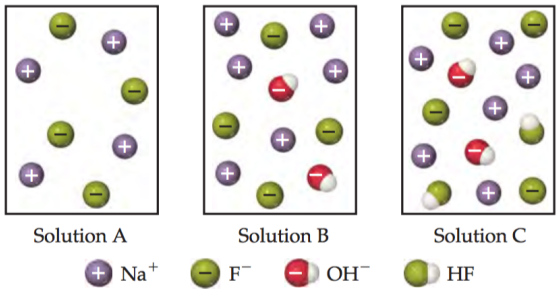


16.13 **(a)** What is the difference between the Arrhenius and the Brønsted–Lowry definitions of an acid? **(b)** $NH_3(g)$ and $HCl(g)$ react to form the ionic solid $NH_4Cl(s)$. Which substance is the Brønsted–Lowry acid in this reaction? Which is the Brønsted–Lowry base?

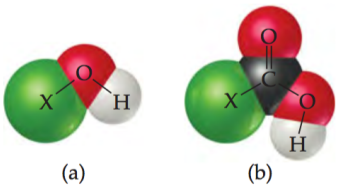
16.7 Each of the three molecules shown here contains an OH group, but one molecule acts as a base, one as an acid, and the third is neither acid nor base. **(a)** Which one acts as a base? Why does only this molecule act as a base? **(b)** Which one acts as an acid? **(c)** Why is the remaining molecule neither acidic nor basic? [Sections 16.6 and 16.7]



16.8 Which of the following diagrams best represents an aqueous solution of NaF? The water molecules are not shown for clarity. Will this solution be acidic, neutral, or basic? [Section 16.9]



16.9 Consider the molecular models shown here, where X represents a halogen atom. **(a)** If X is the same atom in both molecules, which one will be more acidic? **(b)** Does the acidity of each molecule increase or decrease as the electronegativity of the atom X increases? [Section 16.10]



16.14 **(a)** What is the difference between the Arrhenius and the Brønsted–Lowry definitions of a base? **(b)** Can a substance behave as an Arrhenius base if it does not contain an OH group? Explain.

16.16 **(a)** Give the conjugate base of the following Brønsted–Lowry acids: **(i)** HCOOH, **(ii)** HPO_4^{2-}. **(b)** Give the conjugate acid of the following Brønsted–Lowry bases: **(i)** SO_4^{2-}, **(ii)** CH_3NH_2.

16.18 Designate the Brønsted–Lowry acid and the Brønsted–Lowry base on the left side of each equation, and also designate the conjugate acid and conjugate base of each on the right side.

(a) $HBrO(aq) + H_2O(l) \rightleftharpoons H_3O^+(aq) + BrO^-(aq)$

(b) $HSO_4^-(aq) + HCO_3^-(aq) \rightleftharpoons SO_4^{2-}(aq) + H_2CO_3(aq)$

(c) $HSO_3^-(aq) + H_3O^+(aq) \rightleftharpoons H_2SO_3(aq) + H_2O(l)$

16.19 (a) The hydrogen oxalate ion ($HC_2O_4^-$) is amphiprotic. Write a balanced chemical equation showing how it acts as an acid toward water and another equation showing how it acts as a base toward water. (b) What is the conjugate acid of $HC_2O_4^-$? What is its conjugate base?

16.21 Label each of the following as being a strong base, a weak base, or a species with negligible basicity. In each case write the formula of its conjugate acid, and indicate whether the conjugate acid is a strong acid, a weak acid, or a species with negligible acidity: (a) CH_3COO^-, (b) HCO_3^-, (c) O^{2-}, (d) Cl^-, (e) NH_3.

16.24 (a) Which of the following is the stronger Brønsted–Lowry acid, $HClO_3$ or $HClO_2$? (b) Which is the stronger Brønsted–Lowry base, HS^- or HSO_4^-? Briefly explain your choices.

16.25 Predict the products of the following acid–base reactions, and predict whether the equilibrium lies to the left or to the right of the equation:

(a) $O^{2-}(aq) + H_2O(l) \rightleftharpoons$

(b) $CH_3COOH(aq) + HS^-(aq) \rightleftharpoons$

(c) $NO_2^-(aq) + H_2O(l) \rightleftharpoons$

16.27 If a neutral solution of water, with pH = 7.00, is heated to 50 °C, the pH drops to 6.63. Does this mean that the concentration of $[H^+]$ is greater than the concentration of $[OH^-]$? Explain.

16.28 (a) Write a chemical equation that illustrates the autoionization of water. (b) Write the expression for the ion-product constant for water, K_w. Why is $[H_2O]$ absent from this expression? (c) A solution is described as basic. What does this statement mean?

16.29 Calculate $[H^+]$ for each of the following solutions, and indicate whether the solution is acidic, basic, or neutral: (a) $[OH^-] = 0.00045\ M$; (b) $[OH^-] = 8.8 \times 10^{-9}\ M$; (c) a solution in which $[OH^-]$ is 100 times greater than $[H^+]$.

16.31 At the freezing point of water (0 °C), $K_w = 1.2 \times 10^{-15}$. Calculate $[H^+]$ and $[OH^-]$ for a neutral solution at this temperature.

16.33 By what factor does $[H^+]$ change for a pH change of (a) 2.00 units, (b) 0.50 units?

16.38 Complete the following table by calculating the missing entries. In each case indicate whether the solution is acidic or basic.

$[H^+]$	$OH^-(aq)$	pH	pOH	Acidic or basic?
$7.5 \times 10^{-3}\ M$				
	$3.6 \times 10^{-10}\ M$			
		8.25		
			5.70	

16.39 The average pH of normal arterial blood is 7.40. At normal body temperature (37 °C), $K_w = 2.4 \times 10^{-14}$. Calculate $[H^+]$, $[OH^-]$, and pOH for blood at this temperature.

16.41 (a) What is a strong acid? (b) A solution is labeled 0.500 *M* HCl. What is $[H^+]$ for the solution? (c) Which of the following are strong acids: HF, HCl, HBr, HI?

16.42 (a) What is a strong base? (b) A solution is labeled 0.035 *M* $Sr(OH)_2$. What is $[OH^-]$ for the solution? (c) Is the following statement true or false? Because $Mg(OH)_2$ is not very soluble, it cannot be a strong base. Explain.

16.43 Calculate the pH of each of the following strong acid solutions: (a) $8.5 \times 10^{-3}\ M$ HBr, (b) 1.52 g of HNO_3 in 575 mL of solution, (c) 5.00 mL of 0.250 *M* $HClO_4$ diluted to 50.0 mL, (d) a solution formed by mixing 10.0 mL of 0.100 *M* HBr with 20.0 mL of 0.200 *M* HCl.

16.46 Calculate $[OH^-]$ and pH for each of the following strong base solutions: (a) 0.182 *M* KOH, (b) 3.165 g of KOH in 500.0 mL of solution, (c) 10.0 mL of 0.0105 *M* $Ca(OH)_2$ diluted to 500.0 mL, (d) a solution formed by mixing 20.0 mL of 0.015 *M* $Ba(OH)_2$ with 40.0 mL of $8.2 \times 10^{-3}\ M$ NaOH.

16.48 Calculate the concentration of an aqueous solution of $Ca(OH)_2$ that has a pH of 10.05.

16.50 Write the chemical equation and the K_a expression for the acid dissociation of each of the following acids in aqueous solution. First show the reaction with $H^+(aq)$ as a product and then with the hydronium ion: (a) C_6H_5COOH, (b) HCO_3^-.

16.52 Phenylacetic acid ($C_6H_5CH_2COOH$) is one of the substances that accumulates in the blood of people with phenylketonuria, an inherited disorder that can cause mental retardation or even death. A 0.085 *M* solution of $C_6H_5CH_2COOH$ has a pH of 2.68. Calculate the K_a value for this acid.

16.53 A 0.100 *M* solution of chloroacetic acid ($ClCH_2COOH$) is 11.0% ionized. Using this information, calculate $[ClCH_2COO^-]$, $[H^+]$, $[ClCH_2COOH]$, and K_a for chloroacetic acid.

16.55 A particular sample of vinegar has a pH of 2.90. If acetic acid is the only acid that vinegar contains ($K_a = 1.8 \times 10^{-5}$), calculate the concentration of acetic acid in the vinegar.

16.58 The acid-dissociation constant for chlorous acid ($HClO_2$) is 1.1×10^{-2}. Calculate the concentrations of H_3O^+, ClO_2^-, and $HClO_2$ at equilibrium if the initial concentration of $HClO_2$ is 0.0125 *M*.

16.62 The active ingredient in aspirin is acetylsalicylic acid ($HC_9H_7O_4$), a monoprotic acid with $K_a = 3.3 \times 10^{-4}$ at 25 °C. What is the pH of a solution obtained by dissolving two extra-strength aspirin tablets, containing 500 mg of acetylsalicylic acid each, in 250 mL of water?

16.64 Calculate the percent ionization of propionic acid (C_2H_5COOH) in solutions of each of the following concentrations (K_a is given in Appendix D): (a) 0.250 *M*, (b) 0.0800 *M*, (c) 0.0200 *M*.

16.71 Write the chemical equation and the K_b expression for the reaction of each of the following bases with water: (a) dimethylamine, $(CH_3)_2NH$; (b) carbonate ion, CO_3^{2-}; (c) formate ion, CHO_2^-.

16.73 Calculate the molar concentration of OH^- ions in a 0.075 *M* solution of ethylamine ($C_2H_5NH_2$; $K_b = 6.4 \times 10^{-4}$). Calculate the pH of this solution.

16.76 Codeine ($C_{18}H_{21}NO_3$) is a weak organic base. A $5.0 \times 10^{-3} M$ solution of codeine has a pH of 9.95. Calculate the value of K_b for this substance. What is the pK_b for this base?

16.79 (a) Given that K_a for acetic acid is 1.8×10^{-5} and that for hypochlorous acid is 3.0×10^{-8}, which is the stronger acid? (b) Which is the stronger base, the acetate ion or the hypochlorite ion? (c) Calculate K_b values for CH_3COO^- and ClO^-.

16.83 Predict whether aqueous solutions of the following compounds are acidic, basic, or neutral: **(a)** NH_4Br, **(b)** $FeCl_3$, **(c)** Na_2CO_3, **(d)** $KClO_4$, **(e)** $NaHC_2O_4$.

16.85 An unknown salt is either NaF, NaCl, or NaOCl. When 0.050 mol of the salt is dissolved in water to form 0.500 L of solution, the pH of the solution is 8.08. What is the identity of the salt?

16.87 How does the acid strength of an oxyacid depend on **(a)** the electronegativity of the central atom; **(b)** the number of nonprotonated oxygen atoms in the molecule?

16.88 **(a)** Why is NH_3 a stronger base than H_2O? **(b)** Why is NH_3 a stronger base than CH_4?

16.89 Explain the following observations: **(a)** HNO_3 is a stronger acid than HNO_2; **(b)** H_2S is a stronger acid than H_2O; **(c)** H_2SO_4 is a stronger acid than HSO_4^-; **(d)** H_2SO_4 is a stronger acid than H_2SeO_4; **(e)** CCl_3COOH is a stronger acid than CH_3COOH.

16.92 Based on their compositions and structures and on conjugate acid–base relationships, select the stronger base in each of the following pairs: **(a)** NO_3^- or NO_2^-, **(b)** PO_4^{3-} or AsO_4^{3-}, **(c)** HCO_3^- or CO_3^{2-}.

16.94 Indicate whether each of the following statements is true or false. For each statement that is false, correct the statement to make it true. **(a)** Acid strength in a series of H—X molecules increases with increasing size of X. **(b)** For acids of the same general structure but differing electronegativities of the central atoms, acid strength decreases with increasing electronegativity of the central atom. **(c)** The strongest acid known is HF because fluorine is the most electronegative element.

16.95 If a substance is an Arrhenius base, is it necessarily a Brønsted–Lowry base? Is it necessarily a Lewis base? Explain.

16.98 Identify the Lewis acid and Lewis base in each of the following reactions:

(a) $HNO_2(aq) + OH^-(aq) \rightleftharpoons NO_2^-(aq) + H_2O(l)$

(b) $FeBr_3(s) + Br^-(aq) \rightleftharpoons FeBr_4^-(aq)$

(c) $Zn^{2+}(aq) + 4\,NH_3(aq) \rightleftharpoons Zn(NH_3)_4^{2+}(aq)$

(d) $SO_2(g) + H_2O(l) \rightleftharpoons H_2SO_3(aq)$