Class Discussion Questions

These questions are designed to be considered by groups of students in class. Often these questions work well for introducing a particular topic in class.

1. Consider two beakers of pure water at different temperatures. How do their pH values compare? Which is more acidic? more basic? Explain.
2. Differentiate between the terms *strength* and *concentration* as they apply to acids and bases. When is HCl strong? weak? concentrated? dilute? Answer the same questions for ammonia. Is the conjugate base of a weak acid a strong base?
3. Sketch two graphs: (a) percent dissociation for weak acid HA versus the initial concentration of HA ($[HA]_0$) and (b) H^+ concentration versus $[HA]_0$. Explain both.
4. Consider a solution prepared by mixing a weak acid HA and HCl. What are the major species? Explain what is occurring in solution. How would you calculate the pH? What if you added NaA to this solution? then added NaOH?
5. Explain why salts can be acidic, basic, or neutral, and show examples. Do this without specific numbers.
6. Consider two separate aqueous solutions: one of a weak acid HA and one of HCl. Assuming you started with 10 molecules of each:
   a. Draw a picture of what each solution looks like at equilibrium.
   b. What are the major species in each beaker?
   c. From your pictures, calculate the K_a values of each acid.
   d. Order the following from the strongest to the weakest base: H_2O, A^-, Cl^-. Explain your order.
7. You are asked to calculate the H^+ concentration in a solution of NaOH(*aq*). Because sodium hydroxide is a base, can we say there is no H^+, since having H^+ would imply that the solution is acidic?
8. Consider a solution prepared by mixing a weak acid HA, HCl, and NaA. Which of the following statements best describes what happens?
   a. The H^+ from the HCl reacts completely with the A^- from the NaA. Then, the HA dissociates somewhat.
   b. The H^+ from the HCl reacts somewhat with the A^- from the NaA to make HA, while the HA is dissociating. Eventually you have equal amounts of everything.
   c. The H^+ from the HCl reacts somewhat with the A^- from the NaA to make HA while the HA is dissociating. Eventually all the reactions have equal rates.
   d. The H^+ from the HCl reacts completely with the A^- from the NaA. Then the HA dissociates somewhat until "too much" H^+ and A^- are formed, so the H^+ and A^- react to form HA, etc. Eventually equilibrium is reached.

   Justify your choice, and for choices you did not pick, explain what is wrong with them.
9. Consider a solution formed by mixing 100.0 mL of 0.10 *M* HA ($K_a = 1.0 \times 10^{-6}$), 100.00 mL of 0.10 *M* NaA, and 100.0 mL of 0.10 *M* HCl. In calculating the pH for the final solution, you would make some assumptions about the order in which various reactions occur to simplify the calculations. State these assumptions. Does it matter whether or not the reactions actually occur in the assumed order? Explain.
10. A certain sodium compound is dissolved in water to liberate Na^+ ions and a certain negative ion. What evidence would you look for to determine whether the anion is behaving as an acid or a base? How could you tell whether the anion is a strong base? Explain how the anion could behave simultaneously as an acid and a base.
11. Acids and bases can be thought of as chemical opposites (acids are proton donors, and bases are proton acceptors). Therefore, one might think that $K_a = 1/K_b$. Why isn't this the case? What is the relationship between K_a and K_b? Prove it with a derivation.
12. Consider two solutions of the salts NaX(*aq*) and NaY(*aq*) at equal concentrations. What would you need to know in order to determine which solution has the higher pH? Explain how you would decide (perhaps even provide a sample calculation).
13. What is meant by *pH*? True or false, a strong acid solution always has a lower pH than a weak acid solution. Explain.
14. Why is the pH of water at 25°C equal to 7.00?
15. Can the pH of a solution be negative? Explain.

A blue question or exercise number indicates that the answer to that question or exercise appears at the back of this book and a solution appears in the *Solutions Guide*.

Questions

16. Define each of the following using the Arrhenius model.
    a. strong acid **c.** weak acid
    b. strong base **d.** weak base
17. Define each of the following.
    a. Arrhenius acid
    b. Brønsted–Lowry acid
    c. Lewis acid

    Which of the definitions is most general? Write reactions to justify your answer.
18. Why is H_3O^+ the strongest acid and OH^- the strongest base that can exist in significant amounts in aqueous solutions?
19. Give the conditions for a neutral solution at 25°C, in terms of $[H^+]$, pH, and the relationship between $[H^+]$ and $[OH^-]$.
20. How many significant figures are there in the numbers: 10.78, 6.78, 0.78? If these were pH values, to how many significant figures can you express the $[H^+]$? Explain any discrepancies between your answers to the two questions.

21. The presence of what element most commonly results in basic properties for an organic compound?
22. For oxyacids, how does acid strength depend on
    a. strength of the bond to the acidic hydrogen atom?
    b. electronegativity of the element bonded to the oxygen atom that bears the acidic hydrogen?
    c. the number of oxygen atoms?
23. How does the strength of a conjugate base depend on the factors listed in Question 22?
24. In terms of orbitals and electron arrangements, what must be present for a molecule or an ion to act as a Lewis acid? What must be present for a molecule or an ion to act as a Lewis base?
25. Consider the reaction of acetic acid in water

$$CH_3CO_2H(aq) + H_2O(l) \rightleftharpoons CH_3CO_2^-(aq) + H_3O^+(aq)$$

where $K_a = 1.8 \times 10^{-5}$.
    a. Which two bases are competing for the proton?
    b. Which is the stronger base?
    c. In light of your answer to b, why do we classify the acetate ion ($CH_3CO_2^-$) as a weak base? Use an appropriate reaction to justify your answer.
26. In general, as base strength increases, conjugate acid strength decreases. Explain why the conjugate acid of the weak base NH_3 is a weak acid.

Exercises

In this section similar exercises are paired.

Nature of Acids and Bases

27. Write balanced equations that describe the following reactions.
    a. the dissociation of perchloric acid in water
    b. the dissociation of propanoic acid ($CH_3CH_2CO_2H$) in water
    c. the dissociation of ammonium ion in water
28. Write the dissociation reaction and the corresponding K_a equilibrium expression for each of the following acids in water.
    a. $HC_2H_3O_2$ b. $Co(H_2O)_6^{3+}$ c. $CH_3NH_3^+$
29. For each of the following aqueous reactions, identify the acid, the base, the conjugate base, and the conjugate acid.
    a. $HF + H_2O \rightleftharpoons F^- + H_3O^+$
    b. $H_2SO_4 + H_2O \rightleftharpoons H_3O^+ + HSO_4^-$
    c. $HSO_4^- + H_2O \rightleftharpoons SO_4^{2-} + H_3O^+$
30. For each of the following aqueous reactions, identify the acid, the base, the conjugate base, and the conjugate acid.
    a. $Al(H_2O)_6^{3+} + H_2O \rightleftharpoons H_3O^+ + Al(H_2O)_5(OH)^{2+}$
    b. $H_2O + HONH_3^+ \rightleftharpoons HONH_2 + H_3O^+$
    c. $HOCl + C_6H_5NH_2 \rightleftharpoons OCl^- + C_6H_5NH_3^+$
31. Classify each of the following as a strong acid or a weak acid in aqueous solution.
    a. HNO_2 c. HCl
    b. HNO_3 d. HF
32. Classify each of the following as a strong acid or a weak acid in aqueous solution.
    a. $HClO_4$ c. H_2SO_4
    b. HOCl d. HSO_4^-
33. Use Table 14.2 to order the following from the strongest to the weakest acid.

$$H_2O, \quad HNO_3, \quad HOCl, \quad NH_4^+$$

34. Use Table 14.2 to order the following from the strongest to the weakest base.

$$H_2O, \quad NO_3^-, \quad OCl^-, \quad NH_3$$

35. You may need Table 14.2 to answer the following questions.
    a. Which is the stronger acid, HCl or H_2O?
    b. Which is the stronger acid, H_2O or HNO_2?
    c. Which is the stronger acid, HCN or HOC_6H_5?
36. You may need Table 14.2 to answer the following questions.
    a. Which is the stronger base, Cl^- or H_2O?
    b. Which is the stronger base, H_2O or NO_2^-?
    c. Which is the stronger base, CN^- or $OC_6H_5^-$?

Autoionization of Water and the pH Scale

37. Calculate the $[OH^-]$ of each of the following solutions at 25°C. Identify each solution as neutral, acidic, or basic.
    a. $[H^+] = 1.0 \times 10^{-7}\ M$ c. $[H^+] = 1.9 \times 10^{-11}\ M$
    b. $[H^+] = 6.7 \times 10^{-4}\ M$ d. $[H^+] = 2.3\ M$
38. Calculate the $[H^+]$ of each of the following solutions at 25°C. Identify each solution as neutral, acidic, or basic.
    a. $[OH^-] = 3.6\ M$ c. $[OH^-] = 2.2 \times 10^{-7}\ M$
    b. $[OH^-] = 9.7 \times 10^{-9}\ M$ d. $[OH^-] = 1.0 \times 10^{-7}\ M$
39. Values of K_w as a function of temperature are as follows:

Temperature (°C)	K_w
0	1.14×10^{-15}
25	1.00×10^{-14}
35	2.09×10^{-14}
40	2.92×10^{-14}
50	5.47×10^{-14}

    a. Is the autoionization of water exothermic or endothermic?
    b. Calculate $[H^+]$ and $[OH^-]$ in a neutral solution at 50°C.
40. At 40°C, the value of K_w is 2.92×10^{-14}.
    a. Calculate the $[H^+]$ and $[OH^-]$ in pure water at 40°C.
    b. What is the pH of pure water at 40°C?
    c. If the hydroxide ion concentration in a solution is $1.0 \times 10^{-7}\ M$, what is the pH at 40°C?
41. Calculate the pH and pOH of the solutions in Exercise

42. Calculate the pH and pOH of the solutions in Exercise 38.

43. Calculate $[H^+]$ and $[OH^-]$ for each solution at 25°C. Identify each solution as neutral, acidic, or basic.
a. pH = 7.40 (the normal pH of blood)
b. pH = 15.3
c. pH = −1.0
d. pH = 3.20
e. pOH = 5.0
f. pOH = 9.60

44. Calculate $[H^+]$ and $[OH^-]$ for each solution at 25°C. Identify each solution as neutral, acidic, or basic.
a. pH = −0.42
b. pH = 3.42
c. pH = 10.67
d. pOH = 14.30
e. pOH = 9.67
f. pOH = 1.15

45. The pH of a sample of milk is 6.77 at 25°C. Calculate the pOH, $[H^+]$, and $[OH^-]$ for this sample. Is milk acidic or basic?

46. The pOH of a sample of baking soda dissolved in water is 5.74 at 25°C. Calculate the pH, $[H^+]$, and $[OH^-]$ for this sample. Is the solution acidic or basic?

Solutions of Acids

47. What are the major species present in 0.250 *M* solutions of each of the following acids? Calculate the pH of each of these solutions.
a. HCl
b. HBr (a strong acid)

48. What are the major species present in 0.250 *M* solutions of each of the following acids? Calculate the pH of each of these solutions.
a. $HClO_4$
b. HNO_3

49. Calculate the pH of each of the following solutions of a strong acid in water.
a. 0.10 *M* HCl
b. 2.0 *M* HCl
c. 1.0×10^{-11} *M* HCl

50. Calculate the pH of each of the following solutions of a strong acid in water.
a. 2.6×10^{-3} *M* $HClO_4$
b. 2.0 *M* $HClO_4$
c. 8.1×10^{-10} *M* $HClO_4$

51. A solution is prepared by adding 50.0 mL of 0.050 *M* HCl to 150.0 mL of 0.10 *M* HNO_3. Calculate the concentrations of all species in this solution.

52. A solution is prepared by mixing 90.0 mL of 5.00 *M* HCl and 30.0 mL of 8.00 *M* HNO_3. Water is then added until the final volume is 1.00 L. Calculate $[H^+]$, $[OH^-]$, and the pH for this solution.

53. Calculate the concentration of an aqueous HCl solution that has pH = 2.50.

54. Calculate the concentration of an aqueous HNO_3 solution that has pH = 5.10.

55. What are the major species present in 0.250 *M* solutions of each of the following acids? Calculate the pH of each of these solutions.
a. HNO_2
b. CH_3CO_2H ($HC_2H_3O_2$)

56. What are the major species present in 0.250 *M* solutions of each of the following acids? Calculate the pH of each of these solutions.
a. HOC_6H_5
b. HCN

57. Using the K_a values given in Table 14.2, calculate the concentrations of all species present and the pH of a 1.5 *M* HOCl solution.

58. A solution with a total volume of 250.0 mL is prepared by diluting 20.0 mL of glacial acetic acid with water. Calculate $[H^+]$ and the pH of this solution. Assume that glacial acetic acid is pure liquid acetic acid with a density of 1.05 g/cm^3.

59. Calculate the concentration of all species present and the pH of a 0.020 *M* HF solution.

60. Calculate the pH of a 0.20 *M* solution of iodic acid (HIO_3, $K_a = 0.17$).

61. Calculate the pH of a 0.50 *M* solution of chlorous acid ($HClO_2$, $K_a = 1.2 \times 10^{-2}$).

62. Monochloroacetic acid, $HC_2H_2ClO_2$, is a skin irritant that is used in "chemical peels" intended to remove the top layer of dead skin from the face and ultimately improve the complexion. The value of K_a for monochloroacetic acid is 1.35×10^{-3}. Calculate the pH of a 0.10 *M* solution of monochloroacetic acid.

63. Calculate the pH of a solution containing a mixture of 0.10 *M* HCl and 0.10 *M* HOCl.

64. Calculate the pH of a solution that contains 1.0 *M* HF and 1.0 *M* HOC_6H_5. Also calculate the concentration of $OC_6H_5^-$ in this solution at equilibrium.

65. Calculate the percent dissociation of the acid in each of the following solutions.
a. 0.50 *M* acetic acid
b. 0.050 *M* acetic acid
c. 0.0050 *M* acetic acid
d. Use Le Châtelier's principle to explain why percent dissociation increases as the concentration of a weak acid decreases.
e. Even though the percent dissociation increases from solutions a to c, the $[H^+]$ decreases. Explain.

66. Using the K_a values in Table 14.2, calculate the percent dissociation in a 0.20 *M* solution of each of the following acids.
a. nitric acid (HNO_3)
b. nitrous acid (HNO_2)
c. phenol (HOC_6H_5)
d. How is percent dissociation of an acid related to the K_a value for the acid (assuming equal initial concentrations of acids)?

67. For propanoic acid ($HC_3H_5O_2$, $K_a = 1.3 \times 10^{-5}$), calculate the $[H^+]$, pH, and percent dissociation of a 0.10 *M* solution.
68. Calculate the percent dissociation for a 0.22 *M* solution of chlorous acid ($HClO_2$, $K_a = 1.2 \times 10^{-2}$).

69. A 0.15 *M* solution of a weak acid is 3.0% dissociated. Calculate K_a.
70. In a 0.100 *M* solution of HF, the percent dissociation is 8.1%. Calculate K_a.

71. The pH of a 0.063 *M* solution of hypobromous acid (HOBr but usually written HBrO) is 4.95. Calculate K_a.
72. Trichloroacetic acid (CCl_3CO_2H) is a corrosive acid that is used to precipitate proteins. The pH of a 0.050 *M* solution of trichloroacetic acid is the same as the pH of a 0.040 *M* $HClO_4$ solution. Calculate K_a for trichloroacetic acid.

73. A solution of formic acid (HCOOH, $K_a = 1.8 \times 10^{-4}$) has a pH of 2.70. Calculate the initial concentration of formic acid in this solution.
74. One mole of a weak acid HA was dissolved in 2.0 L of water. After the system had come to equilibrium, the concentration of HA was found to be 0.45 *M*. Calculate K_a for HA.

Solutions of Bases

75. Write the reaction and the corresponding K_b equilibrium expression for each of the following substances acting as bases in water.
    a. NH_3 **b.** C_5H_5N
76. Write the reaction and the corresponding K_b equilibrium expression for each of the following substances acting as bases in water.
    a. aniline, $C_6H_5NH_2$ **b.** dimethylamine, $(CH_3)_2NH$

77. Use Table 14.3 to help order the following bases from strongest to weakest.

$$NO_3^-, \quad H_2O, \quad NH_3, \quad C_5H_5N$$

78. Use Table 14.3 to help order the following acids from strongest to weakest.

$$HNO_3, \quad H_2O, \quad NH_4^+, \quad C_5H_5NH^+$$

79. Use Table 14.3 to help answer the following questions.
    a. Which is the stronger base, NO_3^- or NH_3?
    b. Which is the stronger base, H_2O or NH_3?
    c. Which is the stronger base, OH^- or NH_3?
    d. Which is the stronger base, NH_3 or CH_3NH_2?
80. Use Table 14.3 to help answer the following questions.
    a. Which is the stronger acid, HNO_3 or NH_4^+?
    b. Which is the stronger acid, H_2O or NH_4^+?
    c. Which is the stronger acid, NH_4^+ or $CH_3NH_3^+$?

81. Calculate the pH of the following solutions.
    a. 0.10 *M* NaOH **c.** 2.0 *M* NaOH
    b. 1.0×10^{-10} *M* NaOH

82. Calculate the pH of the following solutions.
    a. 0.0062 *M* $Sr(OH)_2$
    b. 0.75 *M* $Sr(OH)_2$
    c. 5.0×10^{-10} *M* $Sr(OH)_2$

83. What are the major species present in 0.150 M solutions of each of the following bases?
    a. KOH **b.** $Ca(OH)_2$
    What is $[OH^-]$ and the pH of each of these solutions?
84. What are the major species present in the following mixtures of bases?
    a. 0.050 *M* NaOH and 0.050 *M* LiOH
    b. 0.0010 *M* $Ba(OH)_2$ and 0.020 *M* RbOH
    What is $[OH^-]$ and the pH of each of these solutions?

85. Calculate the concentration of an aqueous KOH solution that has pH = 10.50.
86. Calculate the concentration of an aqueous $Ba(OH)_2$ that has pH = 10.50.

87. What are the major species present in a 0.150 *M* NH_3 solution? Calculate the $[OH^-]$ and the pH of this solution.
88. For the reaction of hydrazine (N_2H_4) in water,

$$H_2NNH_2(aq) + H_2O(l) \rightleftharpoons H_2NNH_3^+(aq) + OH^-(aq)$$

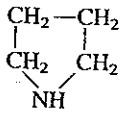
K_b is 3.0×10^{-6}. Calculate the concentrations of all species and the pH of a 2.0 *M* solution of hydrazine in water.

89. Calculate $[OH^-]$, $[H^+]$, and the pH of 0.20 *M* solutions of each of the following amines.
    a. Triethylamine $[(C_2H_5)_3N, K_b = 4.0 \times 10^{-4}]$
    b. Hydroxylamine ($HONH_2$, $K_b = 1.1 \times 10^{-8}$)
90. Calculate $[OH^-]$, $[H^+]$, and the pH of 0.20 *M* solutions of each of the following amines (the K_b values are found in Table 14.3).
    a. Aniline **b.** Pyridine

91. Calculate the pH of a 0.20 *M* $C_2H_5NH_2$ solution ($K_b = 5.6 \times 10^{-4}$).
92. Calculate the pH of a 0.050 *M* $(C_2H_5)_2NH$ solution ($K_b = 1.3 \times 10^{-3}$).

93. Calculate the percent ionization in each of the following solutions.
    a. 0.10 *M* NH_3 **b.** 0.010 *M* NH_3
94. Calculate the percent ionization in each of the following solutions (see Table 14.3 for K_b values).
    a. 0.10 *M* hydroxylamine ($HONH_2$, $K_b = 1.1 \times 10^{-8}$)
    b. 0.10 *M* methylamine (CH_3NH_2)

95. Codeine ($C_{18}H_{21}NO_3$) is a derivative of morphine that is used as an analgesic, narcotic, or antitussive. It was once commonly used in cough syrups but is now available only by prescription because of its addictive properties. If the pH of a 1.7×10^{-3} *M* solution of codeine is 9.59, calculate K_b.
96. The pH of a 1.00×10^{-3} *M* solution of pyrrolidine is 10.63. Calculate K_b.



Pyrrolidine

Polyprotic Acids

97. Write out the stepwise K_a reactions for the diprotic acid H_2SO_3.
98. Write out the stepwise K_a reactions for citric acid ($H_3C_6H_5O_7$), a triprotic acid.
99. Using the K_a values in Table 14.4 and only the first dissociation step, calculate the pH of 0.10 M solutions of each of the following polyprotic acids.
    a. H_3PO_4 b. H_2CO_3
100. Arsenic acid (H_3AsO_4) is a triprotic acid with $K_{a_1} = 5 \times 10^{-3}$, $K_{a_2} = 8 \times 10^{-8}$, and $K_{a_3} = 6 \times 10^{-10}$. Calculate $[H^+]$, $[OH^-]$, $[H_3AsO_4]$, $[H_2AsO_4^-]$, $[HAsO_4^{2-}]$, and $[AsO_4^{3-}]$ in a 0.20 M arsenic acid solution.
101. Calculate the pH of a 2.0 M H_2SO_4 solution.
102. Calculate the pH of a 5.0×10^{-3} M solution of H_2SO_4.

Acid-Base Properties of Salts

103. Arrange the following 0.10 M solutions in order of most acidic to most basic.

    KOH, KCl, KCN, NH_4Cl, HCl
104. Arrange the following 0.10 M solutions in order of most acidic to most basic.

    $Ca(NO_3)_2$, $NaNO_2$, HNO_3, NH_4NO_3, $Ca(OH)_2$
105. Given that the K_a value for acetic acid is 1.8×10^{-5} and the K_a value for hypochlorous acid is 3.5×10^{-8}, which is the stronger base, OCl^- or $C_2H_3O_2^-$?
106. The K_b values for ammonia and methylamine are 1.8×10^{-5} and 4.4×10^{-4}, respectively. Which is the stronger acid, NH_4^+ or $CH_3NH_3^+$?
107. Sodium azide (NaN_3) is sometimes added to water to kill bacteria. Calculate the concentration of all species in a 0.010 M solution of NaN_3. The K_a value for hydrazoic acid (HN_3) is 1.9×10^{-5}.
108. Calculate the concentrations of all species present in a 0.25 M solution of ethylammonium chloride ($C_2H_5NH_3Cl$).
109. Calculate the pH of each of the following solutions.
    a. 0.10 M CH_3NH_3Cl b. 0.050 M NaCN
110. Calculate the pH of each of the following solutions.
    a. 0.12 M KNO_2 c. 0.40 M NH_4ClO_4
    b. 0.45 M NaOCl
111. An unknown salt is either NaCN, $NaC_2H_3O_2$, NaF, NaCl, or NaOCl. When 0.100 mol of the salt is dissolved in 1.00 L of water, the pH of the solution is 8.07. What is the identity of the salt?
112. Consider a solution of an unknown salt having the general formula BHCl, where B is one of the weak bases in Table 14.3. A 0.10 M solution of the unknown salt has a pH of 5.82. What is the actual formula of the salt?
113. Calculate the pH of a 0.050 M $Al(NO_3)_3$ solution. The K_a value for $Al(H_2O)_6^{3+}$ is 1.4×10^{-5}.
114. Calculate the pH of a 0.10 M $CoCl_3$ solution. The K_a value for $Co(H_2O)_6^{3+}$ is 1.0×10^{-5}.
115. Are solutions of the following salts acidic, basic, or neutral? For those that are not neutral, write balanced chemical equations for the reactions causing the solution to be acidic or basic. The relevant K_a and K_b values are found in Tables 14.2 and 14.3.
    a. $NaNO_3$ c. $C_5H_5NHClO_4$ e. KOCl
    b. $NaNO_2$ d. NH_4NO_2 f. NH_4OCl
116. Are solutions of the following salts acidic, basic, or neutral? For those that are not neutral, write balanced equations for the reactions causing the solution to be acidic or basic. The relevant K_a and K_b values are found in Tables 14.2 and 14.3.
    a. KCl c. CH_3NH_3Cl e. NH_4F
    b. $NH_4C_2H_3O_2$ d. KF f. CH_3NH_3CN

Relationships Between Structure and Strengths of Acids and Bases

117. Place the species in each of the following groups in order of increasing acid strength. Explain the order you chose for each group.
    a. HIO_3, $HBrO_3$ c. HOCl, HOI
    b. HNO_2, HNO_3 d. H_3PO_4, H_3PO_3
118. Place the species in each of the following groups in order of increasing base strength. Give your reasoning in each case.
    a. IO_3^-, BrO_3^- b. NO_2^-, NO_3^- c. OCl^-, OI^-
119. Place the species in each of the following groups in order of increasing acid strength.
    a. H_2O, H_2S, H_2Se (bond energies: H—O, 467 kJ/mol; H—S, 363 kJ/mol; H—Se, 276 kJ/mol)
    b. CH_3CO_2H, FCH_2CO_2H, F_2CHCO_2H, F_3CCO_2H
    c. NH_4^+, $HONH_3^+$
    d. NH_4^+, PH_4^+(bond energies: N—H, 391 kJ/mol; P—H, 322 kJ/mol)

    Give reasons for the orders you chose.
120. Using your results from Exercise 119, place the species in each of the following groups in order of increasing base strength.
    a. OH^-, SH^-, SeH^- b. NH_3, PH_3 c. NH_3, $HONH_2$
121. Will the following oxides give acidic, basic, or neutral solutions when dissolved in water? Write reactions to justify your answers.
    a. CaO b. SO_2 c. Cl_2O

122. Will the following oxides give acidic, basic, or neutral solutions when dissolved in water? Write reactions to justify your answers.
a. Li_2O b. CO_2 c. SrO

Lewis Acids and Bases

123. Identify the Lewis acid and the Lewis base in each of the following reactions.
a. $B(OH)_3(aq) + H_2O(l) \rightleftharpoons B(OH)_4^-(aq) + H^+(aq)$
b. $Ag^+(aq) + 2NH_3(aq) \rightleftharpoons Ag(NH_3)_2^+(aq)$
c. $BF_3(g) + F^-(aq) \rightleftharpoons BF_4^-(aq)$

124. Identify the Lewis acid and the Lewis base in each of the following reactions.
a. $Fe^{3+}(aq) + 6H_2O(l) \rightleftharpoons Fe(H_2O)_6^{3+}(aq)$
b. $H_2O(l) + CN^-(aq) \rightleftharpoons HCN(aq) + OH^-(aq)$
c. $HgI_2(s) + 2I^-(aq) \rightleftharpoons HgI_4^{2-}(aq)$

125. Aluminum hydroxide is an amphoteric substance. It can act as either a Brønsted–Lowry base or a Lewis acid. Write a reaction showing $Al(OH)_3$ acting as a base toward H^+ and as an acid toward OH^-.

126. Zinc hydroxide is an amphoteric substance. Write equations that describe $Zn(OH)_2$ acting as a Brønsted–Lowry base toward H^+ and as a Lewis acid toward OH^-.

127. Would you expect Fe^{3+} or Fe^{2+} to be the stronger Lewis acid? Explain.

128. Use the Lewis acid–base model to explain the following reaction.

$$CO_2(g) + H_2O(l) \longrightarrow H_2CO_3(aq)$$

Additional Exercises

129. A 10.0-mL sample of an HCl solution has a pH of 2.000. What volume of water must be added in order to change the pH to 4.000?

130. Thallium(I) hydroxide is a strong base used in the synthesis of some organic compounds. Calculate the pH of a solution containing 2.48 g TlOH per liter.

131. Derive an expression for the relationship between pK_a and pK_b for a conjugate acid–base pair. ($pK = -\log K$.)

132. At 25°C, a saturated solution of benzoic acid ($K_a = 6.4 \times 10^{-5}$) has a pH of 2.80. Calculate the water solubility of benzoic acid in moles per liter.

133. Quinine ($C_{20}H_{24}N_2O_2$) is an important alkaloid derived from cinchona bark. It is used as an antimalarial drug. For quinine $pK_{b_1} = 5.1$ and $pK_{b_2} = 9.7$ ($pK_b = -\log K_b$). One gram of quinine will dissolve in 1900.0 mL of water. Calculate the pH of a saturated aqueous solution of quinine. Consider only the aqueous reaction $Q + H_2O \rightleftharpoons QH^+ + OH^-$ described by pK_{b_1} where Q = quinine.

134. Phosphoric acid is a common ingredient in traditional cola drinks. It is added to provide the drinks with a pleasantly tart taste. Although phosphoric acid is a triprotic acid, its protons are lost one at a time. Assuming that in cola drinks the concentration of phosphoric acid is 0.007 *M*, calculate the pH of this solution.

135. Acrylic acid ($CH_2{=}CHCO_2H$) is a precursor for many important plastics. K_a for acrylic acid is 5.6×10^{-5}.
a. Calculate the pH of a 0.10 *M* solution of acrylic acid.
b. Calculate the percent dissociation of a 0.10 *M* solution of acrylic acid.
c. Calculate the pH of a 0.050 *M* solution of sodium acrylate ($NaC_3H_3O_2$).

136. A 0.20 *M* sodium chlorobenzoate ($NaC_7H_4ClO_2$) solution has a pH of 8.65. Calculate the pH of a 0.20 *M* chlorobenzoic acid ($HC_7H_4ClO_2$) solution.

137. The equilibrium constant K_a for the reaction

$$Fe(H_2O)_6^{3+}(aq) + H_2O(l) \rightleftharpoons Fe(H_2O)_5(OH)^{2+}(aq) + H_3O^+(aq)$$

is 6.0×10^{-3}.
a. Calculate the pH of a 0.10 *M* solution of $Fe(H_2O)_6^{3+}$.
b. Will a 1.0 *M* solution of iron(II) nitrate have a higher or lower pH than a 1.0 *M* solution of iron(III) nitrate? Explain.

138. Rank the following 0.10 *M* solutions in order of increasing pH.
a. HI, HF, NaF, NaI
b. NH_4Br, HBr, KBr, NH_3
c. $C_6H_5NH_3NO_3$, $NaNO_3$, NaOH, HOC_6H_5, KOC_6H_5, $C_6H_5NH_2$, HNO_3

139. Is an aqueous solution of $NaHSO_4$ acidic, basic, or neutral? What reaction occurs with water? Calculate the pH of a 0.10 *M* solution of $NaHSO_4$.

140. Calculate $[CO_3^{2-}]$ in a 0.010 *M* solution of CO_2 in water (H_2CO_3). If all the CO_3^{2-} in this solution comes from the reaction

$$HCO_3^-(aq) \rightleftharpoons H^+(aq) + CO_3^{2-}(aq)$$

what percent of the H^+ ions in the solution are a result of the dissociation of HCO_3^-? When acid is added to a solution of sodium hydrogen carbonate ($NaHCO_3$), vigorous bubbling occurs. How is this reaction related to the existence of carbonic acid (H_2CO_3) molecules in aqueous solution?

141. Hemoglobin (abbreviated Hb) is a protein that is responsible for the transport of oxygen in the blood of mammals. Each hemoglobin molecule contains four iron atoms that are the binding sites for O_2 molecules. The oxygen binding is pH dependent. The relevant equilibrium reaction is

$$HbH_4^{4+}(aq) + 4O_2(g) \rightleftharpoons Hb(O_2)_4(aq) + 4H^+(aq)$$

Use Le Châtelier's principle to answer the following questions.
a. What form of hemoglobin, HbH_4^{4+} or $Hb(O_2)_4$, is favored in the lungs? What form is favored in the cells?