22. Why is H_3O^+ the strongest acid and OH^- the strongest base that can exist in significant amounts in aqueous solutions?

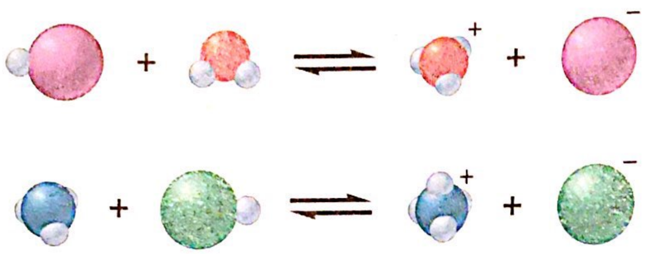
23. How many significant figures are there in the following numbers: 10.78, 6.78, 0.78? If these were pH values, to how many significant figures can you express the $[H^+]$? Explain any discrepancies between your answers to the two questions.

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 autoionization of liquid ammonia:

Label each of the species in the equation as an acid or a base and explain your answer.

26. The following are representations of acid–base reactions:



a. Label each of the species in both equations as an acid or a base and explain your answers.

b. For those species that are acids, which labels apply: Arrhenius acid, Brønsted–Lowry acid, Lewis acid? What about the bases?

27. Give three example solutions that fit each of the following descriptions.

a. a strong electrolyte solution that is very acidic

b. a strong electrolyte solution that is slightly acidic

c. a strong electrolyte solution that is very basic

d. a strong electrolyte solution that is slightly basic

e. a strong electrolyte solution that is neutral

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

29. Consider the following statements. Write out an example reaction and K expression that is associated with each statement.

a. The autoionization of water.

b. An acid reacts with water to produce the conjugate base of the acid and the hydronium ion.

c. A base reacts with water to produce the conjugate acid of the base and the hydroxide ion.

30. Which of the following statements is(are) *true*? Correct the false statements.

a. When a base is dissolved in water, the lowest possible pH of the solution is 7.0.

b. When an acid is dissolved in water, the lowest possible pH is 0.

c. A strong acid solution will have a lower pH than a weak acid solution.

d. A 0.0010-*M* $Ba(OH)_2$ solution has a pOH that is twice the pOH value of a 0.0010-*M* KOH solution.

31. Consider the following mathematical expressions.

a. $[H^+] = [HA]_0$

b. $[H^+] = (K_a \times [HA]_0)^{1/2}$

c. $[OH^-] = 2[B]_0$

d. $[OH^-] = (K_b \times [B]_0)^{1/2}$

For each expression, give three solutions where the mathematical expression would give a good approximation for the $[H^+]$ or $[OH^-]$. $[HA]_0$ and $[B]_0$ represent initial concentrations of an acid or a base.

32. Consider a 0.10-*M* H_2CO_3 solution and a 0.10-*M* H_2SO_4 solution. Without doing any detailed calculations, choose one of the following statements that best describes the $[H^+]$ of each solution and explain your answer.

a. The $[H^+]$ is less than 0.10 *M*.

b. The $[H^+]$ is 0.10 *M*.

c. The $[H^+]$ is between 0.10 *M* and 0.20 *M*.

d. The $[H^+]$ is 0.20 *M*.

33. Of the hydrogen halides, only HF is a weak acid. Give a possible explanation.

34. Explain why the following are done, both of which are related to acid–base chemistry.

a. Power plants burning coal with high sulfur content use scrubbers to help eliminate sulfur emissions.

b. A gardener mixes lime (CaO) into the soil of his garden.

Exercises

In this section similar exercises are paired.

Nature of Acids and Bases

35. 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

36. Write the dissociation reaction and the corresponding K_a equilibrium expression for each of the following acids in water.

a. HCN

b. HOC_6H_5

c. $C_6H_5NH_3^+$

37. For each of the following aqueous reactions, identify the acid, the base, the conjugate base, and the conjugate acid.

a. $H_2O + H_2CO_3 \rightleftharpoons H_3O^+ + HCO_3^-$

b. $C_5H_5NH^+ + H_2O \rightleftharpoons C_5H_5N + H_3O^+$

c. $HCO_3^- + C_5H_5NH^+ \rightleftharpoons H_2CO_3 + C_5H_5N$

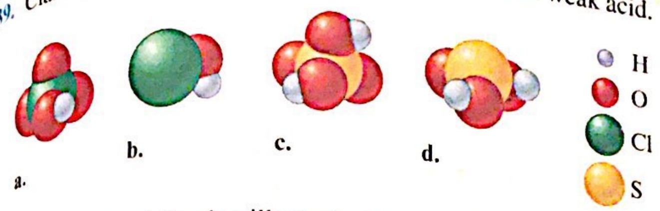
38. For each of the following aqueous reactions, identify the acid, the base, the conjugate base, and the conjugate acid.

a. $Al(H_2O)_6^{3+} + H_2O \rightleftharpoons H_3O^+ + Al(H_2O)_5(OH)^{2+}$

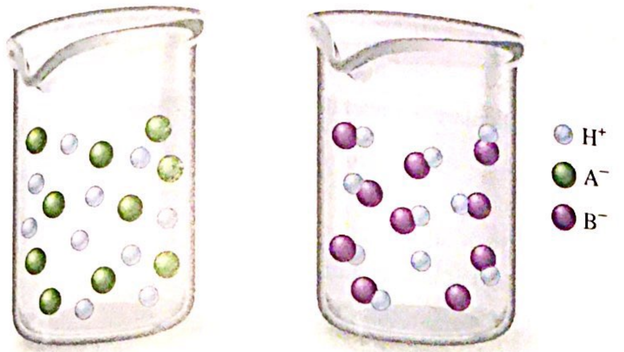
b. $H_2O + HONH_3^+ \rightleftharpoons HONH_2 + H_3O^+$

c. $HOCl + C_6H_5NH_2 \rightleftharpoons OCl^- + C_6H_5NH_3^+$

39. Classify each of the following as a strong acid or a weak acid.



40. Consider the following illustrations:



Which beaker best illustrates what happens when the following acids are dissolved in water?

a. HNO_2
b. HNO_3
c. HCl
d. HF
e. $HC_2H_3O_2$

41. Use Table 14.2 to order the following from the strongest to the weakest acid.

$HClO_2$, H_2O, NH_4^+, $HClO_4$

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

ClO_2^-, H_2O, NH_3, ClO_4^-

43. 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?

44. 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

45. Calculate the $[OH^-]$ of each of the following solutions at 25°C. Identify each solution as neutral, acidic, or basic.

a. $[H^+] = 1.0 \times 10^{-7}\ M$
b. $[H^+] = 8.3 \times 10^{-16}\ M$
c. $[H^+] = 12\ M$
d. $[H^+] = 5.4 \times 10^{-5}\ M$

46. Calculate the $[H^+]$ of each of the following solutions at 25°C. Identify each solution as neutral, acidic, or basic.

a. $[OH^-] = 1.5\ M$
b. $[OH^-] = 3.6 \times 10^{-15}\ M$
c. $[OH^-] = 1.0 \times 10^{-7}\ M$
d. $[OH^-] = 7.3 \times 10^{-4}\ M$

47. 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.

48. 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 0.10 *M*, what is the pH at 40.°C?

49. Calculate the pH and pOH of the solutions in Exercises 45 and 46.

50. 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

51. Fill in the missing information in the following table.

	pH	pOH	$[H^+]$	$[OH^-]$	Acidic, Basic, or Neutral?
Solution a	6.88				
Solution b				$8.4 \times 10^{-14}\ M$	
Solution c		3.11			
Solution d			$1.0 \times 10^{-7}\ M$		

52. Fill in the missing information in the following table.

	pH	pOH	$[H^+]$	$[OH^-]$	Acidic, Basic, or Neutral?
Solution a	9.63				
Solution b				$3.9 \times 10^{-6}\ M$	
Solution c			0.027 *M*		
Solution d		1.22			

53. The pH of a sample of gastric juice in a person's stomach is 2.1. Calculate the pOH, $[H^+]$, and $[OH^-]$ for this sample. Is gastric juice acidic or basic?

54. 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

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. $HClO_4$ b. HNO_3

56. A solution is prepared by adding 50.0 mL of 0.050 *M* HBr to 150.0 mL of 0.10 *M* HI. Calculate $[H^+]$ and the pH of this solution. HBr and HI are both considered strong acids.

57. Calculate the pH of each of the following solutions of a strong acid in water.
 a. 0.10 *M* HCl
 b. 5.0 *M* HCl
 c. 1.0×10^{-11} *M* HCl

58. Calculate the pH of each of the following solutions containing a strong acid in water.
 a. 2.0×10^{-2} *M* HNO_3
 b. 4.0 *M* HNO_3
 c. 6.2×10^{-12} *M* HNO_3

59. Calculate the concentration of an aqueous HI solution that has pH = 2.50. HI is a strong acid.

60. Calculate the concentration of an aqueous HBr solution that has pH = 4.25. HBr is a strong acid.

61. How would you prepare 1600 mL of a pH = 1.50 solution using concentrated (12 *M*) HCl?

62. A solution is prepared by adding 50.0 mL concentrated hydrochloric acid and 20.0 mL concentrated nitric acid to 300 mL water. More water is added until the final volume is 1.00 L. Calculate $[H^+]$, $[OH^-]$, and the pH for this solution. [*Hint:* Concentrated HCl is 38% HCl (by mass) and has a density of 1.19 g/mL; concentrated HNO_3 is 70.% HNO_3 (by mass) and has a density of 1.42 g/mL.]

63. 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 ($HC_2H_3O_2$)

64. 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

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

66. Calculate the percent dissociation for a 0.22-*M* solution of chlorous acid ($HClO_2$, $K_a = 1.2 \times 10^{-2}$).

67. For propanoic acid ($HC_3H_5O_2$, $K_a = 1.3 \times 10^{-5}$), determine the concentration of all species present, the pH, and the percent dissociation of a 0.100-*M* solution.

68. A solution is prepared by dissolving 0.56 g benzoic acid ($C_6H_5CO_2H$, $K_a = 6.4 \times 10^{-5}$) in enough water to make 1.0 L of solution. Calculate $[C_6H_5CO_2H]$, $[C_6H_5CO_2^-]$, $[H^+]$, $[OH^-]$, and the pH of this solution.

69. 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.

70. A typical aspirin tablet contains 325 mg acetylsalicylic acid ($HC_9H_7O_4$). Calculate the pH of a solution that is prepared by dissolving two aspirin tablets in enough water to make one cup (237 mL) of solution. Assume the aspirin tablets are pure acetylsalicylic acid, $K_a = 3.3 \times 10^{-4}$.

71. 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.

72. A solution is made by adding 50.0 mL of 0.200 *M* acetic acid ($K_a = 1.8 \times 10^{-5}$) to 50.0 mL of 1.00×10^{-3} *M* HCl.
 a. Calculate the pH of the solution.
 b. Calculate the acetate ion concentration.

73. 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.

74. 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)?

75. A 0.15-*M* solution of a weak acid is 3.0% dissociated. Calculate K_a.

76. An acid HX is 25% dissociated in water. If the equilibrium concentration of HX is 0.30 *M*, calculate the K_a value for HX.

77. 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.

78. The pH of a 0.063-*M* solution of hypobromous acid (HOBr but usually written HBrO) is 4.95. Calculate K_a.

79. 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.

80. A typical sample of vinegar has a pH of 3.0. Assuming that vinegar is only an aqueous solution of acetic acid ($K_a = 1.8 \times 10^{-5}$), calculate the concentration of acetic acid in vinegar.

81. One mole of a weak acid HA was dissolved in 2.0 L of solution. After the system had come to equilibrium, the concentration of HA was found to be 0.45 *M*. Calculate K_a for HA.

82. You have 100.0 g saccharin, a sugar substitute, and you want to prepare a pH = 5.75 solution. What volume of solution can be prepared? For saccharin, $HC_7H_4NSO_3$, $pK_a = 11.70$ ($pK_a = -\log K_a$).

Solutions of Bases

83. 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

84. 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, $(CH_3)_2NH$

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

NO_3^-, H_2O, NH_3, C_5H_5N

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

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

87. Use Table 14.3 to help answer the following questions.

a. Which is the stronger base, ClO_4^- or $C_6H_5NH_2$?
b. Which is the stronger base, H_2O or $C_6H_5NH_2$?
c. Which is the stronger base, OH^- or $C_6H_5NH_2$?
d. Which is the stronger base, $C_6H_5NH_2$ or CH_3NH_2?

88. Use Table 14.3 to help answer the following questions.

a. Which is the stronger acid, $HClO_4$ or $C_6H_5NH_3^+$?
b. Which is the stronger acid, H_2O or $C_6H_5NH_3^+$?
c. Which is the stronger acid, $C_6H_5NH_3^+$ or $CH_3NH_3^+$?

89. Calculate the pH of the following solutions.

a. 0.10 *M* NaOH
b. 1.0×10^{-10} *M* NaOH
c. 2.0 *M* NaOH

90. Calculate $[OH^-]$, pOH, and pH for each of the following.

a. 0.00040 *M* $Ca(OH)_2$
b. a solution containing 25 g KOH per liter
c. a solution containing 150.0 g NaOH per liter

91. What are the major species present in 0.015 *M* solutions of each of the following bases?

a. KOH b. $Ba(OH)_2$

What is $[OH^-]$ and the pH of each of these solutions?

92. 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* $Ca(OH)_2$ and 0.020 *M* RbOH

What is $[OH^-]$ and the pH of each of these solutions?

93. What mass of KOH is necessary to prepare 800.0 mL of a solution having a pH = 11.56?

94. Calculate the concentration of an aqueous $Sr(OH)_2$ that has pH = 10.50.

95. What are the major species present in a 0.150-*M* NH_3 solution? Calculate the $[OH^-]$ and the pH of this solution.

96. 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.

97. 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 $(HONH_2, K_b = 1.1 \times 10^{-8})$

98. Calculate $[OH^-]$, $[H^+]$, and the pH of 0.40 *M* solutions of each of the following amines (the K_b values are found in Table 14.3).

a. aniline b. methylamine

99. Calculate the pH of a 0.20-*M* $C_2H_5NH_2$ solution (K_b = 5.6×10^{-4}).

100. Calculate the pH of a 0.050-*M* $(C_2H_5)_2NH$ solution (K_b = 1.3×10^{-3}).

101. What is the percent ionization in each of the following solutions?

a. 0.10 *M* NH_3 c. 0.10 *M* CH_3NH_2
b. 0.010 *M* NH_3

102. Calculate the percentage of pyridine (C_5H_5N) that forms pyridinium ion, $C_5H_5NH^+$, in a 0.10-*M* aqueous solution of pyridine ($K_b = 1.7 \times 10^{-9}$).

103. The pH of a 0.016-*M* aqueous solution of *p*-toluidine $(CH_3C_6H_4NH_2)$ is 8.60. Calculate K_b.

104. Calculate the mass of $HONH_2$ required to dissolve in enough water to make 250.0 mL of solution having a pH of 10.00 (K_b = 1.1×10^{-8}).

Polyprotic Acids

105. Write out the stepwise K_a reactions for the diprotic acid H_2SO_3.

106. Write out the stepwise K_a reactions for citric acid $(H_3C_6H_5O_7)$, a triprotic acid.

107. A typical vitamin C tablet (containing pure ascorbic acid, $H_2C_6H_6O_6$) weighs 500. mg. One vitamin C tablet is dissolved in enough water to make 200.0 mL of solution. Calculate the pH of this solution. Ascorbic acid is a diprotic acid.

108. Arsenic acid (H_3AsO_4) is a triprotic acid with $K_{a_1} = 5.5 \times 10^{-3}$, $K_{a_2} = 1.7 \times 10^{-7}$, and $K_{a_3} = 5.1 \times 10^{-12}$. Calculate $[H^+]$, $[OH^-]$, $[H_3AsO_4]$, $[H_2AsO_4^-]$, $[HAsO_4^{2-}]$, and $[AsO_4^{3-}]$ in a 0.20-*M* arsenic acid solution.

109. Calculate the pH and $[S^{2-}]$ in a 0.10-*M* H_2S solution. Assume $K_{a_1} = 1.0 \times 10^{-7}$; $K_{a_2} = 1.0 \times 10^{-19}$.

110. Calculate $[CO_3^{2-}]$ in a 0.010-*M* solution of CO_2 in water (usually written as 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 percentage of the H^+ ions in the solution is 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?

111. Calculate the pH of a 2.0-*M* H_2SO_4 solution.

112. Calculate the pH of a 5.0×10^{-3}-*M* solution of H_2SO_4.