Name: Solutions Date: _____

Period: ____

Chemistry 30: Acids and Bases

Practice Problems

Properties of Acids and Bases

1. List four characteristic properties of acids and of bases.

Acids: sour taste, react with metals & carbonates, turns litmus red
Bases: slippery feel, bitter taste, react with acids, turns litmus blue

2. Classify each of the following as either an acid or a base:
   a. The substance has a bitter taste BASE
   b. H_2SO_4 ACID
   c. litmus paper dipped in this turns red ACID
   d. reacts with active metals to produce hydrogen gas ACID
   e. KOH BASE
   f. NH_3 BASE
   g. has a slippery feel BASE
   h. has a sour taste ACID
   i. a proton donor ACID
   j. a proton acceptor BASE

3. Copy the chart and fill it in with definitions.

	Acid	Base
Arrhenius	Contains H and dissolves to produce H^+	Contains OH and dissolves to produce OH^-
Brønsted-Lowry	H^+ donor in rxns	H^+ acceptor in rxns

4. Which of the following could be considered Brønsted-Lowry bases? → must be able to get an H^+
   a. Br^- yes
   b. Li^+ no
   c. H_3PO_4 no
   d. NH_4^+ no
   e. H_2O yes
   f. NH_2^- yes

Conjugate Acid-Base Pairs

5. Identify the acid, base, conjugate acid and conjugate base for each of the following.

a. $\overset{A}{HClO_4}(aq) + \overset{B}{H_2O}(l) \rightleftharpoons \overset{CA}{H_3O^+}(aq) + \overset{CB}{ClO_4^-}(aq)$

b. $\overset{A}{H_2SO_3}(aq) + \overset{B}{H_2O}(l) \rightleftharpoons \overset{CA}{H_3O^+}(aq) + \overset{CB}{HSO_3^-}(aq)$

c. $\overset{A}{HC_2H_3O_2}(aq) + \overset{B}{H_2O}(l) \rightleftharpoons \overset{CA}{H_3O^+}(aq) + \overset{CB}{C_2H_3O_2^-}(aq)$

d. $\overset{A}{H_2S}(g) + \overset{B}{H_2O}(l) \rightleftharpoons \overset{CA}{H_3O^+}(aq) + \overset{CB}{HS^-}(aq)$

e. $\overset{A}{HSO_3^-}(aq) + \overset{B}{H_2O}(l) \rightleftharpoons \overset{CA}{H_3O^+}(aq) + \overset{CB}{SO_3^{2-}}(aq)$

f. $\overset{B}{NH_3}(g) + \overset{A}{H_2O}(l) \rightleftharpoons \overset{CA}{NH_4^+}(aq) + \overset{CB}{OH^-}(aq)$

g. $\overset{A}{HF}(aq) + \overset{B}{HSO_3^-}(aq) \rightleftharpoons \overset{CB}{F^-}(aq) + \overset{CA}{H_2SO_3}(aq)$

h. $\overset{A}{HNO_2}(aq) + \overset{B}{HS^-}(aq) \rightleftharpoons \overset{CB}{NO_2^-}(aq) + \overset{CA}{H_2S}(aq)$

6. Complete the equation for the reaction of each of the following with water. Then:
   i. Indicate whether the ion or molecule is an acid or base; and,
   ii. Indicate whether each reaction is explained by Arrhenius, Brønsted-Lowry, or both.

a. $HI(aq) + H_2O(l) \rightleftharpoons H_3O^+ + I^-$ (A, B; BOTH)

b. $HF(aq) + H_2O(l) \rightleftharpoons F^- + H_3O^+$ (A, B; BOTH)

c. $C_2H_3O_2^-(aq) + H_2O(l) \rightleftharpoons HC_2H_3O_2 + OH^-$ (B, A; B-L only)

d. $CO_3^{2-}(aq) + H_2O(l) \rightleftharpoons HCO_3^- + OH^-$ (B, A; B-L only) — base must have OH^-

e. $O^{2-}(aq) + H_2O(l) \rightleftharpoons 2OH^-$ (B, A; B-L only.)

7. Define the term **amphoteric**. Give an example of an amphoteric compound.

amphoteric compounds can act as either an acid or a base, depending on what they are combined with (e.g. H_2O, HCO_3^-, $H_2PO_4^-$)

8. Write the formula for the conjugate base of:

a. H_2SO_3 HSO_3^- b. HCO_3^- CO_3^{2-} c. NH_4^+ NH_3

1. What are the conjugate bases of these acids?

remove one H^+

original acid	conjugate base
HNO_3	NO_3^-
H_2O	OH^-
H_3O^+	H_2O
H_2SO_4	HSO_4^-
HBr	Br^-
HCO_3^-	CO_3^{2-}

9. What are the conjugate acids of these bases?

add one H^+

original base	conjugate acid
OH^-	H_2O
H_2O	H_3O^+
HCO_3^-	H_2CO_3
SO_4^{2-}	HSO_4^-
ClO_4^-	$HClO_4$

10. Write the formula for the conjugate acid of:

a. H_2O H_3O^+ b. CO_3^{2-} HCO_3^- c. PH_3 PH_4^+

11. Which of the following represent conjugate acid-base pairs?

a. H_2O, H_3O^+ yes ↳ different by ONE H^+
b. OH^-, HNO_3 no
c. H_2SO_4, SO_4^{-2} no
d. $HC_2H_3O_2$, $C_2H_3O_2^-$ yes

Strength of Acids and Bases

12. What is the difference between a strong acid and a weak acid? Give an example of both.

A strong acid ionizes completely in a solution $HCl \rightarrow H^+ + Cl^-$
A weak acid ionizes less than 50% in solution
$HC_2H_3O_2 \rightleftharpoons H^+ + C_2H_3O_2^-$

13. Explain the difference between the terms "concentrated" and "dilute" with respect to both strong and weak acids.

Concentrated < strong → lots of H^+ and A^- ions
Concentrated < weak → lots of HA molecules and H^+ and A^- ions
weak < strong → a few H^+ and A^- ions
weak < weak → a few HA molecules and even fewer H^+ and A^- ions

14. Finish the following reactions:

a. $H_2SO_4 + H_2O \rightleftharpoons HSO_4^- + H_3O^+$

b. $HCl + OH^- \rightleftharpoons H_2O + Cl^-$

c. $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$

d. $HCl + NH_3 \rightleftharpoons NH_4^+ + Cl^-$

15. Write a dissociation equation for each acid or base in an aqueous solution. Remember to use a single arrow (→) for strong acids and bases and a double arrow (⇌) for weak acids and bases.

a. HCl: $HCl \rightarrow H^+ + Cl^-$

b. NaOH: $NaOH \rightarrow Na^+ + OH^-$

c. $Cu(OH)_2$ (not technically weak): $Cu(OH)_2 \rightleftharpoons Cu^{2+} + 2OH^-$

d. HCN: $HCN \rightleftharpoons H^+ + CN^-$

e. H_2SO_4: $H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$

f. $HC_2H_3O_2$: $HC_2H_3O_2 \rightleftharpoons H^+ + C_2H_3O_2^-$

g. NH_3: $NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$

16. Write balanced equations for:

a. The dissociation of calcium hydroxide: $Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-$

b. The ionization of nitric acid: $HNO_3 \rightarrow H^+ + NO_3^-$

c. The ionization of propionic acid: $HC_3H_5O_2 \rightleftharpoons H^+ + C_3H_5O_2^-$

d. The dissociation of pyridine: $C_5H_5N + H_2O \rightleftharpoons C_5H_5NH^+ + OH^-$

K_a and K_b

17. Given the following balanced ionization reactions for the following weak acids and bases, write the K_a or K_b expressions for each.

a. ascorbic acid: $HC_6H_7O_6\ (aq) \rightleftharpoons H^+\ (aq) + C_6H_7O_6^-\ (aq)$

$$K_a = \frac{[H^+][C_6H_7O_6^-]}{[HC_6H_7O_6]}$$

b. boric acid: $H_3BO_3\ (aq) \rightleftharpoons H^+\ (aq) + H_2BO_3^-\ (aq)$

$$K_a = \frac{[H^+][H_2BO_3^-]}{[H_3BO_3]}$$

c. methylamine: $CH_3NH_2\ (aq) + H_2O\ (l) \rightleftharpoons CH_3NH_3^+\ (aq) + OH^-\ (aq)$

$$K_B = \frac{[CH_3NH_3^+][OH^-]}{[CH_3NH_2]}$$

18. Calculate $[H^+]$ for a 1.0×10^{-3} M solution of hydrochloric acid.

$HCl \rightarrow H^+ + Cl^-$

1.0×10^{-3} 1.0×10^{-3} 1.0×10^{-3}

$[H^+] = 1.0\times10^{-3}\ M$

19. Calculate $[H^+]$ in a 0.20 M solution of formic acid. $K_a = 1.8 \times 10^{-4}$

$$HCOOH \rightleftharpoons H^+ + HCOO^-$$

$K_a = \frac{[H^+][HCOO^-]}{[HCOOH]}$ $\quad 1.8\times10^{-4} = \frac{x^2}{0.20 - x}$ $\quad [H^+] = x = 0.0060\,M$

20. Ethylamine ($C_2H_5NH_2$) is a weak base. Calculate $[OH^-]$ in a 2.32×10^{-3} M solution if $K_b = 5.6 \times 10^{-4}$.

$$C_2H_5NH_2 + H_2O \rightleftharpoons C_2H_5NH_3^+ + OH^-$$

$K_b = \frac{[C_2H_5NH_3^+][OH^-]}{[C_2H_5NH_2]}$ $\quad 5.6\times10^{-4} = \frac{x^2}{2.32\times10^{-3} - x}$ $\quad [OH^-] = x = 0.0011\,M$

21. Calculate $[OH^-]$ is a solution containing 100.0 g of potassium hydroxide in 2.50 L solution. Potassium hydroxide is a strong base.

$M_{KOH} = 56.11\,g/mol$

$n = \frac{m}{M} = \frac{100.0}{56.11} = 1.78\,mol$

$C = \frac{n}{V} = \frac{1.78}{2.50} = 0.712\,M$

$[KOH] = [OH^-] = 0.712\,M$

22. A solution is prepared that contains 0.0445 mole of sulfuric acid in a total solution volume of 12.1 L. Sulfuric acid typically undergoes complete ionization according to the equation:

$$H_2SO_4 \rightarrow 2H^+ + SO_4^{2-}$$

Calculate $[H^+]$. Sulfuric acid is a strong acid.

$[H_2SO_4] = \frac{n}{V} = \frac{0.0445}{12.1} = 0.00368\,M$

$[H^+] = 2[H_2SO_4] = 0.00736\,M$

23. Calculate the hydroxide ion concentration in a 0.045M solution of ammonia, NH_3, a weak base with $K_b = 1.8\times10^{-5}$.

$$NH_3 + H_2O \rightleftharpoons NH_4^+ + OH^-$$

$K_b = \frac{[NH_4^+][OH^-]}{[NH_3]}$ $\quad 1.8\times10^{-5} = \frac{x^2}{0.045 - x}$ $\quad [OH^-] = x = 9.0\times10^{-4}\,M$

pH and pOH

24. Determine pH and pOH for each concentration.

a. $[H^+] = 0.023$ M

$pH = 1.6 \quad pOH = 12.4$

b. $[H^+] = 6.6 \times 10^{-6}$ M

$pH = 5.2 \quad pOH = 8.8$

c. $[OH^-] = 0.0334$ M

$pOH = 1.48 \quad pH = 12.52$

d. $[OH^-] = 9.01 \times 10^{-4}$ M

$pOH = 3.05 \quad pH = 10.95$

e. $[H^+] = 8.96 \times 10^{-3}$ M

$pH = 2.05 \quad pOH = 11.95$

25. Determine $[H^+]$ and $[OH^-]$ for each pH value.

a. pH = 2.5

$[H^+] = 0.0032M \quad [OH^-] = 3.2\times10^{-12}M$

b. pH = 11.3

$[H^+] = 5.0\times10^{-12}M \quad [OH^-] = 2.0\times10^{-3}$

c. pOH = 4.6

$[OH^-] = 2.5\times10^{-5}M \quad [H^+] = 4.0\times10^{-10}M$

d. pOH = 8.7

$[OH^-] = 2.0\times10^{-9}M$

$[H^+] = 5.0\times10^{-6}M$

e. pH = 7.65

$[H^+] = 2.2\times10^{-8}M$

$[OH^-] = 4.5\times10^{-7}M$

26. 4.52 g of calcium hydroxide, a strong base, is dissolved in 1.00 L of water. What is the pH of the resulting solution?

$Ca(OH)_2 \rightarrow Ca^{2+} + 2OH^-$

$M_{Ca(OH)_2} = 74.10 g/mol$

$C = \frac{m}{MV} = \frac{4.52}{(74.10)(1.00)} = 0.0610M$

$[OH^-] = 2[Ca(OH)_2] = 0.122M$

$pOH = -\log[OH^-] = 0.914$

$pH = 13.0$

27. Methanoic acid ($HCHO_2$) is a weak acid that undergoes the following ionization reaction:

FORMIC

$$HCHO_2 \rightleftharpoons H^+ + CHO_2^-$$

If 25.0 g of methanoic acid is dissolved to make 0.500 L of solution, what is the pH?

$[HCHO_2] = 1.09M$

$K_a = \frac{[H^+][CHO_2^-]}{[HCHO_2]}$

$1.7\times10^{-4} = \frac{x^2}{1.09}$

$[H^+] = x = 0.014M$

$pH = 1.9$

28. A weak base, methylamine, is dissolved in water according to the following dissociation reaction:

$$CH_3NH_2\,(aq) + H_2O\,(l) \rightleftharpoons CH_3NH_3^+\,(aq) + OH^-\,(aq)$$

If 0.00355 moles of methylamine is present in 1.25 L of solution, what is the pH?

$[CH_3NH_2] = 0.00284M$

$K_b = \frac{[CH_3NH_3^+][OH^-]}{[CH_3N_2]}$

$4.4\times10^{-4} = \frac{x^2}{0.00284}$

$[OH^-] = x = 0.0011M$

$pOH = 3.0$

$pH = 11.0$

29. Phosphoric acid is a **weak** acid that undergoes the following ionization reaction:

$$H_3PO_4(aq) \rightleftharpoons H^+(aq) + H_2PO_4^-(aq)$$

If there is 1.32×10^{-2} mol of phosphoric acid present in 875 mL of solution, calculate the concentration of hydrogen ions, H^+, in solution. K_a for phosphoric acid is 7.0×10^{-3}.

$[H_3PO_4] = 0.0151M$

$K_a = \frac{[H^+][H_2PO_4^-]}{[H_3PO_4]}$

$7.0\times10^{-3} = \frac{x^2}{0.0151}$

$[H^+] = x = 1.1\times10^{-4}M$

30. A solution of acetic acid contains 12.0 g of $HC_2H_3O_2$ in 500 mL of solution. Calculate $[H^+]$.

$[HC_2H_3O_2] = 0.400M$

$K_a = \frac{[H^+][C_2H_3O_2^-]}{[HC_2H_3O_2]}$

$1.7\times10^{-5} = \frac{x^2}{0.400}$

$[H^+] = x = 0.0026M$

31. Why would the pH be different for a 0.05 M solution of HCl and a 0.05 M solution of acetic acid? What is the difference in pH?

$K_a = \frac{[H^+][C_2H_3O_2^-]}{[HC_2H_3O_2]}$

HCl

$[H^+] = 0.05M$

$HC_2H_3O_2$

$1.7\times10^{-5} = \frac{x^2}{0.05}$

$[H^+] = x = 9.2\times10^{-4}M$

one is strong (completely ionizes) and the other is weak (ionizes very little)

32. Calculate the pH of a 0.00345 M solution of analine, $C_6H_5NH_2$, a weak base.

$K_b = \frac{[C_6H_5NH_3^+][OH^-]}{[C_6H_5NH_2]}$

$4.2\times10^{-10} = \frac{x^2}{0.00345}$

$[OH^-] = x = 1.2\times10^{-6}M$

$pOH = 5.9 \quad pH = 8.1$

33. Calculate the $[H^+]$ in a solution in which $[OH^-] = 2.0\times10^{-2}$ M. Is this solution acidic, neutral, or basic?

$[H^+] = \frac{K_w}{[OH^-]} = \frac{10^{-14}}{2.0\times10^{-2}} = 5.0\times10^{-13}\ M$

basic

34. Find pH of each of the following. Identify each as an acidic, neutral, or basic.

a. $[H^+] = 0.0015$ M — $pH = 2.8$ acidic

b. $[H^+] = 5.0\times10^{-9}$ M — $pH = 8.3$ basic

c. $[OH^-] = 3.27\times10^{-4}$ M — $pOH = 3.49$, $pH = 10.51$ basic

d. $[OH^-] = 1.00\times10^{-12}$ M — $pOH = 12$, $pH = 2$ acidic

35. What is the pH, pOH, $[H^+]$, and $[OH^-]$ for a 3.2×10^{-4} M solution of sodium hydroxide?

NaOH

$[OH^-] = 3.2\times10^{-4}\ M \quad pOH = 3.5$

$[H^+] = 3.2\times10^{-11}\ M \quad pH = 10.5$

36. What is the pH, pOH, $[H^+]$, and $[OH^-]$ for a 9.20×10^{-3} M solution of sulfuric acid?

H_2SO_4

$[H^+] = 0.0184M \quad pH = 1.74$

$[OH^-] = 5.43\times10^{-13}M \quad pOH = 12.26$

Neutralization

~~37. For each reaction:~~

~~a. Balance the reaction;~~

~~b. Write the complete ionic equation and the net ionic equation; and,~~

~~c. List the spectator ions.~~

~~Remember that if an acid or base is **not** strong, it is written as a molecule, not as an ion.~~

~~i. $H_3PO_{4\,(aq)} + KOH_{(aq)} \rightarrow H_2O_{(l)} + K_3PO_{4\,(aq)}$~~

3 3

~~ii. $HClO_{(aq)} + Ba(OH)_{2\,(aq)} \rightarrow H_2O_{(l)} + Ba(ClO)_{2\,(aq)}$~~

~~iii. $NH_{3\,(aq)} + HCl_{(aq)} \rightarrow NH_4Cl_{(aq)}$~~

38. How many moles of NaOH are needed to completely neutralize 0.432 mol of H_2SO_4?

$2NaOH + H_2SO_4 \rightarrow Na_2SO_4 + 2H_2O$

$0.432\ mol\ H_2SO_4 \times \frac{2\ mol\ NaOH}{1\ mol\ H_2SO_4} = 0.864\ mol\ NaOH$

39. How many moles of $Ca(OH)_2$ are needed to completely neutralize 0.530 mol of H_3PO_4?

$3Ca(OH)_2 + 2H_3PO_4 \rightarrow Ca_3(PO_4)_2 + 6H_2O$

$0.530\ mol\ H_3PO_4 \times \frac{3\ mol\ Ca(OH)_2}{2\ mol\ H_3PO_4} = 0.795\ mol\ Ca(OH)_2$

40. It takes 38 mL of 0.75 M NaOH solution to completely neutralize 155 mL of a sulfuric acid solution (H_2SO_4). What is the concentration of the H_2SO_4 solution?

$n_{NaOH} = CV = (0.75)(0.038) = 0.0285\ mol$

$n_{H_2SO_4} = 0.0285\ mol\ NaOH \times \frac{1\ mol\ H_2SO_4}{2\ mol\ NaOH} = 0.0143\ mol$

$[H_2SO_4] = \frac{n}{V} = \frac{0.0143}{0.155} = 0.0923\ M$

41. It takes 12.5 mL of a 0.30 M CH_3COOH solution to completely neutralize 285 mL of NaOH solution. What is the concentration of the NaOH solution?

$[NaOH] = 0.013\ M$

42. It takes 50 mL of 0.500 M KOH solution to completely neutralize 125 mL of sulfuric acid solution. What is the pH of the sulfuric acid solution?

$[H_2SO_4] = 0.10\ M$ $\quad pH = 0.70$

43. What is the pH of a NaOH solution if it takes 100.0 mL to neutralize 150.0 mL of 3.00 M H_2CO_3 solution?

$[NaOH] = 9.0\,M$ $\quad pOH = -0.95$

$pH = 14.95$

44. Titration reveals that 11.6 mL of 3.0 M sulfuric acid are required to neutralize the sodium hydroxide in 25.00 mL of NaOH solution. What is the molarity of the NaOH solution?

$[NaOH] = 2.78\,M$

45. When 34.2 mL of a 1.02 M NaOH solution is added from a buret to 25.00 mL of a phosphoric acid solution that contains phenolphthalein, the solution changes from colorless to pink. What is the molarity of the phosphoric acid?

$[H_3PO_4] = 0.465\,M$