Acids and Bases

Objective #1: Know the distinguishing properties of acids and bases (must memorize!)

Acids	Bases
Taste:	Taste:
Feel:	Feel:
Reacts with metal:	Reacts with metal:
Electrolyte (conducts electricity):	Electrolyte (conducts electricity):
Turns litmus paper:	Turns litmus paper:
Turns phenolphthalein:	Turns phenolphthalein:

Objective #2: Know Arrhenius Theory of Acids and Bases

1) Arrhenius Acid: a substance whose water solution contains a ______________________ (   )
or ________________________________ (   ) ion as the *only positive ion* in solution

Arrhenius

Example: (Ionization) $HCl_{(l)} \xrightarrow{H_2O}$ ______________________________

- A _________________ acid is one which is *completely* ionized in water
  * these are at the top of Table K

- A _________________ acid will only partially ionize in water
  * these are at the bottom of Table K

Table K
Common Acids

Formula	Name
$HCl(aq)$	hydrochloric acid
$HNO_2(aq)$	nitrous acid
$HNO_3(aq)$	nitric acid
$H_2SO_3(aq)$	sulfurous acid
$H_2SO_4(aq)$	sulfuric acid
$H_3PO_4(aq)$	phosphoric acid
$H_2CO_3(aq)$ or $CO_2(aq)$	carbonic acid
$CH_3COOH(aq)$ or $HC_2H_3O_2(aq)$	ethanoic acid (acetic acid)

2) Arrhenius Base: a substance whose water solution contains a _________________________
(   ) ion as the *only negative ion* in solution

**Substance MUST also contain a ____________________
in order to ionize in water to produce OH^{-1} ion (ionic compound)

Example: Ionization $KOH_{(aq)} \xrightarrow{H_2O}$ __________________________________

- A _________________ base is one which is *completely* ionized in water
  * these are at the top of Table L

- A _________________ base will only partially ionize in water
  * these are at the bottom of Table L

Table L
Common Bases

Formula	Name
$NaOH(aq)$	sodium hydroxide
$KOH(aq)$	potassium hydroxide
$Ca(OH)_2(aq)$	calcium hydroxide
$NH_3(aq)$	aqueous ammonia

Arrhenius Acid - Base Questions

1. Which compound turns litmus paper blue?
   (1) H_2O (2) KOH (3) HNO_2 (4) CO_2

2. Which substance feels slippery?
   (1) H_2SO_4 (2) H_2SO_4 (3) KCl (4) NH_3

3. Which substance will react with metals?
   (1) $Ba(OH)_2$ (3) $Ca(OH)_2$
   (2) H_3PO_4 (4) NH_3

4. Which solution turns phenolphthalein pink?
   (1) CH_3COOH (3) CH_3OH
   (2) HCl (4) KOH

5. The Arrhenius theory explains the behavior of
   (1) acids and bases
   (2) alcohols and amines
   (3) isomers and isotopes
   (4) metals and nonmetals

6. Which two substances are electrolytes?
   (1) $C_6H_{12}O_6$ and CH_3CH_2OH
   (2) $C_6H_{12}O_6$ and HCl
   (3) NaOH and HCl
   (4) NaOH and CH_3CHOH

7. Which substance turns litmus paper red?
   (1) NH_3 (3) H_2CO_3
   (2) NaOH (4) NaCl

8. When one compound dissolves in water, the only positive ion produced in the solution is $H^+(aq)$. This compound is classified as
   (1) a Bronsted-Lowry acid
   (2) a Bronsted-Lowry base
   (3) an Arrhenius acid
   (4) an Arrhenius base

9. Which substance remains colorless in phenolphthalein?
   (1) KOH (3) CH_3COOH
   (2) KCl (4) NH_3

10. An Arrhenius base yields which ion as the only negative ion in an aqueous solution?
    (1) hydride ion (3) hydronium ion
    (2) hydrogen ion (4) hydroxide ion

11. Which two formulas represent Arrhenius acids?
    (1) CH_3COOH and CH_3CH_2OH
    (2) $HC_2H_3O_2$ and H_3PO_4
    (3) $KHCO_3$ and $KHSO_4$
    (4) NaSCN and $Na_2S_2O_3$

12. Which formula represents a hydronium ion?
    (1) H_3O^+ (3) NH_4^+
    (2) OH^- (4) HCO_3^-

13. Which substance is an Arrhenius acid?
    (1) $Mg(OH)_2$ (3) CH_3COOCH_3
    (2) H_2SO_4 (4) LiCl

14. Which substance is an Arrhenius base?
    (1) CH_3OH (3) CH_3Cl
    (2) LiOH (4) LiCl

15. The only positive ion found in $H_2SO_4(aq)$ is the
    (1) ammonium ion (3) hydrogen ion
    (2) hydroxide ion (4) sulfate ion

16. Which substance, when dissolved in water, forms a solution that conducts an electric current?
    (1) C_2H_5OH (3) $C_{12}H_{22}O_{11}$
    (2) $C_6H_{12}O_6$ (4) CH_3COOH

Objective #3: Know Bronsted-Lowry Theory of Acids and Bases

1) Bronsted-Lowry Acid: any substance that ______________________ (__________________) a hydrogen ion (H^+)
   - Also known as a "proton donor"

   Ex) $HNO_3 + H_2O \rightarrow$ ____________________ + ______________________

2) Bronsted-Lowry Base: any substance that ______________________ (__________________) a hydrogen ion (H^+)
   - Also known as a "proton acceptor"

   Ex) $NH_3 + H_2O \rightarrow$ ____________________ + _____________________

Lowry

A species that has the potential to act both as an acid and as a base according to Brønsted-Lowry Theory is said to be ______________________________.
- _________________________ has the potential to act both as an acid and as a base [H_2O can also be written as ________________]

For each acid-base reaction, label the B-L acid and base on the <u>reactant</u> side.

Bronsted

$H_2O_{(l)} + HF_{(aq)} \leftrightarrow H_3O^+_{(aq)} + F^-_{(aq)}$

$HI_{(aq)} + NH_{3(aq)} \leftrightarrow NH_4^+{}_{(aq)} + I^-_{(aq)}$

$NH_4^+{}_{(aq)} + OH^-_{(aq)} \leftrightarrow NH_{3(aq)} + H_2O_{(l)}$

$H_2O_{(l)}$ $H_2SO_{4(aq)} + H_2SO_{4(aq)} \leftrightarrow HSO_4^-{}_{(aq)} + H_3O^+_{(aq)}$

Now, each acid on the reactant side produces a corresponding base on the product side. The base is called the **conjugate base (CB)**. Similarly, a base on the reactant side will produce a **conjugate acid (CA)**. These pairs are known as **conjugate acid-base pairs**.

Ex) $H_3PO_4 + H_2O \leftrightarrow H_2PO_4^{-1} + H_3O^+$

Bronsted – Lowry Acid Base Questions

___1. One acid-base theory defines a base as an

(1) H^+ donor (2) OH^- donor (3) H^+ acceptor (4) OH^- acceptor

___2. One alternate acid-base theory states that an acid is a(n)

(1) H^+ donor (2) OH^- donor (3) H^+ acceptor (4) OH^- acceptor

___3. According to one acid-base theory, a water molecule acts as an acid when the water molecule

(1) accepts an H+ (2) accepts an OH– (3) donates an H+ (4) donates an OH–

___4. Given the equation representing a reaction at equilibrium:

$$NH_3(g) + H_2O(l) \leftrightarrow NH_4^+(aq) + OH^-(aq)$$

The H^+ acceptor on the reactant side is

(1) H_2O (l) (2) NH_4^+ (aq) (3) NH_3 (g) (4) OH^- (aq)

___5. Which formula represents a hydronium ion?

(1) H_3O^+ (2) OH^- (3) NH_4^+ (4) HCO_3^-

___6. Given the balanced equation representing a reaction:

$$NH_3(g) + H_2O(l) \leftrightarrow NH_4^+(aq) + OH^-(aq)$$

According to one acid-base theory, the $NH_3(g)$ molecules act as

(1) an acid because they accept H^+ ions

(2) an acid because they donate H^+ ions

(3) a base because they accept H^+ ions

(4) a base because they donate H^+ ions

___7. Which statement describes an alternate theory of acids and bases?

(1) Acids and bases are both H^+ acceptors.

(2) Acids and bases are both H^+ donors.

(3) Acids are H^+ acceptors, and bases are H^+ donors.

(4) Acids are H^+ donors, and bases are H^+ acceptors.

___8. Which substance is the conjugate acid in the reaction below?

$$H_3PO_4 + H_2O \leftrightarrow H_2PO_4^{-1} + H_3O^{+1}$$

(1) H_3PO_4 (2) H_2O (3) $H_2PO_4^{-1}$ (4) H_3O^{+1}

For the following two reversible reactions link together the acid to the conjugate base, and the base to the conjugate acid. Then label the acid, base, conjugate acid (CA) and conjugate base (CB).

9. $HCO_3^{-1} + HCl \leftrightarrow H_2CO_3 + Cl^{-1}$

10. $HCl + NH_3 \leftrightarrow NH_4^{+1} + Cl^{-1}$

Objective #4: Working with the pH/pOH Scale

A) pH = the potential of hydrogen ions

- relates the concentration of ________________________ ions in solution to a number between 0 - 14 on the pH scale

$[H^{+1}]$ = __________________________ of hydrogen ions in solution

Formula: $\boxed{}$

B) pOH = the potential of hydroxide ions

- relates the concentration of ________________________ ions in solution to a number between 0 - 14 on the pOH scale

$[OH^{-1}]$ = __________________________ of hydroxide ions in solution

Formula: $\boxed{}$

For every change in pH or pOH by _______ unit, the $[H^{+1}]$ or $[OH^{-1}]$ concentration changes by _____________

pH	$[H^+]$	$[OH^-]$	pOH
14	1×10^{-14}	1×10^{-0}	0
13	1×10^{-13}	1×10^{-1}	1
12	1×10^{-12}	1×10^{-2}	2
11	1×10^{-11}	1×10^{-3}	3
10	1×10^{-10}	1×10^{-4}	4
9	1×10^{-9}	1×10^{-5}	5
8	1×10^{-8}	1×10^{-6}	6
7	1×10^{-7}	1×10^{-7}	7
6	1×10^{-6}	1×10^{-8}	8
5	1×10^{-5}	1×10^{-9}	9
4	1×10^{-4}	1×10^{-10}	10
3	1×10^{-3}	1×10^{-11}	11
2	1×10^{-2}	1×10^{-12}	12
1	1×10^{-1}	1×10^{-13}	13
0	1×10^{0}	1×10^{-14}	14

Complete the table below:

$[H^+]$	pH	$[OH^-]$	pOH	Acid, Base or Neutral
	9			
		1.0×10^{-6}		
			0	
1.0×10^{-4}				
	1			
		1.0×10^{-3}		

Complete the table below:

pH Change	$[H^+]$ increase or decrease?	$[OH^-]$ increase or decrease?	Does the solution become more acidic or basic?	By a factor of…
6 to 8				
8 to 5				
3 to 7				
11 to 9				
14 to 13				
4 to 8				

pH/pOH Questions:

___1. Which of these pH numbers indicates the highest level of acidity?
(1) 5 (2) 8 (3) 10 (4) 12

___2. A solution has a hydrogen concentration of 1×10^{-3} M. What is the pOH of the solution?
(1) 3 (2) 4 (3) 11 (4) 13

___3. A solution has a hydroxide concentration of 1×10^{-12} M. What is the pH of the solution?
(1) 2 (2) 3 (3) 8 (4) 12

___4. Which change in pH represents a hundredfold increase in the concentration of hydrogen ions in a solution?
(1) pH 1 to pH 2 (2) pH 1 to pH 3 (3) pH 2 to pH 1 (4) pH 3 to pH 1

___5. The pH of a solution changes from 4 to 3 when the hydrogen ion concentration in the solution is
(1) decreased by a factor of 100
(2) decreased by a factor of 10
(3) increased by a factor of 100
(4) increased by a factor of 10

___6. Solution A has a pH of 3 and solution Z has a pH of 6. How many times greater is the hydronium ion concentration in solution A than the hydrogen ion concentration in solution Z?

(1) 100 (2) 3 (3) 2 (4) 1000

___7. What is the pH of a solution that has a hydrogen ion concentration 100 times greater than a solution with a pH of 4?

(1) 5 (2) 3 (3) 2 (4) 6

___8. What is the pOH of a solution that has a hydroxide ion concentration 1000 times greater than a solution with a pOH of 6?

(1) 3 (2) 1 (3) 12 (4) 9

___9. Which of these $[H^{+1}]$ values indicates the highest concentration of OH^{-1} ions?

(1) 1.0×10^{0} (2) 1.0×10^{-6} (3) 1.0×10^{-11} (4) 1.0×10^{-14}

___10. If the $[H^{+}]$ changes from 1.0×10^{-8} to 1.0×10^{-5}, the pH would

(1) increase by 3 (2) decrease by 3 (3) increase by 100 (4) decrease by 100

Objective #5: Working with Indicators

Indicator: a substance that changes color when it gains or loses a hydrogen ion (H^{+}).

How to use Table M:

- If the pH is below the first value, the solution will be the first color listed
- If the pH is above the second value, the solution will be the second color listed
- If the pH is between the two values, the solution will be a mix of the two colors

Table M
Common Acid–Base Indicators

Indicator	Approximate pH Range for Color Change	Color Change
methyl orange	3.1–4.4	red to yellow
bromthymol blue	6.0–7.6	yellow to blue
phenolphthalein	8–9	colorless to pink
litmus	4.5–8.3	red to blue
bromcresol green	3.8–5.4	yellow to blue
thymol blue	8.0–9.6	yellow to blue

Source: *The Merck Index*, 14th ed., 2006, Merck Publishing Group

Examples:

If you add bromthymol blue…

to a solution with a pH of 9, it will be ________________

to a solution with a pH of 7, it will be ________________

to a solution with a pH of 4, it will be ________________

If you add methyl orange…

to a solution with a pH of 2, it will be ________________

to a solution with a pH of 12, it will be ________________

to a solution with a pH of 4, it will be ________________

If you add litmus…

to a solution with a pH of 3, it will be ________________

to a solution with a pH of 9, it will be ________________

to a solution with a pH of 7, it will be ________________

Determine the approximate pH range for each of the unknown solutions using the indicators on Table M.

	Unknown X	Unknown Y	Unknown Z
Methyl Orange - Color			
- pH range			
Bromothymol Blue - Color			
- pH range			
Litmus - Color			
- pH range			
Bromcresol Green - Color			
- pH range			
Thymol Blue - Color			
- pH range			

Approximate pH Range: X: _____________ Y: _____________ Z: _____________

Indicator Questions:

1. Which indicator, when added to a solution, changes color from yellow to blue as the pH of the solution is changed from 5.5 to 8.0?
   (1) bromcresol green (3) litmus
   (2) bromthymol blue (4) methyl orange

2. Which indicator would best distinguish between a solution with a pH of 5.9 and another with a pH of 7.7?
   (1) bromthymol blue (3) litmus
   (2) bromcresol green (4) thymol blue

3. In which solution will phenolphthalein appear pink?
   (1) 1 M NaCl (3) 1 M NH_3
   (2) 1 M H_2CO_3(4) 1 M CH_3COOH

4. In which solution will thymol blue indicator appear blue?
   (1) 0.1 M CH_3COOH (3) 0.1 M KOH
   (2) 0.1 M HCl (4) 0.1 M H_2SO_4

5. What is the color of the indicator methyl orange in a solution that has a pH of 2?
   (1) blue (3) yellow
   (2) orange (4) red

6. In a solution with a pH of 3, what color is litmus?
   (1) yellow (3) green
   (2) blue (4) red

7. At what pH will bromothymol blue be yellow and bromcrescol green be blue?
   (1)10.5 (2) 5.7
   (3)7.0 (4) 2.9

8. A student used blue litmus paper and phenolphthalein paper as indicators to test the pH of distilled water and five aqueous household solutions. The student then used a pH meter to measure the pH value of the distilled water and each solution. The results are in the table to the right.

Testing Results

Liquid Tested	Color of Blue Litmus Paper	Color of Phenolphthalein Paper	Measured pH Value Using a pH Meter
2% milk	blue	colorless	6.4
distilled water	blue	colorless	7.0
household ammonia	blue	pink	11.5
lemon juice	red	colorless	2.3
tomato juice	red	colorless	4.3
vinegar	red	colorless	3.3

a) Identify the liquid tested that has the lowest hydronium (hydrogen) ion concentration.

b) Explain, in terms of the pH range for color change on Reference Table M, why litmus is not appropriate to differentiate the acidity levels of tomato juice and vinegar.

c) Based on the measured pH values, identify the liquid tested that is 10 times more acidic than vinegar.

d) Which liquid tested has an equal amount of hydrogen and hydroxide ions present?

Objective #6: Identifying and writing acid – base neutralization reactions

1) Neutralization:
   In a balanced neutralization reaction, an acid reacts with a base to produce a water and an ionic salt. ** This reaction is written just as you would write a double replacement reaction**

   ________________ + ________________ → __________________+ ___________________

Predict the products of and balance the following neutralization reactions:

___ HF (aq) + ___ $LiOH$ (aq) → ___ ________________ + ___ ________________

___ HNO_3 (aq) + ___ KOH (aq) → ___ ________________ + ___ ________________

___ HCl (aq) + ___ $Ca(OH)_2$ (aq) → ___ ________________ + ___ ________________

___ H_2CO_3 (aq) + ___ $NaOH$ (aq) → ___ ________________ + ___ ________________

Predict the products of and balance the following neutralization reactions:

___ H_2SO_3 (aq) + ___ $Ca(OH)_2$ (aq) → ___ ________________ + ___ ________________

___ H_3PO_4 (aq) + ___ KOH (aq) → ___ ________________ + ___ ________________

___ H_3PO_4 (aq) + ___ $Ca(OH)_2$ (aq) → ___ ________________ + ___ ________________

Neutralization Practice Questions:

1. What are the products of a reaction between KOH(aq) and HCl(aq)?
   (1) H_2 and KClO (2) KH and HClO (3) H_2O and KCl (4) KOH and HCl

2. Which word equation represents neutralization?
   (1) base + acid →salt + water
   (2) base + salt →water + acid
   (3) salt + acid →base + water
   (4) salt + water →acid + base

3. Which compound could serve as a reactant in a neutralization reaction?
   (1) NaCl (2) KOH (3) CH_3OH (4) CH_3CHO

4. Which substance is always a product when an Arrhenius acid in an aqueous solution reacts with an Arrhenius base in an aqueous solution?
   (1) HBr (2) H_2O (3) KBr (4) KOH

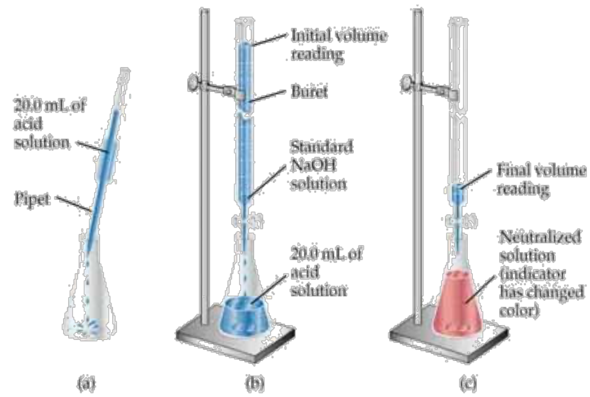
5. Which two reactants will form the “salt” $CaSO_4$(s) in a neutralization reaction?
   (1) H_2S(g) and $Ca(ClO_4)_2$(s)
   (2) H_2SO_3(aq) and $Ca(NO_3)_2$(aq)
   (3) H_2SO_4(aq) and $Ca(OH)_2$(aq)
   (4) SO_2(g) and CaO(s)

6. Sulfuric acid, H_2SO_4(aq), can be used to neutralize barium hydroxide, $Ba(OH)_2$(aq). What is the formula for the salt produced by this neutralization?
   (1) Ba_2SO_4 (2) $BaSO_2$ (3) $Ba(SO_4)_2$ (4) $BaSO_4$

7. Which chemical equation represents the reaction of an Arrhenius acid and an Arrhenius base?
   (1) $HC_2H_3O_2(aq) + NaOH(aq) \rightarrow NaC_2H_3O_2(aq) + H_2O(l)$
   (2) $C_3H_8(g) + 5\ O_2(g) \rightarrow 3\ CO_2(g) + 4\ H_2O(l)$
   (3) $Zn(s) + 2\ HCl(aq) \rightarrow ZnCl_2(aq) + H_2(g)$
   (4) $BaCl_2(aq) + Na_2SO_4(aq) \rightarrow BaSO_4(s) + 2\ NaCl(aq)$

Objective #7: Defining and solving titration problems

Titration is the ________________________ of adding measured volumes of an acid or a base of known concentration to an acid or a base of unknown concentration until ______________________________________ occurs.



- Standard solution = the acid or base substance of _____________________ molarity (M) concentration
- Equivalence point = the point at which the solution is __________________________ with a pH of _________ (#H^+ ions = #OH^- ions)
- Endpoint point = the pH at which an _____________________________ changes color

*** MODIFIED ***
Titration Formula (Table T):

M_A and M_B = the concentration (molarity) of the acid and base, respectively
V_A and V_B = the volume (mL or L) of the acid and base, respectively
(H^+) and (OH^-) = the number of ions in the formula given, respectively

Examples:
1. What volume of 3.50 M KOH must be used to neutralize 25.0 mL of a 1.75 M H_2SO_4 solution?

2. What is the molarity of a LiOH solution, if 15.0 mL of the LiOH solution is neutralized with 27.4 mL of 0.150 M H_2SO_4 solution?

3. In a reaction, 28.0 mL of 0.400 M HCl is required to neutralize 48.0 mL of the unknown $Mg(OH)_2$ solution. What is the concentration of the $Mg(OH)_2$ solution?

4. A titration was set up and used to determine the unknown molar concentration of a solution of NaOH. A 2.0 M HCl solution was used as the titration standard. The following data were collected.

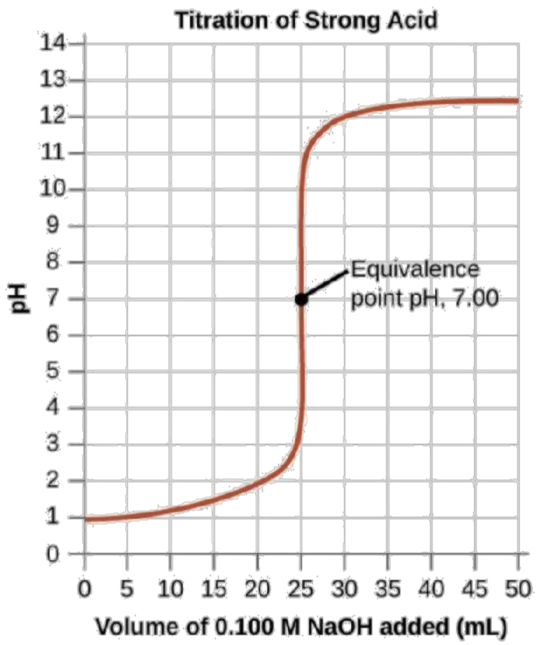
	Trial 1	Trial 2	Trial 3
Volume of 2.0 M HCl	10.0 mL	10.0 mL	10.0 mL
Initial reading NaOH	0.0 mL	12.2 mL	23.2 mL
Final reading NaOH	12.2 mL	23.2 mL	35.2 mL
Volume of NaOH used			
Molarity of NaOH			

a. Determine the volume of NaOH used for each of the three trials.

b. Determine the molarity of the NaOH for Trial 2 using the titration data above.

Titration Practice Problems

1. The following graph is a titration curve. It shows the changes in pH for an acid of unknown molarity as a base of known molarity is added.



a) Using the graph to the left, what is the volume of NaOH added to neutralize the acid at the equivalence point?

b) If 15.0 mL of the strong acid are used, what is the unknown molarity at the equivalence point?

a) What would be the best indicator to use for a color change at the equivalence point?

2. Which volume of 0.10 M NaOH(aq) exactly neutralizes 15.0 milliliters of 0.20 M HNO_3(aq)?
(1) 1.5 mL (2) 7.5 mL (3) 3.0 mL (4) 30. mL

3. In which laboratory process could a student use 0.10 M NaOH(aq) to determine the concentration of an aqueous solution of HBr?
(1) chromatography (2) decomposition (3) evaporation (4) titration

4. The data collected from a laboratory titration are used to calculate the
(1) rate of a chemical reaction (3) concentration of a solution
(2) heat of a chemical reaction (4) boiling point of a solution

5. Which volume of 2.0 M NaOH(aq) exactly neutralizes 24 milliliters of 1.0 M HCl(aq)?
(1) 6.0 mL (2) 12 mL (3) 24 mL (4) 48 mL

6. What volume of 0.120 M HNO_3(aq) is needed to completely neutralize 150. milliliters of 0.100 M NaOH(aq)?
(1) 62.5 mL (2) 125 mL (3) 180. mL (4) 360. mL

7. If it takes 50.0 mL of a 0.5 M potassium hydroxide solution to completely neutralize 125 mL of sulfuric acid solution, what is the concentration of the sulfuric acid? *(*hint: use Table L and M to look up formulas of acid and base)*