Tutorial 4

SOLUTION STOICHIOMETRY

Solution stoichiometry calculations involve chemical reactions taking place in solution.

Of the various methods of expressing solution concentration the most convenient for general laboratory use is molarity, which is defined:

$$\text{Molarity} = \frac{\text{Moles of solute}}{\text{Liters of solution}} \quad \text{or} \quad M = \frac{n_{solute}}{L_{soln}}$$

Chemical reactions are written in terms of moles of reactants and products; this molarity concentration unit relates moles of solute to volume of solution. Thus, easily measured solution volumes provide a simple method of measuring moles of reactants.

EXAMPLE: What is the molarity of a solution made by dissolving 5.67 g of potassium chloride in enough water to make 100.0 mL of solution?

This data gives a relationship between amount of solute and volume of solution: 5.67 g KCl / 100.0 mL. To find molarity we must convert grams KCl to moles KCl and mL solution to L:

$$\frac{5.67 \text{ g KCl}}{100.0 \text{ mL}} \quad x \quad \frac{1 \text{ mol KCl}}{74.6 \text{ g KCl}} \quad x \quad \frac{1000 \text{ mL}}{L} \quad = \quad \frac{0.760 \text{ mol KCl}}{L} \quad \text{or} \quad 0.760 \text{ M KCl}$$

Whenever the solution concentration is given in molarity, M, you must change to the equivalent units, mol/L or mol/1000 mL, to use as a conversion factor.

EXAMPLE: What mass of solute is contained in 15.0 mL of a 0.760 M KCl solution?

The conversion sequence is:

mL solution $\rightarrow$ L solution $\rightarrow$ mol KCl $\rightarrow$ g KCl

$$15.0 \text{ mL} \quad x \quad \frac{1 \text{ L}}{1000 \text{ mL}} \quad x \quad \frac{0.760 \text{ mol KCl}}{L} \quad x \quad \frac{74.6 \text{ g KCl}}{\text{mol KCl}} \quad = \quad 0.850 \text{ g KCl}$$

OR, use the conversion sequence:

$$mL \text{ solution} \rightarrow mol \text{ KCl} \rightarrow g \text{ KCl}$$

$$15.0 \text{ mL} \times \frac{0.760 \text{ mol KCl}}{1000 \text{ mL}} \times \frac{74.6 \text{ g KCl}}{\text{mol KCl}} = 0.850 \text{ g KCl}$$

<u>EXAMPLE</u>: What mass of potassium chloride would be needed to prepare 250.0 mL of a 0.500 M solution?

$$250.0 \text{ mL} \times \frac{1 \text{ L}}{1000 \text{ mL}} \times \frac{0.500 \text{ mol KCl}}{\text{L}} \times \frac{74.6 \text{ g KCl}}{\text{mol KCl}} = 9.32 \text{ g KCl (needed)}$$

OR

$$250.0 \text{ mL} \times \frac{0.500 \text{ mol KCl}}{1000 \text{ mL}} \times \frac{74.6 \text{ g KCl}}{\text{mol KCl}} = 9.32 \text{ g KCl (needed)}$$

Please note: the preceding two EXAMPLES are the same kind of problem worded differently: conversion from volume of solution to mass of solute.

<u>EXAMPLE</u>: Silver nitrate solution is added to 25.00 mL of a 0.500 M potassium chloride solution until no more precipitate forms. What mass of silver chloride will be formed?

The chemical equation for the reaction is:

$$KCl \text{ (aq)} + AgNO_3 \text{ (aq)} \rightarrow AgCl \text{ (s)} + KNO_3 \text{ (aq)}$$
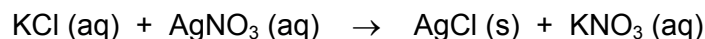
Since the concentration and volume of silver nitrate solution are not specified, we can assume it is in excess. First find the number of moles of KCl in the 25.00 mL of 0.500 M solution:

(A) $$25.00 \text{ mL} \times \frac{0.500 \text{ mol KCl}}{1000 \text{ mL}} = 0.0125 \text{ mol KCl}$$

From the mole ratio in the balanced chemical equation:

(B) $\quad$ 0.0125 ~~mol KCl~~ x $\dfrac{\text{1 mol AgCl}}{\text{1 ~~mol KCl~~}}$ = 0.0125 mol AgCl formed

Then convert to grams of AgCl:

(C) $\quad$ 0.0125 ~~mol AgCl~~ x $\dfrac{\text{143.4 g AgCl}}{\text{~~mol AgCl~~}}$ = 1.79 g AgCl formed
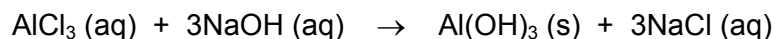
Steps (A), (B), and (C) may be combined:

$$25.00 \text{ ~~mL~~ x } \dfrac{0.500 \text{ ~~mol KCl~~}}{1000 \text{ ~~mL~~}} \text{ x } \dfrac{1 \text{ ~~mol AgCl~~}}{1 \text{ ~~mol KCl~~}} \text{ x } \dfrac{143.4 \text{ g AgCl}}{\text{~~mol AgCl~~}} = 1.79 \text{ g AgCl}$$
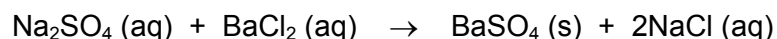
Please note: the steps in solving this problem are essentially the same as used in Tutorial 3; the only difference is the method of first finding moles: thereafter they are identical problems.

If volume and concentration of both reactant solutions are given then you are dealing with a limiting reagent problem. The first step is to find the moles of each reactant from the volume and concentration of the solution. Once moles are found the process is the same as shown in Tutorial 3, p T-23.

The following equations are needed for some of the problems in this Tutorial.

$$Na_2SO_4 \text{ (aq)} + BaCl_2 \text{ (aq)} \rightarrow BaSO_4 \text{ (s)} + 2NaCl \text{ (aq)}$$

$$BaCl_2 \text{ (aq)} + 2AgNO_3 \text{ (aq)} \rightarrow 2AgCl \text{ (s)} + Ba(NO_3)_2 \text{ (aq)}$$

$$Ca(OH)_2 \text{ (aq)} + 2HCl \text{ (aq)} \rightarrow CaCl_2 \text{ (aq)} + 2H_2O \text{ (l)}$$

$$2Al(OH)_3 \text{ (s)} + 3H_2SO_4 \text{ (aq)} \rightarrow Al_2(SO_4)_3 \text{ (aq)} + 6H_2O \text{ (l)}$$

$$AlCl_3 \text{ (aq)} + 3NaOH \text{ (aq)} \rightarrow Al(OH)_3 \text{ (s)} + 3NaCl \text{ (aq)}$$

$$3KOH \text{ (aq)} + H_3PO_4 \text{ (aq)} \rightarrow K_3PO_4 \text{ (aq)} + 3H_2O \text{ (l)}$$
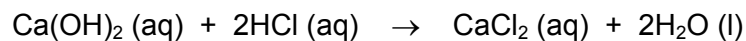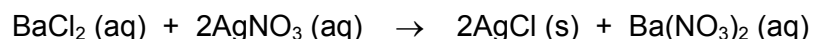
1) Calculate the molarity of the following solutions:

   a) 15.5 g of potassium chloride in 250.0 mL of solution.

   b) 1.25 x 10^{-2} g of silver nitrate in 100.0 mL of solution.

   c) 0.0555 g of barium chloride in 500.0 mL of solution.

   d) 15.0 mg of calcium hydroxide in 50.0 mL of solution.

   e) 25.55 g of aluminum chloride in 1500.0 mL of solution.

   f) 1.00 g of potassium hydroxide in 0.250 L of solution.

   g) 0.655 g of sodium carbonate in 100.0 mL of solution.

   h) 2.50 x 10^{-6} kg of potassium phosphate in 500.0 mL of solution.

2) What mass of solute is contained in 25.00 mL of a 0.500 M sodium hydroxide solution?

3) What mass of solute is needed to prepare 250.0 mL of a 1.50 M potassium nitrate solution?

4) What mass of solute is contained in 100.0 mL of a 1.00 M barium nitrate solution?

5) What volume of 0.157 M silver nitrate contains 0.555 gram of silver nitrate?

6) What volume of 0.225 M aluminum chloride solution contains 5.00 g of solute?

7) 100.0 mL of a 0.500 M sodium chloride solution was evaporated to dryness. What mass of solid remained?

8) In what total volume must 5.00 g of sodium nitrate be dissolved to make a 0.250 M solution?

9) Barium chloride solution is added to 25.00 mL of a 0.500 M sodium sulfate solution until no more precipitate forms. What mass of barium sulfate forms?

10) Excess barium chloride solution is added to 25.00 mL of 0.100 M silver nitrate solution. What mass of silver chloride is formed?

11) What mass of aluminum hydroxide is required to completely react with 50.0 mL of 0.255 M sulfuric acid solution?

12) Excess sodium hydroxide solution is added to 15.00 mL of 0.135 M aluminum chloride solution. What mass of aluminum hydroxide is formed?

13) What volume of 1.25 M sulfuric acid is needed to dissolve 0.750 g of aluminum hydroxide? What is the molarity of the resulting solution of aluminum sulfate? (Assume final solution volume = volume of sulfuric acid used.)

14) Silver chloride is formed by mixing silver nitrate and barium chloride solutions. What volume of 1.50 M barium chloride solution is needed to form 0.525 g of silver chloride?

15) What volume of 0.250 M potassium hydroxide solution is needed to react completely with a solution containing 1.00 g of phosphoric acid?

16) What volume of 1.25 M hydrochloric acid is needed to react completely with a solution containing 2.50 g of calcium hydroxide?

17) 25.00 mL of 0.500 M barium chloride solution is mixed with 25.00 mL of 0.500 silver nitrate solution. What mass of silver chloride will be formed?

18) 15.0 mL of 0.200 M barium chloride solution is mixed with 25.0 mL of 0.250 M silver nitrate solution. What mass of silver chloride will be formed?

19) 25.00 mL of 0.125 M aluminum chloride solution is mixed with 25.00 mL of 0.100 M sodium hydroxide solution. What mass of aluminum hydroxide will be formed?

20) 100.0 mL of a solution containing 2.55 g of potassium hydroxide is mixed with 100.0 mL of a 1.50 M phosphoric acid solution. Will the resulting mixture be acidic or basic? What will be the molarity of the potassium phosphate formed? (Assume the volumes are additive.)

21) 25.00 mL of 1.50 M phosphoric acid solution is titrated with 0.455 M potassium hydroxide solution. What volume of base solution is needed for complete neutralization?

22) 25.00 mL of a barium chloride solution is titrated with 0.150 M silver nitrate solution. 18.55 mL of the silver nitrate solution is required to completely precipitate the chloride ion as silver chloride. What is the molarity of the barium chloride solution?

23) 25.00 mL of a phosphoric acid solution required 27.55 mL of a 0.155 M potassium hydroxide solution for neutralization. What is the molarity of the acid?

24) 25.00 mL of a 0.0525 M calcium hydroxide solution is titrated with 0.111 M hydrochloric acid solution. What volume of acid is needed for complete neutralization?

25) 25.00 mL of 0.0962 M hydrochloric acid is titrated with a calcium hydroxide solution, and 32.53 mL of the base is required for complete neutralization. What is the molarity of the calcium hydroxide solution?

Answers to Problems

1) a) 0.831 M KCl

    b) 7.36 x 10^{-4} M AgNO$_3$

    c) 5.33 x 10^{-4} M BaCl$_2$

    d) 4.05 x 10^{-3} M Ca(OH)$_2$

    e) 0.1276 M AlCl$_3$

    f) 0.0713 M KOH

    g) 0.0618 M Na$_2$CO$_3$

    h) 2.36 x 10^{-5} M K$_3$PO$_4$

2) 0.500 g NaOH

3) 37.9 g KNO$_3$

4) 26.1 g Ba(NO$_3$)$_2$

5) 20.8 mL AgNO$_3$

6) 166 mL AlCl$_3$

7) 2.92 g NaCl

8) 235 mL

9) 2.92 g BaSO$_4$

10) 0.358 g AgCl

11) 0.663 g Al(OH)$_3$

12) 0.158 g Al(OH)$_3$

13) 11.5 mL H$_2$SO$_4$; 0.418 M Al$_2$(SO$_4$)$_3$

14) 1.22 mL BaCl$_2$

15) 122 mL KOH

16) 54.0 mL HCl

17) AgNO$_3$ limiting; 1.79 g AgCl

18) BaCl$_2$ limiting; 0.860 g AgCl

19) NaCl limiting; 0.0650 g Al(OH)$_3$

20) acidic; 0.0758 M K$_3$PO$_4$

21) 247 mL KOH

22) 0.0556 M BaCl$_2$

23) 0.0569 M H$_3$PO$_4$

24) 23.6 mL HCl

25) 0.0370 M Ca(OH)$_2$