

TOPIC 10.

CHEMICAL CALCULATIONS IV - solution stoichiometry.

Calculations involving solutions.

Frequently reactions occur between species which are present in solution. One type of chemical analysis called **VOLUMETRIC ANALYSIS** makes use of the fact that volumes are easier and faster to measure than mass. Volumetric analysis is done using specialised glassware in a process called **TITRATION**.

In order to deduce the amount of a dissolved species (called the **SOLUTE**) which is present in a given volume of a solution, it is necessary to know the **CONCENTRATION** of the solution. Concentration is most commonly expressed as how much solute is present **per unit volume** (e.g. per mL or L) of the solution. The concentration of a solution is therefore independent of the volume taken and to calculate the amount of solute in any given volume of solution, the concentration must be multiplied by that volume. There are many ways of expressing concentrations, for example % m/v means "the mass of solute in 100 mL of solution". In chemical calculations, by far the most commonly used concentration unit is the number of moles of solute present per litre of solution, and this is termed the **MOLARITY** of the solution, abbreviated as M.

$$\text{molarity} = \frac{\text{moles of solute}}{\text{litres of solution}} \quad \text{or} \quad \text{moles of solute} = \text{molarity} \times \text{volume (in L)}$$

Thus a 1 molar solution (written as 1 M) of a compound would contain 1 mole of that compound dissolved in solvent so that the total volume of solution is 1 litre, while a 2 molar solution (2 M) would have 2 moles of the compound per litre of solution and a 10 M solution contains 10 moles of compound per litre of solution. As an example, a 1 M solution of sodium chloride, NaCl (1 M), would contain 1 mole of NaCl (= 22.99 + 35.45 g) dissolved in enough water so that the final volume of the solution was 1 litre.

*Note: The molarity applies to the **solute formula**. Thus, while the amount of sodium chloride, NaCl, dissolved is 1 mole, there are actually 1 mole of Na^+ ions and 1 mole of Cl^- ions present in that solution. Similarly, a 1 M solution of barium chloride, BaCl_2 , contains 1 mole of the solute per litre of solution which would provide 1 mole of Ba^{2+} ions and 2 mole of Cl^- ions per litre of solution.*

The following examples show how molarity, volume and moles are related. If two of these quantities are known, then the third can be deduced.

Example 1. What mass of sodium chloride is present in 500 mL of NaCl (2.00 M) solution?

$$\text{molarity} = \frac{\text{moles}}{\text{litres}} \quad \text{or} \quad \text{moles} = \text{molarity} \times \text{litres}$$

$$\text{i.e. moles of NaCl} = 2.00 \times 0.500 \text{ mol} = 1.00 \text{ mol}$$

$$\text{and mass of NaCl} = \text{moles} \times \text{molar mass} = 1.00 \times (22.99 + 35.45) \text{ g} = 58.4 \text{ g}$$

Example 2. Calculate the concentration in moles per litre of a solution containing 45.2 g of magnesium chloride, MgCl_2 , in a total volume of 800 mL.

The first step is to calculate the molar mass (gram formula weight) of MgCl_2 .

$$\text{Molar mass} = (24.31 + 2 \times 35.45) = 95.21 \text{ g mol}^{-1}$$

i.e. 95.21 g of MgCl_2 is exactly 1 mole.

Then calculate how many moles are in 45.2 g of MgCl_2 .

$$\text{Moles of } \text{MgCl}_2 \text{ in } 45.2 \text{ g} = \frac{45.2}{95.21} = 0.475 \text{ mol}$$

Finally, from its definition, calculate the molarity.

$$\text{Concentration of } \text{MgCl}_2 = \text{moles / litres} = \frac{0.475}{0.800} = 0.594 \text{ M}$$

[Again, note that the concentration always applies to the solute specified, MgCl_2 here, not its component ions if the solute is ionic. Thus in this example, while the concentration of MgCl_2 dissolved is 0.594 M, the solution actually contains Mg^{2+} ions at a concentration = 0.594 M and Cl^- ions at a concentration = $2 \times 0.594 \text{ M} = 1.19 \text{ M}$, because there are 1 Mg^{2+} and 2 Cl^- ions in each formula unit of the compound.]

Example 3. What volume of 0.450 M sodium carbonate solution contains 10.0 g of the solute?

Firstly, it is necessary to convert the mass of sodium carbonate to moles.

$$\text{Moles of } \text{Na}_2\text{CO}_3 = \frac{10.0}{(2 \times 22.99 + 12.01 + 3 \times 16.00)} = 0.0943 \text{ mol}$$

$$\text{As molarity} = \frac{\text{moles of solute}}{\text{volume of solution in litres}}$$

then the volume containing a specified amount of solute is given by the expression

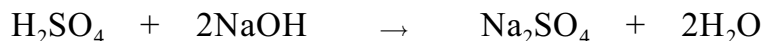
$$\text{volume in litres} = \frac{\text{moles of solute}}{\text{molarity}} = \frac{0.0943}{0.450} = 0.210 \text{ L or } 210 \text{ mL}$$

The next set of examples shows how stoichiometric calculations can be carried out when solutions are involved.

Example 4. A solution of sodium hydroxide of unknown concentration is titrated against a **STANDARD** sulfuric acid solution (i.e. one of known concentration). The volume of 0.104 M sulfuric acid needed for complete reaction with 25.00 mL of the sodium hydroxide solution was 20.05 mL. Calculate the concentration of the sodium hydroxide solution.

The procedure is essentially the same as in earlier examples.

Step 1: Write a **balanced formula equation**.



Step 2: Write down the mole ratios of the known and unknown species.



Step 3: From step 2, deduce number of moles of the unknown (NaOH) that requires 1 mole of the standard (H_2SO_4) for complete reaction. This number is known as the **EQUATION FACTOR**.

1 mole of standard requires 2 moles of unknown. \therefore equation factor = 2

Step 4: Calculate the moles of standard reacting.

$$\begin{aligned} \text{Moles of } \text{H}_2\text{SO}_4 \text{ in } 20.05 \text{ mL} &= \text{volume (in litres)} \times \text{molarity} \\ &= 0.02005 \times 0.104 \text{ mol} = 2.085 \times 10^{-3} \text{ mol} \end{aligned}$$

Step 5: Using the equation factor, calculate the moles of unknown reacting.

As 1 mole of H_2SO_4 uses 2 moles of NaOH,

$$\text{then moles of NaOH needed} = 2 \times 2.085 \times 10^{-3} \text{ mol} = 4.170 \times 10^{-3} \text{ mol}$$

Step 6: From the volume of NaOH solution used, its concentration can now be deduced.

As 4.170×10^{-3} mole of NaOH are in 25.00 mL, then

$$\text{concentration of NaOH} = \frac{\text{moles}}{\text{litres}} = \frac{4.170 \times 10^{-3}}{0.02500} = 0.167 \text{ M}$$

Example 5. Sodium carbonate (10.0 g) is reacted completely with hydrochloric acid (0.115 M). What is the minimum volume of the acid solution required?



Mole ratios: 1 mol 2 mol

Equation factor: 1 mole of Na_2CO_3 (known) requires 2 moles of HCl (unknown), \therefore equation factor = 2.

As moles = mass \div molar mass,

$$\text{moles of the known (Na}_2\text{CO}_3) \text{ used} = 10.0 / 105.99 = 0.09435 \text{ mol}$$

$$\text{Thence, moles of unknown (HCl)} = 2 \times 0.09435 \text{ mol} = 0.1887 \text{ mol}$$

Finally, calculate the volume of hydrochloric acid solution:

1000 mL hydrochloric acid contains 0.115 mole hydrochloric acid

$$\begin{aligned} \therefore \frac{1000}{0.115} \times 0.1887 \text{ mL} &\text{ contains } 0.1887 \text{ mole hydrochloric acid} \\ &= 1641 \text{ ml or } 1.64 \text{ L} \end{aligned}$$

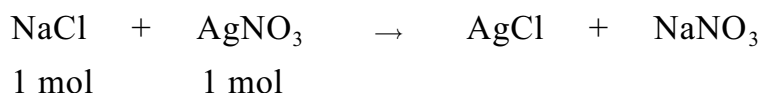
Alternatively the final step can be completed using the expression

$$V \text{ (litres)} = n \text{ (moles)} / M \text{ (molarity)}$$

$$\text{Substituting, } V = 0.1887 / 0.115 = 1.64 \text{ L}$$

[In Example 5, note that the known compound, Na_2CO_3 , was not in solution, so in the calculation the number of moles is simply = mass \div molar mass.]

Example 6. A solution of sodium chloride (0.0823 M) is added to 21.40 mL of a solution of silver nitrate (0.962 M) and a precipitate of silver chloride results. Calculate the minimum volume of the sodium chloride solution required for complete reaction.



\therefore equation factor = 1

$$\begin{aligned} \text{Moles of AgNO}_3 &= \text{volume in litres} \times \text{molarity} \\ &= 0.02140 \times 0.962 \text{ mol} \\ &= 0.02059 \text{ mol} \end{aligned}$$

From the equation factor, 1 mole of NaCl requires 1 mole of AgNO_3

\therefore moles of NaCl = 0.02059 mol

1000 mL NaCl solution contains 0.0823 mole NaCl

\therefore 1000 / 0.0823 mL of NaCl solution contains 1 mole NaCl

$$\begin{aligned} \text{and } \frac{1000}{0.0823} \times 0.02059 \text{ mL of NaCl solution contains } 0.02059 \text{ mole NaCl} \\ = 250 \text{ mL} \end{aligned}$$

Test your understanding of this section.

Define the terms (i) solute (ii) concentration.

What does the concentration unit % v/v mean?

What is a 1 molar solution?

A 2 molar solution of a solute is prepared. What would be the concentration of that solute in (i) 10 mL and (ii) 100 mL of the solution?

Distinguish between moles and molarity.

What are the abbreviations used for (i) moles (ii) molarity ?

In a 1 molar solution of calcium chloride, which ions would be present and at what concentrations?

If 500 mL of a 1.00 M solution of a given solute is diluted to a total volume of 1.00 L, what would be the concentration of the final solution?

Objectives of this Topic.

When you have completed this Topic, including the tutorial questions, you should have achieved the following goals:

1. Understand the terms solute, volumetric analysis; concentration; titration; standard solution.
2. Understand the concept of molarity of a solution and be able to use it to calculate a solution concentration or the amount of solute in a given volume of a solution.
3. Be able to use the concept of concentration in stoichiometric calculations.

SUMMARY

Reactions between species in solution (solutes) can be used as a convenient basis for one form of chemical analysis, called volumetric analysis, because volumes are easier and quicker to measure than mass. The amount of solute per unit volume of solution is called its concentration and therefore concentration is independent of the volume of solution taken. The amount of solute in a given volume of a solution is the product of the volume taken and the concentration of the solute in the solution.

The concentration of a solution can be expressed in a number of ways, but the most common in chemical analysis is as the number of moles of solute per litre of solution, called the molarity of the solution. Thus the molarity of a given solute in a solution is the number of moles of that solute divided by the number of litres of the solution. Conversely, the number of moles of the solute in a given volume is its molarity multiplied by the volume of solution.

Using the concept of concentration, stoichiometric calculations can be done by basically the same procedure as used earlier except that the amount of each reacting solute is obtained from its molarity and volume reacting.

TUTORIAL QUESTIONS - TOPIC 10.

Before starting these questions, it is essential to complete sufficient of the questions from Topics 7, 8 and 9 to ensure that you understand the concepts covered previously.

1. What amount (moles) of solute is present in 125 mL of a 0.864 M solution?
2. What mass of sodium chloride must be dissolved in water to give 1.50×10^3 mL of 0.100 M sodium chloride solution?
3. Sodium hydroxide (4.62 g) is dissolved in water to give a final volume of 350 mL. What is the molarity of the solution?
4. What mass of formic acid, HCOOH, should be diluted to obtain 1.00 litre of a 0.0750 M water solution?
5. What volume of sulfuric acid (0.77 M) contains 0.50 mole of H₂SO₄?
6. What volume of silver nitrate (0.54 M) contains 0.34 g of solute?
7. A solution of 12.0 M hydrochloric acid (100 mL) is diluted to 2000 mL. What is the molarity of the diluted solution?
8. A solution contains 0.200 mole of solute in 500 mL of solution. What is the molarity of this solution?
9. What mass of barium chromate can be precipitated by adding excess barium chloride solution to 50.0 mL of potassium chromate (0.469 M)?
10. What volume of barium nitrate (0.280 M) is required to precipitate all the sulfate ion from 25.0 mL of aluminium sulfate (0.350 M) as barium sulfate?
11. An aliquot (25.0 mL) of a solution of sodium hydroxide is titrated with hydrochloric acid (0.452 M). What is the molarity of the sodium hydroxide if 18.4 mL of acid are required for neutralisation?
12. What volume of sulfuric acid (0.755 M) is required to just neutralise 20.0 mL of sodium hydroxide (0.493 M)?

13. Hydrochloric acid (23.95 mL) reacts completely with sodium carbonate (0.217g). Calculate the concentration of the hydrochloric acid.

14. What volume of sulfuric acid (0.171 M) would be required to react completely with 0.217 g of sodium carbonate?

15. Calculate the molarity of a sodium chloride solution, 25.00 mL of which requires 21.40 mL of silver nitrate (0.0962 M) to reach an end point. [Note that this is not an acid/base reaction but a precipitation reaction - see Topic 6.]

16. A solution of potassium permanganate containing 79.0 g of solute dissolved in water to give a total volume of 1.00 L is prepared.

(a) Calculate the molarity of the solution.

(b) The solution is then diluted to a final volume of 4.00 L. Calculate the molarity of the new solution.

(c) Calculate the number of MnO_4^- ions present in 1.00 mL of the final solution.

ANSWERS TO TUTORIAL TOPIC 10

1. 0.108 mol

2. 8.77 g

3. 0.330 M

4. 3.45 g

5. 0.65 L

6. 3.7 mL

7. 0.600 M

8. 0.400 M

9. 5.94 g

10. 93.8 mL

11. 0.333 M

12. 6.53 mL

13. 0.171 M

14. 12.0 mL

15. 0.0823 M

16. (a) 0.500 M (b) 0.125 M (c) 7.53×10^{19}

Full solutions to the above problems are on the following pages.

WORKED SOLUTIONS

1. Amount of solute = volume of solution \times concentration

If amount is expressed in moles and concentration in moles/litre (mol L^{-1} or M),
then moles of solute = molarity \times volume in litres

$$= 0.864 \times 0.125 \text{ mol}$$

$$= 0.108 \text{ mol}$$

2. First the number of moles of sodium chloride must be calculated from the volume and concentration of the solution and then the mass can be deduced.

$$\text{Volume} = 1.50 \times 10^3 \text{ mL} = 1.50 \text{ L}$$

$$\text{Concentration} = 0.100 \text{ M}$$

$$\text{Amount (mol)} = \text{molarity (M)} \times \text{volume (L)}$$

$$= 0.100 \times 1.50 = 0.150 \text{ mol}$$

$$\text{Molar mass of NaCl} = 58.44 \text{ g mol}^{-1}$$

$$\therefore \text{mass} = \text{moles} \times \text{molar mass} = 0.150 \times 58.44 = 8.77 \text{ g}$$

3. The mass of sodium hydroxide must first be converted to moles and then the molarity of the solution can be deduced.

$$\text{Molar mass of NaOH} = 40.0 \text{ g mol}^{-1}$$

$$\therefore \text{moles of NaOH} = \text{mass} / \text{molar mass}$$

$$= 4.62 / 40.0 = 0.1155 \text{ mol}$$

$$\text{Volume} = 350 \text{ mL} = 0.350 \text{ L}$$

$$\text{Molarity of NaOH in solution} = \text{moles of NaOH} / \text{volume (L)}$$

$$= 0.1155 / 0.350 = 0.330 \text{ M}$$

4. Given the volume of solution and its concentration, the number of moles of formic acid, HCOOH, can be calculated and thence the mass required.

$$\text{Concentration} = 0.0750 \text{ M}$$

$$\text{Volume} = 1.00 \text{ L}$$

$$\text{Moles of HCOOH} = \text{concentration (M)} \times \text{volume (L)}$$

$$= 0.0750 \times 1.00 = 0.0750 \text{ mol}$$

$$\text{Molar mass of HCOOH} = 46.0 \text{ g mol}^{-1}$$

$$\text{Mass of formic acid} = \text{moles} \times \text{molar mass} = 0.0750 \times 46.0 = 3.45 \text{ g}$$

5. From its definition, molarity = moles of solute / volume of solution

i.e. $M = n / V$ where n = number of moles of solute and V is expressed in litres.

$$\therefore \text{volume containing a given number of moles} = \text{moles of solute} / \text{molarity}$$

$$\text{i.e. } V = n / M$$

$$\text{Moles of H}_2\text{SO}_4 = 0.50 \text{ mol}$$

$$\text{Concentration of sulfuric acid} = 0.77 \text{ M}$$

$$\therefore \text{volume containing } 0.50 \text{ mol} = 0.50 / 0.77 = 0.65 \text{ L}$$

Alternative method using proportion.

1.000 L of 0.77 M sulfuric acid contains 0.77 mol

\therefore 1.000 / 0.77 L contains 1.0 mol

and $(1.000 / 0.77) \times 0.50$ L contains 0.50 mol = 0.65 L

[The concept of proportion is encountered frequently in chemical calculations. If you want to revise this concept, please consult the Maths Revision Notes available on the downloads page of the School of Chemistry at <http://www.chemlab.chem.usyd.edu.au/download.htm>

6. Convert mass of silver nitrate to moles.

Moles of AgNO_3 = mass / molar mass

Molar mass of AgNO_3 = 169.9 g mol⁻¹

\therefore moles = 0.34 / 169.9 = 2.00×10^{-3} mol

As in Q 5, $V = n / M = 2.00 \times 10^{-3} / 0.54 = 3.7 \times 10^{-3}$ L or 3.7 mL

or, using the proportion method in the final step,

1.000 L contains 0.54 moles of AgNO_3 ,

so $(1.000 / 0.54) \times 2.00 \times 10^{-3}$ L contains 2.00×10^{-3} moles of AgNO_3
 = 3.7×10^{-3} L or 3.7 mL

7. Hydrochloric acid is a water solution of hydrogen chloride, HCl.

There are two methods by which this problem can be solved.

First method: Calculate the moles of HCl in the initial solution and then using the final volume, deduce the concentration of the diluted solution.

Moles of HCl in 100 mL of 0.200 M solution = molarity \times volume

$$= 12.0 \times 0.100 = 1.20 \text{ mol}$$

Diluted volume = 2000 mL = 2.000 L

\therefore concentration of hydrochloric acid in the diluted solution = moles / volume

$$= 1.20 / 2.000 = 0.600 \text{ M}$$

Second method: By proportion, it depends on the fact that the number of moles of HCl is constant in both the original and diluted solutions, and is given by the expression

moles = volume \times molarity, or $n = V \times M$.

Let the initial solution volume and molarity be represented as V_1 and M_1 respectively. Then moles of HCl present = $V_1 \times M_1$ and this is the same number of moles as are in the diluted solution. Let the volume and molarity of the diluted solution be represented as V_2 and M_2 respectively. The number of moles of HCl in this solution is given by $V_2 \times M_2$, identical to the number initially present given by $V_1 \times M_1$.

Thus $V_1 \times M_1 = V_2 \times M_2$.

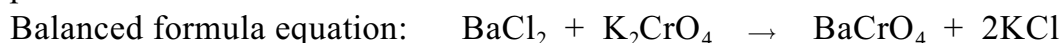
Substituting the data, $0.100 \times 12.0 = 2.000 \times M_2$ where M_2 is the required molarity.

$\therefore M_2 = (0.100 \times 12.0) / 2.000 = 0.600 \text{ M}$.

Note: This expression can only be applied to dilution calculations - **it is not appropriate to use it in titration problems.** Also note that when using this equation, the volumes do not need to be expressed in litres as long as the same units (e.g. mL) are used on both sides as the units cancel.

8. Molarity = moles / volume (L) = $0.200 / 0.500 = 0.400 \text{ M}$

9. This problem is essentially the same as those solved in Topic 9 except that the amount of potassium chromate reacting (and thus the moles of barium chromate produced) must be calculated from the volume and concentration (molarity) of the potassium chromate solution.



(Note that the amounts of the other reactant and product are not relevant to this calculation.)

1 mole of the known (K_2CrO_4) produces 1 mole of the unknown (BaCrO_4).

\therefore equation factor = 1

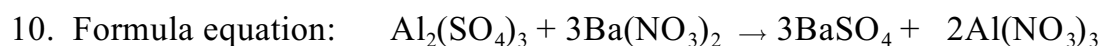
Moles of known: $n = V \times M = 0.050 \times 0.469 = 0.02345 \text{ mol}$

Moles of unknown: As the equation factor = 1,

moles of BaCrO_4 produced = 0.02345 mol

Molar mass of $\text{BaCrO}_4 = 253.3 \text{ g mol}^{-1}$

\therefore mass of barium chromate = moles \times molar mass of BaCrO_4
 $= 0.02345 \times 253.3 = 5.94 \text{ g}$



\therefore Equation factor = 3

As both the concentration and volume of the aluminium sulfate are given, it is the known or standard solution and the volume of the barium nitrate solution of known concentration is the unknown quantity.

Moles of aluminium sulfate in 25.0 mL of solution = $M \times V = 0.350 \times 25.0 \times 10^{-3}$
 $= 8.750 \times 10^{-3} \text{ mol}$

As the equation factor = 3, then

moles of barium nitrate required = $3 \times 8.750 \times 10^{-3} \text{ mol} = 2.625 \times 10^{-2} \text{ mol}$

Concentration of barium nitrate = 0.280 M

moles of barium nitrate, $n = V \times M = V \times 0.280 = 2.625 \times 10^{-2} \text{ mol}$

$\therefore V = (2.625 \times 10^{-2}) / 0.280 = 9.38 \times 10^{-2} \text{ L}$ or 93.8 mL



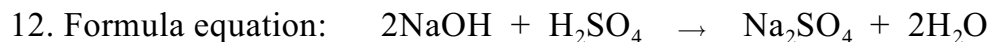
\therefore Equation factor = 1

As both the concentration and volume of the hydrochloric acid are given, it is the known or standard solution and the concentration of the sodium hydroxide is the unknown.

$$\begin{aligned}\text{Moles of HCl in 18.4 mL of solution} &= M \times V = 0.452 \times 18.4 \times 10^{-3} \\ &= 8.317 \times 10^{-3} \text{ mol}\end{aligned}$$

As the equation factor = 1, then moles of NaOH in 25.0 mL = 8.317×10^{-3} mol

$$\begin{aligned}\text{Concentration of sodium hydroxide} &= \text{moles} / \text{volume} \\ &= 8.317 \times 10^{-3} / 25.0 \times 10^{-3} = 0.333 \text{ M}\end{aligned}$$



Mole ratio of reactants: 2 mol 1 mol

The known (standard) reactant is the sodium hydroxide and as 1 mole of it requires 0.5 mole of sulfuric acid for complete reaction, the equation factor = 0.5.

$$\begin{aligned}\text{Moles of NaOH in 20.0 mL of solution} &= M \times V \\ &= 0.493 \times 20.0 \times 10^{-3} = 9.86 \times 10^{-3} \text{ mol}\end{aligned}$$

$$\begin{aligned}\text{The equation factor} &= 0.5, \text{ so moles of H}_2\text{SO}_4 \text{ required} = 0.5 \times 9.86 \times 10^{-3} \\ &= 4.93 \times 10^{-3} \text{ mol}\end{aligned}$$

In this problem, the molarity of the unknown sulfuric acid is given and the volume required is to be calculated.

$$n = M \times V$$

$$4.93 \times 10^{-3} = 0.755 \times V$$

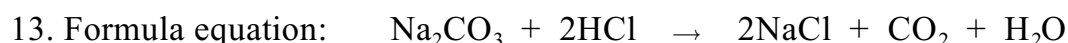
$$\therefore V = 4.93 \times 10^{-3} / 0.755 = 6.53 \times 10^{-3} \text{ L or } 6.53 \text{ mL}$$

Alternatively, using the proportion method in the last step:

1.000 L of sulfuric acid contains 0.755 mol

$$\therefore (1.000 / 0.755) \times 4.93 \times 10^{-3} \text{ L contains } 4.93 \times 10^{-3} \text{ mol}$$

i.e. 6.53×10^{-3} L or 6.53 mL of sulfuric acid solution are required.



Mole ratios: 1 mol 2 mol

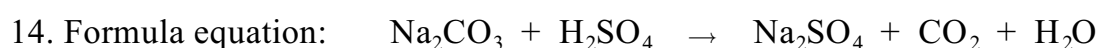
The sodium carbonate is the known as its mass is given so its moles can be calculated, and the hydrochloric acid is the unknown.

Equation factor = 2

$$\begin{aligned}\text{Moles of known (Na}_2\text{CO}_3) \text{ in } 0.217 \text{ g} &= \text{mass} / \text{molar mass of Na}_2\text{CO}_3 \\ &= 0.217 / 106.0 = 2.047 \times 10^{-3} \text{ mol}\end{aligned}$$

$$\begin{aligned}\text{The equation factor} &= 2, \text{ so moles of HCl in } 23.95 \text{ mL} = 2 \times 2.047 \times 10^{-3} \\ &= 4.094 \times 10^{-3} \text{ mol}\end{aligned}$$

$$\begin{aligned}\text{Concentration of HCl} &= \text{moles} / \text{volume} = 4.094 \times 10^{-3} / 23.95 \times 10^{-3} \\ &= 0.171 \text{ M}\end{aligned}$$



Mole ratios: 1 mol 1 mol

As in the previous question, the sodium carbonate is the known as its mass is given so its moles can be calculated, and the sulfuric acid is the unknown.

Equation factor = 1

$$\begin{aligned}\text{Moles of known (Na}_2\text{CO}_3) \text{ in } 0.217 \text{ g} &= \text{mass} / \text{molar mass of Na}_2\text{CO}_3 \\ &= 0.217 / 106.0 = 2.047 \times 10^{-3} \text{ mol}\end{aligned}$$

The equation factor = 1, so moles of H_2SO_4 required
 $= 2.047 \times 10^{-3} \text{ mol}$

In this problem, the molarity of the unknown sulfuric acid is given and the volume required is to be calculated.

$$n = M \times V$$

$$2.047 \times 10^{-3} = 0.171 \times V$$

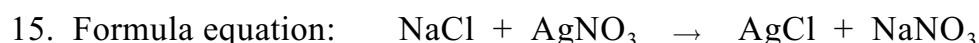
$$\therefore V = 2.047 \times 10^{-3} / 0.171 = 12.0 \times 10^{-3} \text{ L or } 12.0 \text{ mL}$$

Alternatively, using the proportion method in the last step:

1.000 L of sulfuric acid contains 0.171 mol

$$\therefore (1.000 / 0.171) \times 2.047 \times 10^{-3} \text{ L contains } 2.047 \times 10^{-3} \text{ mol}$$

i.e. $12.0 \times 10^{-3} \text{ L or } 12.0 \text{ mL}$ of sulfuric acid solution are required.



Mole ratio of reactants: 1 mol 1 mol

\therefore Equation factor = 1

As both the concentration and volume of the silver nitrate solution are given, it is the known or standard solution and the concentration of the sodium chloride is the unknown.

$$\begin{aligned} \text{Moles of AgNO}_3 \text{ in } 21.40 \text{ mL of solution} &= M \times V = 0.0962 \times 21.40 \times 10^{-3} \\ &= 2.059 \times 10^{-3} \text{ mol} \end{aligned}$$

As the equation factor = 1, then moles of NaCl in 25.00 mL = $2.059 \times 10^{-3} \text{ mol}$

$$\begin{aligned} \text{Concentration of sodium chloride} &= \text{moles} / \text{volume} \\ &= 2.059 \times 10^{-3} / 25.0 \times 10^{-3} = 0.0823 \text{ M} \end{aligned}$$

16. (a) Moles of $\text{KMnO}_4 = \text{mass} / \text{molar mass}$
 $= 79.0 / 158.0$
 $= 0.500 \text{ mol}$

Volume of solution = 1.00 L

$$\begin{aligned} \therefore \text{concentration of solution} &= \text{moles} / \text{volume} \\ &= 0.500 / 1.00 \\ &= 0.500 \text{ M} \end{aligned}$$

(b) Moles of $\text{KMnO}_4 = 0.500 \text{ mol}$.

Diluted volume = 4.00 L

$$\begin{aligned} \therefore \text{concentration of KMnO}_4 \text{ in the diluted solution} &= \text{moles} / \text{volume} \\ &= 0.500 / 4.00 \\ &= 0.125 \text{ M} \end{aligned}$$

Alternatively, using the expression $V_1 \times M_1 = V_2 \times M_2$ which can be applied to dilution calculations,

$$1.00 \times 0.500 = 4.00 \times M_2$$

$$\begin{aligned} \therefore M_2 &= (1.00 \times 0.500) / 4.00 \\ &= 0.125 \text{ M} \end{aligned}$$

(c) Moles of KMnO_4 in 1.00 mL of 0.125 M solution = concentration \times volume

$$= 0.125 \times 1.00 \times 10^{-3}$$
$$= 1.25 \times 10^{-4} \text{ mol}$$

The formula for potassium permanganate contains one MnO_4^- so moles of MnO_4^- ions in 1.00 mL of solution is also 1.25×10^{-4} mol.

As 1 mole of any species contains N_A of that species, then 1.25×10^{-4} mol of MnO_4^- ions contains $1.25 \times 10^{-4} \times N_A$ MnO_4^- ions

$$= 1.25 \times 10^{-4} \times 6.022 \times 10^{23}$$
$$= 7.53 \times 10^{19} \text{ MnO}_4^- \text{ ions.}$$