

Simple Step-by-Step  
Guides to Solving  
Chemistry Problems

# Volumetric Analysis



Nigel Freestone  
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## VOLUMETRIC ANALYSIS

A solution of accurately known concentration is called a **standard solution**. Standard solutions are used in volumetric (**titrimetric**) analysis, used to determine the unknown concentration of an identified chemical species (**analyte**). The volume of one solution that will react with a known volume of a standard solution (titrant) is determined. The point at which the exact amount of titrant added to just react with all the other reagent present is called the **end point** or equivalence point. Indicators, normally added to the solution of known volume, which change colour, are often used to determine the end point.

Volumetric analysis is widely used to determine the concentration of a broad range variety of parameters including basicity, acidity, total hardness and chloride levels.

Titration can be categorised based on chemical reactions:

**Acid-Base** titrations are used to determine the concentration of an acid or base by exactly neutralising the acid or base with an acid or base of known concentration. This permits to quantitative analysis of the concentration of an unknown acid or base solution.

**Redox** titrations can be used to determine oxidizing or reducing agents in a solution. The reducing or oxidizing agent is used as the titrant against the other agent.

**Back Titrations** are used where analytes are either partially soluble or too slow to give a reaction. A known amount of excess reagent is used. The remaining excess reagent is then titrated with another second reagent to determine how much of the excess reagent was used in the first titration, allowing the original analyte's concentration to be determined.

**Example 1:** Chloride concentrations in water can be determined by titration against standardised silver nitrate solutions. A 50 cm<sup>3</sup> water sample was titrated against 0.05 M silver nitrate solution, using potassium chromate as the indicator. This indicator changes colour when all the chloride has been precipitated out of solution as silver chloride. This colour change occurred after the addition of 10.9 cm<sup>3</sup> of 0.05 M silver nitrate. What is the concentration of chloride ions in the water sample?

**Step 1:** Write the balanced chemical equation, insert the information given in the question and identify what you are trying to calculate

	$\text{Cl}^-_{(\text{aq})}$	+	$\text{AgNO}_{3(\text{aq})}$	→	$\text{AgCl}_{(\text{s})} + \text{NO}_{3}^-_{(\text{aq})}$
Volume (cm <sup>3</sup> )	50		10.9		
Moles					
Concentration (M)	?		0.05		
Reaction coefficient:	1	:	1		

Please note volumetric analysis (titrations) are predominantly concerned with the reaction coefficient (stoichiometric) relationship between the reactants. The products are included in the above table for the sake of completeness.

**Step 2:** If two pieces of information from volume, number of moles, and concentration are known for a given species, the third can be calculated using:

**Concentration (M) = Number of Moles / Volume of solution (L)**

$$c = n / v$$

OR

**Number of Moles = Concentration (M) x Volume of Solution (L)**

$$n = c \times v$$

OR

**Volume of Solution (L) = Number of Moles / Concentration (M)**

$$v = n / c$$

	$\text{Cl}^-_{(\text{aq})}$	+	$\text{AgNO}_{3(\text{aq})}$	$\rightarrow$	$\text{AgCl}_{(\text{s})}$	+ $\text{NO}_{3}^-_{(\text{aq})}$
Volume ( $\text{cm}^3$ )	50		10.9			
	(0.05 L)					
Moles			$10.9 \times 0.05 / 1000$			
			$= 5.45 \times 10^{-4}$			
Concentration (M)	?		0.05			
Reaction coefficient	1	:	1			

**Step 4:** At the end point the amount of each species present is in accordance with the reaction coefficient (stoichiometric) relationship of the balanced chemical equation for the reaction. In this example the number of moles of  $\text{Cl}^-$  in  $50 \text{ cm}^3$  = the number of moles  $\text{Ag}^+$  in  $10.89 \text{ cm}^3$

	$\text{Cl}^-_{(\text{aq})}$	+	$\text{AgNO}_{3(\text{aq})}$	$\rightarrow$	$\text{AgCl}_{(\text{s})}$	+ $\text{NO}_{3}^-_{(\text{aq})}$
Volume ( $\text{cm}^3$ )	50		10.9			
	(0.05 L)					
Moles	$5.45 \times 10^{-4}$		$10.9 \times 0.05 / 1000$			
			$= 5.45 \times 10^{-4}$			
Concentration (M)	?		0.05			
Reaction coefficients	1	:	1			

**Step 4:** Since we know both the number of moles of  $\text{Cl}^-$  and its volume, we can calculate its concentration.

	$\text{Cl}^-_{(\text{aq})}$	+	$\text{AgNO}_{3(\text{aq})}$	$\rightarrow$	$\text{AgCl}_{(\text{s})}$	+ $\text{NO}_{3}^-_{(\text{aq})}$
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Volume (cm <sup>3</sup> )	50 (0.05 L)	10.9
Moles	$5.45 \times 10^{-4}$	$10.9 \times 0.05 / 1000$ $= 5.45 \times 10^{-4}$
Concentration (M)	$5.45 \times 10^{-4} / 0.05$ <b>=0.0109</b>	0.05
Reaction coefficients	1	: 1

**Answer:** Concentration of Cl<sup>-</sup> in tap water = **0.0109 M**

**Example 2:** A standard solution was prepared by dissolving 2.6061 g of anhydrous sodium carbonate in distilled water and making up to 250 cm<sup>3</sup>. A 25 cm<sup>3</sup> portion of this solution was titrated against hydrochloric acid, using methyl orange as an indicator. This indicator changes colour when all the sodium carbonate has been converted into sodium chloride. 18.7 cm<sup>3</sup> of the acid were required for neutralisation. What is the concentration of the acid?

**Step 1:** Fill in the information given in the question

	Na <sub>2</sub> CO <sub>3(aq)</sub>	+	2HCl <sub>(aq)</sub>	→	2NaCl + CO <sub>2</sub> + H <sub>2</sub> O
Volume (cm <sup>3</sup> )	25		18.7		
No. of moles					
Concentration (M)			?		
Reaction coefficients	2	:	1		

**Step 2:** You need to know two pieces of information (volume, number of moles or concentration) about one of the species and one piece of information about another to solve volumetric (titrimetric) problems. If this information is not given directly in the question, then it can be calculated from the information provided- in this example the concentration of Na<sub>2</sub>CO<sub>3</sub>.

$$M_r [\text{Na}_2\text{CO}_3] = 106$$

$$\text{Number of moles of Na}_2\text{CO}_3 \text{ in } 2.6061 \text{ g} = \text{mass}/M_r = 2.6061/106 = 0.0246$$

$$\text{Therefore, the number of moles of Na}_2\text{CO}_3 \text{ in } 250 \text{ cm}^3 \text{ (0.25 L)} = 0.0246$$

$$25 \text{ cm}^3 \text{ of the Na}_2\text{CO}_3 \text{ solution contains } 0.0246 \times 25/250 = 2.46 \times 10^{-3} \text{ moles of Na}_2\text{CO}_3$$

$$\text{Concentration (ie number of moles in } 1000 \text{ cm}^3) = \text{number of moles / volume} = 0.0246/0.25 = 0.098 \text{ M}$$

	Na <sub>2</sub> CO <sub>3</sub>	+	2HCl <sub>(aq)</sub>	→	2NaCl + CO <sub>2</sub> + H <sub>2</sub> O
Volume (cm <sup>3</sup> )	25		18.7		
Moles	0.098				
Concentration (M)	$2.46 \times 10^{-3}$		?		
Reaction coefficient	2	:	1		

**Step 3:**

At the end point (ie. when the indicator changes colour) there are 2 moles of HCl for every mole of Na<sub>2</sub>CO<sub>3</sub>.

Number of moles of HCl at the end point = 2 x the number of moles of Na<sub>2</sub>CO<sub>3</sub>  
 = 2 x 2.46 x 10<sup>-3</sup>  
 = 4.92 x 10<sup>-3</sup> moles

	Na <sub>2</sub> CO <sub>3(aq)</sub>	+	2HCl <sub>(aq)</sub>	→	2NaCl + CO <sub>2</sub> + H <sub>2</sub> O
Volume (cm <sup>3</sup> )	25		18.7		
Moles	0.0246		0.0246 x 2 = 4.92 x 10 <sup>-3</sup>		
Concentration (M)	0.098				
Reaction coefficient	2	:	1		

**Step 4:**

Thus, the number of moles of HCl in 18.7 cm<sup>3</sup> = 4.92 x 10<sup>-3</sup> moles

Concentration is defined as the number of moles in 1 L i.e. = number of moles / volume

Convert volume from cm<sup>3</sup> to L, 18.7 cm<sup>3</sup> = 18.7/1000 = 0.0187 L

Therefore concentration of HCl = number of moles/volume = 4.92 x 10<sup>-3</sup> / 0.0187 = 0.263 M

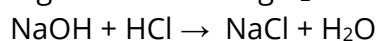
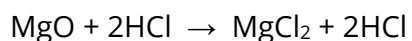
	Na <sub>2</sub> CO <sub>3(aq)</sub>	+	2HCl <sub>(aq)</sub>	→	2NaCl + CO <sub>2</sub> + H <sub>2</sub> O
Volume (cm <sup>3</sup> )	25		18.7		
Moles	0.0246		4.92 x 10 <sup>-3</sup>		
Concentration (M)	2.46 x 10 <sup>-3</sup>		<b>0.263</b>		
Reaction coefficient	2	:	1		

**Answer:** HCl concentration = **0.263 M**

**Example 3:** Magnesium oxide is not very soluble in water, and is difficult to titrate directly. Its purity can be determined by use of a 'back titration' method. 4.06 g of impure magnesium oxide was completely dissolved in 100 cm<sup>3</sup> of hydrochloric acid, of concentration 2.0M (in excess). The excess acid required 19.7 cm<sup>3</sup> of sodium hydroxide (0.20M) for neutralisation. This second titration is called a 'back-titration', and is used to determine the unreacted acid.

a) write equations for the two neutralisation reactions.

**Answer:**



b) calculate the moles of hydrochloric acid added to the magnesium oxide.

**Answer:**

Number of moles of HCl in 100 cm<sup>3</sup> of 2M = volume x concentration = 100/1000 x 2 = 0.2 moles

c) calculate the moles of excess hydrochloric acid titrated.

*Answer:*

Number of moles in 19.7 cm<sup>3</sup> (0.0197 L) of 0.2M HCl = volume x concentration = 0.0197 x 0.2 = 0.0197 moles

(d) calculate the moles of hydrochloric acid reacting with the magnesium oxide.

*Answer:*

Number of mole reacting with MgO = 0.2 – 0.01986 = 0.1804 moles

(e) calculate the moles and mass of magnesium oxide that reacted with the initial hydrochloric acid.

*Answer:*

$M_r [\text{MgO}] = 40$

According to the reaction coefficients, 2 moles of HCl react with 1 mole of MgO

Therefore, the number of moles of MgO = 0.1804 = 0.0902

Mass of MgO = number of moles x  $M_r$  = 0.0902 x 40 = 3.608 g

(f) hence the % purity of the magnesium oxide.

*Answer:*

% purity = 3.608/4.06 x 100 = 88.9%

**Example 4:** A sample of sodium hydrogencarbonate was tested for purity using the following method. 0.400g of the solid was dissolved in 100.0 cm<sup>3</sup> of water and titrated with 0.200 M hydrochloric acid using methyl orange indicator. 23.75 cm<sup>3</sup> of acid was required for complete neutralisation. Determine the mass of sodium hydrogen carbonate titrated and hence the purity of the sample.

*Answer:*

	NaHCO <sub>3(aq)</sub>	+	HCl <sub>(aq)</sub>	→	NaCl + CO <sub>2</sub> + H <sub>2</sub> O
Volume (cm <sup>3</sup> )	100 (0.1L)		23.75		
Moles	4.75 x 10 <sup>-3</sup>		23.75/1000 x 0.2 = 4.75 x 10 <sup>-3</sup>		
Concentration (M)	4.76 x 10 <sup>-3</sup> /0.1 = <b>0.0476</b>		<b>0.2</b>		
Reaction coefficient	<b>1</b>	:	<b>1</b>		

$M_r [\text{NaHCO}_3] = 84$

Number of moles in 23.75 cm<sup>3</sup> 0.2M HCl = volume x concentration

$$= 23.75/1000 \times 0.2 = 4.75 \times 10^{-3}$$

Volume = 100 cm<sup>3</sup> = 0.1 L

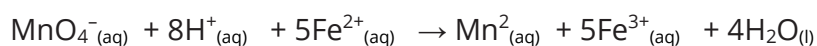
Concentration of prepared NaHCO<sub>3</sub> solution = number of moles / volume  
 $= 4.76 \times 10^{-3} / 0.1 = 0.0476 \text{ M}$

At the end point the number of moles of NaHCO<sub>3</sub> = number of moles of HCl  
 $= 4.75 \times 10^{-3}$

Mass of  $4.75 \times 10^{-3}$  of NaHCO<sub>3</sub> = number of moles x M<sub>r</sub>  
 $= 4.75 \times 10^{-3} \times 84 = \mathbf{0.399 \text{ g}}$

Purity (%) = 0.399/0.400 x 100  
 $= \mathbf{99.75\%}$

**Example 5:** The redox reaction between permanganate ions and iron(II) ions is:



What volume (in cm<sup>3</sup>) of permanganate solution of concentration 0.04M would react exactly with 30 cm<sup>3</sup> of a solution of iron(II) which has a concentration of 0.3 M?

**Answer:**

	MnO <sub>4</sub> <sup>-</sup>	+	8H <sup>+</sup>	+	5Fe <sup>2+</sup>	→	Mn <sup>2+</sup> + 5Fe <sup>3+</sup> + 4H <sub>2</sub> O
Volume (cm <sup>3</sup> )	1.8 x 10 <sup>-3</sup> /0.4 x 1000 <b>= 4.5</b>				30		
Moles	1/5 x 9 x 10 <sup>-3</sup> <b>= 1.8 x 10<sup>-3</sup></b>				30/1000 x 0.3 <b>= 9 x 10<sup>-3</sup></b>		
Concentration (M)	0.4				0.3		
Reaction Coefficient	1		8	:	5		

Number of moles in 30cm<sup>3</sup>, 0.3M Fe<sup>2+</sup> = volume x concentration = 30/1000 x 0.3 = 9 x 10<sup>-3</sup>

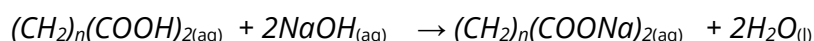
According to the reaction coefficients, at the end point number of moles of MnO<sub>4</sub><sup>-</sup> = 1/5 x number of moles of Fe<sup>2+</sup>

$$= 1/5 \times 9 \times 10^{-3}$$

$$= 1.8 \times 10^{-3}$$

Volume of KMnO<sub>4</sub> = number of moles x concentration = 1.8 x 10<sup>-3</sup> / 0.4 x 1000 = **4.5 cm<sup>3</sup>**

**Example 6:** Succinic acid has the formula (CH<sub>2</sub>)<sub>n</sub>(COOH)<sub>2</sub> and reacts with dilute sodium hydroxide as follows:



2.0 g of succinic acid were dissolved in water and the solution made up to 250 cm<sup>3</sup>. This solution was placed in a burette and 18.4 cm<sup>3</sup> was required to neutralise 25 cm<sup>3</sup> of 0.1M NaOH. Deduce the molecular formula of the acid and hence the value of n.

**Answer:**

	$(\text{CH}_2)_n(\text{COOH})_2(\text{aq})$	+	$2\text{NaOH}(\text{aq})$	$\rightarrow$	$(\text{CH}_2)_n(\text{COONa})_2 + 2\text{H}_2\text{O}$
Volume ( $\text{cm}^3$ )	18.4 (0.0184 L)		25		
Moles	$0.5 \times 2.5 \times 10^{-3} = 1.25 \times 10^{-3}$		$25/1000 \times 0.1 = 2.5 \times 10^{-3}$		
Concentration (M)	$1.25 \times 10^{-3} / 0.0184 = 0.068$		0.1		
Reaction coefficient	<b>1</b>	:	<b>2</b>		

Number of moles of NaOH in  $25 \text{ cm}^3$ ,  $0.1 \text{ M NaOH} = \text{volume} \times \text{concentration} = 25/1000 \times 0.1 = 2.5 \times 10^{-3}$

At the end point, the number of moles of  $(\text{CH}_2)_n(\text{COOH})_2$  in  $18.4 \text{ cm}^3 = 0.5 \times \text{number of moles of NaOH}$

$$= 0.5 \times 2.5 \times 10^{-3} = 1.25 \times 10^{-3}$$

Number of moles of  $(\text{CH}_2)_n(\text{COOH})_2$  in  $250 \text{ cm}^3 = 250/18.7 \times 1.25 \times 10^{-3} = 0.017 \text{ moles}$

Thus  $0.017 \text{ moles of } (\text{CH}_2)_n(\text{COOH})_2$  has a mass of  $2 \text{ g}$

$M_r [(\text{CH}_2)_n(\text{COOH})_2] = \text{mass} / \text{number of moles} = 2 / 0.017 = \mathbf{118}$

$M_r [\text{CH}_2] = 14$

$M_r [(\text{COOH})_2] = 90$

Thus  $14n + 90 = 118$

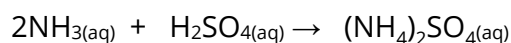
Rearranging,  $14n = 118 - 90 :$

$n = 28/14 = \mathbf{2}$



## PRACTICE PROBLEMS

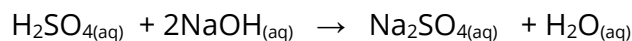
1. If it takes  $24 \text{ cm}^3$  of  $0.1 \text{ M NaOH}$  to neutralise  $20 \text{ cm}^3$  of an HCl solution, what is the concentration of the HCl?
2. If it takes  $1 \text{ cm}^3$  of  $0.05 \text{ M HNO}_3$  to neutralise  $25 \text{ cm}^3$  of NaOH solution, what is the concentration of the NaOH solution?
3. If it takes  $50 \text{ cm}^3$  of  $0.5 \text{ M KOH}$  solution to completely neutralise  $125 \text{ cm}^3$  of sulfuric acid solution ( $\text{H}_2\text{SO}_4$ ), what is the concentration of the  $\text{H}_2\text{SO}_4$  solution?
4. An ammonia solution was reacted with sulfuric acid as shown in the equation below.



Calculate the concentration of the ammonia solution given that it takes  $30.8 \text{ cm}^3$  of a  $1.24 \text{ M}$  solution of sulfuric acid to neutralise  $25 \text{ cm}^3$  of this ammonia solution for complete reaction.



5. A 50.0 cm<sup>3</sup> sample of sulfuric acid was diluted to 1.00 L. A sample of the diluted sulfuric acid was analysed by titrating with aqueous sodium hydroxide. In the titration, 25.0 cm<sup>3</sup> of 1.00 M aqueous sodium hydroxide required 20.0 cm<sup>3</sup> of the diluted sulfuric acid for neutralisation. Calculate the concentration of the original concentrated sulfuric acid solution.



Calculate the concentration of the original concentrated sulfuric acid solution.

6. How many grams of Ca(OH)<sub>2</sub> are required to neutralise 52.68 cm<sup>3</sup> of a 0.750 M H<sub>2</sub>SO<sub>4</sub> solution?
7. What volume of 1.0M sulfuric acid will be needed to neutralise 25.00 cm of 0.8M sodium hydroxide solution?
8. Calculate the volume of 0.10M sodium hydroxide solution needed to neutralise 20.00 cm<sup>3</sup> of 0.25M hydrochloric acid.
9. 100 cm<sup>3</sup> of a magnesium hydroxide solution required 4.5 cm<sup>3</sup> of sulfuric acid (of concentration 0.100M) for complete neutralisation. Determine the concentration of the magnesium hydroxide in g cm<sup>-3</sup>.
10. A solution made from pure barium hydroxide contained 2.74 g in exactly 100 cm<sup>3</sup> of water. Using phenolphthalein indicator, titration of 20.0 cm<sup>3</sup> of this solution required 18.7 cm<sup>3</sup> of a hydrochloric acid solution for complete neutralisation. Calculate the molarity of the HCl.

**Answers are given on the next page.**

## Volumetric Analysis Answers:

1. If it takes 24 cm<sup>3</sup> of 0.1 M NaOH to neutralise 20 cm<sup>3</sup> of an HCl solution, what is the concentration of the HCl?

*Answer:*

	NaOH <sub>(aq)</sub>	+	HCl <sub>(aq)</sub>	→	NaCl <sub>(aq)</sub> + H <sub>2</sub> O <sub>(l)</sub>
Volume (cm <sup>3</sup> )	24		20		
No. of moles	2.4 × 10 <sup>-3</sup>		2.4 × 10 <sup>-3</sup>		
Concentration (M)	0.1		<b>0.12</b>		
Reaction Coefficients	1		1		

Number of moles of NaOH in 24 cm<sup>3</sup> 0.1M = volume x concentration = 24/1000 x 0.1 = 2.4 × 10<sup>-3</sup>

At the end point the number of moles of NaOH in 24 cm<sup>3</sup> = number of moles of HCl in 20cm<sup>3</sup>

Therefore, number of moles of HCl in 20cm<sup>3</sup> (0.02 L) = 2.4 × 10<sup>-3</sup>

Concentration = number of moles / volume

$$= 2.4 \times 10^{-3} / 0.02 = \mathbf{0.12 \text{ M}}$$

2. If it takes 1 cm<sup>3</sup> of 0.05 M HNO<sub>3</sub> to neutralise 25 cm<sup>3</sup> of NaOH solution, what is the concentration of the NaOH solution?

*Answer:*

	NaOH <sub>(aq)</sub>	+	HNO <sub>3(aq)</sub>	→	2NaNO <sub>3(aq)</sub> + H <sub>2</sub> O <sub>(l)</sub>
Volume (cm <sup>3</sup> )	25		1		
No. of moles	5 × 10 <sup>-5</sup>		5 × 10 <sup>-5</sup>		
Concentration (mol M)	<b>2 × 10<sup>-3</sup></b>		0.05		
Reaction coefficients	1		1		

Number of moles of HNO<sub>3</sub> in 1 cm<sup>3</sup> (0.001 L) 0.05M = volume x concentration = 0.001 x 0.05 = 5 × 10<sup>-5</sup>

At the end point the number of moles of HNO<sub>3</sub> in 1 cm<sup>3</sup> = number of moles of NaOH in 25cm<sup>3</sup>

Therefore, number of moles of NaOH in 25 cm<sup>3</sup> (0.025 L) = 5 × 10<sup>-5</sup>

Concentration = number of moles / volume

$$= 5 \times 10^{-5} / 0.025$$

$$= \mathbf{2 \times 10^{-3} \text{ M}}$$

3. If it takes 50 cm<sup>3</sup> of 0.5 M KOH solution to completely neutralise 125 cm<sup>3</sup> of sulfuric acid solution (H<sub>2</sub>SO<sub>4</sub>), what is the concentration of the H<sub>2</sub>SO<sub>4</sub> solution?

*Answer:*

	2KOH <sub>(aq)</sub>	+	H <sub>2</sub> SO <sub>4(aq)</sub>	→	K <sub>2</sub> SO <sub>4(aq)</sub> + H <sub>2</sub> O <sub>(l)</sub>
Volume (cm <sup>3</sup> )	50		125		
No. of moles	0.025		0.0125		
Concentration (mol M)	0.5		<b>0.1</b>		
Reaction coefficients	2		1		

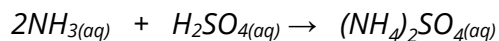
Number of moles of KOH in 50 cm<sup>3</sup> 0.5 M = volume x concentration 50/1000 x 0.5 = 0.025

At the end point the number of moles of KOH in 50 cm<sup>3</sup> = 0.5 x number of moles of H<sub>2</sub>SO<sub>4</sub> in 125 cm<sup>3</sup>

Therefore, number of moles of KOH in 125 cm<sup>3</sup> (0.125 L) = ½ x 0.025 = 0.0125

Concentration of KOH = number of moles / volume = 0.0125 / 0.125 = **0.1 M**

4. An ammonia solution was reacted with sulfuric acid as shown in the equation below.



Calculate the concentration of the ammonia solution given that it takes 30.8 cm<sup>3</sup> of a 1.24 M solution of sulfuric acid to neutralise 25 cm<sup>3</sup> of this ammonia solution for complete reaction.

**Answer:**

	2NH <sub>3(aq)</sub>	+	H <sub>2</sub> SO <sub>4(aq)</sub>	→	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>
Volume (cm <sup>3</sup> )	25 (0.025 L)		30.8		
No. of moles	0.0382 x 2 = 0.0764		0.0382		
Concentration (M)	0.0764 /0.025 = <b>3.1</b>		1.24		
Reaction coefficients	2		1		1

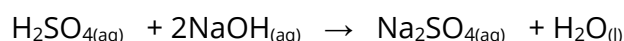
Number of moles in 30.8 cm<sup>3</sup> of 1.24 M H<sub>2</sub>SO<sub>4</sub> = volume x concentration = 30.8/1000 x 1.24 = 0.0382

At the end point, the number of moles of NH<sub>3</sub> = 2 x number of mole of H<sub>2</sub>SO<sub>4</sub> = 0.0382 x 2 = 0.0764

Thus number of moles of NH<sub>3</sub> in 25 cm<sup>3</sup> (0.025 L) = 0.076

Concentration of NH<sub>3</sub> = number of moles / volume = 0.076 / 0.025 = **3.1 M**

5. A 50.0 cm<sup>3</sup> sample of sulfuric acid was diluted to 1.00 L. A sample of the diluted sulfuric acid was analysed by titrating with aqueous sodium hydroxide. In the titration, 25.0 cm<sup>3</sup> of 1.00 M aqueous sodium hydroxide required 20.0 cm<sup>3</sup> of the diluted sulfuric acid for neutralisation. Calculate the concentration of the original concentrated sulfuric acid solution.



Calculate the concentration of the original concentrated sulfuric acid solution.

**Answer:**

	H <sub>2</sub> SO <sub>4(aq)</sub>	+	2NaOH <sub>(aq)</sub>	→	Na <sub>2</sub> SO <sub>4</sub> + H <sub>2</sub> O
Volume (cm <sup>3</sup> )	20 (0.02L)		25		
No. of moles	0.5 x 0.025 = 0.0125		25/1000 x 1 = 0.025		
Concentration (M)	0.0125/0.02 = 0.625		1		
Reaction coefficients	1		2		

Number of moles in 25 cm<sup>3</sup> of 1 M NaOH = volume x concentration = 25/1000 x 1 = 0.025

At the end point, the number of moles of H<sub>2</sub>SO<sub>4</sub> = 0.5 x number of mole of NaOH = 0.5 x 0.025 = 0.0125

Thus number of moles of H<sub>2</sub>SO<sub>4</sub> in 20 cm<sup>3</sup> (0.02 L) = 0.0125

Concentration of H<sub>2</sub>SO<sub>4</sub> = number of moles / volume = 0.0125/0.02 = 0.625 M

Therefore, concentration of the original H<sub>2</sub>SO<sub>4</sub> sample = 1000/50 x 0.625 = **12.5 M**

6. How many grams of  $\text{Ca(OH)}_2$  are required to neutralise  $52.68 \text{ cm}^3$  of a  $0.750 \text{ M H}_2\text{SO}_4$  solution ?

**Answer:**

	$\text{Ca(OH)}_{2(\text{aq})}$	+	$\text{H}_2\text{SO}_{4(\text{aq})}$	$\rightarrow$	$\text{CaSO}_4 + \text{H}_2\text{O}$
Volume ( $\text{cm}^3$ )			52.68		
Moles	0.0395		$52.68/1000$ $\times 0.75 =$ 0.0395		
Concentration (M)			0.75		
Mass	<b>2.92</b>	:			
Reaction coefficient	<b>1</b>		1		

$M_r [\text{Ca(OH)}_2] = 74$

The number of moles in  $52.68 \text{ cm}^3$  of a  $0.750 \text{ M H}_2\text{SO}_4 = \text{volume} \times \text{concentration} = 52.68/1000 \times 0.75 = 0.0395$

According to the reaction coefficients, at the end point, the number of moles of  $\text{Ca(OH)}_2 =$  the number of moles of  $\text{H}_2\text{SO}_4$

Thus, the number of moles of  $\text{Ca(OH)}_2 = 0.0395$

Mass of  $0.0395$  moles  $\text{Ca(OH)}_2 = \text{number of moles} \times M_r = 0.0395 \times 74 = \mathbf{2.92 \text{ g}}$

7. What volume of  $1.0\text{M}$  sulfuric acid will be needed to neutralise  $25.00 \text{ cm}^3$  of  $0.8\text{M}$  sodium hydroxide solution?

**Answer:**

	$2\text{NaOH}_{(\text{aq})}$	+	$\text{H}_2\text{SO}_{4(\text{aq})}$	$\rightarrow$	$\text{Na}_2\text{SO}_4 + \text{H}_2\text{O}$
Volume ( $\text{cm}^3$ )	25		<b>10 (0.01 L)</b>		
Moles	$25/1000 \times$ $0.8 = 0.02$		$0.01/1 = 0.01$		
Concentration (M)	0.8		1		
Reaction coefficient	2	:	1		

Number of moles in  $25\text{cm}^3$ ,  $0.8\text{M NaOH} = \text{volume} \times \text{concentration} = 25/1000 \times 0.8 = 0.02$

At the end point, the number of moles of  $\text{H}_2\text{SO}_4 = 0.5 \times \text{number of moles of NaOH} = 0.5 \times 0.02 = 0.01$

Volume of  $\text{H}_2\text{SO}_4 = \text{number of moles} / \text{concentration} = 0.01 / 1 = 0.01 \text{ L} = 10 \text{ cm}^3$

8. Calculate the volume of  $0.10\text{M}$  sodium hydroxide solution needed to neutralise  $20.00 \text{ cm}^3$  of  $0.25\text{M}$  hydrochloric acid.

**Answer:**

	$\text{NaOH}_{(\text{aq})}$	+	$\text{HCl}_{(\text{aq})}$	$\rightarrow$	$\text{NaCl} + \text{H}_2\text{O}$
Volume ( $\text{cm}^3$ )	$5 \times 10^{-3} / 0.1$ $= = 0.50 \text{ L} =$ <b>50</b>		20		
Moles	$5 \times 10^{-3}$		$20/1000 \times$ $0.25 = 5 \times$ $10^{-3}$		
Concentration (M)	0.1		0.25		
Reaction coefficient	1	:	1		

The number of moles in  $20\text{cm}^3$ ,  $0.25\text{M HCl} = \text{volume} \times \text{concentration} = 20/1000 \times 0.25 = 5 \times 10^{-3}$

At the end point, the number of moles of NaOH = number of moles of HCl =  $5 \times 10^{-3}$   
 Volume of NaOH = number of moles / concentration =  $5 \times 10^{-3} / 0.1 = 0.05 \text{ L} = 50 \text{ cm}^3$

9.  $100 \text{ cm}^3$  of a magnesium hydroxide solution required  $4.5 \text{ cm}^3$  of sulfuric acid (of concentration  $0.100 \text{ M}$ ) for complete neutralisation. Determine the concentration of the magnesium hydroxide in  $\text{g cm}^{-3}$ .

**Answer:**

	$\text{Mg(OH)}_2(\text{aq})$	+	$\text{H}_2\text{SO}_4(\text{aq})$	→	$\text{MgSO}_4 + \text{H}_2\text{O}$
Volume ( $\text{cm}^3$ )	100		4.5 ( $4.5 \times 10^{-3} \text{ L}$ )		
Moles	$4.5 \times 10^{-5}$		$4.5 \times 10^{-3} \times 0.1 = 4.5 \times 10^{-4}$		
Concentration (M)	$4.5 \times 10^{-4} / 0.1 = 4.5 \times 10^{-3}$		0.1		
Reaction coefficient	1	:	1		

$M_r[\text{Mg(OH)}_2] = 58$

Number of moles in  $4.5 \text{ cm}^3$   $0.1 \text{ M H}_2\text{SO}_4$  = volume x concentration =  $4.5/1000 \times 0.1 = 4.5 \times 10^{-4}$

At the end point, the number of moles of  $\text{H}_2\text{SO}_4$  = Number of moles of  $\text{Mg(OH)}_2$

Thus the number of moles of  $\text{Mg(OH)}_2$  in  $100 \text{ cm}^3$  ( $0.1 \text{ L}$ ) =  $4.5 \times 10^{-4}$

Concentration of  $\text{Mg(OH)}_2$  = number of moles / volume =  $4.5 \times 10^{-4} / 0.1 = 4.5 \times 10^{-3} \text{ M}$

To convert from M to g/mol multiply by  $M_r$

Concentration of  $\text{Mg(OH)}_2 = 4.5 \times 10^{-3} \times 58 = 0.26 \text{ g/L}$

10. A solution made from pure barium hydroxide contained  $2.74 \text{ g}$  in exactly  $100 \text{ cm}^3$  of water. Using phenolphthalein indicator, titration of  $20.0 \text{ cm}^3$  of this solution required  $18.7 \text{ cm}^3$  of a hydrochloric acid solution for complete neutralisation. Calculate the molarity of the HCl.

**Answer:**

	$\text{Ba(OH)}_2(\text{aq})$	+	$2\text{HCl}(\text{aq})$	→	$\text{BaCl}_2 + 2\text{H}_2\text{O}$
Volume ( $\text{cm}^3$ )	20 (0.02L)		18.7		
Moles	$20/1000 \times 0.16 = 3.2 \times 10^{-3}$		$6.4 \times 10^{-3}$		
Concentration (M)	0.16		$1000/18.7 \times 6.4 \times 10^{-3} = 0.34$		
Reaction coefficient	1	:	2		

$M_r[\text{Ba(OH)}_2] = 171$

Number of moles in  $2.74 \text{ g Ba(OH)}_2 = \text{mass}/M_r = 2.74/171 = 0.016$

Concentration of  $\text{Ba(OH)}_2 = \text{number of moles} / \text{volume} = 0.016 / 0.1 = 0.16 \text{ M}$

At the end point of the titration, number of moles of HCl = 2 x the number of moles of  $\text{Ba(OH)}_2$

Thus number of moles of HCl in  $18.7 \text{ cm}^3$  ( $0.0187 \text{ L}$ ) = 2 x number of moles  $\text{Ba(OH)}_2$  in  $20 \text{ cm}^3$  ( $0.02 \text{ L}$ )  
 $= 2 \times 0.02 \times 0.16 = 6.4 \times 10^{-3}$

Concentration of HCl = number of moles/volume =  $6.4 \times 10^{-3} / 0.0187 = 0.34 \text{ M}$