Mastering Chemistry

- Book 2A
- Topic 4 Acids and Bases

Content

Continued on next page

Content

17.1 Concentration of a solution (p.103)

- The concentration of a solution can be expressed in g dm^{-3}.

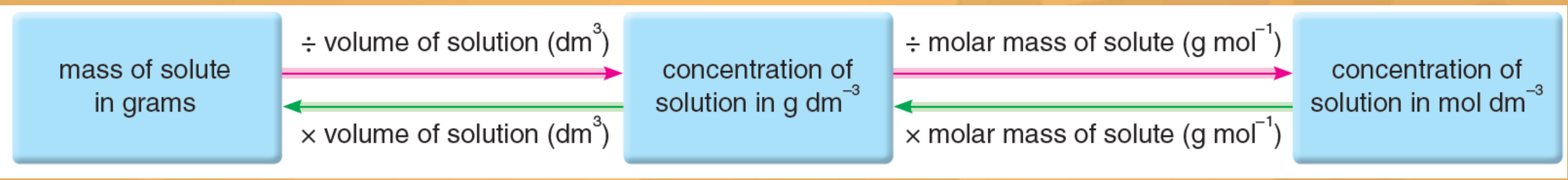
$$\text{Concentration of solution (in g dm}^{-3}\text{)} = \frac{\text{mass of solute (in g)}}{\text{volume of solution (in dm}^{3}\text{)}}$$

- The two units of concentration (mol dm^{-3} and g dm^{-3}) are related by the expression below.

$$\text{Concentration of solution (in mol dm}^{-3}\text{)} = \frac{\text{concentration of solution (in g dm}^{-3}\text{)}}{\text{molar mass of solute (in g mol}^{-1}\text{)}}$$

17.1 Concentration of a solution (p.103)

- The interconversion between concentration in g dm^{-3} and concentration in mol dm^{-3} of a solution.



17.1 Concentration of a solution (p.103)

Q (Example 17.1)

200.0 cm^3 of a solution contain 5.68 g of magnesium chloride. What is the concentration of the solution in g dm^{-3}?

A

$$\text{Volume of solution} = \frac{200.0}{1\ 000}\ dm^3$$

$$\text{Concentration of solution} = \frac{\text{mass of } MgCl_2}{\text{volume of solution}}$$

$$= \frac{5.68\ g}{\left(\frac{200.0}{1\ 000}\right)\ dm^3}$$

$$= 28.4\ g\ dm^{-3}$$

∴ the concentration of the magnesium chloride solution is 28.4 g dm^{-3}.

17.1 Concentration of a solution (p.103)

Q (Example 17.2)

Lead found in tap water usually comes from the corrosion of old fixtures or from the lead-containing solder that connects pipes. A city states that the concentration of lead ions in drinking water should not exceed 2.40 x 10^{-8} g cm^{-3}. Express this concentration in mol dm^{-3}.
(Relative atomic mass: Pb = 207.2)

A

Concentration of lead ions in drinking water $= 2.40 \times 10^{-8}$ g cm^{-3}
$= 2.40 \times 10^{-8} \times 1\,000$ g dm^{-3}
$= 2.40 \times 10^{-5}$ g dm^{-3}

$$\text{Molar concentration of lead ions in drinking water} = \frac{\text{concentration (in g dm}^{-3})}{\text{molar mass of lead (in g mol}^{-1})}$$

$$= \frac{2.40 \times 10^{-5} \text{ g dm}^{-3}}{207.2 \text{ g mol}^{-1}}$$

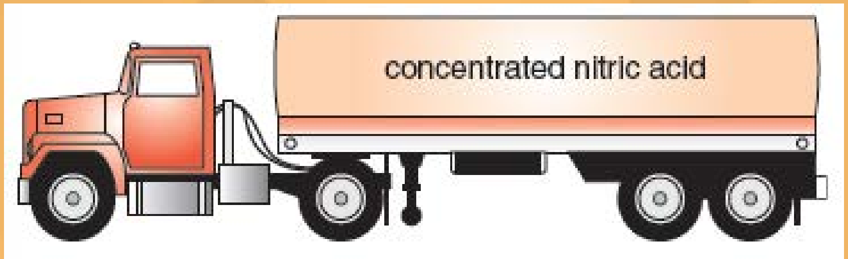
$$= 1.16 \times 10^{-7} \text{ mol dm}^{-3}$$

∴ the concentration of lead ions in drinking water should not exceed 1.16×10^{-7} mol dm^{-3}.

17.1 Concentration of a solution (p.103)

Q (Example 17.3)

The diagram below shows a truck with a storage tank for transporting concentrated nitric acid.



The storage tank contains 62 000 kg of concentrated nitric acid, which occupies a volume of 45.0 m^3. If the percentage by mass of HNO_3 in the acid is 67.8%, calculate the concentration of the acid

a) in g dm^{-3};

b) in mol dm^{-3}.

(Relative atomic masses: H = 1.0, N = 14.0, O = 16.0)

17.1 Concentration of a solution (p.103)

Q (Example 17.3) (continued)

A

a) Mass of HNO_3 in 45.0 m^3 of acid = 62 000 000 g x 67.8%
= 42 036 000 g

Concentration of nitric acid (in g dm^{-3}) = $\frac{\text{mass of } HNO_3}{\text{volume of solution}}$

= $\frac{42\ 036\ 000\ g}{45\ 000\ dm^3}$

= 934 g dm^{-3}

1 m^3 = 100 x 100 x 100 cm^3
= 1 000 dm^3

b) Molar mass of HNO_3 = (1.0 + 14.0 + 3 x 16.0) g mol^{-1}
= 63.0 g mol^{-1}

Concentration of nitric acid (in mol dm^{-3}) = $\frac{\text{concentration of nitric acid (in g } dm^{-3})}{\text{molar mass of } HNO_3 \text{ (in g } mol^{-1})}$

= $\frac{934\ g\ dm^{-3}}{63.0\ g\ mol^{-1}}$

= 14.8 mol dm^{-3}

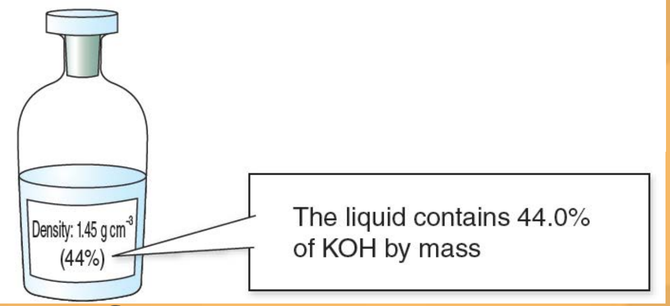
∴ the concentration of the nitric acid is 934 g dm^{-3} and 14.8 mol dm^{-3}.

17.1 Concentration of a solution (p.103)

Practice 17.1

1 The concentration of a solution is 15.6 g dm^{-3}. What mass of solute is there in 750.0 cm^3 of the solution?

2 A bottle of concentrated potassium hydroxide solution is shown below:



According to the information on the label, calculate the concentration of the concentrated potassium hydroxide solution

a) in g dm^{-3};

b) in mol dm^{-3}.

(Relative atomic masses: H = 1.0, O = 16.0, K = 39.1)

17.1 Concentration of a solution (p.103)

Practice 17.1 (continued)

1 Mass of solute in solution

= concentration of solution (in g dm^{-3}) x volume of solution (in dm^3)

= 15.6 g dm^{-3} x $\frac{750.0}{1\ 000}$ dm^3

= 11.7 g

2 Mass of 1 000 cm^3 solution

= density x volume

= 1.45 g cm^{-3} x 1 000 cm^3

= 1 450 g

Mass of KOH in 1 000 cm^3 solution

= 1450 g x 44.0%

= 638 g

a) Concentration of KOH solution (in g dm^{-3}) = 638 g dm^{-3}

b) Molar mass of KOH

= (39.1 + 16.0 + 1.0) g mol^{-1}

= 56.1 g mol^{-1}

Concentration of KOH solution (in mol dm^{-3})

$$= \frac{\text{concentration of KOH solution (in g dm}^{-3}\text{)}}{\text{molar mass of KOH (in g mol}^{-1}\text{)}}$$

$$= \frac{638 \text{ g dm}^{-3}}{56.1 \text{ g mol}^{-1}}$$

= 11.4 mol dm^{-3}

∴ the concentration of the KOH solution is 638 g dm^{-3} and 11.4 mol dm^{-3}.

17.2 Diluting solutions (p.106)

- **Dilution (稀釋)** is an important procedure in analysis.
- Chemical analysis often involves preparing a solution of an unknown sample. It may then be necessary to dilute the solution before analysing it by titration or by some instrumental methods.
- When a concentrated solution is diluted with water, the amount of solute (in moles) in the solution remains unchanged.

i.e. number of moles of solute in solution before dilution = number of moles of solute in solution after dilution

17.2 Diluting solutions (p.106)

- Suppose M is the molarity (in mol dm^{-3}) and V is the volume (in dm^3) of a solution, then the number of moles of solute in solution = MV.

(MV) before dilution = (MV) after dilution

where M = molarity (in mol dm^{-3})
V = volume (in dm^3)

17.2 Diluting solutions (p.106)

Q (Example 17.4)

75.0 cm^3 of 0.600 mol dm^{-3} sodium hydroxide solution are diluted with 300.0 cm^3 of water. What is the molarity of the diluted alkali?

(Assume the volume of the solution obtained is 375.0 cm^3.)

A

(MV) before dilution = (MV) after dilution, where M = molarity, V = volume

$$0.600 \times \frac{75.0}{1\ 000} = M \times \frac{375.0}{1\ 000}$$

$$M = 0.120$$

$\therefore$ molarity of the diluted sodium hydroxide solution is 0.120 mol dm^{-3}.

17.2 Diluting solutions (p.106)

Q (Example 17.5)

The pH of a sample of sulphuric acid is 2.50. 100.0 cm^3 of this sample are mixed with 400.0 cm^3 of water. What is the pH of the resulting mixture?
(Assume the volume of the solution obtained is 500.0 cm^3.)

A

$$pH_{\text{before dilution}} = 2.50$$
$$= -\log[H^+(aq)]_{\text{before dilution}}$$

$$[H^+(aq)]_{\text{before dilution}} = 10^{-2.50}$$
$$= 3.16 \times 10^{-3}\ \text{mol dm}^{-3}$$

(MV) before dilution = (MV) after dilution, where M = molarity, V = volume

$$3.16 \times 10^{-3}\ \text{mol dm}^{-3} \times \frac{100.0}{1\ 000} = [H^+(aq)]_{\text{after dilution}} \times \frac{500.0}{1\ 000}$$
$$[H^+(aq)]_{\text{after dilution}} = 6.32 \times 10^{-4}\ \text{mol dm}^{-3}$$

$$pH_{\text{after dilution}} = -\log(6.32 \times 10^{-4})$$
$$= 3.20$$

∴ the pH of the resulting mixture is 3.20.

17.2 Diluting solutions (p.106)

Q (Example 17.6)

Calculate the volume of water needed to prepare 500.0 cm^3 of a 0.450 mol dm^{-3} nitric acid from a solution of concentration 3.0 mol dm^{-3} .

A

Suppose V cm^3 of 3.00 mol dm^{-3} nitric acid is needed for the dilution.

(MV) before dilution = (MV) after dilution, where M = molarity, V = volume

$$3.00 \times \frac{V}{1\ 000} = 0.450 \times \frac{500.0}{1\ 000}$$

$$V = 75.0$$

$\therefore$ volume of water used = (500.0 – 75.0) cm^3
= 425.0 cm^3

$\therefore$ 75.0 cm^3 of 3.00 mol dm^{-3} nitric acid should be diluted by 425.0 cm^3 of water.

17.2 Diluting solutions (p.106)

Practice 17.2

1 What is the concentration of the solution obtained by diluting 50.0 cm^3 of 2.00 mol dm^{-3} sodium carbonate solution with water to make up to 800.0 cm^3?

2 The pH of a sample of hydrochloric acid is 1.20. How much water should be mixed with 100.0 cm^3 of the acid to obtain a resulting mixture of pH 2.20?

17.2 Diluting solutions (p.106)

Practice 17.2 (continued)

1 (MV) before dilution = (MV) after dilution, where M = molarity, V = volume

$$2.00 \times \frac{50.0}{1\ 000} = M \times \frac{800.0}{1\ 000}$$

$$M = 0.125$$

∴ molarity of the diluted sodium carbonate solution is 0.125 mol dm^{-3}.

2 $pH_{before\ dilution} = 1.20$

$$[H^+(aq)]_{before\ dilution} = 10^{-1.20}$$
$$= 0.0631 \text{ mol dm}^{-3}$$

$pH_{after\ dilution} = 2.20$

$$[H^+(aq)]_{after\ dilution} = 10^{-2.20}$$
$$= 6.31 \times 10^{-3} \text{ mol dm}^{-3}$$

Suppose the volume of the resulting mixture is V cm^3.

(MV) before dilution = (MV) after dilution, where M = molarity, V = volume

$$0.0631 \times \frac{100.0}{1\ 000} = 6.31 \times 10^{-3} \times \frac{V}{1\ 000}$$

$$V = 1\ 000$$

∴ volume of water = (1 000 – 100.0) cm^3
= 900 cm^3

∴ 900 cm^3 of water should be mixed with the acid.

17.3 Why are titrations useful? (p.108)

- Titration is a practical method for measuring the volumes of two solutions that react exactly with each other.
- From the measured volumes and the known concentration of one of the solutions, you can find out the concentration (or amount) of the chemical species in question.

The concentration of citric acid in orange juice is checked using titration during production

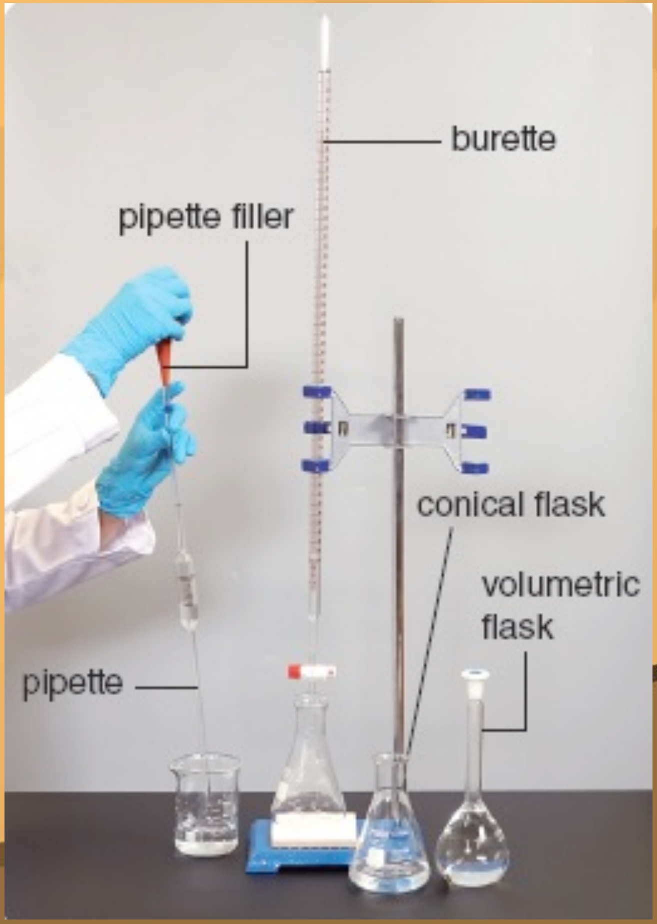
17.3 Why are titrations useful? (p.108)

- Titration is also known as **volumetric analysis (容量分析)** because the measurement of volumes plays a key role.
- Volumetric analysis is widely used in **quantitative analysis (定量分析)**, an analysis that measures how much a chemical species is present in a sample.
- The most common type of laboratory titration involves reacting an acid with an alkali.

17.3 Why are titrations useful? (p.108)

Apparatus used in a titration

- The main pieces of apparatus used in a titration, including:
  - a pipette and a pipette filler;
  - a burette;
  - a volumetric flask; and
  - several conical flasks.



17.3 Why are titrations useful? (p.108)

- A pipette and a pipette filler are used for accurately delivering a fixed volume of liquid (typically 25.00 cm^3).
- A burette is used to deliver various volumes of liquid accurately.
- A volumetric flask is used when diluting one of the solutions to a fixed accurate volume before carrying out a titration. It can also be used when preparing a solution of a solid with a fixed accurate volume.
- A conical flask is used in a titration as it can be swirled easily to mix the reactants.

17.4 What are standard solutions and primary standards? (p.110)

- One of the reactants needed in a titration is a **standard solution (標準溶液)**.

A standard solution is a solution whose concentration is accurately known.

17.4 What are standard solutions and primary standards? (p.110)

- One obvious way to prepare a standard solution is to dissolve a known mass of a chemical in water to make a known volume of solution. The chemical should
  - be available in a high degree of purity;
  - have a known chemical formula (including the number of molecules of water of crystallisation in a hydrated compound);
  - be chemically stable (neither decompose nor react with substances in the air);
  - not absorb moisture from the air;
  - be completely soluble in water;
  - react rapidly and completely with the other substances used in titrations;
  - have a high molar mass (to minimise weighing errors).

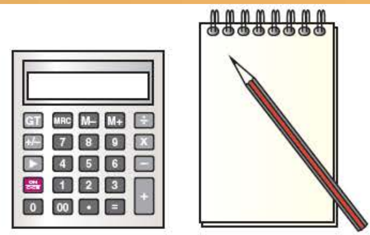
17.4 What are standard solutions and primary standards? (p.110)

- Chemicals that meet these criteria are called **primary standards (基本標準)**.
- Several chemicals that are often used in titrations are not suitable as primary standards. For example, solid sodium hydroxide absorbs moisture and carbon dioxide from the air.
- Ethanedioic acid crystals ($(COOH)_2 \cdot 2H_2O$) and anhydrous sodium carbonate (Na_2CO_3) are suitable as primary standards.

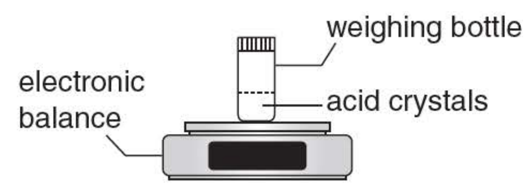
17.4 What are standard solutions and primary standards? (p.110)

Preparing solutions of known concentrations *Ref.*

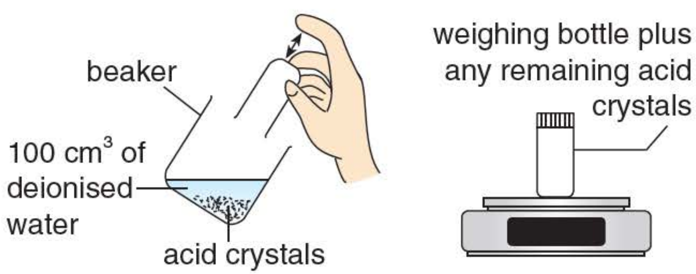
Preparing a standard solution of ethanedioic acid



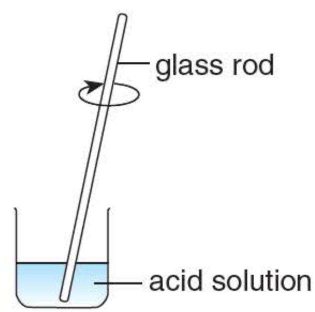
1 Calculate the mass of the acid crystals required.



2 a) Place a weighing bottle onto an electronic balance and add in approximately the required mass of the acid crystals.
b) Accurately weigh the mass of the acid crystals plus the weighing bottle.



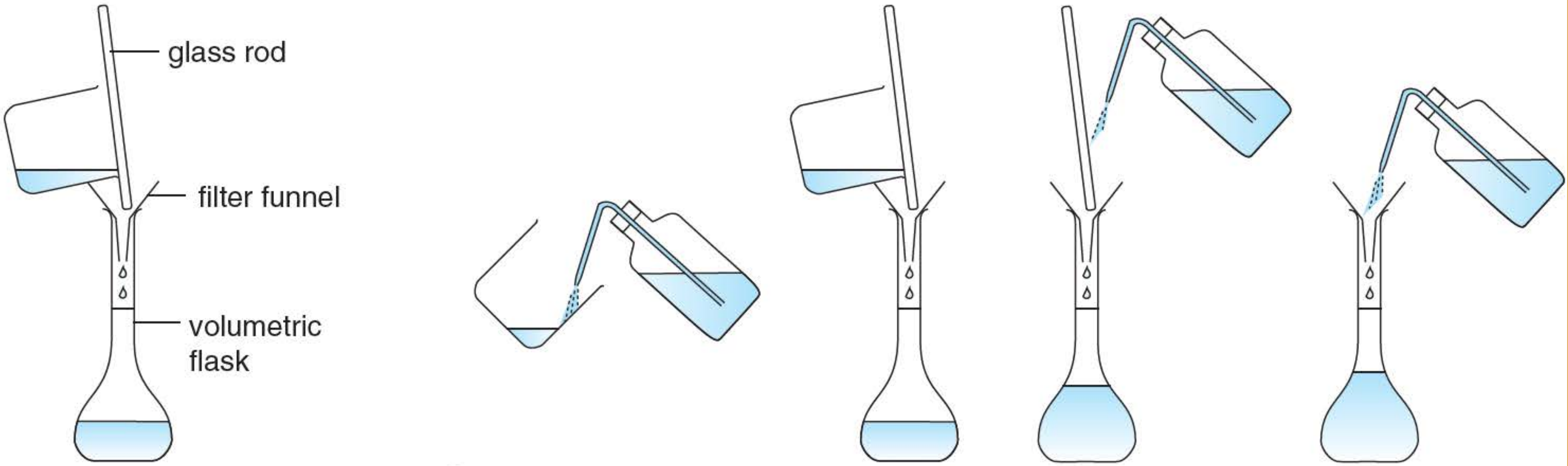
3 a) Carefully empty the acid crystals into a beaker containing 100 cm^3 of deionised water.
b) Accurately reweigh the empty weighing bottle plus any remaining acid crystals.



4 Stir the mixture in the beaker to ensure the acid crystals have dissolved completely.

17.4 What are standard solutions and primary standards? (p.110)

Preparing a standard solution of ethanedioic acid

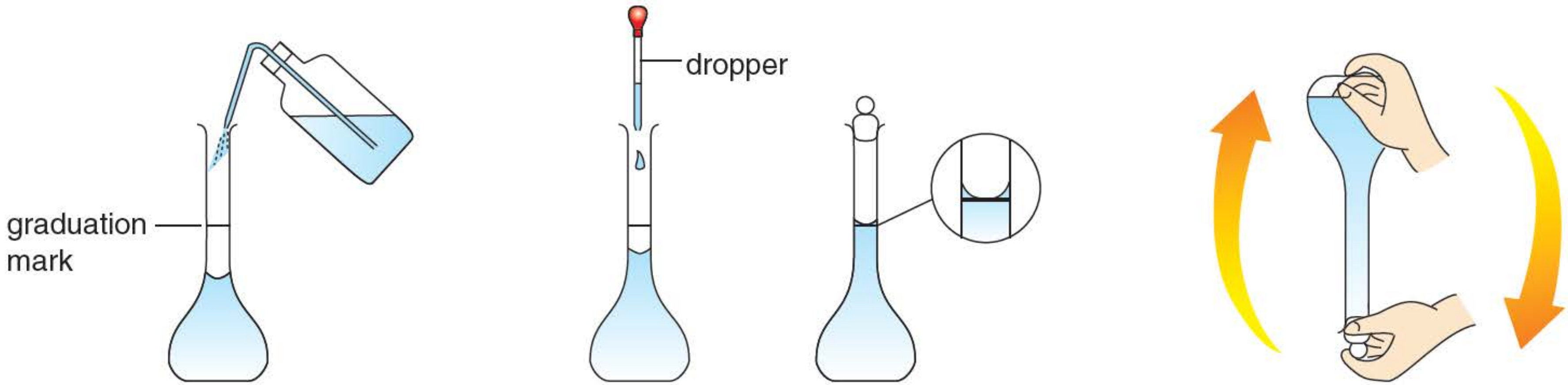


5 Transfer the solution to a 250.0 cm^3 volumetric flask with the aid of a filter funnel.

6 Rinse the beaker, the glass rod and the filter funnel well with deionised water. Make sure all the washings go into the volumetric flask.

17.4 What are standard solutions and primary standards? (p.110)

Preparing a standard solution of ethanedioic acid



7 Add deionised water to the solution until the level is within about 2 cm of the graduation mark on the neck of the volumetric flask.

8 Using a dropper to add deionised water so that the bottom of the *meniscus* is level with the graduation mark on the neck of the flask when looking at it at eye level.

9 Insert the stopper in the flask and invert it, shaking thoroughly to ensure complete mixing.

17.4 What are standard solutions and primary standards? (p.110)

- You can calculate an accurate value for the concentration of the solution of ethanedioic acid, using the data of the example below.

Mass of weighing bottle + acid crystals = 57.24 g

Mass of weighing bottle + any remaining acid crystals = 25.11 g

Mass of acid crystals used = (57.24 – 25.11) g
= 32.13 g

Molar mass of $(COOH)_2{\bullet}2H_2O$
= [2 x (12.0 + 2 x 16.0 + 1.0) + 2 x (2 x 1.0 + 16.0)] g mol^{-1}
= 126.0 g mol^{-1}

Number of moles of $(COOH)_2{\bullet}2H_2O$ used

$$= \frac{\text{mass}}{\text{molar mass}}$$

$$= \frac{32.13 \text{ g}}{126.0 \text{ g mol}^{-1}}$$

= 0.255 mol

Concentration of the acid solution

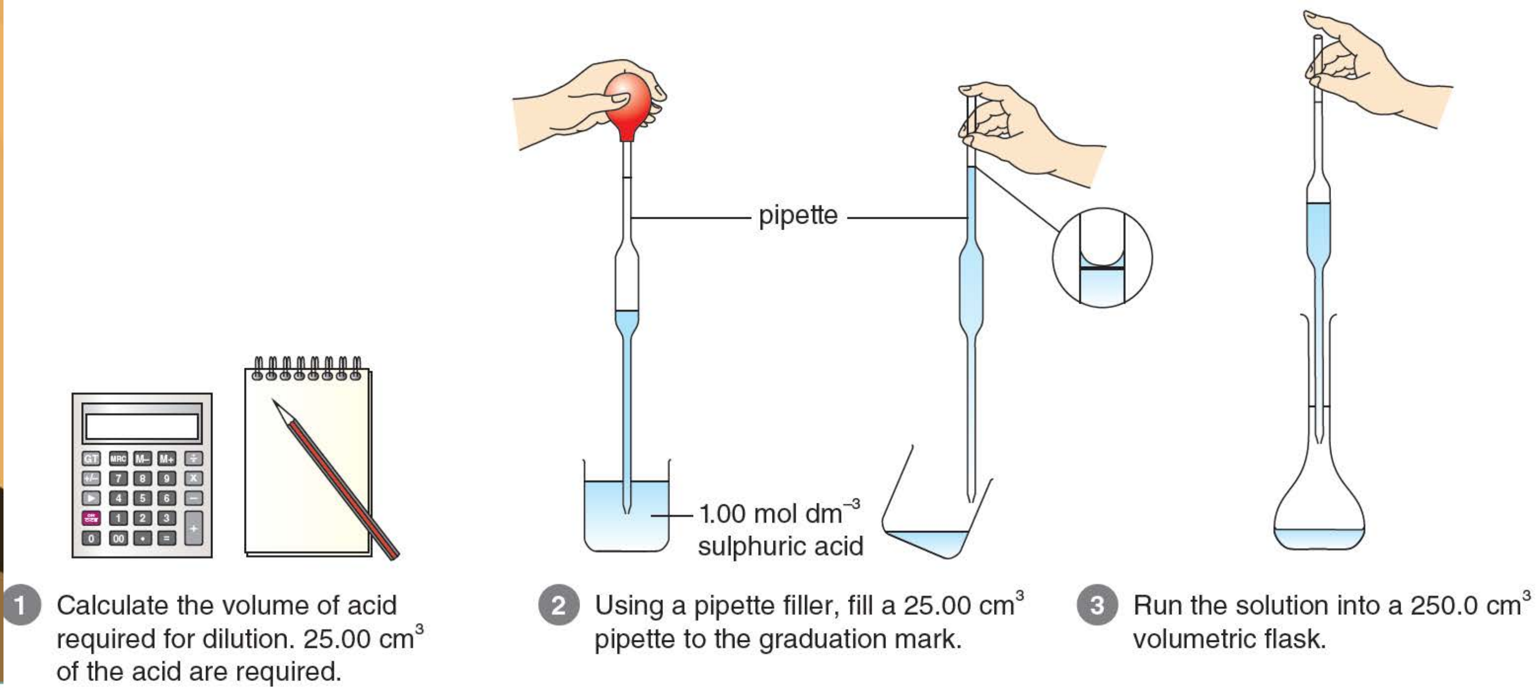
$$= \frac{\text{number of moles of } (COOH)_2{\bullet}2H_2O}{\text{volume of solution}}$$

$$= \frac{0.255 \text{ mol}}{\left(\frac{250.0}{1\ 000}\right) \text{dm}^3}$$

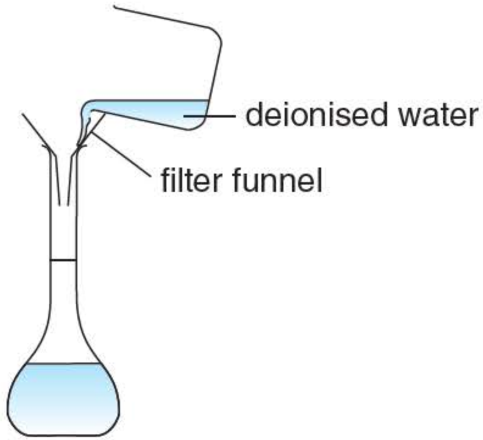
= 1.02 mol dm^{-3}

17.5 Making a standard solution by dilution (p.113)

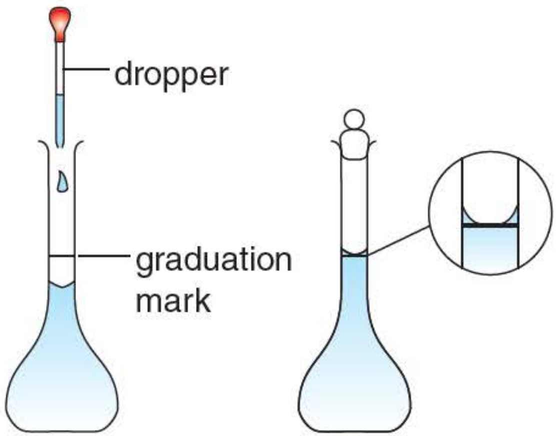
- A standard solution can be prepared by dissolving a solid or by accurate dilution of another standard solution.
- In this example, 1.00 mol dm^{-3} sulphuric acid is diluted to produce 250.0 cm^3 of 0.100 mol dm^{-3} sulphuric acid.



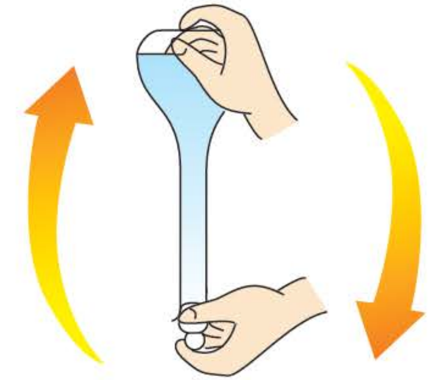
17.5 Making a standard solution by dilution (p.113)



4 Add deionised water to the solution until the level is within about 2 cm of the graduation mark on the neck of the volumetric flask.



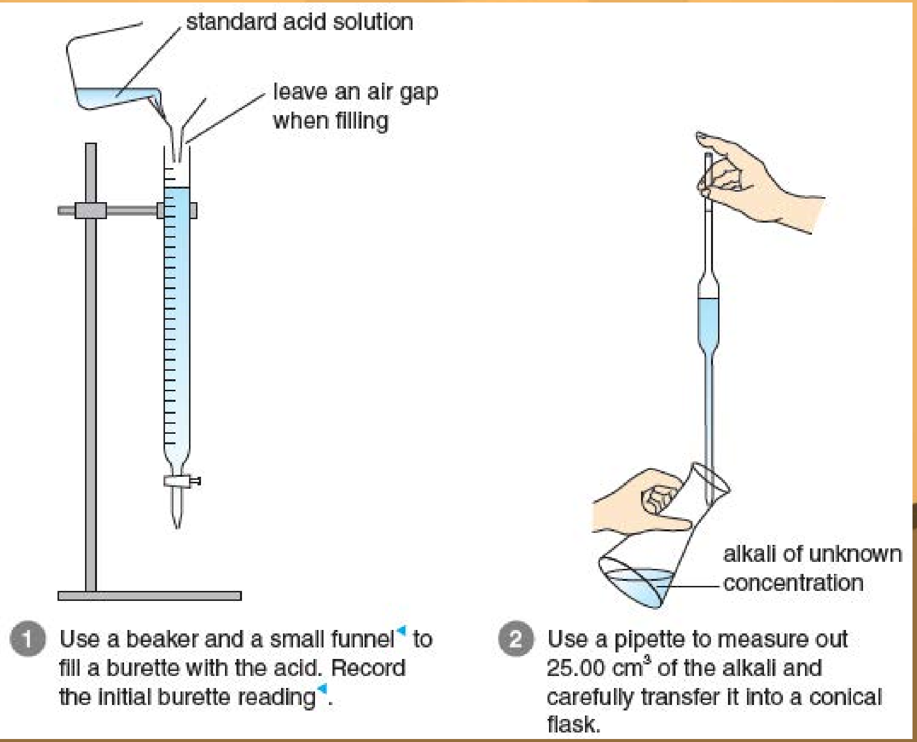
5 Using a dropper to add deionised water so that the bottom of the meniscus is level with the graduation mark on the neck of the flask when looking at it at eye level.



6 Insert the stopper in the flask and invert it, shaking thoroughly to ensure complete mixing.

17.6 Acid-alkali titration: the basic procedure (p.114)

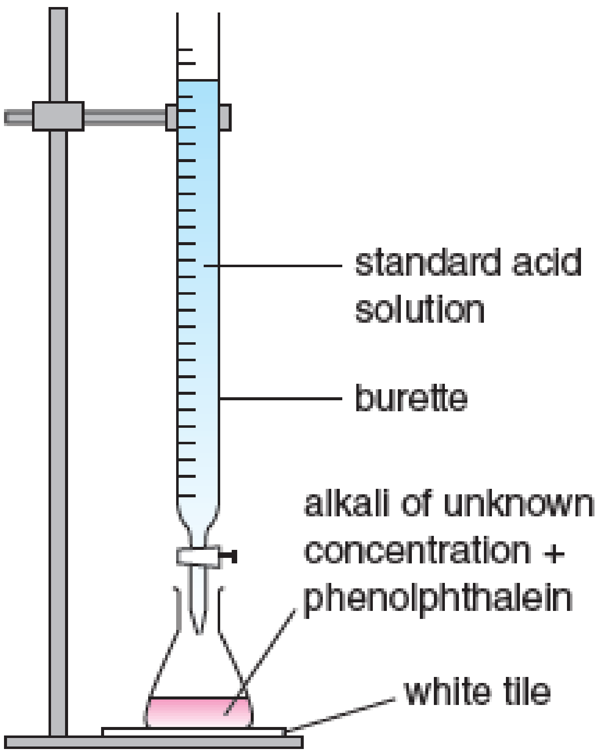
- Acid-alkali titration is used to determine the concentration of an acid or an alkali accurately.
- The procedure described below assumes that you are titrating an acid of known concentration against an alkali of which the concentration is to be determined. Phenolphthalein is used as an indicator.

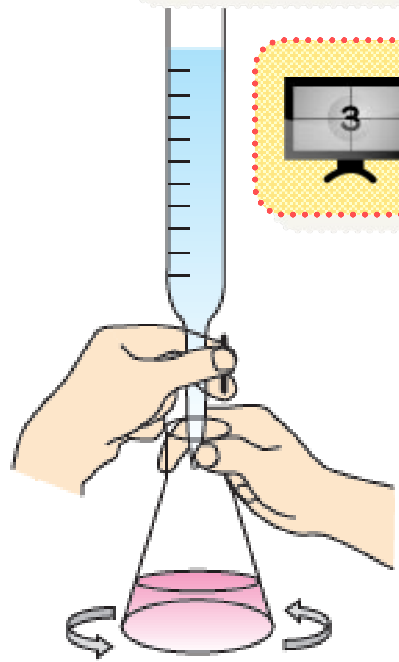


17.6 Acid-alkali titration: the basic procedure (p.114)

Titrating sodium hydroxide solution with ethanedioic acid *Ref.*

Titrating hydrochloric acid with sodium carbonate solution *Ref.*





3 Add a few drops of phenolphthalein to the conical flask. Put the flask on a white tile under the burette.

4 Run the acid from the burette into the alkali until the indicator becomes colourless, showing that the alkali is neutralised. Record the final burette reading.

17.6 Acid-alkali titration: the basic procedure (p.114)

- The **titration end point (滴定終點)** is the point at which the indicator just changes colour.
- The **titre (滴定值)** is the volume delivered from the burette into the conical flask until the titration end point is reached.
- The first titration is usually a rough run, do it quickly so that you can get an idea of what the titre is.
- In later runs, you can quickly add the acid to within a few cm^3 of the rough titre, then add the acid drop by drop.
- Repeat the titration until you obtain three concordant titres (i.e. titres within 0.10 cm^3 of each other).

17.6 Acid-alkali titration: the basic procedure (p.114)

Recording and processing titration results

- A typical table used to record titration results.

Reading (cm^3)	Titration number			
	1 (trial)	2	3	4
Final burette reading				
Initial burette reading				
Titre				

- A burette has graduations up to 0.10 cm^3. Record the readings to two decimal places, ending in 0 if the bottom of the meniscus is on a burette line, or 5 if the meniscus is between two lines.
- When calculating the mean titre, ignore the trial and any result which is not within 0.10 cm^3 of the other accurate titration values. The mean titre must be stated to 2 decimal places.

17.6 Acid-alkali titration: the basic procedure (p.114)

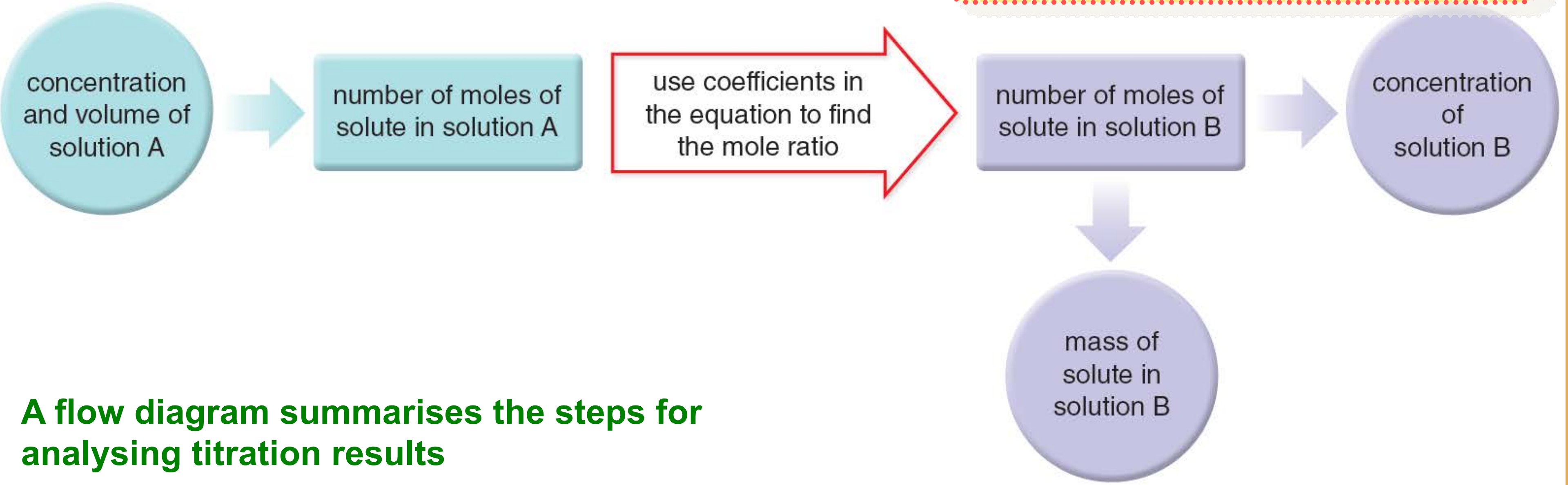
Washing apparatus in volumetric analysis

- For the results of a volumetric analysis to be reliable and accurate, it is essential to wash the apparatus with appropriate liquids.

Wash with \ Apparatus	Pipette	Conical flask	Burette	Volumetric flask
deionised water first	✔	✔	✔	✔
then the solution it is going to contain	✔		✔	

17.7 Titration calculations

Determining the molarity of ethanoic acid in vinegar *Ref.*



A flow diagram summarises the steps for analysing titration results

- Titration results can be used for
  - finding the concentration of a solution (Examples 17.7, 17.8 and 17.11);
  - determining the basicity of an acid (Example 17.9);
  - determining the number of water of crystallisation in a hydrated compound (Example 17.10);
  - finding the percentage purity or molar mass of a substance;
  - identifying an unknown chemical species.

17.7 Titration calculations (p.116)

Q (Example 17.7)

In a titration experiment, portions of 25.00 cm^3 of sodium hydroxide solution were titrated with 0.135 mol dm^{-3} standard ethanedioic acid, $(COOH)_2(aq)$. Phenolphthalein was used as an indicator.

a) State the colour change at the titration end point.

b) The following results were obtained:

Reading (cm^3)	Titration number			
	1 (trial)	2	3	4
Final burette reading	26.00	25.05	26.15	24.05
Initial burette reading	0.00	1.00	2.05	0.00
Titre	26.00	24.05	24.10	24.05

i) Write down the concordant titres.

ii) Use the answer in (i) to calculate the mean titre.

iii) The equation for the reaction between sodium hydroxide solution and ethanedioic acid is:

$$2NaOH(aq) + (COOH)_2(aq) \longrightarrow (COONa)_2(aq) + 2H_2O(l)$$

Calculate the concentration of the sodium hydroxide solution in mol dm^{-3}.

17.7 Titration calculations (p.116)

Q (Example 17.7) (continued)

A

a) From pink to colourless.

b) i) $24.05\ cm^3$, $24.10\ cm^3$, $24.05\ cm^3$

ii) Mean titre $= \frac{24.05 + 24.10 + 24.05}{3}\ cm^3$

$= 24.07\ cm^3$

iii) $2NaOH(aq) + (COOH)_2(aq) \longrightarrow (COONa)_2(aq) + 2H_2O(l)$

? $mol\ dm^{-3}$	0.135 $mol\ dm^{-3}$
25.00 cm^3	24.07 cm^3

Number of moles of $(COOH)_2$ in 24.07 cm^3 solution

= molarity of solution x volume of solution

$= 0.135\ mol\ dm^{-3} \times \frac{24.07}{1\ 000}\ dm^3$

= 0.00325 mol

17.7 Titration calculations (p.116)

Q (Example 17.7) (continued)

A

According to the equation, 2 moles of NaOH require 1 mole of $(COOH)_2$ for complete neutralisation.

i.e. number of moles of NaOH in 25.00 cm^3 solution = 2 x 0.00325 mol
= 0.00650 mol

$$\text{Concentration of sodium hydroxide solution} = \frac{\text{number of moles of NaOH}}{\text{volume of solution}}$$

$$= \frac{0.00650 \text{ mol}}{\left(\frac{25.00}{1\ 000}\right) \text{dm}^3}$$

$$= 0.260 \text{ mol dm}^{-3}$$

∴ the concentration of the sodium hydroxide solution is 0.260 mol dm^{-3}.

17.7 Titration calculations (p.116)

Q (Example 17.8)

In order to determine the concentration of concentrated sulphuric acid, 5.00 cm^3 of the sample were diluted to 1 000.0 cm^3 with deionised water. Portions of 25.00 cm^3 of the diluted sample were titrated with 0.126 mol dm^{-3} NaOH(aq), using methyl orange as an indicator. An average of 26.35 cm^3 of NaOH(aq) was used to reach the end point.

a) State the expected colour change at the end point.
b) Based on the titration result, calculate the number of moles of H_2SO_4 in 25.00 cm^3 of the diluted acid.
c) Calculate the concentration of the concentrated sulphuric acid in mol dm^{-3}.

17.7 Titration calculations (p.116)

Q (Example 17.8) (continued)

A

a) From red to orange.

b) $2NaOH(aq) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$

0.126 mol dm^{-3} ? mol dm^{-3}

26.35 cm^3 25.00 cm^3

Number of moles of NaOH in 26.35 cm^3 solution

= molarity of solution x volume of solution

$= 0.126 \text{ mol dm}^{-3} \times \dfrac{26.35}{1\ 000} \text{ dm}^3$

$= 3.32 \times 10^{-3}$ mol

Notice the colour changes for methyl orange in the titration:

not enough alkali	just right	too much alkali

You will learn about this later in this unit.

According to the equation, 1 mole of H_2SO_4 requires 2 moles of NaOH for complete neutralisation.

i.e. number of moles of H_2SO_4 in 25.00 cm^3 diluted acid $= \dfrac{3.32 \times 10^{-3}}{2}$ mol

$= 1.66 \times 10^{-3}$ mol

17.7 Titration calculations (p.116)

Q (Example 17.8) (continued)

A

c) Number of moles of H_2SO_4 in 1 000.0 cm^3 diluted acid

= number of moles of H_2SO_4 in 5.00 cm^3 concentrated acid

$$= 1.66 \times 10^{-3} \times \frac{1\ 000.0}{25.00} \text{ mol}$$

= 0.0664 mol

$$\text{Molarity of concentrated sulphuric acid} = \frac{\text{number of moles of } H_2SO_4}{\text{volume of solution}}$$

$$= \frac{0.0664 \text{ mol}}{\left(\frac{5.00}{1\ 000}\right) \text{dm}^3}$$

$$= 13.3 \text{ mol dm}^{-3}$$

∴ the concentration of the concentrated sulphuric acid is 13.3 mol dm^{-3}.

17.7 Titration calculations (p.116)

Practice 17.3

A glass cleanser contains ammonia. The concentration of ammonia in the cleanser can be found by a titration using dilute hydrochloric acid. For this purpose, 25.00 cm^3 of the cleanser were diluted to 250.0 cm^3.

a) State the name of the apparatus used to

i) measure out exactly 25.00 cm^3 of the cleanser;
25.00 cm^3 pipette

ii) contain exactly 250.0 cm^3 of the diluted cleanser.
250.0 cm^3 volumetric flask

17.7 Titration calculations (p.116)

Practice 17.3 (continued)

b) Portions of 25.00 cm^3 of the diluted cleanser were titrated with 0.206 mol dm^{-3} HCl(aq) added from a burette, using methyl orange as an indicator. The following results were obtained.

Reading (cm^3)	Titration number			
	1 (trial)	2	3	4
Final burette reading	37.15	35.85	36.85	35.80
Initial burette reading	0.00	0.05	1.00	0.00
Titre	37.15	35.80	35.85	35.80

i) Outline the procedure for cleaning the burette before titration.
ii) Suggest why a trial (a rough titration) was carried out.
iii) Calculate the mean titre.
iv) Write the chemical equation for the reaction between ammonia and dilute hydrochloric acid.
v) Calculate the concentration of ammonia in the original cleanser in mol dm^{-3}.

17.7 Titration calculations (p.116)

Practice 17.3 (continued)

b) i) Wash with deionised water, and then with 0.206 mol dm^{-3} HCl(aq).

ii) Any one of the following:

- So that in accurate titration, a certain volume of HCl(aq) could be added quickly before adding drop by drop.
- To save time before doing accurate titrations.
- To give a rough idea of what the titre is.

iii) Mean titre

$$= \frac{35.80 + 35.85 + 35.80}{3} \text{ cm}^3$$

$$= 35.82 \text{ cm}^3$$

iv) $NH_3(aq) + HCl(aq) \longrightarrow NH_4Cl(aq)$

17.7 Titration calculations (p.116)

Practice 17.3 (continued)

b) v)

$$NH_3(aq) + HCl(aq) \longrightarrow NH_4Cl(aq)$$

NH_3: 25.00 cm^3 → 250.0 cm^3 → (used) 25.00 cm^3

HCl: 0.206 mol dm^{-3}, 35.82 cm^3

Number of moles of HCl in 35.82 cm^3 solution = molarity of solution x volume of solution

$= 0.206 \text{ mol dm}^{-3} \times \frac{35.82}{1\ 000} \text{ dm}^3$

$= 7.38 \times 10^{-3}$ mol

According to the equation, 1 mole of NH_3 requires 1 mole of HCl for complete neutralisation.

i.e. number of moles of NH_3 in 25.00 cm^3 diluted cleanser = 7.38×10^{-3} mol

Number of moles of NH_3 in 250.0 cm^3 diluted cleanser

$= 10 \times 7.38 \times 10^{-3}$ mol

$= 7.38 \times 10^{-2}$ mol

= number of moles of NH_3 in original cleanser

Concentration of NH_3 in original cleanser $= \frac{\text{number of moles of } NH_3}{\text{volume of cleanser}}$

$= \frac{7.38 \times 10^{-2} \text{ mol}}{\frac{25.00}{1\ 000} \text{ dm}^3}$

$= 2.95 \text{ mol dm}^{-3}$

∴ the concentration of ammonia in the original cleanser is 2.95 mol dm^{-3}.

17.7 Titration calculations (p.116)

Q (Example 17.9)

2.42 g of citric acid were dissolved in deionised water and diluted to 250.0 cm^3. After that, portions of 25.00 cm^3 of the diluted solution were withdrawn and titrated with 0.148 mol dm^{-3} NaOH(aq), using phenolphthalein as an indicator. An average of 25.55 cm^3 of the NaOH(aq) was required to reach the end point. What is the basicity of citric acid?

(Molar mass of citric acid = 192.0 g mol^{-1}.)

17.7 Titration calculations (p.116)

Q (Example 17.9) (continued)

A

Let n be the basicity of citric acid. The acid can be represented by H_nX. It reacts with NaOH(aq) according to the equation below.

$$H_nX(aq) + nNaOH(aq) \longrightarrow Na_nX(aq) + nH_2O(l)$$

H_nX: 2.42 g → 250.0 cm^3 → (used) 25.00 cm^3

NaOH: 0.148 mol dm^{-3}, 25.55 cm^3

Number of moles of NaOH used to react with 25.00 cm^3 acid

= molarity of solution x volume of solution

$$= 0.148 \text{ mol dm}^{-3} \times \frac{25.55}{1\ 000} \text{ dm}^3$$

= 3.78×10^{-3} mol

17.7 Titration calculations (p.116)

Q (Example 17.9) (continued)

A

Number of moles of citric acid in 250.0 cm^3 solution $= \dfrac{\text{mass}}{\text{molar mass}}$

$= \dfrac{2.42\ g}{192.0\ g\ mol^{-1}}$

$= 0.0126$ mol

Number of moles of citric acid in 25.00 cm^3 solution $= \dfrac{0.0126}{10}$ mol

$= 1.26 \times 10^{-3}$ mol

$$n = \frac{\text{Number of moles of NaOH}}{\text{Number of moles of citric acid}} = \frac{3.78 \times 10^{-3}\ mol}{1.26 \times 10^{-3}\ mol}$$

$n = 3$

$\therefore$ the basicity of citric acid is 3.

17.7 Titration calculations (p.116)

Q (Example 17.10)

A sample of borax ($Na_2B_4O_7 \cdot nH_2O$) of mass 3.40 g was dissolved in deionised water to make a solution of volume 100.0 cm^3. Portions of 25.00 cm^3 of borax solution were titrated with 0.148 mol dm^{-3} HCl(aq), using methyl orange as an indicator. An average of 30.15 cm^3 of HCl(aq) was used to reach the end point.

Borax reacts with hydrochloric acid according to the chemical equation below.

$$Na_2B_4O_7 + 2HCl(aq) + 5H_2O(l) \longrightarrow 2NaCl(aq) + 4H_3BO_3(aq)$$

Calculate the value of *n*.

(Relative atomic masses: H = 1.0, B = 10.8, O = 16.0, Na = 23.0)

17.7 Titration calculations (p.116)

Q (Example 17.10) (continued)

A

$$Na_2B_4O_7(aq) + 2HCl(aq) + 5H_2O(l) \longrightarrow 2NaCl(aq) + 4H_3BO_3(aq)$$

$Na_2B_4O_7$: 3.40 g → 100.0 cm^3 → (used) 25.00 cm^3

HCl: 0.148 mol dm^{-3}, 30.15 cm^3

Number of moles of HCl in 30.15 cm^3 solution = molarity of solution x volume of solution

$$= 0.148 \text{ mol dm}^{-3} \times \frac{30.15}{1\ 000} \text{ dm}^3$$

$$= 4.46 \times 10^{-3} \text{ mol}$$

According to the equation, 1 mole of $Na_2B_4O_7$ requires 2 moles of HCl for complete reaction.

i.e. number of moles of $Na_2B_4O_7$ in 25.00 cm^3 solution $= \frac{4.46 \times 10^{-3}}{2}$ mol

$$= 2.23 \times 10^{-3} \text{ mol}$$

17.7 Titration calculations (p.116)

Q (Example 17.10) (continued)

A

Number of moles of $Na_2B_4O_7$ in 100.0 cm^3 solution

$= 2.23 \times 10^{-3} \times \frac{100.0}{25.00}$ mol

$= 8.92 \times 10^{-3}$ mol

= number of moles of $Na_2B_4O_7$ in 3.40 g sample

Molar mass of $Na_2B_4O_7 \bullet nH_2O = (2 \times 23.0 + 4 \times 10.8 + 7 \times 16.0 + n(2 \times 1.0 + 16.0))$ g mol^{-1}

$= (201.2 + 18n)$ g mol^{-1}

Number of moles of $Na_2B_4O_7 \bullet nH_2O$ in 3.40 g sample $= \frac{3.40 \text{ g}}{(201.2 + 18n) \text{ g mol}^{-1}}$

$$\frac{3.40 \text{ g}}{(201.2 + 18n) \text{ g mol}^{-1}} = 8.92 \times 10^{-3} \text{ mol}$$

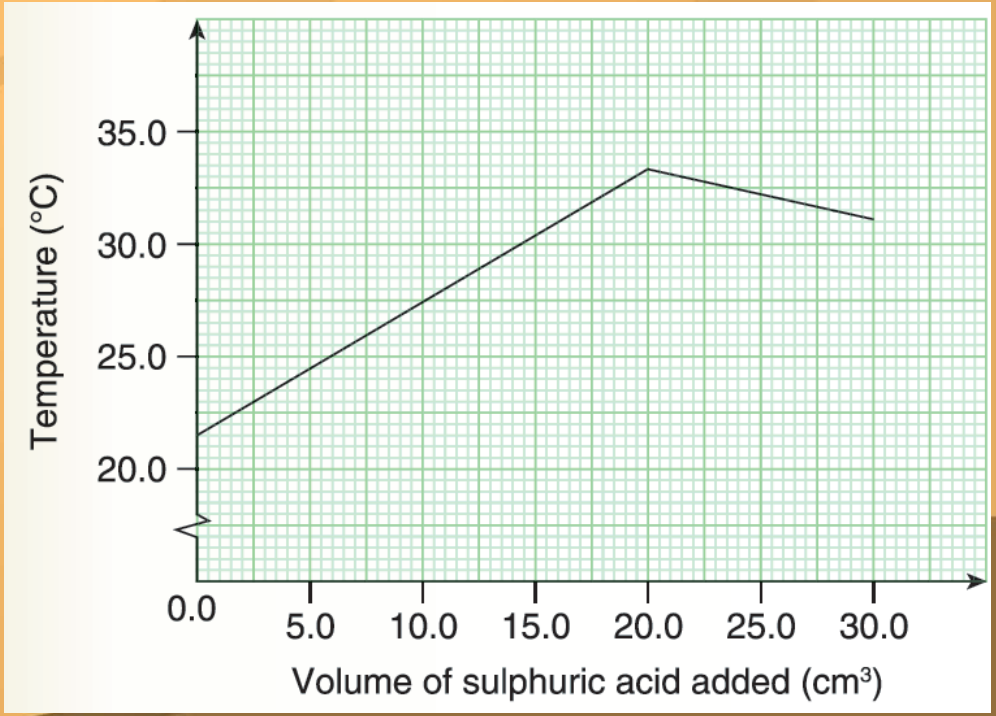
$$n = 10$$

$\therefore$ the value of n is 10.

17.7 Titration calculations (p.116)

Q (Example 17.11)

In an experiment, 25.00 cm^3 of sodium hydroxide solution were transferred to an expanded polystyrene cup. 1.00 mol dm^{-3} sulphuric acid was then added to the solution from a burette, and the temperature of the solution mixture was measured with a temperature sensor connected to a datalogger. The graph shows the experimental results:



a) Write the ionic equation for the reaction involved.
b) With reference to the above graph, explain the temperature change of the solution mixture throughout the experiment.
c) Calculate the molarity of the sodium hydroxide solution used.

17.7 Titration calculations (p.116)

Q (Example 17.11) (continued)

A

a) $H^+(aq) + OH^-(aq) \longrightarrow H_2O(l)$

b) Neutralisation is exothermic. Temperature of the solution mixture rose when sulphuric acid was added to the sodium hydroxide solution.

When the sodium hydroxide was just completely reacted, the temperature reached a maximum value. No more heat was produced.

After that, the addition of excess cold sulphuric acid lowered the temperature of the solution mixture.

17.7 Titration calculations (p.116)

Q (Example 17.11) (continued)

A

c) $H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$

1.00 mol dm^{-3} ? mol dm^{-3}

20.0 cm^3 25.00 cm^3

Number of moles of H_2SO_4 in 20.0 cm^3 solution = molarity of solution x volume of solution

$$= 1.00 \text{ mol dm}^{-3} \times \frac{20.0}{1\ 000} \text{ dm}^3$$

$$= 0.0200 \text{ mol}$$

According to the equation, 2 moles of NaOH require 1 mole of H_2SO_4 for complete neutralisation.

i.e. number of moles of NaOH in 25.00 cm^3 solution = 2 x 0.0200 mol
= 0.0400 mol

$$\text{Molarity of sodium hydroxide solution} = \frac{\text{number of moles of NaOH}}{\text{volume of solution}}$$

$$= \frac{0.0400 \text{ mol}}{\left(\frac{25.00}{1\ 000}\right) \text{dm}^3}$$

$$= 1.60 \text{ mol dm}^{-3}$$

∴ the molarity of the sodium hydroxide solution is 1.60 mol dm^{-3}.

17.7 Titration calculations (p.116)

Practice 17.4

1 Tartaric acid ($C_4H_6O_6$) is a dibasic acid found in many plants. A solid sample contained tartaric acid and other soluble inert substances. 2.00 g of the sample were dissolved in deionised water and diluted to 250.0 cm^3. Portions of 25.00 cm^3 of this solution were titrated with 0.122 mol dm^{-3} NaOH(aq), using phenolphthalein as an indicator. An average of 19.35 cm^3 of NaOH(aq) was used to reach the end point.

(Molar mass of tartaric acid = 150.0 g mol^{-1})

a) Name the piece of apparatus that could be used to add NaOH(aq) to the acid solution during the titration.

b) State the expected colour change at the end point.

c) Calculate the percentage by mass of tartaric acid in the solid sample.

17.7 Titration calculations (p.116)

Practice 17.3 (continued)

1 a) Burette

b) From colourless to pale pink / just pink

c) Tartaric acid is a dibasic acid. 1 mole of the acid requires 2 moles of NaOH for complete neutralisation.

$$C_4H_6O_6(aq) + 2NaOH(aq) \longrightarrow Na_2C_4H_4O_6(aq) + 2H_2O(l)$$

$C_4H_6O_6$: 2.00 g → 250.0 cm^3 → (used) 25.00 cm^3

NaOH: 0.122 mol dm^{-3}, 19.35 cm^3

Number of moles of NaOH in 19.35 cm^3 solution = molarity of solution x volume of solution

$$= 0.122 \text{ mol dm}^{-3} \times \frac{19.35}{1\ 000} \text{ dm}^3$$

$$= 2.36 \times 10^{-3} \text{ mol}$$

According to the equation, 1 mole of $C_4H_6O_6$ requires 2 moles of NaOH for complete neutralisation.

i.e. number of moles of $C_4H_6O_6$ in 25.00 cm^3 solution $= \frac{2.36 \times 10^{-3}}{2}$ mol

$$= 1.18 \times 10^{-3} \text{ mol}$$

Number of moles of $C_4H_6O_6$ in 250.0 cm^3 solution $= 10 \times 1.18 \times 10^{-3}$ mol

$$= 1.18 \times 10^{-2} \text{ mol}$$

Molar mass of $C_4H_6O_6$ = (4 x 12.0 + 6 x 1.0 + 6 x 16.0) g mol^{-1}

$$= 150.0 \text{ g mol}^{-1}$$

Mass of $C_4H_6O_6$ in 2.00 g of sample = number of moles x molar mass

$$= 1.18 \times 10^{-2} \text{ mol} \times 150.0 \text{ g mol}^{-1}$$

$$= 1.77 \text{ g}$$

Percentage by mass of $C_4H_6O_6$ in sample $= \frac{1.77 \text{ g}}{2.00 \text{ g}} \times 100\%$

$$= 88.5\%$$

∴ the percentage by mass of tartaric acid in the sample is 88.5%.

17.7 Titration calculations (p.116)

Practice 17.4 (continued)

2 A student performed the following experiment to identify metal X. The chemical formula of its hydrated hydroxide is $X(OH)_2 \cdot 8H_2O$. The hydroxide is soluble in water.

18.76 g of the hydroxide were dissolved in deionised water. Deionised water was added to make the solution up to exactly 250.0 cm^3 in a volumetric flask. Portions of 25.00 cm^3 of the solution were titrated with 0.350 mol dm^{-3} hydrochloric acid, using methyl orange as an indicator. An average of 34.00 cm^3 of the acid was required to reach the end point.

a) Calculate the number of moles of HCl required to react with 25.00 cm^3 of the hydroxide solution.

b) Calculate the molar mass of $X(OH)_2 \cdot 8H_2O$.

c) Identify metal X. (Refer to the Periodic Table.)

(Relative atomic masses: H = 1.0, O = 16.0)

17.7 Titration calculations (p.116)

Practice 17.4 (continued)

2

a) Number of moles of HCl required to react with 25.00 cm^3 of hydroxide solution
= molarity of solution x volume of solution

$$= 0.350 \text{ mol dm}^{-3} \times \frac{34.00}{1\ 000} \text{ dm}^3$$

= 0.0119 mol

b) $X(OH)_2(aq) + 2HCl(aq) \longrightarrow XCl_2(aq) + 2H_2O(l)$

$X(OH)_2$: 18.76 g → 250.0 cm^3 → (used) 25.00 cm^3

HCl: 0.350 mol dm^{-3}, 34.00 cm^3

According to the equation, 1 mole of $X(OH)_2$ requires 2 moles of HCl for complete neutralisation.

i.e. number of moles of $X(OH)_2$ in 25.00 cm^3 solution $= \frac{0.0119}{2}$ mol
$= 5.95 \times 10^{-3}$ mol

Number of moles of $X(OH)_2$ in 250.0 cm^3 solution $= 10 \times 5.95 \times 10^{-3}$ mol
= 0.0595 mol
= number of moles of $X(OH)_2$ in 18.76 g of hydroxide

Number of moles of $X(OH)_2$ in 18.76 g of hydroxide = 0.0595 mol

$$= \frac{18.76 \text{ g}}{\text{molar mass of } X(OH)_2 \bullet 8H_2O}$$

Molar mass of $X(OH)_2 \bullet 8H_2O = \frac{18.76 \text{ g}}{0.0595 \text{ mol}}$
$= 315.3 \text{ g mol}^{-1}$

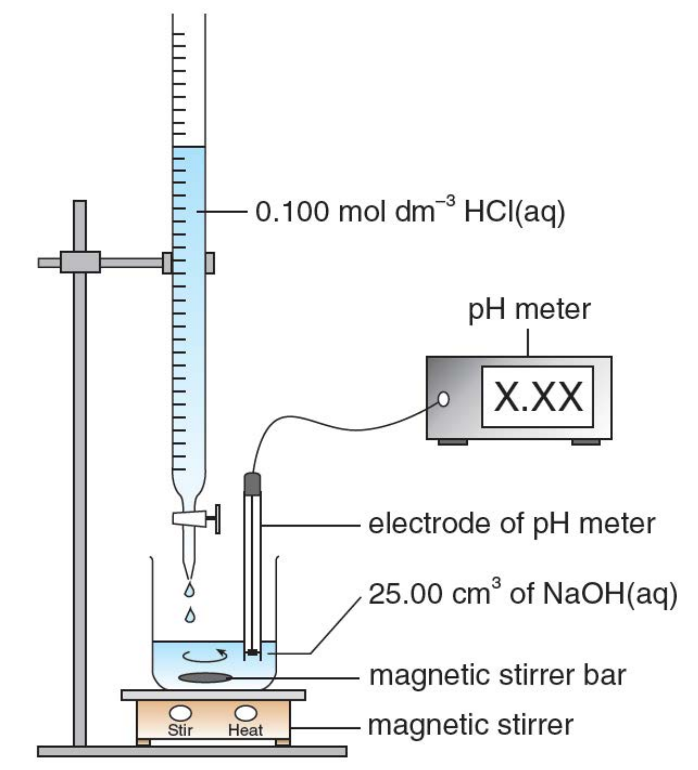
c) Let *m* be the relative atomic mass of X.

Molar mass of $X(OH)_2 \bullet 8H_2O = (m + 2 \times 16.0 + 2 \times 1.0 + 8 \times 18.0) \text{ g mol}^{-1}$
$= 315.3 \text{ g mol}^{-1}$
$\therefore m = 137.3 \text{ g mol}^{-1}$

∴ X is barium.

17.8 Changes in pH during a titration (p.125)

- As 0.100 mol dm^{-3} hydrochloric acid is added to 25.00 cm^3 of 0.100 mol dm^{-3} sodium hydroxide solution, the pH of the solution mixture changes. The changes in pH can be measured by using a pH meter or a pH sensor connected to a datalogger.

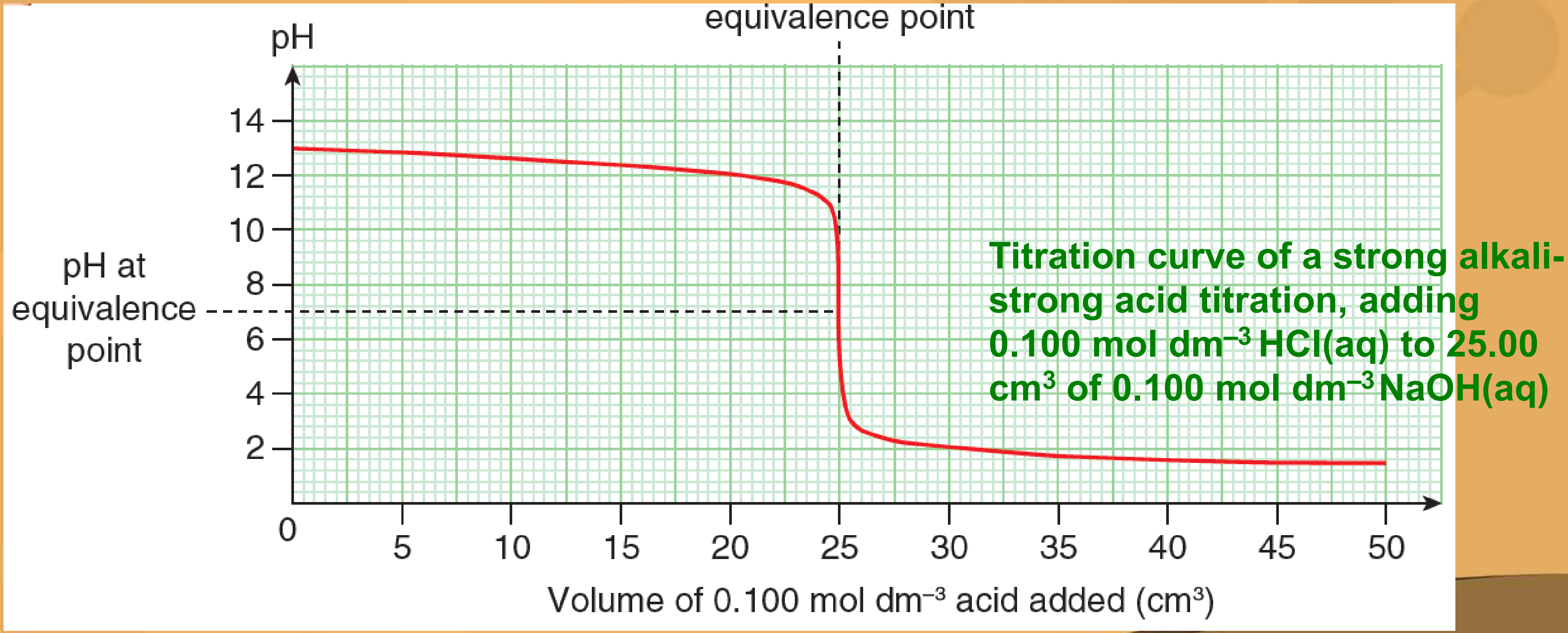


Experimental set-up for measuring the pH change during a titration by using a pH meter

Following the pH change of the reacting mixture of an acid-alkali titration *Ref.*

17.8 Changes in pH during a titration (p.125)

- The figure below shows the changes in pH of the solution mixture as the acid is added. This is a **titration curve (滴定曲線)**.



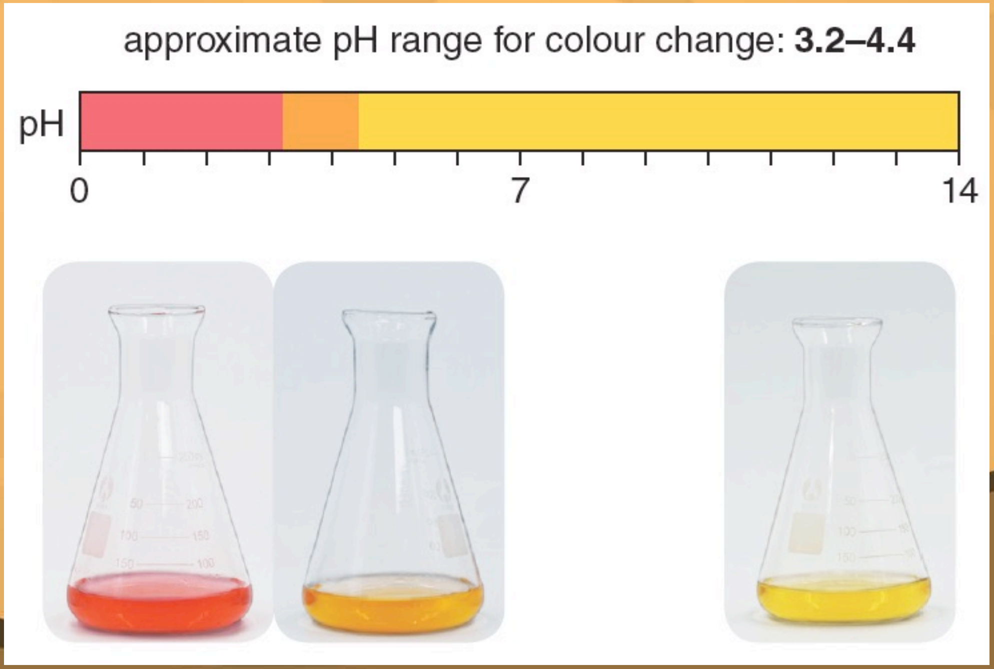
Titration curve *Ref.*

17.8 Changes in pH during a titration (p.125)

- Initially, when a small volume of acid is added to the alkali, the decrease in pH is very small.
- In a titration, the **equivalence point (當量點)** is the point at which sufficient acid has been added to just neutralise the alkali (or vice versa).
- There is a large and rapid change of pH at the equivalence point (when 25.0 cm^3 of HCl(aq) have been added). The pH at the equivalence point is 7.00.
- As further acid is added, there is a small additional decrease in pH.

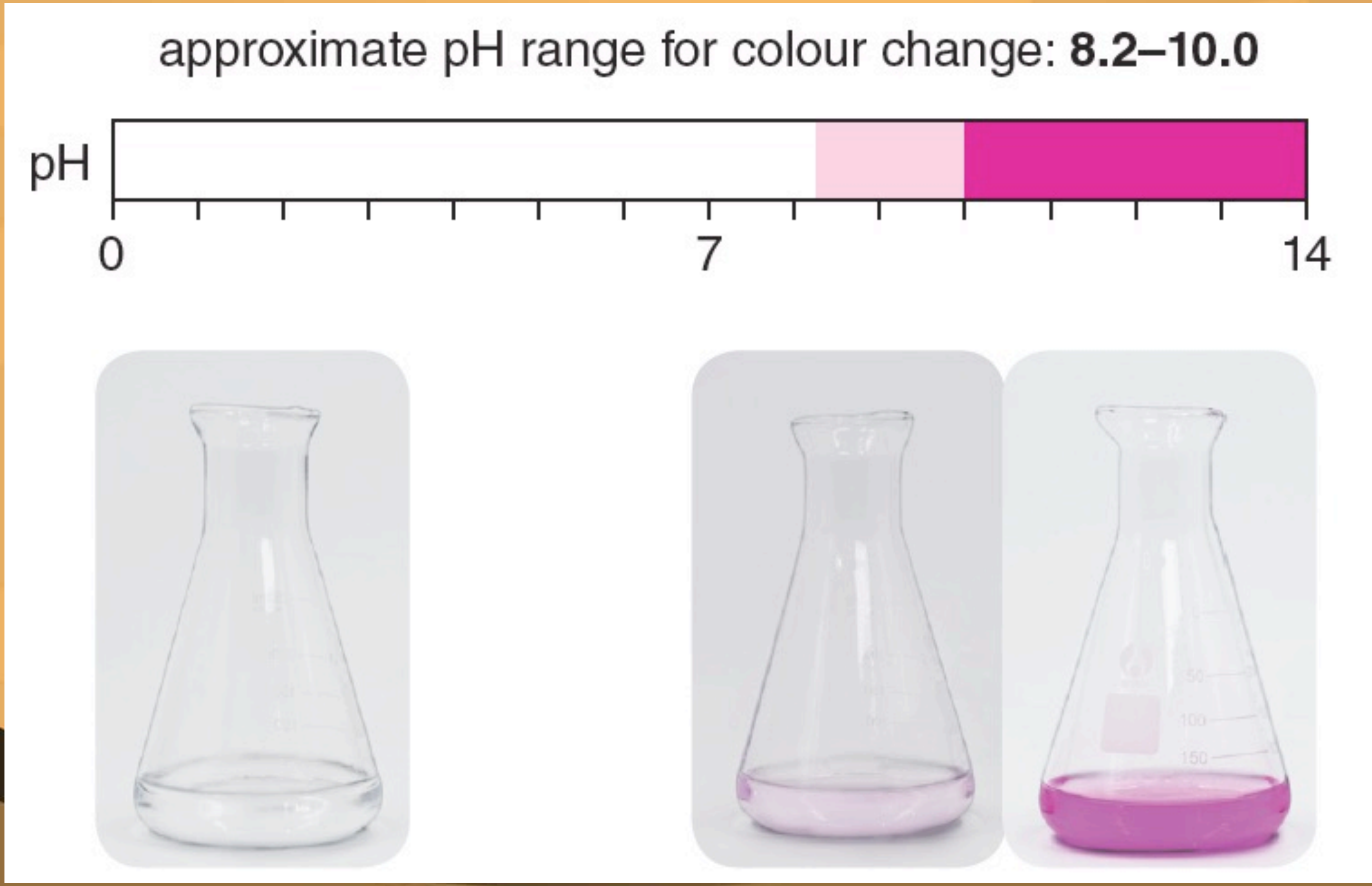
17.9 Acid-alkali indicators (p.126)

- An acid-alkali indicator is a dye or mixture of dyes that changes colour over a specific pH range.
- Indicators usually change colour over a range between 1 and 2 pH units. For example, methyl orange is red in solution with pH less than 3.2 and yellow in solution with pH greater than 4.4. The colour change takes place between pH 3.2–4.4.



17.9 Acid-alkali indicators (p.126)

- Phenolphthalein is colourless in solution with pH less than 8.2 and pink in solution with pH greater than 10.0. The colour change takes place between pH 8.2–10.0.



17.10 Choice of indicators for acid-alkali titrations (p.127)

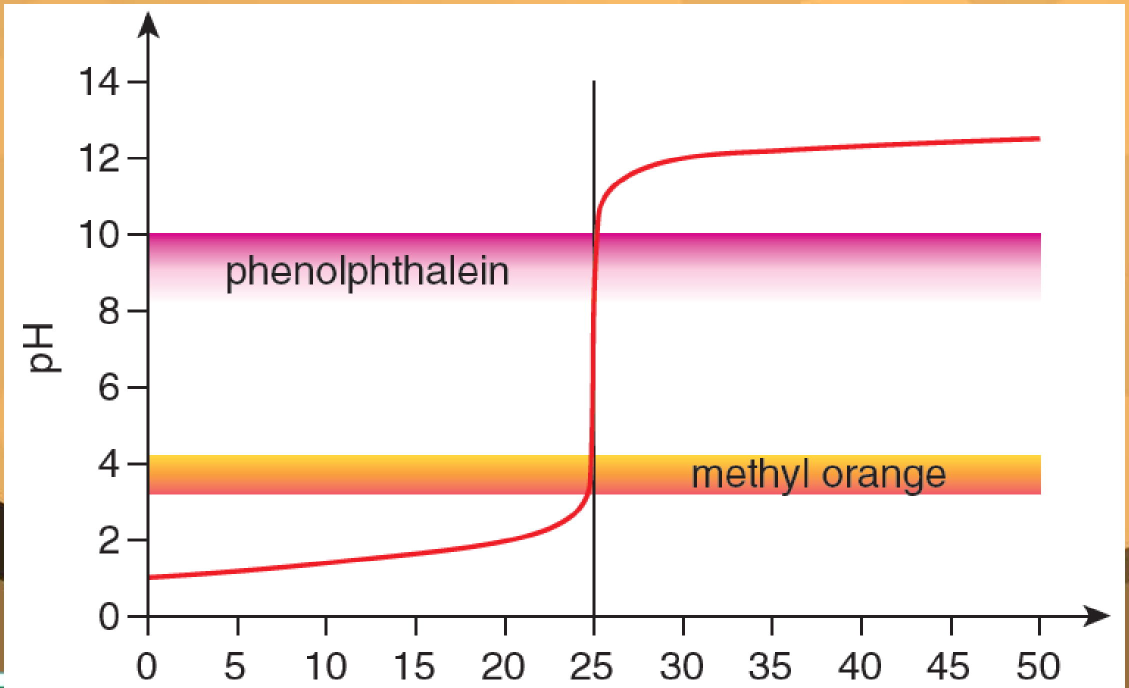
- A suitable indicator for a particular titration needs the following properties:
  - The colour change must be sharp at the end point, that is, no more than one drop of acid (or alkali) is needed to give a complete colour change.
  - The end point of the titration given by the indicator must be the same as the equivalence point, otherwise the titration will give a wrong result.
  - The indicator should give a distinct colour change. For example, the colour change of phenolphthalein from colourless to pink is easier to see than the colour change of methyl orange from red to orange.
- For an indicator to work, the range over which it changes colour must lie within the pH range of the vertical part of the titration curve.

17.10 Choice of indicators for acid-alkali titrations (p.127)

A strong acid-strong alkali titration curve *Ref.*

Strong acid-strong alkali titration

- The pH ranges over which the two indicators change colour are shown. Both indicators change colour within the pH range of the vertical part of the titration curve. Hence both are suitable indicators for the titration.

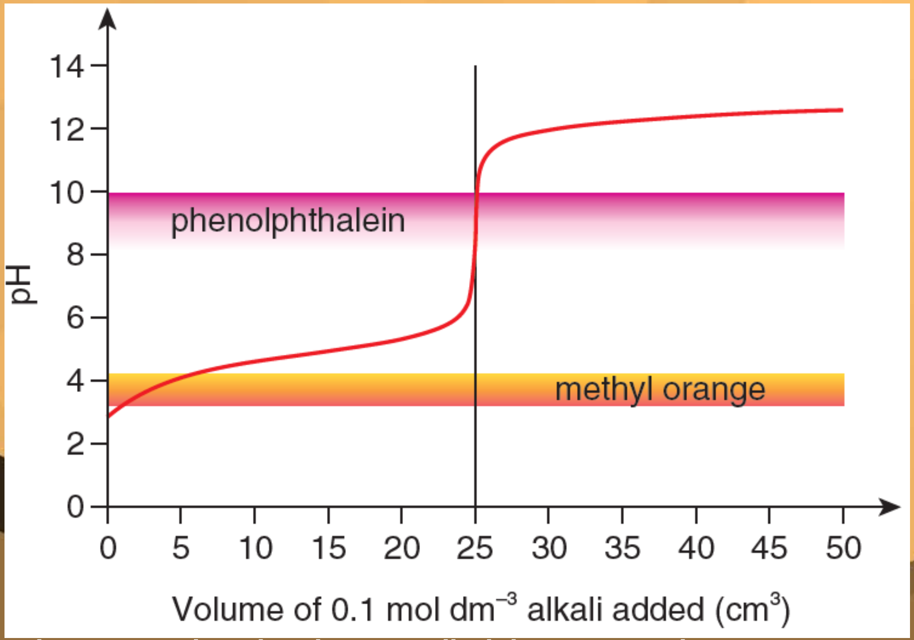


Titration curve of a strong acid-strong alkali titration, adding 0.1 mol dm^{-3} NaOH(aq) to 25.00 cm^{3} of 0.1 mol dm^{-3} HCl(aq)

17.10 Choice of indicators for acid-alkali titrations (p.127)

Weak acid-strong alkali titration

- Phenolphthalein changes colour within the pH range of the vertical part of the titration curve. Hence it is a suitable indicator for the titration.
- Methyl orange is not suitable as it does not change colour within the pH range of the vertical part of the titration curve.

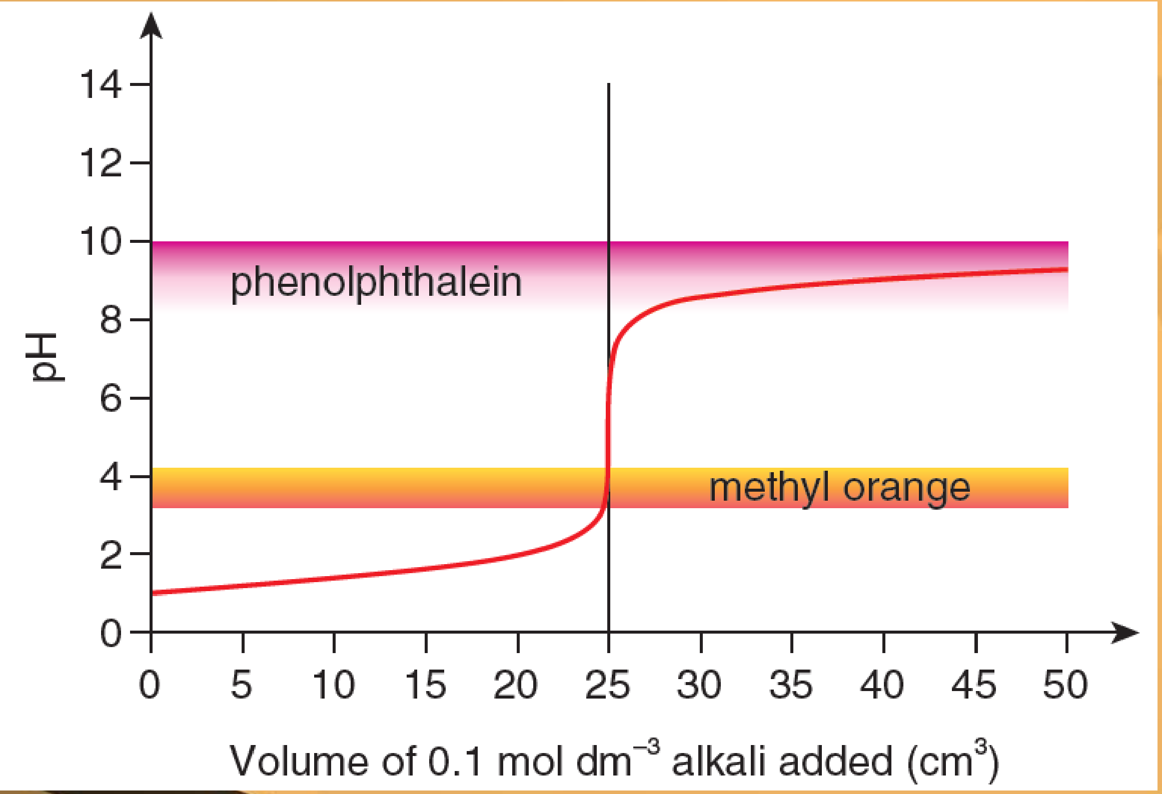


Titration curve of a weak acid-strong alkali titration, adding 0.1 mol dm^{-3} NaOH(aq) to 25.00 cm^3 of 0.1 mol dm^{-3} CH_3COOH(aq)

17.10 Choice of indicators for acid-alkali titrations (p.127)

Strong acid-weak alkali titration

- Methyl orange is a suitable indicator for the titration.

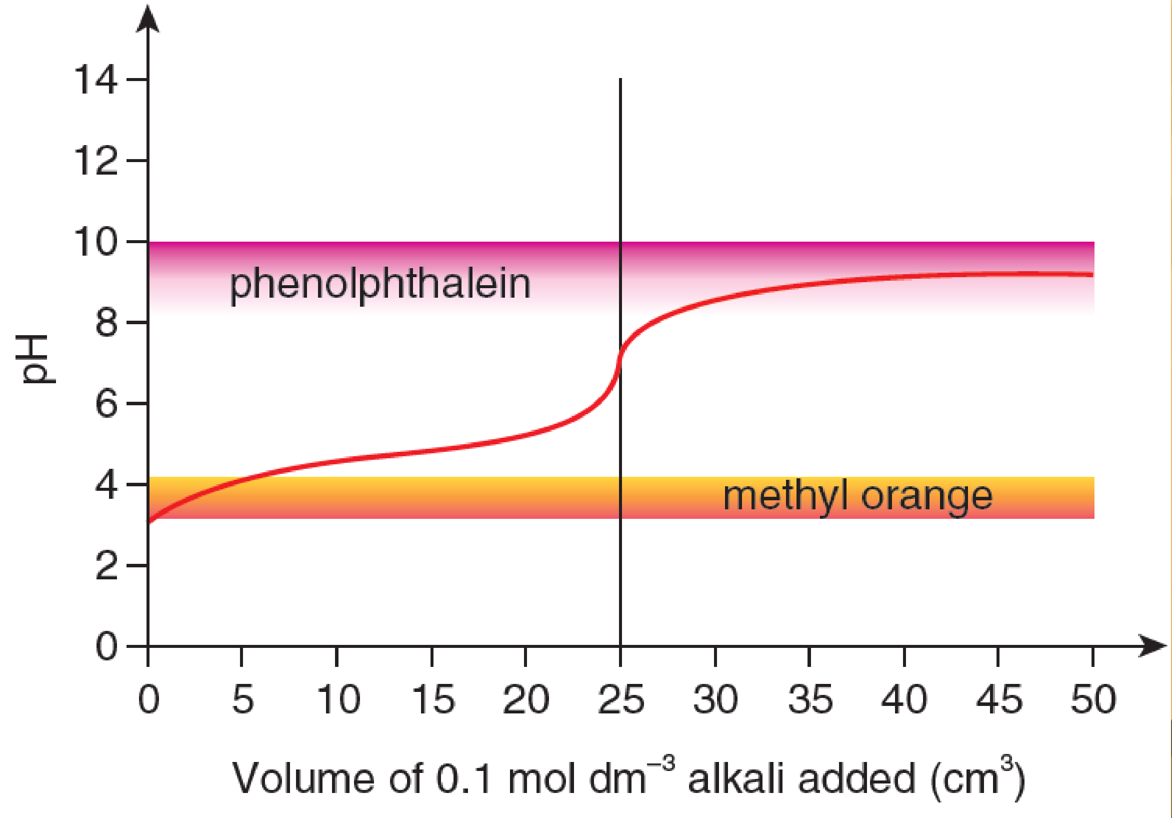


Titration curve of a strong acid-weak alkali titration, adding 0.1 mol dm^{-3} NH_3(aq) to 25.00 cm^3 of 0.1 mol dm^{-3} HCl(aq)

17.10 Choice of indicators for acid-alkali titrations (p.127)

Weak acid-weak alkali titration

- There is no sudden change in pH. Hence no indicator is suitable.



Titration curve of a weak acid-weak alkali titration, adding 0.1 mol dm^{-3} NH_3(aq) to 25.00 cm^3 of 0.1 mol dm^{-3} CH_3COOH(aq)

17.10 Choice of indicators for acid-alkali titrations (p.127)

- The suitable indicators for different types of acid-alkali titration.

Acid	Alkali	Indicator
strong	strong	methyl orange or phenolphthalein
weak	strong	phenolphthalein
strong	weak	methyl orange
weak	weak	none

17.10 Choice of indicators for acid-alkali titrations (p.127)

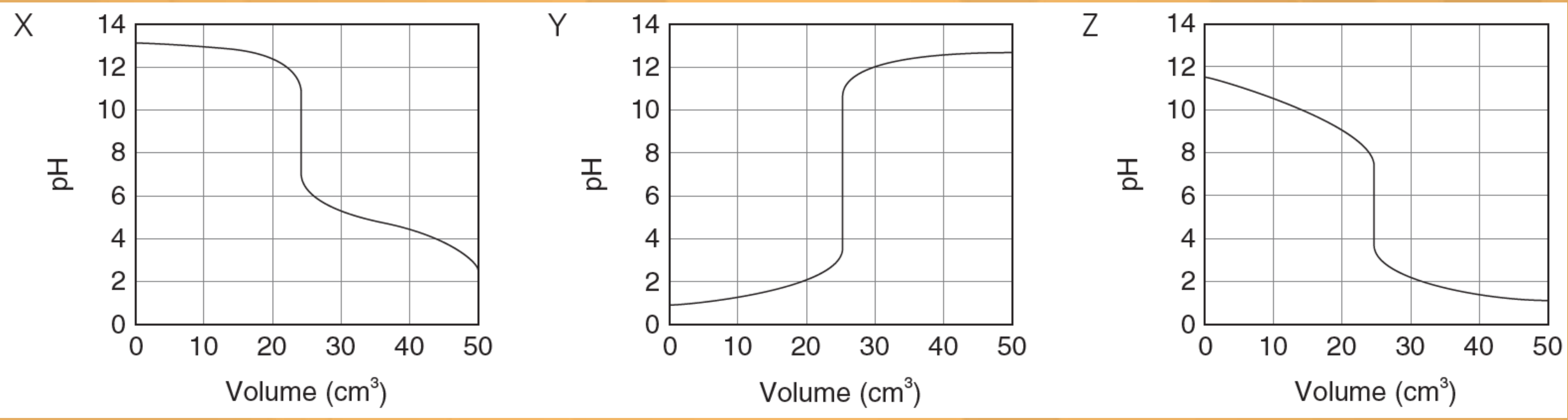
- The colour changes of methyl orange and phenolphthalein at titration end point under different situations.

Titration	Indicator used	Colour change at titration end point
Adding an acid from a burette into an alkali in a conical flask	methyl orange	yellow to first tinge of orange
	phenolphthalein	pink to just colourless
Adding an alkali from a burette into an acid in a conical flask	methyl orange	red to first tinge of orange
	phenolphthalein	colourless to just pink

17.10 Choice of indicators for acid-alkali titrations (p.127)

Practice 17.5

Titration curves labelled X, Y and Z for combinations of different acids and alkalis are shown below. All solutions have a concentration of 0.1 mol dm^{-3}.



a) From the curves, choose the curve produced by the addition of

i) hydrochloric acid to 25.00 cm^3 of aqueous ammonia; Z

ii) sodium hydroxide solution to 25.00 cm^3 of hydrochloric acid. Y

17.10 Choice of indicators for acid-alkali titrations (p.127)

Practice 17.5 (continued)

b) The table below lists the pH ranges over which three indicators change colour.

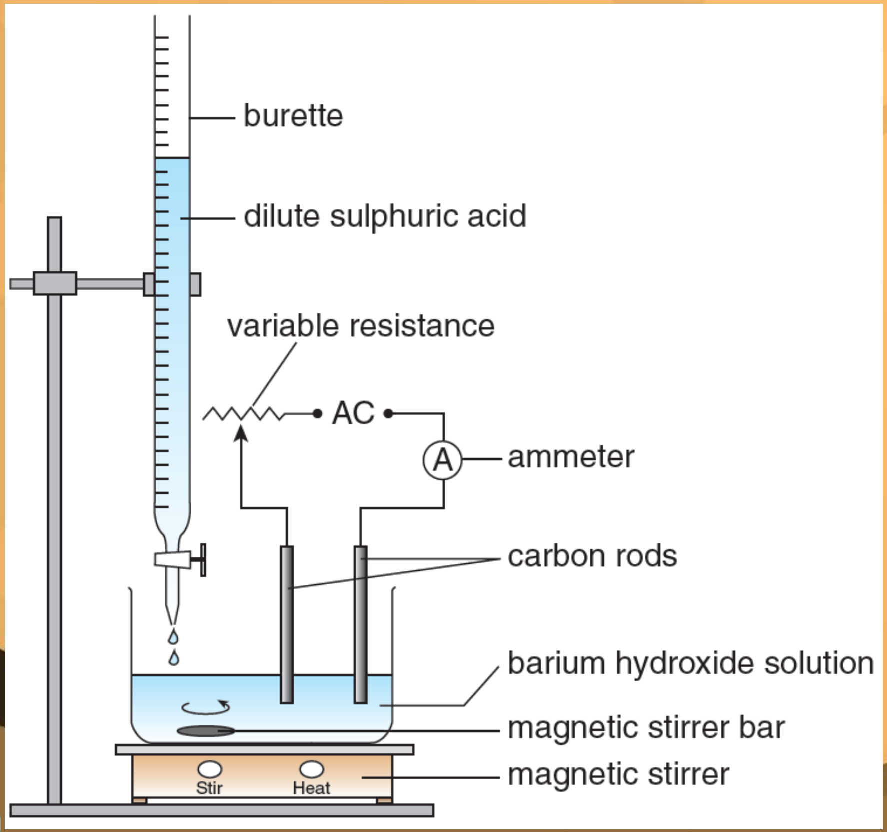
Indicator	pH range of colour change
Orange IV	1.2–2.8
Methyl red	4.4–6.2
Thymolphthalein	9.1–9.6

From the table, select an indicator that could be used in the titration shown in X. Explain your choice.

Thymolphthalein This indicator changes colour within the pH range of the vertical part of the titration curve.

17.11 Conductometric titrations (p.131)

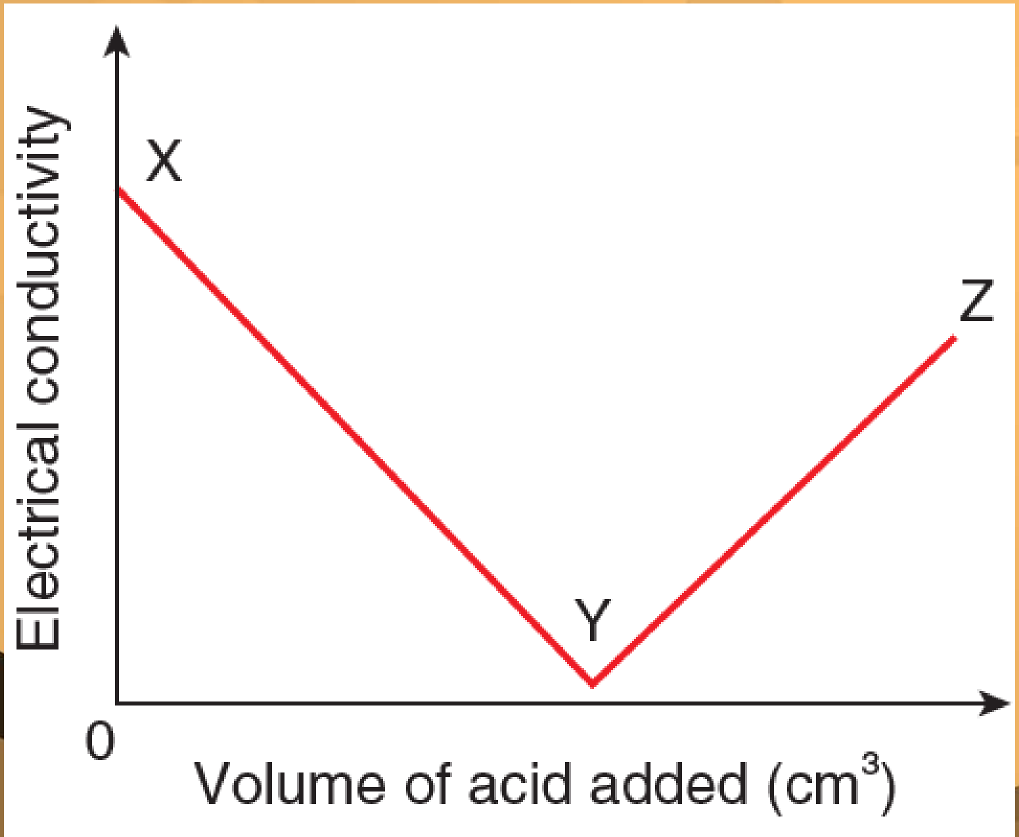
- The equivalence point of an acid-alkali titration can be found by monitoring the electrical conductivity of the reaction mixture when an alkali is progressively neutralised by the addition of an acid.



Experimental set-up for monitoring the electrical conductivity of the reaction mixture when dilute sulphuric acid is added gradually to barium hydroxide solution

17.11 Conductometric titrations (p.131)

- Barium hydroxide solution and dilute sulphuric acid react according to the following equation:
  $Ba(OH)_2(aq) + H_2SO_4(aq) \longrightarrow BaSO_4(s) + 2H_2O(l)$



The change in electrical conductivity of the reaction mixture when dilute sulphuric acid is added gradually to barium hydroxide solution

17.11 Conductometric titrations (p.131)

- When dilute sulphuric acid is added to the barium hydroxide solution, barium sulphate and water are formed. The concentrations of barium ions and hydroxide ions in the reaction mixture decrease. Hence the electrical conductivity of the reaction mixture decreases from X to Y.
- The electrical conductivity falls to almost zero at the equivalence point Y because all the barium ions and hydroxide ions have been removed.
- After Y, the concentrations of hydrogen ions and sulphate ions increase when excess dilute sulphuric acid is introduced into the reaction mixture. Hence the electrical conductivity rises from Y to Z.
- Similar results are obtained when any alkali is titrated against any acid. The trough of the V-shaped graph corresponds to the volume of acid required to achieve complete neutralisation of the alkali.

17.12 Back titrations (p.132)

Determining the percentage by mass of calcium carbonate in eggshells by back titration *Ref.*

- In an acid-alkali titration, the concentration (or amount) of a chemical species in a sample can be determined by gradual addition of a standard acid / alkali until the end point is reached. This process is known as direct titration.
- Calcium carbonate is insoluble in water and reacts very slowly with an acid. Hence it is difficult to determine the amount of calcium carbonate in the sample of chalk by a direct titration with an acid.
- To overcome the difficulty, you can use a method called **back titration (返滴定)**. Follow the procedure listed below.
  1 Weigh a sample of the chemical species being investigated.
  2 Add an excess of a standard solution of an acid or an alkali to the sample.
  3 After the reaction, either titrate the excess acid or alkali directly or make up the solution to 250.0 cm^3 and titrate the diluted solution.
- The acid or alkali used up by the chemical species being investigated is the total amount of acid or alkali added at the start minus the amount of acid or alkali left at the end.

17.12 Back titrations (p.132)

Q (Example 17.12)

A student performed the following experiment to determine the percentage by mass of calcium carbonate in a sample of chalk.

Step 1 2.96 g of chalk were dissolved in 80.00 cm^3 of 1.00 mol dm^{-3} hydrochloric acid to form a solution.

Step 2 The solution was placed in a volumetric flask and then diluted to 250.0 cm^3 with deionised water. The solution was labelled 'S'.

Step 3 Portions of 25.00 cm^3 of 'S' were titrated with 0.122 mol dm^{-3} sodium hydroxide solution using a suitable indicator. An average of 26.25 cm^3 of sodium hydroxide solution was needed to reach the end point.

a) Based on the titration result, calculate the amount of HCl in 25.00 cm^3 of solution 'S'.

b) Calculate the amount of HCl left over after reaction with calcium carbonate in chalk in *Step 1*.

c) Calculate the amount of HCl that was added in *Step 1*.

d) Hence calculate the percentage by mass of calcium carbonate in the sample of chalk.

(Relative atomic masses: C = 12.0, O = 16.0, Ca = 40.1)

17.12 Back titrations (p.132)

Q (Example 17.12) (continued)

A

a) $NaOH(aq) + HCl(aq) \longrightarrow NaCl(aq) + H_2O(l)$

0.122 mol dm^{-3}
26.25 cm^3

Number of moles of NaOH in 26.25 cm^3 solution = molarity of solution x volume of solution

$$= 0.122 \text{ mol dm}^{-3} \times \frac{26.25}{1\ 000} \text{ dm}^3$$

$$= 3.20 \times 10^{-3} \text{ mol}$$

According to the equation, 1 mole of HCl requires 1 mole of NaOH for complete neutralisation.

i.e. number of moles of HCl in 25.00 cm^3 'S' = 3.20×10^{-3} mol

b) Number of moles of HCl left over after reaction with $CaCO_3$ in chalk in *Step 1*

$$= 3.20 \times 10^{-3} \text{ mol} \times \frac{250.0 \text{ cm}^3}{25.00 \text{ cm}^3}$$

$$= 0.0320 \text{ mol}$$

17.12 Back titrations (p.132)

Q (Example 17.16) (continued)

A

c) Number of moles of HCl added in *Step 1* = molarity of solution x volume of solution

$= 1.00 \text{ mol dm}^{-3} \times \frac{80.00}{1\ 000} \text{ dm}^3$

$= 0.0800 \text{ mol}$

d) Number of moles of HCl reacted with $CaCO_3$ in chalk = (0.0800 – 0.0320) mol

= 0.0480 mol

$CaCO_3(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

According to the equation, 1 mole of $CaCO_3$ requires 2 moles of HCl for complete reaction.

i.e. number of moles of $CaCO_3$ in chalk $= \frac{0.0480}{2}$ mol

= 0.0240 mol

Molar mass of $CaCO_3$ = $(40.1 + 12.0 + 3 \times 16.0) \text{ g mol}^{-1}$

$= 100.1 \text{ g mol}^{-1}$

Mass of $CaCO_3$ in chalk = number of moles x molar mass

$= 0.0240 \text{ mol} \times 100.1 \text{ g mol}^{-1}$

= 2.40 g

Percentage by mass of $CaCO_3$ in chalk $= \frac{2.40 \text{ g}}{2.96 \text{ g}} \times 100\%$

= 81.1%

∴ the percentage by mass of $CaCO_3$ in the sample of chalk is 81.1%.

17.12 Back titrations (p.132)

- The calculation in the above example starts with the volume of sodium hydroxide solution needed to reach the titration end point. The steps involved in the calculation are summarised below.

1

mean titre → number of moles of NaOH used → number of moles of HCl in 25.00 cm^3 of 'S' → number of moles of HCl left over after reaction with $CaCO_3$ in chalk sample

2

volume of acid added at start → number of moles of HCl added at start

3

number of moles of HCl added at start − number of moles of HCl left over after reaction with $CaCO_3$ in chalk sample = number of moles of HCl required for complete reaction with $CaCO_3$ in chalk sample

→ number of moles of $CaCO_3$ in chalk sample → mass of $CaCO_3$ in chalk sample → % by mass of $CaCO_3$ in chalk sample

17.12 Back titrations (p.132)

Practice 17.6

A fertiliser only contains ammonium nitrate (NH_4NO_3) and potassium chloride. An experiment was performed to determine the percentage by mass of ammonium nitrate in this fertiliser.

Step 1 Excess KOH(aq) was added slowly to 5.50 g of the fertiliser and the mixture was heated gently.

Step 2 The ammonia liberated from the reaction between NH_4NO_3 and KOH was passed into 120.0 cm^3 of 0.600 mol dm^{-3} HCl(aq).

Step 3 The solution with remained acid was made up to 250.0 cm^3 and labelled 'S'.

Step 4 Portions of 25.00 cm^3 of 'S' were titrated with 0.100 mol dm^{-3} NaOH(aq), using a suitable indicator. An average of 26.50 cm^3 of NaOH(aq) was used to reach the end point.

a) Write the ionic equation for the reaction between NH_4NO_3 and KOH.

b) Based on the titration result, calculate the number of moles of NaOH used to neutralise 25.00 cm^3 of 'S'.

c) Calculate the percentage by mass of NH_4NO_3 in this fertiliser.
(Molar mass of NH_4NO_3 = 80.0 g mol^{-1})

17.12 Back titrations (p.132)

Practice 17.6 (continued)

a) $NH_4^+(aq) + OH^-(aq) \longrightarrow NH_3(aq) + H_2O(l)$

b) $NaOH(aq) + HCl(aq) \longrightarrow NaCl(aq) + H_2O(l)$

0.100 mol dm^{-3}

26.50 cm^3

Number of moles of NaOH used to neutralise 25.00 cm^3 of 'S'

= molarity of solution x volume of solution

$= 0.100 \text{ mol dm}^{-3} \times \frac{26.50}{1\,000} \text{ dm}^3$

$= 2.65 \times 10^{-3}$ mol

17.12 Back titrations (p.132)

Practice 17.6 (continued)

c) According to the equation, 1 mole of HCl requires 1 mole of NaOH for complete neutralisation.

i.e. number of moles of HCl in 25.00 cm^3 of 'S'
$= 2.65 \times 10^{-3}$ mol

Number of moles of HCl in 250.0 cm^3 of 'S'
$= 10 \times 2.65 \times 10^{-3}$ mol
= 0.0265 mol

Number of moles of HCl used in *Step 2*
= molarity of solution x volume of solution
$= 0.600 \text{ mol dm}^{-3} \times \frac{120.0}{1\ 000} \text{ dm}^3$
= 0.0720 mol

Number of moles of HCl reacted with NH_3
= (0.0720 – 0.0265) mol
= 0.0455 mol

17.12 Back titrations (p.132)

Practice 17.6 (continued)

c)

$NH_3(aq) + HCl(aq) \longrightarrow NH_4Cl(aq)$

According to the equation, 1 mole of NH_3 requires 1 mole of HCl for complete neutralisation.

i.e. number of moles of NH_3 = 0.0455 mol

According to the equation in (a), 1 mole of NH_4NO_3 reacts with KOH to give 1 mole of NH_3.

i.e. number of moles of NH_4NO_3 in fertiliser = 0.0455 mol

Molar mass of NH_4NO_3 = (2 x 14.0 + 4 x 1.0 + 3 x 16.0) g mol^{-1}
= 80.0 g mol^{-1}

Mass of NH_4NO_3 in fertiliser = number of moles x molar mass
= 0.0455 mol x 80.0 g mol^{-1}
= 3.64 g

Percentage by mass of NH_4NO_3 in fertiliser = $\frac{3.64\ g}{5.50\ g} \times 100\%$
= 66.2%

∴ the percentage by mass of NH_4NO_3 in the fertiliser is 66.2%.

Key terms (p.136)

dilution	稀釋	titration end point	滴定標準
volumetric analysis	容量分析	titre	滴定值
quantitative analysis	定量分析	titration curve	滴定曲線
standard solution	標準溶液	equivalence point	當量點
primary standard	基本標準	back titration	返滴定

Summary (p.137)

1 Concentration of solution (in g dm^{-3})

$$= \frac{\text{mass of solute (in g)}}{\text{volume of solution (in } dm^3)}$$

2 When a concentrated solution is diluted with water, the amount of solute (in moles) in the solution remains unchanged.

i.e. (MV) before dilution = (MV) after dilution,

where M = molarity, V = volume.

3 Titration is a practical method for measuring the volumes of two solutions that react exactly with each other. From the measured volumes and known concentration of one of the solutions, you can find out the concentration (or amount) of the chemical species in question.

Summary (p.137)

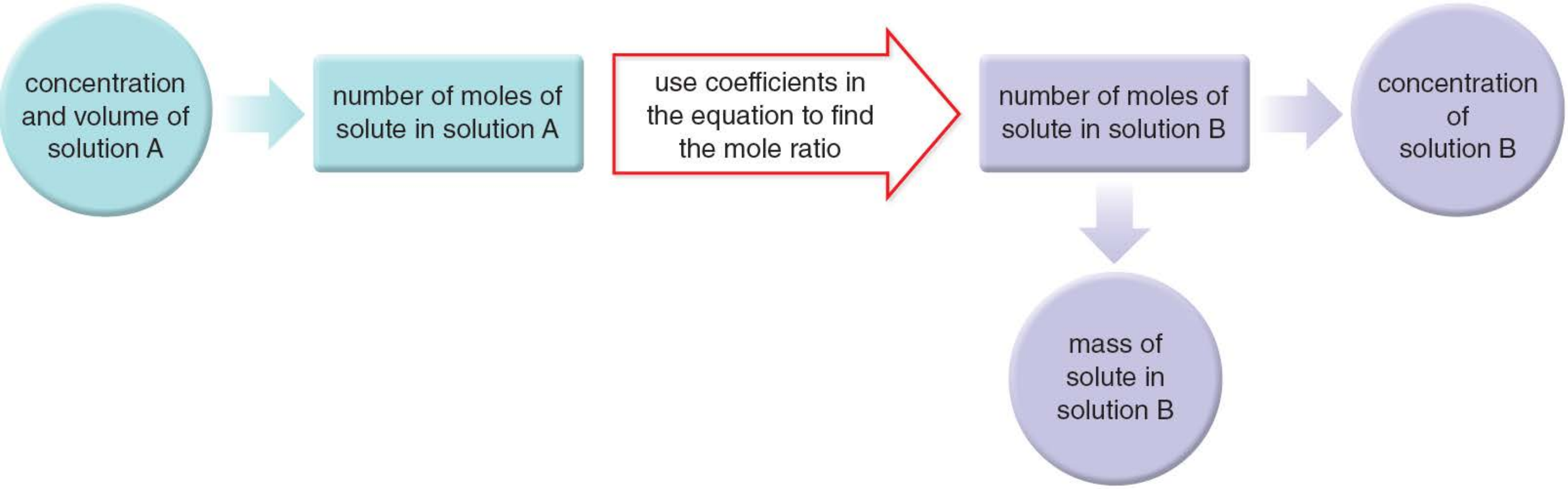
4 Main pieces of apparatus used in a titration include
- a pipette and a pipette filler;
- a burette;
- a volumetric flask;
- several conical flasks.

5 A standard solution is a solution whose concentration is accurately known.

6 The titration end point is the point at which the indicator just changes colour.

Summary (p.137)

7 The following diagram summarises the steps for titration calculations.



8 In a titration, the equivalence point is the point at which sufficient acid has been added to just neutralise the alkali (or vice versa).

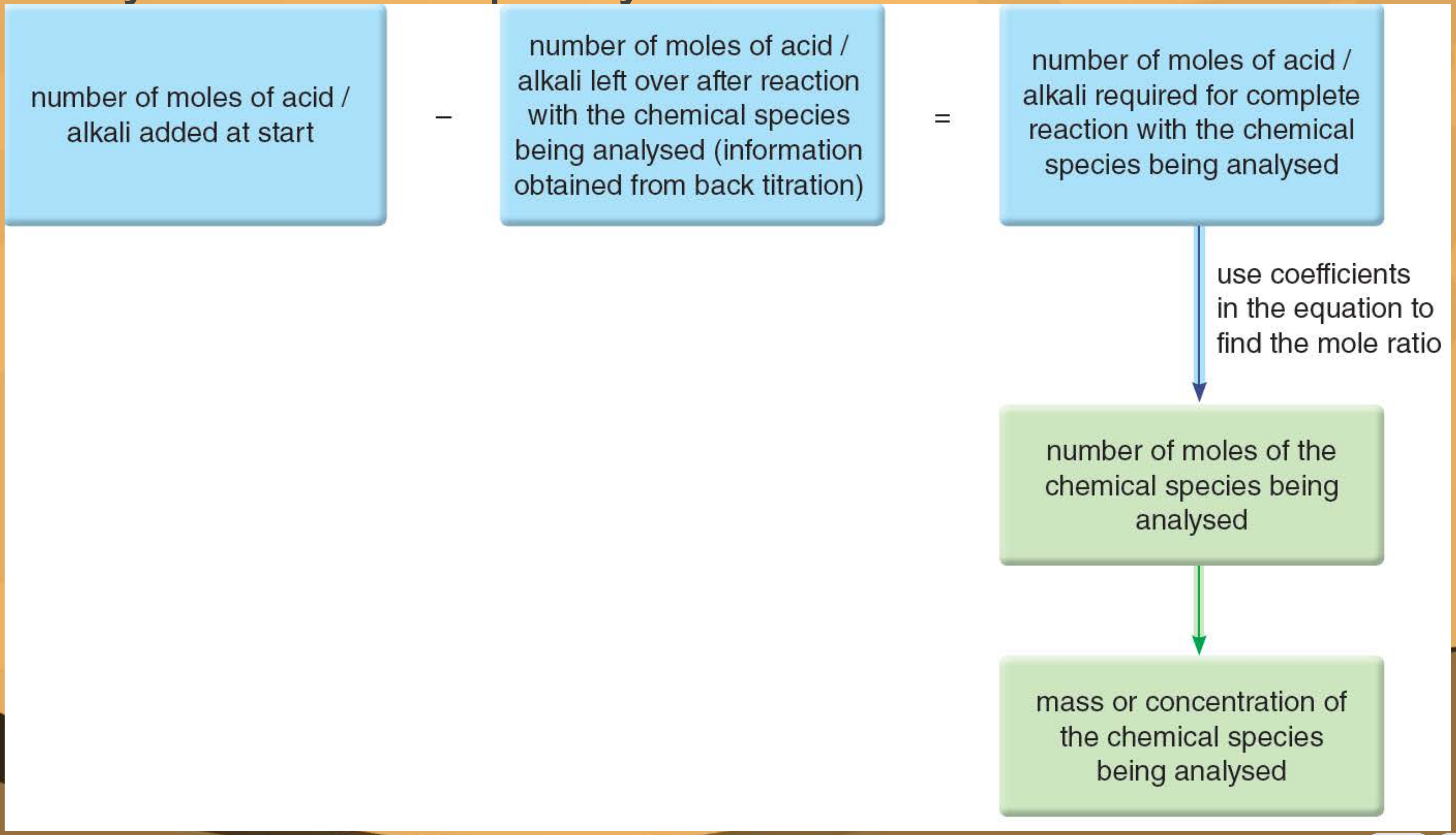
Summary (p.137)

9 The suitable indicators for different types of acid-alkali titration are summarised in the table below.

Acid	Alkali	Indicator
strong	strong	methyl orange or phenolphthalein
weak	strong	phenolphthalein
strong	weak	methyl orange
weak	weak	none

Summary (p.137)

10 The following diagram summarises the steps for calculating the amount or concentration of a chemical species being analysed in a sample by back titration.



Unit Exercise (p.139)

Note: Questions are rated according to ascending level of difficulty (from 1 to 5):

question targeted at level 3 and above;

question targeted at level 4 and above;

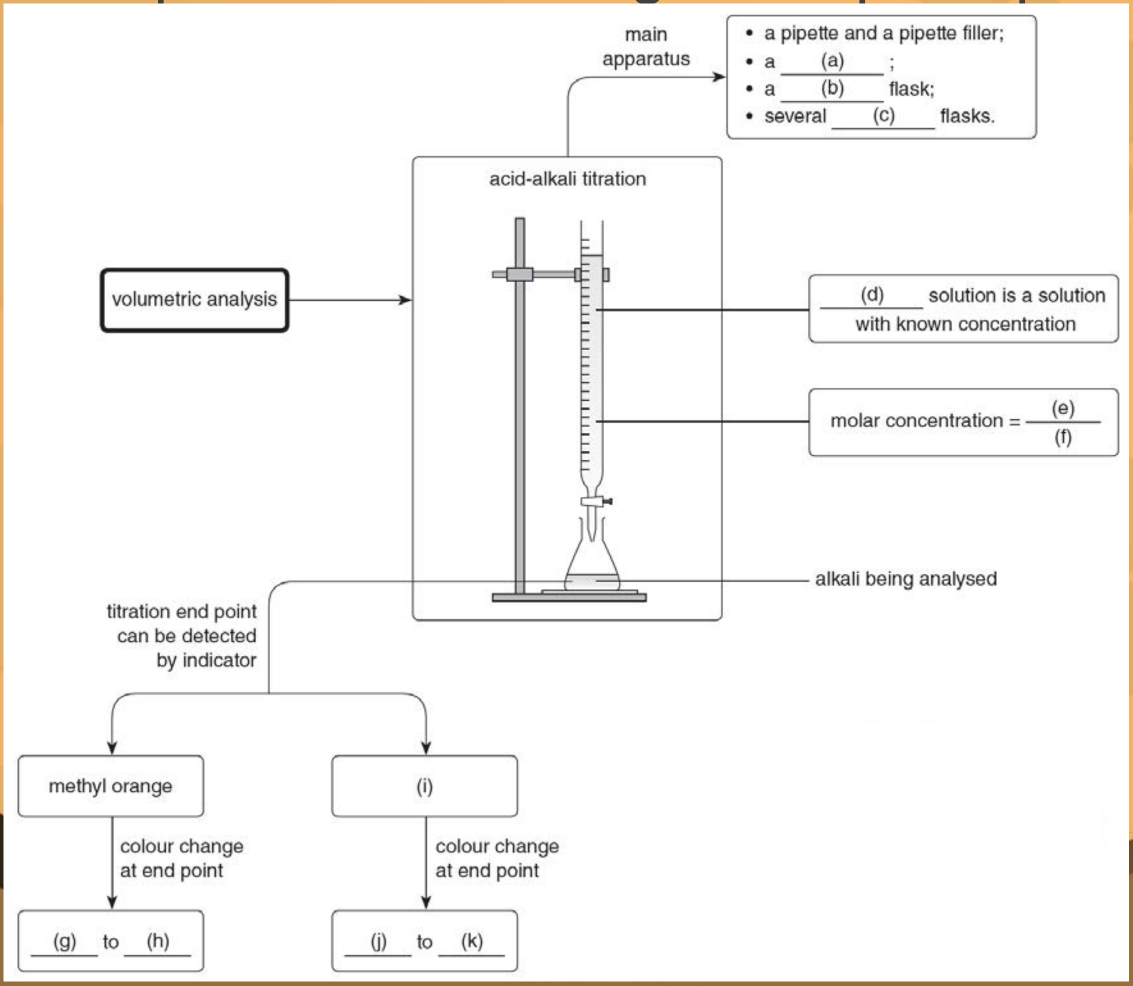
question targeted at level 5.

‘ * ’ indicates 1 mark is given for effective communication.

Unit Exercise (p.139)

PART I KNOWLEDGE AND UNDERSTANDING

1 Complete the following concept map.



a) burette
b) volumetric
c) conical
d) standard
e) number of moles of solute
f) volume of solution (dm^3)
g) yellow
h) orange
i) phenolphthalein
j) pink
k) colourless

Unit Exercise (p.139)

PART II MULTIPLE CHOICE QUESTIONS

2 What volume of 0.400 mol dm^{-3} sodium hydroxide solution should be diluted to 1.00 dm^3 to make a 0.0100 mol dm^{-3} solution?

A 15.0 cm^3
B 20.0 cm^3
C 25.0 cm^3
D 40.0 cm^3

Explanation:

Answer: C

(MV) before dilution = (MV) after dilution, where M = molarity, V = volume

$$0.400 \times \frac{V}{1\ 000} = 0.0100 \times 1.00$$

$$V = 25.0\ cm^3$$

Unit Exercise (p.139)

3 1.62 dm^3 of 3.00 mol dm^{-3} HNO_3(aq) are diluted to 18.0 dm^3. What is the concentration of the diluted solution in g dm^{-3}? (Relative atomic masses: H = 1.0, N = 14.0, O = 16.0)

A 6.48 g dm^{-3}
B 9.72 g dm^{-3}
C 11.1 g dm^{-3}
D 17.0 g dm^{-3}

Explanation:

(MV) before dilution = (MV) after dilution,
where M = molarity, V = volume

3.00 x 1.62 = M x 18.0
M = 0.270 mol dm^{-3}

Molar mass of HNO_3 = (1.0 + 14.0 + 3 x 16.0) g mol^{-1}
= 63.0 g mol^{-1}

Concentration of HNO_3 (in g dm^{-3})
= concentration of HNO_3 (in mol dm^{-3}) x molar mass of HNO_3
= 0.270 mol dm^{-3} x 63.0 g mol^{-1}
= 17.0 g dm^{-3}

Answer: D

Unit Exercise (p.139)

4 The pH of a sample of sulphuric acid is 2.6. 100 cm^3 of this sample is mixed with 100 cm^3 of water. What is the pH of the resulting mixture?

A 5.8
B 2.9
C 2.6
D 1.3

(HKDSE, Paper 1A, 2016, 6)

Answer: B

Unit Exercise (p.139)

5 Which of the following apparatus are required for preparing 0.100 mol dm^{-3} sulphuric acid from 1.00 mol dm^{-3} sulphuric acid?

A 1 cm^3 dropping pipette and 10 cm^3 measuring cylinder
B 10 cm^3 measuring cylinder and 250 cm^3 volumetric flask
C 10 cm^3 pipette and 250 cm^3 conical flask
D 25 cm^3 pipette and 250 cm^3 volumetric flask

Answer: D

Unit Exercise (p.139)

6 30.0 cm^3 of hydrochloric acid are needed to neutralise 25.00 cm^3 of 0.120 mol dm^{-3} calcium hydroxide solution.

$$2HCl(aq) + Ca(OH)_2(aq) \longrightarrow CaCl_2(aq) + 2H_2O(l)$$

What is the concentration of the hydrochloric acid?

A 0.100 mol dm^{-3}
B 0.150 mol dm^{-3}
C 0.200 mol dm^{-3}
D 0.250 mol dm^{-3}

Answer: C

Explanation:

$2HCl(aq)$	+	$Ca(OH)_2(aq)$	$\longrightarrow$	$CaCl_2(aq)$	+	$2H_2O(l)$
? mol dm^{-3}		0.120 mol dm^{-3}				
30.0 cm^3		25.00 cm^3				

Number of moles of $Ca(OH)_2$ in 25.00 cm^3 solution = molarity of solution x volume of solution

$$= 0.120 \text{ mol dm}^{-3} \times \frac{25.00}{1\ 000} \text{ dm}^3$$

$$= 3.00 \times 10^{-3} \text{ mol}$$

According to the equation, 1 mole of $Ca(OH)_2$ requires 2 moles of HCl for complete neutralisation.

i.e. number of moles of HCl in 30.00 cm^3 solution = $2 \times 3.00 \times 10^{-3}$ mol
= 6.00×10^{-3} mol

$$\text{Concentration of HCl} = \frac{\text{number of moles of HCl}}{\text{volume of solution}}$$

$$= \frac{6.00 \times 10^{-3} \text{ mol}}{\frac{30.0}{1\ 000} \text{ dm}^3}$$

$$= 0.200 \text{ mol dm}^{-3}$$

Unit Exercise (p.139)

7 In an experiment, 25.0 cm^3 of HCl(aq) is measured with apparatus X and is placed in apparatus Y. The HCl(aq) in Y is then titrated with a standard NaOH(aq). Which of the following combinations is correct?

	X	Y
A	measuring cylinder	beaker
B	measuring cylinder	conical flask
C	pipette	beaker
D	pipette	conical flask

Answer: D

(HKDSE, Paper 1A, 2015, 8)

Unit Exercise (p.139)

Directions: Questions 8 and 9 refer to the following information. A sample of 0.600 mol dm^{-3} H_2SO_4(aq) reacted completely with 25.00 cm^3 of 1.02 mol dm^{-3} Na_2CO_3(aq).

8 What is the volume of the sample of H_2SO_4(aq)?

A 20.0 cm^3
B 42.5 cm^3
C 85.0 cm^3
D 125 cm^3

Explanation:

$$H_2SO_4(aq) + Na_2CO_3(aq) \longrightarrow Na_2SO_4(aq) + H_2O(l) + CO_2(g)$$

0.600 mol dm^{-3} 1.02 mol dm^{-3}
? cm^3 25.00 cm^3

Number of moles of Na_2CO_3 in 25.00 cm^3 solution
= molarity of solution x volume of solution
$= 1.02 \text{ mol dm}^{-3} \times \frac{25.00}{1\ 000} \text{ dm}^3$
= 0.0255 mol

According to the equation, 1 mole of H_2SO_4 requires 1 mole of Na_2CO_3 for complete reaction.

i.e. number of moles of H_2SO_4 in the sample of acid = 0.0255 mol

$$\text{Volume of the sample of acid} = \frac{\text{number of moles of } H_2SO_4}{\text{molarity of acid}} = \frac{0.0255 \text{ mol}}{0.600 \text{ mol dm}^{-3}} = 0.0425 \text{ dm}^3 = 42.5 \text{ cm}^3$$

Answer: B

Unit Exercise (p.139)

9 What is the concentration of the sodium sulphate solution obtained?

A $0.378 \text{ mol dm}^{-3}$
B $0.567 \text{ mol dm}^{-3}$
C $0.756 \text{ mol dm}^{-3}$
D $0.945 \text{ mol dm}^{-3}$

Explanation:

Number of moles of Na_2SO_4 formed in the reaction = 0.0255 mol

Total volume of reaction mixture = $(25.00 + 42.5)\text{ cm}^3$ = 67.5 cm^3

$$\text{Concentration of } Na_2SO_4 \text{ solution} = \frac{\text{number of moles of } Na_2SO_4}{\text{volume of solution}} = \frac{0.0255 \text{ mol}}{\frac{67.5}{1\,000}\text{ dm}^3} = 0.378 \text{ mol dm}^{-3}$$

Answer: A

Unit Exercise (p.139)

10 Which of the following pairs of aqueous solutions, upon mixing, would have the lowest electrical conductivity?

A 20.0 cm^3 of 0.1 M HNO_3 and 20.0 cm^3 of 0.1 M KOH
B 20.0 cm^3 of 0.1 M H_2SO_4 and 20.0 cm^3 of 0.1 M $Ba(OH)_2$
C 20.0 cm^3 of 0.1 M CH_3COOH and 20.0 cm^3 of 0.1 M NH_3
D 20.0 cm^3 of 0.1 M HCl and 20.0 cm^3 of 0.1 M $C_6H_{12}O_6$ (glucose)

(HKDSE, Paper 1A, 2014, 7)

Answer: B

Unit Exercise (p.139)

11 A student carries out a titration. Sodium hydroxide solution is transferred to a conical flask using a pipette. Methyl orange indicator is added to the flask. Hydrochloric acid is added from a burette until the indicator changes colour.

Which of the following would lead to the titre being larger than it should be?

A Rinsing the conical flask with water before adding the sodium hydroxide solution.
B Rinsing the burette with water before filling it with hydrochloric acid.
C Rinsing the pipette with water before filling it with sodium hydroxide solution.
D Adding extra drops of indicator.

Explanation:
Rinsing the burette with just water would dilute the hydrochloric acid. Thus, more hydrochloric acid is needed to neutralise the sodium hydroxide solution.

Answer: B

(OCR Advanced Subsidiary Level, Chem. B (Salters), H033/01, Sample Question Paper, 2016, 9)

Unit Exercise (p.139)

12 In an experiment, 10 cm^3 of 1 mol dm^{-3} sulphuric acid are mixed with 30 cm^3 of 1 mol dm^{-3} potassium hydroxide solution.
Which of the following statements concerning this experiment is / are correct?

(1) 0.01 mole of water is produced.
(2) The pH of the resulting mixture is greater than 7.
(3) After water is completely evaporated from the resulting mixture, pure potassium sulphate crystals are obtained.

A (1) only
B (2) only
C (1) and (3) only
D (2) and (3) only

Explanation:

$$H_2SO_4(aq) + 2KOH(aq) \longrightarrow K_2SO_4(aq) + 2H_2O(l)$$

$H_2SO_4(aq)$	$KOH(aq)$
1 mol dm^{-3}	1 mol dm^{-3}
10 cm^3	30 cm^3

According to the equation, 1 mole of H_2SO_4 requires 2 moles of KOH for complete neutralisation.

i.e. 10 cm^3 of 1 mol dm^{-3} $H_2SO_4(aq)$ require 20 cm^3 of 1 mol dm^{-3} KOH(aq).

(1) Number of moles H_2SO_4
= molarity of solution x volume of solution
$= 1 \text{ mol dm}^{-3} \times \frac{10}{1\,000} \text{ dm}^3$
= 0.01 mol
According to the equation, 1 mole of H_2SO_4 neutralises KOH to produce 2 moles of H_2O.
i.e. number of moles of H_2O produced = 2 x 0.01 mol
= 0.02 mol

(2) 10 cm^3 of 1 mol dm^{-3} KOH(aq) remain unreacted. Thus, the pH of the resulting mixture is greater than 7.

Answer: B

Unit Exercise (p.139)

13 In a titration experiment, which of the following apparatus should be rinsed with deionised water only?

(1) Burette
(2) Conical flask
(3) Volumetric flask

A (1) only
B (2) only
C (1) and (3) only
D (2) and (3) only

Explanation:
(1) Burette should be rinsed with deionised water and the solution it is going to contain.

Answer: D

Unit Exercise (p.139)

PART III STRUCTURED QUESTIONS

14 The density of a sample of concentrated nitric acid is 1.41 g cm^{-3}. The liquid contains 69.7% of HNO_3 by mass.
What is the acid
a) in g dm^{-3}?
b) in mol dm^{-3}?
(Relative atomic masses: H = 1.0, N = 14.0, O = 16.0)

a) Mass of 1 000 cm^3 of the sample = density x volume
= 1.41 g cm^{-3} x 1 000 cm^3
= 1 410 g (1)

Mass of HNO_3 in 1 000 cm^3 of sample = 1 410 g x 69.7%
= 983 g

$$\text{Concentration of nitric acid} = \frac{\text{mass of } HNO_3}{\text{volume of solution}}$$
$$= \frac{983 \text{ g}}{1.00 \text{ dm}^3}$$
$$= 983 \text{ g dm}^{-3}$$ (1)

b) Molar mass of HNO_3 = (1.0 + 14.0 + 3 x 16.0) g mol^{-1}
= 63.0 g mol^{-1}

$$\text{Concentration of nitric acid (in mol dm}^{-3}) = \frac{\text{concentration of nitric acid (in g dm}^{-3})}{\text{molar mass of } HNO_3 \text{ (in g mol}^{-1})}$$
$$= \frac{983 \text{ g dm}^{-3}}{63.0 \text{ g mol}^{-1}}$$
$$= 15.6 \text{ mol dm}^{-3}$$ (1)

∴ the concentration of the nitric acid is 983 g dm^{-3} and 15.6 mol dm^{-3}.

Unit Exercise (p.139)

15 Calculate the volume of water needed to prepare 1.00 dm^3 of 0.120 mol dm^{-3} sodium carbonate solution from a solution of concentration 2.50 mol dm^{-3}.

Suppose V cm^3 of 2.50 mol dm^{-3} sodium carbonate solution is needed for the dilution.

(MV) before dilution = (MV) after dilution, where M = molarity, V = volume

$$2.50 \times \frac{V}{1\ 000} = 0.120 \times 1.00 \quad (1)$$

$$V = 48.0 \quad (1)$$

∴ volume of water needed = (1 000 – 48.0) cm^3

= 952 cm^3 (1)

∴ 952 cm^3 of water are needed.

Unit Exercise (p.139)

16 35.0 cm^3 of 0.0420 mol dm^{-3} hydrochloric acid were diluted. The pH of the resulting solution was 2.09. Calculate the total volume of the solution formed.

$pH_{after\ dilution} = 2.09$

$[H^+(aq)]_{after\ dilution} = 8.13 \times 10^{-3}$ mol dm^{-3} (1)

(MV) before dilution = (MV) after dilution, where M = molarity, V = volume

$0.0420 \times \frac{35.0}{1\ 000} = 8.13 \times 10^{-3} \times V$ (1)

$V = 0.181\ dm^3$ (1)

∴ the total volume of solution formed is 0.181 dm^3.

Unit Exercise (p.139)

17 Brand X toilet cleanser contains sulphuric acid. A technician was asked to find out the concentration of sulphuric acid in the cleanser.
The technician titrated 10.00 cm^3 portions of the cleanser with 2.60 mol dm^{-3} sodium hydroxide solution and obtained the following results.

Reading (cm^3)	Titration number			
	1	2	3	4
Final burette reading	38.25	37.30	37.45	37.40
Initial burette reading	0.00	0.00	0.10	0.10
Titre	38.25	37.30	37.35	37.30

The technician decided that the mean titre was 37.32 cm^3.

a) The technician did not include the result in the first titration when calculating the mean titre. Explain why.

b) Calculate the molarity of sulphuric acid in the toilet cleanser.

c) Explain why titrations involving the use of 2.60 mol dm^{-3} sodium hydroxide solution would NOT be advisable in a school laboratory.

Unit Exercise (p.139)

17 (continued)

a) Any one of the following:

- It is only a range finder. (1)
- It is only an estimation. (1)
- It is only a rough titre. (1)
- It is not consistent with the other titres. (1)

b)

$$H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$$

$H_2SO_4(aq)$	$2NaOH(aq)$
? mol dm^{-3}	2.60 mol dm^{-3}
10.0 cm^3	37.32 cm^3

Number of moles of NaOH in 37.32 cm^3 solution = molarity of solution x volume of solution

$= 2.60 \text{ mol dm}^{-3} \times \frac{37.32}{1\ 000} \text{ dm}^3$

$= 0.0970$ mol (1)

According to the equation, 1 mole of H_2SO_4 requires 2 moles of NaOH for complete neutralisation.

i.e. number of moles of H_2SO_4 in 10.0 cm^3 of toilet cleanser $= \frac{0.0970}{2}$ mol

$= 0.0485$ mol (1)

Concentration of sulphuric acid $= \frac{\text{number of moles of } H_2SO_4}{\text{volume of solution}}$

$= \frac{0.0485 \text{ mol}}{\frac{10.0}{1\ 000} \text{ dm}^3}$

$= 4.85 \text{ mol dm}^{-3}$ (1)

∴ the concentration of sulphuric acid in the toilet cleanser is 4.85 mol dm^{-3}.

Unit Exercise (p.139)

17 (continued)

c) The sodium hydroxide solution is corrosive. (1)
It may damage the eyes / burn the skin. (1)

Unit Exercise (p.139)

18 Two students were provided with separate samples of hydrated sodium carbonate ($Na_2CO_3 \cdot xH_2O$). They were asked to determine the value of *x*. For this purpose, they prepared 250.0 cm^3 of solution from the hydrated sodium carbonate.

a) One of the students proposed to make the solution by the following method. The extract below was taken from her notes.

- Place the hydrated sodium carbonate in a beaker and add 250.0 cm^3 of deionised water.
- Stir the mixture until all the sodium carbonate dissolves.
- Transfer the solution to a 250.0 cm^3 volumetric flask and shake.

The teacher said that the method was INCORRECT. Suggest TWO changes that the student should make to her method.

Unit Exercise (p.139)

18 (continued)

a) Any two of the following:

- Add less water initially. (1)
- Rinse the beaker / glass rod / filter funnel with deionised water. Pour all the washings into the volumetric flask. (1)
- Add deionised water so that the bottom of the meniscus is level with the graduation mark on the neck of the volumetric flask. (1)

Unit Exercise (p.139)

18 (continued)

b) The other student prepared 250.0 cm^3 of solution from 14.31 g of hydrated sodium carbonate using a correct method. Portions of 25.00 cm^3 of this solution were titrated with 0.215 mol dm^{-3} sulphuric acid. The mean titre was 23.25 cm^3.

i) Suggest a suitable indicator and state the expected colour change at the end point.

ii) Calculate the value of x.

(Relative atomic masses: H = 1.0, C = 12.0, O = 16.0, Na = 23.0)

Unit Exercise (p.139)

18 (continued)

b) i) Methyl orange (1)

From yellow to orange (1)

ii) $Na_2CO_3(aq) + H_2SO_4(aq) \longrightarrow Na_2SO_4(aq) + H_2O(l) + CO_2(g)$

Na_2CO_3: 14.31 g → 250.0 cm^3 → (used) 25.00 cm^3

H_2SO_4: 0.215 mol dm^{-3}, 23.25 cm^3

Number of moles of H_2SO_4 in 23.25 cm^3 solution = molarity of solution x volume of solution

$= 0.215 \text{ mol dm}^{-3} \times \frac{23.25}{1\ 000} \text{ dm}^3$

$= 0.00500$ mol (1)

According to the equation, 1 mole of Na_2CO_3 requires 1 mole of H_2SO_4 for complete reaction.

i.e. number of moles of Na_2CO_3 in 25.00 cm^3 solution = 0.00500 mol (1)

Number of moles of Na_2CO_3 in 250.0 cm^3 solution
= 10 x 0.00500 mol
= 0.0500 mol
= number of moles of Na_2CO_3 in 14.31 g of hydrated sodium carbonate

Molar mass of $Na_2CO_3 \bullet xH_2O$ = $(2 \times 23.0 + 12.0 + 3 \times 16.0 + 18x)$ g mol^{-1}
= $(106.0 + 18x)$ g mol^{-1}

$$\frac{\text{mass of } Na_2CO_3 \bullet xH_2O}{\text{molar mass of } Na_2CO_3 \bullet xH_2O} = \frac{14.31 \text{ g}}{(106.0 + 18x) \text{ g mol}^{-1}} = 0.0500 \text{ mol} \quad (1)$$

$x = 10$ (1)

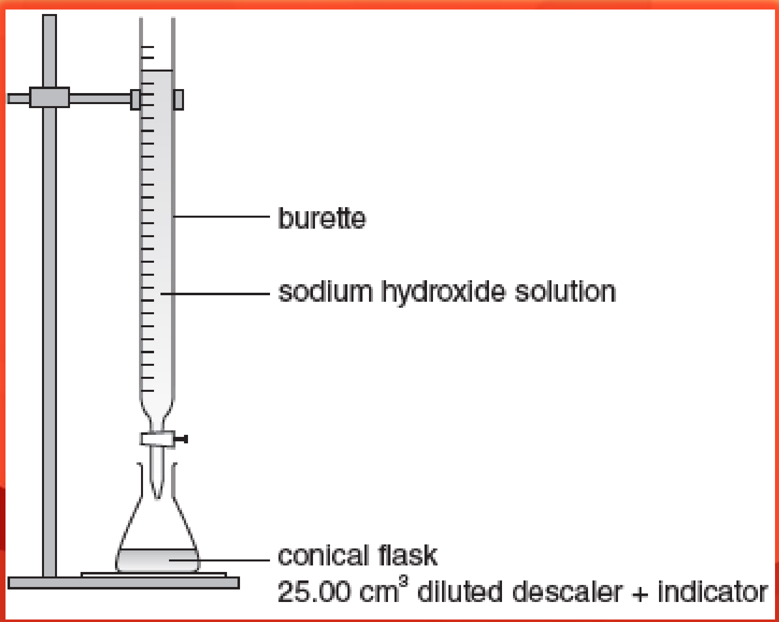
∴ the value of x is 10.

Unit Exercise (p.139)

19 'Magic' is a brand of descaler for kettles. Citric acid ($H_3C_6H_5O_7$) is the only acidic substance and also the active ingredient in the descaler.

A bottle of 'Magic' contains 100 cm^3 of liquid. The following experiment was carried out to determine the concentration of citric acid in the descaler. 25.00 cm^3 of the descaler were diluted to 250.0 cm^3 with deionised water. 25.00 cm^3 portions of the diluted descaler were titrated with 0.420 mol dm^{-3} NaOH(aq).

a) Draw a labelled diagram of the experimental set-up for the titration.



(2)

Unit Exercise (p.139)

19 (continued)

b) The titration results are shown in the table below.

Reading (cm^3)	Titration number			
	1	2	3	4
Final burette reading	28.20	26.40	26.45	26.55
Initial burette reading	0.05	0.00	0.05	0.10

i) Calculate the mean titre by selecting the appropriate results.

ii) Citric acid reacts with NaOH(aq) according to the equation below.

$H_3C_6H_5O_7(aq) + 3NaOH(aq) \longrightarrow Na_3C_6H_5O_7(aq) + 3H_2O(l)$

Calculate the concentration of citric acid in the undiluted descaler.

Unit Exercise (p.139)

19 (continued)

b)

i) Mean titre $= \dfrac{26.40 + 26.40 + 26.45}{3}$ cm^3

$= 26.42$ cm^3 (1)

ii) $H_3C_6H_5O_7(aq) + 3NaOH(aq) \longrightarrow Na_3C_6H_5O_7(aq) + 3H_2O(l)$

$H_3C_6H_5O_7$: 25.00 cm^3 → 250.0 cm^3 → (used) 25.00 cm^3

NaOH: 0.420 mol dm^{-3}, 26.42 cm^3

Number of moles of NaOH in 26.42 cm^3 solution = molarity of solution x volume of solution

$= 0.420 \text{ mol dm}^{-3} \times \dfrac{26.42}{1\ 000} \text{ dm}^3$

$= 0.0111$ mol (1)

According to the equation, 1 mole of citric acid requires 3 moles of NaOH for complete neutralisation.

i.e. number of moles of citric acid in 25.00 cm^3 of diluted descaler $= \dfrac{0.0111}{3}$ mol

$= 3.70 \times 10^{-3}$ mol (1)

Number of moles of citric acid in 250.0 cm^3 of diluted descaler

$= 10 \times 3.70 \times 10^{-3}$ mol

$= 3.70 \times 10^{-2}$ mol

= number of moles of citric acid in 25.00 cm^3 of undiluted descaler

Concentration of citric acid in undiluted descaler $= \dfrac{\text{number of moles of citric acid}}{\text{volume of solution}}$

$= \dfrac{3.70 \times 10^{-2} \text{ mol}}{\dfrac{25.00}{1\ 000} \text{ dm}^3}$

$= 1.48$ mol dm^{-3} (1)

∴ the concentration of citric acid in the undiluted descaler is 1.48 mol dm^{-3}.

Unit Exercise (p.139)

19 (continued)

c) Comment whether it is appropriate to prepare the 0.420 mol dm^{-3} NaOH(aq) by the following procedure:

'Weigh a sample of solid sodium hydroxide, dissolve it in some deionised water and make up to a known volume of solution.'

Not appropriate as sodium hydroxide absorbs moisture / carbon dioxide / acidic gases in the air readily. (1)

Unit Exercise (p.139)

20 Glycolic acid ($CH_2OHCOOH$) is widely used in cosmetic skin-care products. It is a crystalline solid that is very soluble in water.

A student carried out the following experiment to determine the concentration of a solution of glycolic acid.

Step 1 25.00 cm^3 of the solution were diluted to 250.0 cm^3 with deionised water.

Step 2 25.00 cm^3 of the diluted solution were placed in a conical flask. A few drops of phenolphthalein were added. 0.300 mol dm^{-3} sodium hydroxide solution was run from a burette into the flask. 25.60 cm^3 of sodium hydroxide solution were required to reach the end point.

a) Describe how the dilution process in *Step 1* should be carried out by using suitable apparatus.

Using a pipette filler, fill a 25.00 cm^3 pipette to the graduation mark. (1)
Run the solution into a 250.0 cm^3 volumetric flask. (1)
Add deionised water so that the bottom of the meniscus is level with the graduation mark on the neck of the flask. (1)
Insert the stopper in the flask and invert it, shaking thoroughly to ensure complete mixing. (1)

Unit Exercise (p.139)

20 (continued)

b) State the expected colour change of phenolphthalein at the end point.

From colourless to just pink (1)

c) Suggest another method for detecting the titration end point without the use of any acid-alkali indicator.

Any one of the following:

- Measuring the pH of the solution. (1)
- Measuring the temperature of the solution mixture. (1)

Unit Exercise (p.139)

20 (continued)

d) Glycolic acid reacts with sodium hydroxide solution according to the following equation:

$CH_2OHCOOH(aq) + NaOH(aq) \longrightarrow CH_2OHCOO^-Na^+(aq) + H_2O(l)$

Calculate the concentration of the solution of glycolic acid.

$CH_2OHCOOH(aq) + NaOH(aq) \longrightarrow CH_2OHCOO^-Na^+(aq) + H_2O(l)$

$CH_2OHCOOH$: $25.00\ cm^3$ ↓ $250.0\ cm^3$ ↓ (used) $25.00\ cm^3$

$NaOH$: $0.300\ mol\ dm^{-3}$, $25.60\ cm^3$

Number of moles of NaOH in $25.60\ cm^3$ solution = molarity of solution x volume of solution

$= 0.300\ mol\ dm^{-3} \times \frac{25.60}{1\ 000}\ dm^3$

$= 7.68 \times 10^{-3}\ mol$ (1)

According to the equation, 1 mole of $CH_2OHCOOH$ requires 1 mole of NaOH for neutralisation.

i.e. number of moles of $CH_2OHCOOH$ in $25.00\ cm^3$ of diluted solution $= 7.68 \times 10^{-3}\ mol$ (1)

Number of moles of $CH_2OHCOOH$ in $250.0\ cm^3$ of diluted solution

$= 10 \times 7.68 \times 10^{-3}\ mol$

$= 7.68 \times 10^{-2}\ mol$

= number of moles of $CH_2OHCOOH$ in $25.00\ cm^3$ of undiluted solution

Concentration of solution of glycolic acid $= \frac{\text{number of moles of glycolic acid}}{\text{volume of solution}}$

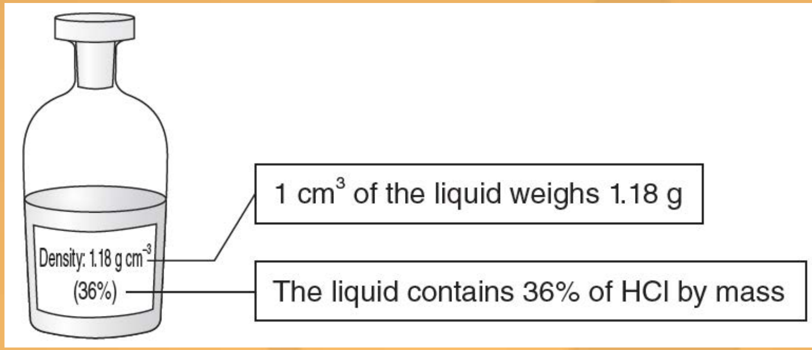
$= \frac{7.68 \times 10^{-2}\ mol}{\frac{25.00}{1\ 000}\ dm^3}$

$= 3.07\ mol\ dm^{-3}$ (1)

∴ the concentration of the solution of glycolic acid is $3.07\ mol\ dm^{-3}$.

Unit Exercise (p.139)

21 A bottle of concentrated hydrochloric acid HCl(aq) is shown below:



a) According to the information on the label, calculate the concentration of the concentrated hydrochloric acid in mol dm^{-3}.

b) To find out the concentration of the concentrated acid, a laboratory technician first drew from the bottle a sample of 10.00 cm^3 of the concentrated acid and diluted it to 100.0 cm^3 in a volumetric flask. The diluted acid sample was then used to titrate a standard sodium carbonate solution placed in a conical flask using methyl orange as an indicator. 10.00 cm^3 of 1.06 mol dm^{-3} sodium carbonate solution required 20.30 cm^3 of the diluted acid sample to reach the end point.

i) Briefly describe the procedure in preparing a standard sodium carbonate solution.

ii) Using the titration result, calculate the concentration, in mol dm^{-3}, of the concentrated hydrochloric acid in the bottle.

c) Suggest a possible reason why the concentration of the concentrated hydrochloric acid in the bottle obtained from (b)(ii) would be smaller than that obtained from (a) above.

(HKDSE, Paper 1B, 2014, 7)

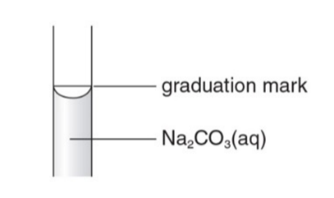
Answers for the questions of the public examinations in Hong Kong are not provided (if applicable).

Unit Exercise (p.139)

22 A student followed the steps below to determine the concentration of a sample of sulphuric acid.

Step 1 A conical flask was rinsed with deionised water.

Step 2 A 25.00 cm^3 pipette was rinsed with deionised water and then with standard Na_2CO_3(aq). It was then filled with standard Na_2CO_3(aq) to the level as shown in the diagram.



Step 3 Standard Na_2CO_3(aq) in the pipette was transferred to the conical flask. To ensure that all the solution was transferred, the student blew through the pipette.

Step 4 A few drops of a suitable indicator were added to the conical flask.

Step 5 A burette was rinsed with deionised water and then with the sample of sulphuric acid. It was then filled with the acid by using a filter funnel.

Step 6 A titration was carried out with the filter funnel remaining on top od the burette.

a) Identify the mistake made in *Step 3*, and propose a change that would increase the validity of the result.

Mistake: Blowing through the pipette (1)

Change: Touch the tip of the pipette to the surface of the conical flask to draw out the liquid. (1)

Unit Exercise (p.139)

22 (continued)

b) Explain why the mistakes made in *Steps 2* and *6* would lead to inaccurate titration results.

Step 2 The meniscus of Na_2CO_3(aq) did not reach the graduation mark of the pipette. So the pipette contained fewer moles of Na_2CO_3. Hence the volume of acid used (as revealed from the burette reading) would be smaller than the actual value. (1)

Step 6 Sulphuric acid clinging onto the stem of the filter funnel may fall into the burette. Thus, the volume of acid used (as revealed from the burette reading) may be smaller than expected. (1)

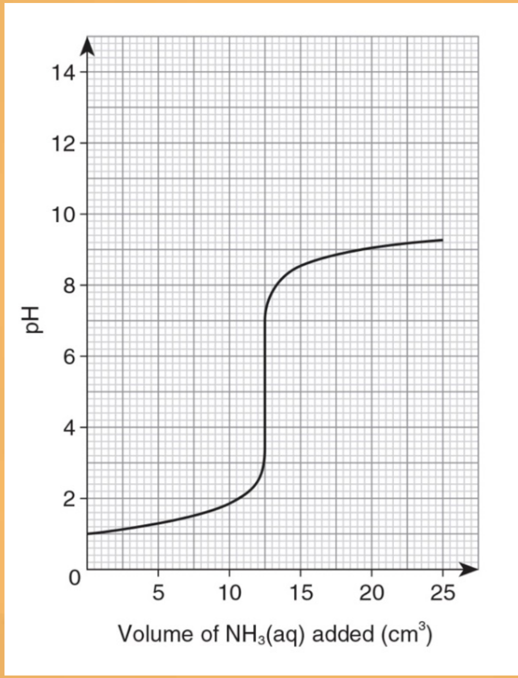
c) Suggest a suitable indicator for this titration and state the expected colour change at end point.

Methyl orange (1)

From yellow to orange (1)

Unit Exercise (p.139)

23 A student was asked to investigate how the pH changed during the reaction between nitric acid and aqueous ammonia. She slowly added aqueous ammonia into 25.00 cm^3 of nitric acid. She recorded the pH of the solution mixture using a pH meter. The results are shown in the graph below.



a) Name a suitable apparatus to measure 25.00 cm^3 of nitric acid.

Pipette (1)

Unit Exercise (p.139)

23 (continued)

b) Use the graph to obtain the pH of the nitric acid before adding the aqueous ammonia. Hence calculate the concentration of the nitric acid.

pH of nitric acid = 1.00

$[H^+(aq)]$ = $10^{-1\ 00}$ (1)

= 0.100 mol dm^{-3} (1)

c) The student could also have investigated the pH change using universal indicator solution.
Give ONE advantage of using a pH meter to investigate changes in pH.

Any one of the following:

- More precise measurements (1)
- Continuous (1)
- Graph produced automatically (1)

d) i) Define the 'equivalence point'.

The equivalence point is the point at which sufficient alkali has been added to just neutralise the acid. (1)

ii) Identify the volume of aqueous ammonia added at the equivalence point. 12.5 cm^3 (1)

Unit Exercise (p.139)

24 Barium sulphate can be made by adding barium hydroxide solution to dilute sulphuric acid.

The chemical equation for the reaction is:

$$H_2SO_4(aq) + Ba(OH)_2(aq) \longrightarrow BaSO_4(s) + 2H_2O(l)$$

A student investigated how the electrical conductivity of dilute sulphuric acid changed as barium hydroxide solution was added.

This was the method she used.

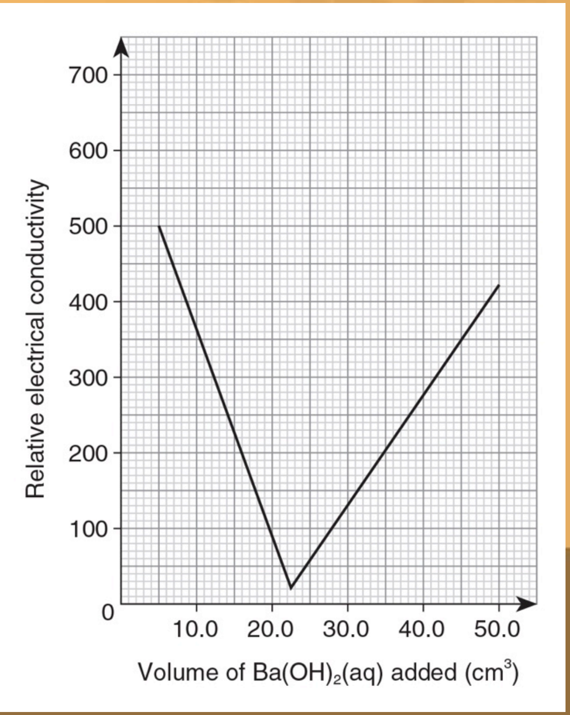
Step 1 Place 25.0 cm^3 of dilute sulphuric acid in a conical flask.

Step 2 Add 50.0 cm^3 of barium hydroxide solution, 5.0 cm^3 at a time.

Step 3 Stir the mixture after each addition.

Step 4 Use a conductivity meter to measure the electrical conductivity of the mixture after each addition.

The student's results are shown in the graph below.



Unit Exercise (p.139)

24 (continued)

a) i) Use the graph to estimate the relative electrical conductivity of the dilute sulphuric acid before any barium hydroxide solution was added.

Extrapolation on the graph 630–640 (1)

ii) Explain why dilute sulphuric acid conducts electricity.

Dilute sulphuric acid contains mobile ions. (1)

b) i) What was the volume of barium hydroxide solution added when the relative electrical conductivity of the mixture was the lowest?

22.5 cm^3 (1)

ii) Suggest why the relative electrical conductivity became almost zero.

No dissolved ionic substance in the solution. (1)

c) The concentration of the barium hydroxide solution was 1.20 mol dm^{-3}. What was the concentration of the sulphuric acid?

$Ba(OH)_2(aq)$	+ $H_2SO_4(aq)$
1.20 mol dm^{-3}	? mol dm^{-3}
22.5 cm^3	25.0 cm^3

$\longrightarrow BaSO_4(s) + 2H_2O(l)$

Number of moles of $Ba(OH)_2$ in 22.5 cm^3 solution

= molarity of solution x volume of solution

$= 1.20 \text{ mol dm}^{-3} \times \frac{22.5}{1\ 000} \text{ dm}^3$

= 0.0270 mol (1)

According to the equation, 1 mole of H_2SO_4 requires 1 mole of $Ba(OH)_2$ for complete neutralisation.

i.e. number of moles of H_2SO_4

= 0.0270 mol (1)

Concentration of sulphuric acid

$= \frac{\text{number of moles of } H_2SO_4}{\text{volume of solution}}$

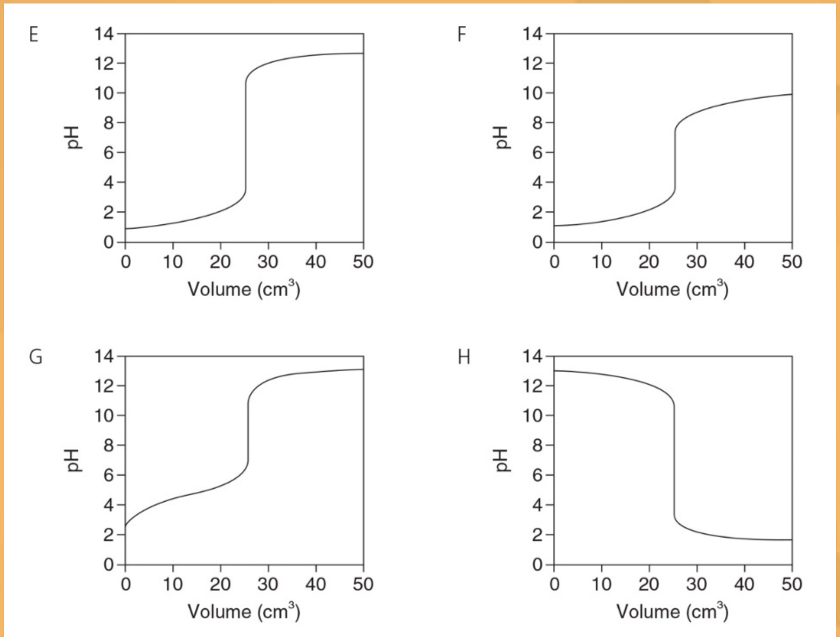
$= \frac{0.0270 \text{ mol}}{\frac{25.0}{1\ 000} \text{ dm}^3}$

= 1.08 mol dm^{-3} (1)

∴ the concentration of the sulphuric acid is 1.08 mol dm^{-3}.

Unit Exercise (p.139)

25 Titration curves, labelled E, F, G and H, for combinations of different aqueous solutions of acids and bases are shown below.
All solutions have concentrations of 0.1 mol dm^{-3}.



a) From the curves E, F, G and H, choose the curve produced by the addition of
i) sodium hydroxide solution to 25 cm^3 of ethanoic acid; G (1)
ii) aqueous ammonia to 25 cm^3 of hydrobromic acid; F (1)
iii) hydrochloric acid to 25 cm^3 of potassium hydroxide solution. H (1)

Unit Exercise (p.139)

25 (continued)

b) The table below shows information about some acid-base indicators.

Indicator	pH range	Lower pH colour	Higher pH colour
Pentamethoxy red	1.2–3.2	violet	colourless
Naphthyl red	3.7–5.0	red	yellow
4-nitrophenol	5.6–7.0	colourless	yellow
Cresol purple	7.6–9.2	yellow	purple

i) Which indicator in the above table could be used for the titration that produces curve E but NOT for the titration that produces curve F? Cresol purple (1)

ii) Give the colour change at the end point of the titration that produces curve H when naphthyl red is used as the indicator.

Yellow to red (1)

(AQA Advanced Level, Unit 4, Jun. 2015, 3)

Unit Exercise (p.139)

26 An antacid tablet contains magnesium hydroxide as the only active ingredient.

To determine the amount of magnesium hydroxide in the tablet, a student dissolved one tablet in 20.0 cm^3 of 1.00 mol dm^{-3} sulphuric acid to form a solution. The solution was then diluted to 250.0 cm^3 with deionised water. Portions of 25.00 cm^3 of the diluted solution were titrated with 0.120 mol dm^{-3} NaOH(aq), using a suitable indicator.

An average of 18.50 cm^3 of NaOH(aq) was needed to reach the end point.

a) Write the chemical equation for the reaction between magnesium hydroxide and dilute sulphuric acid.

$Mg(OH)_2(s) + H_2SO_4(aq) \longrightarrow MgSO_4(aq) + 2H_2O(l)$ (1)

b) Suggest a suitable indicator for the titration and state the expected colour change at the end point.

Any one of the following:

- methyl orange — from red to orange (1 + 1)
- phenolphthalein — from colourless to just pink (1 + 1)

Unit Exercise (p.139)

26 (continued)

c) Based on the titration result, calculate the number of moles of excess sulphuric acid in 25.00 cm^3 of the diluted solution.

2NOH(aq)	+	H_2SO_4(aq)	→	Na_2SO_4(aq)	+	$2H_2O$(l)
0.120 mol dm^{-3}						
18.50 cm^3		25.00 cm^3				

Number of moles of NaOH in 18.50 cm^3 solution = molarity of solution x volume of solution

= 0.120 mol dm^{-3} x $\frac{18.50}{1\,000}$ dm^3

= 2.22 x 10^{-3} mol (1)

According to the equation, 1 mole of H_2SO_4 requires 2 moles of NaOH for complete neutralisation.

i.e. number of moles of excess H_2SO_4 in 25.00 cm of diluted solution = $\frac{2.22 \times 10–3}{2}$ mol

= 1.11 x 10^{-3} mol (1)

Unit Exercise (p.139)

26 (continued)

d) Calculate the number of moles of sulphuric acid used to dissolve the antacid tablet.

Number of moles of H_2SO_4 used = molarity of solution x volume of solution

= 1.00 mol dm^{-3} x $\frac{20.0}{1\,000}$ dm^3

= 0.0200 mol

Number of moles of excess H_2SO_4 in 250.0 cm^3 of diluted solution = 10 x 1.11 x 10^{-3} mol

= 1.11 x 10^{-2} mol

Number of moles of H_2SO_4 used to dissolve one tablet = (0.0200 – 1.11 x 10^{-2}) mol

= 8.90 x 10^{-3} mol (1)

e) Hence calculate the mass of magnesium hydroxide in the antacid tablet.
(Molar mass of $Mg(OH)_2$ = 58.3 g mol^{-1})

According to the equation in (a), 1 mole of $Mg(OH)_2$ requires 1 mole of H_2SO_4 for complete neutralisation.

i.e. number of moles of $Mg(OH)_2$ in one tablet = 8.90 x 10^{-3} mol

Mass of $Mg(OH)_2$ in one tablet = number of moles x molar mass

= 8.90 x 10^{-3} mol x 58.3 g mol^{-1}

= 0.519 g (1)

∴ the mass of magnesium hydroxide in one antacid tablet is 0.519 g.

Unit Exercise (p.139)

27 The chemical formula of an oxide of metal M is MO. 3.924 g of this oxide were completely dissolved in 30.0 cm^3 of 2.00 mol dm^{-3} sulphuric acid. The resulting solution was made up to 100.0 cm^3. 25.00 cm^3 of this solution were neutralised by 27.50 cm^3 of 0.100 mol dm^{-3} sodium hydroxide solution.

a) Write chemical equations for the two neutralisation reactions involved.

$MO(s) + H_2SO_4(aq) \longrightarrow MSO_4(aq) + H_2O(l)$ (1)

$H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$ (1)

b) Based on the titration result, calculate the amount of sulphuric acid left over after the reaction with the oxide.

$H_2SO_4(aq) + 2NaOH(aq) \longrightarrow Na_2SO_4(aq) + 2H_2O(l)$

H_2SO_4: 100.0 cm^3 ↓ (used) 25.00 cm^3

NaOH: 0.100 mol dm^{-3}, 27.50 cm^3

Number of moles of NaOH in 27.50 cm^3 solution = molarity of solution x volume of solution

$= 0.100 \text{ mol dm}^{-3} \times \frac{27.50}{1\,000} \text{ dm}^3$

$= 2.75 \times 10^{-3}$ mol (1)

According to the equation, 1 mole of H_2SO_4 requires 2 moles of NaOH for complete neutralisation.

i.e. number of moles of excess H_2SO_4 in 25.00 cm^3 of diluted solution = $\frac{2.75 \text{ x } 10–3}{2}$ mol

= 1.375 x 10–3 mol

Unit Exercise (p.139)

27 (continued)

b) Number of moles of H_2SO_4 in 100.0 cm^3 of solution
= 4 x 1.375 x 10^{-3} mol
= 5.50 x 10^{-3} mol
= number of moles of H_2SO_4 left over after reaction with the oxide (1)

c) Calculate the amount of sulphuric acid that was used to dissolve the oxide at the start.

Number of moles of H_2SO_4 used = molarity of solution x volume of solution

$$= 2.00 \text{ mol dm}^{-3} \times \frac{30.0}{1\ 000} \text{ dm}^3$$
$$= 0.0600 \text{ mol} \quad (1)$$

Unit Exercise (p.139)

27 (continued)

d) Hence calculate the relative atomic mass of metal M. Identify the metal. (Refer to the Periodic Table.)
(Relative atomic mass: O = 16.0)

Number of moles of H_2SO_4 reacted with the oxide = $(0.0600 - 5.50 \times 10^{-3})$ mol
= 0.0545 mol

According to the equation in (a), 1 mole of MO requires 1 mole of H_2SO_4 for complete neutralisation.
i.e. number of moles of MO in 3.924 g of oxide = 0.0545 mol
Number of moles of MO in 3.924 g of oxide = 0.0545 mol

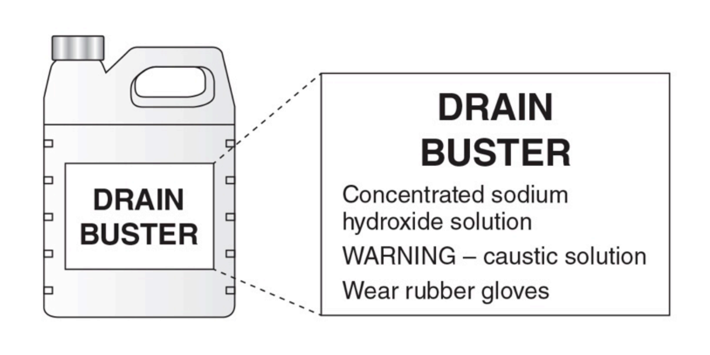
$$= \frac{3.924 \text{ g}}{\text{Molar mass of MO}} \quad (1)$$

Molar mass of MO = 72.0 g mol^{-1}
Relative atomic mass of M = 72.0 – 16.0
= 56.0 (1)

∴ the metal is iron. (1)

Unit Exercise (p.139)

28 Drain Buster is used to clear and degrease drains. Sodium hydroxide is the main chemical substance in Drain Buster.



a) A student planned an experiment to find the concentration of the sodium hydroxide solution in Drain Buster.
The teacher had to dilute the Drain Buster before the student could use it.
Explain why.

Drain Buster is a concentrated sodium hydroxide solution that would damage the skin. (1)
Thus, it is diluted so that it is safe to use for the experiment.

Unit Exercise (p.139)

28 (continued)

*b) The student wanted to find the volume of hydrochloric acid that reacts with a known volume of diluted Drain Buster.
Describe how the student could do this by titration.
In your description you should include
- the names of pieces of apparatus used; and
- the names of the substances used.

(AQA GCSE (Higher Tier), Further Additional Science, Unit 2, Chem. 3, Specimen paper, 2)

Procedure
- Wash a burette with deionised water and then hydrochloric acid.
- Fill the burette with the acid. Record the initial burette reading. (1)
- Wash a pipette with deionised water and then diluted Drain Buster.
- Use the pipette to measure out 25.00 cm3 of the diluted Drain Buster and carefully transfer it into a conical flask.
- Add a few drops of phenolphthalein / methyl orange to the conical flask. Put the flask on a white tile under the burette. (1) (1)
- Run the acid from the burette into the diluted Drain Buster until the indicator becomes colourless / orange, showing that the alkali is neutralised. Record the final burette reading. (1)
- Repeat the titration until three concordant titres are obtained. (1)

Example of risk assessment
Wear safety glasses to protect the eyes because
- hydrochloric acid is corrosive / irritant; or
- sodium hydroxide is corrosive. (1)

Communication mark (1)

Topic Exercise (p.150)

Note: Questions are rated according to ascending level of difficulty (from 1 to 5):

 **question targeted at level 3 and above;**

 **question targeted at level 4 and above;**

 **question targeted at level 5.**

‘ * ’ indicates 1 mark is given for effective communication.

Topic Exercise (p.150)

PART I MULTIPLE CHOICE QUESTIONS

1 Which of the following statements is correct?

A All aqueous solutions contain $H^+(aq)$ ions.
B The pH of all acid solutions is greater than zero.
C All acidic compounds contain hydrogen as their constituent elements.
D A 'corrosive' hazard warning label must be displayed on all reagent bottles containing acid solution.

(HKDSE, Paper 1A, 2015, 1)

Answer: A

Topic Exercise (p.150)

2 40.0 cm^3 of sodium carbonate solution contain 1.00 x 10^{-2} moles of sodium ions. What is the molarity of the solution?

A 1.00 x 10^{-4} mol dm^{-3}
B 1.25 x 10^{-4} mol dm^{-3}
C 1.00 x 10^{-1} mol dm^{-3}
D 1.25 x 10^{-1} mol dm^{-3}

Explanation:

1 mole of Na_2CO_3 contains 2 moles Na^+ ions.

Number of moles of Na_2CO_3 in the solution = $\frac{1.00 \times 10^{-2}}{2}$ mol

= 5.00 x 10^{-3} mol

Molarity of solution = $\frac{\text{Number of moles of } Na_2CO_3}{\text{volume of solution}}$

$$= \frac{5.00 \times 10^{-3} \text{ mol}}{\frac{40.0}{1\,000} \text{ dm}^3}$$

= 1.25 x 10^{-1} mol dm^{-3}

Answer: D

Topic Exercise (p.150)

3 100.0 cm^3 of 0.200 mol dm^{-3} KCl(aq) are mixed with 150.0 cm^3 of 0.200 mol dm^{-3} K_2SO_4(aq).

What is the concentration of K^+ ions in the solution mixture?

A 0.120 mol dm^{-3}
B 0.200 mol dm^{-3}
C 0.250 mol dm^{-3}
D 0.320 mol dm^{-3}

Explanation:

1 mole of KCl contains 1 mole of K^+ ions.

Number of moles of K^+ ions in KCl(aq)

$= 0.200 \text{ mol dm}^{-3} \times \frac{100.0}{1\,000} \text{ dm}^3$

$= 0.0200$ mol

1 mole of K_2SO_4 contains 2 moles of K^+ ions.

Number of moles of K^+ ions in K_2SO_4(aq)

$= 2 \times 0.200 \text{ mol dm}^{-3} \times \frac{150.0}{1\,000} \text{ dm}^3$

$= 0.0600$ mol

Total number of moles of K^+ ions = (0.0200 + 0.0600) mol
= 0.0800 mol

Total volume of solution mixture = (100.0 + 150.0) cm^3
= 250.0 cm^3

Concentration of K^+ ions in solution mixture $= \frac{0.0800 \text{ mol}}{\frac{250.0}{1\,000} \text{ dm}^3}$

$= 0.320 \text{ mol dm}^{-3}$

Answer: D

Topic Exercise (p.150)

4 Consider the solutions W, X, Y and Z below:

W: 100 cm^3 of 0.20 M HNO_3(aq)
X: 50 cm^3 of 0.20 M HCl(aq)
Y: 100 cm^3 of 0.20 M CH_3CO_2H(aq)
Z: 50 cm^3 of 0.10 M NaOH(aq)

Which of the following statements is correct?

A The pH of Y equals –log 0.2.
B Mixing W and Z gives a neutral solution.
C The pH of the mixture of W and X is lower than that of W.
D The pH of the mixture of W and X is lower than that of the mixture of X and Y.

Answer: D

(HKDSE, Paper 1A, 2018, 11)

Topic Exercise (p.150)

5 Which of the following statements about potassium hydroxide solution is INCORRECT?

A When potassium hydroxide solution is added to iron(III) sulphate solution, a dirty green precipitate is formed.

B When potassium hydroxide solution is heated with ammonium chloride solution, ammonia gas is liberated.

C Dilute potassium hydroxide solution contains K^+(aq) ions, H^+(aq) ions and OH^-(aq) ions.

D Concentrated potassium hydroxide solution is corrosive.

(HKDSE, Paper 1A, 2013, 9)

Answer: A

Topic Exercise (p.150)

6 What is the volume of 0.800 mol dm^{-3} hydrochloric acid required to react with 1.49 g of lithium oxide for complete neutralisation?

(Relative atomic masses: Li = 6.9, O = 16.0)

A 50.0 cm^3
B 62.5 cm^3
C 100.0 cm^3
D 125.0 cm^3

Answer: D

Explanation:

$$Li_2O(s) + 2HCl(aq) \longrightarrow 2LiCl(aq) + H_2O(l)$$

1.49 g   0.800 mol dm^{-3}

Molar mass of Li_2O = (2 x 6.9 + 16.0) g mol^{-1}
= 29.8 g mol^{-1}

Number of moles of Li_2O = $\dfrac{\text{mass}}{\text{molar mass}}$

= $\dfrac{1.49\ g}{29.8\ g\ mol^{-1}}$

= 0.0500 mol

According to the equation, 1 mole of Li_2O requires 2 moles of HCl for complete neutralisation.

i.e. number of moles of HCl
= 2 x 0.0500 mol
= 0.100 mol

Volume of HCl

= $\dfrac{\text{number of moles of HCl}}{\text{concentration of HCl}}$

= $\dfrac{0.100\ mol}{0.800\ mol\ dm^{-3}}$

= 0.125 dm^3
= 125 cm^3

Topic Exercise (p.150)

7 Calcium phosphate is insoluble in water. What is the theoretical number of moles of calcium phosphate obtained when 100.0 cm^3 of 0.30 mol dm^{-3} $CaCl_2(aq)$ is mixed with 300.0 cm^3 of 0.10 mol dm^{-3} $Na_3PO_4(aq)$?
(Relative atomic masses: O = 16.0, Na = 23.0, P = 31.0, Cl = 35.5, Ca = 40.1)

A 0.010
B 0.015
C 0.020
D 0.030

(HKDSE, Paper 1A, 2017, 10)

Answer: A

Topic Exercise (p.150)

8 Which of the following statements concerning aqueous ammonia is / are correct?

(1) It contains both ammonia molecules and hydroxide ions.

(2) It is commonly used as the active ingredient in drain cleansers.

(3) It gives a colourless solution with methyl orange.

A (1) only

B (2) only

C (1) and (3) only

D (2) and (3) only

Explanation:

(2) Sodium hydroxide is commonly used as the active ingredient in drain cleansers.

(3) Aqueous ammonia gives a yellow solution with methyl orange.

Answer: A

Topic Exercise (p.150)

9 Which of the following pairs of aqueous solutions will produce precipitates when mixed?

(1) Copper(II) chloride and magnesium sulphate
(2) Potassium carbonate and calci um nitrate
(3) Zinc sulphate and barium chloride

A (1) and (2) only
B (1) and (3) only
C (2) and (3) only
D (1), (2) and (3)

Explanation:
(2) Aqueous solutions of potassium carbonate and calcium nitrate produce a precipitate (calcium carbonate) when mixed.
(3) Aqueous solutions of zinc sulphate and barium chloride produce a precipitate (barium sulphate) when mixed.

Answer: C

Topic Exercise (p.150)

10 Which of the following can distinguish a sample of $AgNO_3$(aq) from a sample of $NaNO_3$(aq)?

(1) Adding $Cu(NO_3)_2$(aq) to the samples
(2) Adding HCl(aq) to the samples
(3) Adding KOH(aq) to the samples

A (1) and (2) only
B (1) and (3) only
C (2) and (3) only
D (1), (2) and (3)

Answer: C

Topic Exercise (p.150)

11 Consider the three substances below:

potassium carbonate solution
sodium chloride solution
dilute sulphuric acid

Which of the following reagents can be used to distinguish the above three substances?

(1) Acidified silver nitrate solution
(2) Dilute aqueous ammonia
(3) Dilute nitric acid

A (1) only
B (2) only
C (1) and (3) only
D (2) and (3) only

Explanation:

(1) Potassium carbonate solution gives effervescence with acidified silver nitrate solution.
Sodium chloride solution gives a white precipitate with acidified silver nitrate solution.

Answer: A

Topic Exercise (p.150)

Directions: *Each question (Questions 12–15) consists of two separate statements. Decide whether each of the two statements is true or false; if both are true, then decide whether or not the second statement is a correct explanation of the first statement. Then select one option from A to D according to the following table :*
A Both statements are true and the 2nd statement is a correct explanation of the 1st statement. B Both statements are true but the 2nd statement is NOT a correct explanation of the 1st statement. C The 1st statement is false but the 2nd statement is true. D Both statements are false.

Topic Exercise (p.150)

12 <u>1st statement</u>

Solid citric acid can react with magnesium to give hydrogen gas.

<u>2nd statement</u>

Solid citric acid contains hydrogen ions.

Explanation:
Solid citric acid CANNOT react with magnesium.
Solid citric acid does NOT contain hydrogen ions.

Answer: D

Topic Exercise (p.150)

13 1st statement

1 mol dm^{-3} sulphuric acid can react with copper but 1 mol dm^{-3} ethanoic acid cannot.

2nd statement

Sulphuric acid is a stronger acid than ethanoic acid.

Explanation:

Both 1 mol dm^{-3} sulphuric acid and 1 mol dm^{-3} ethanoic acid do NOT react with copper.

Answer: C

Topic Exercise (p.150)

14 1st statement

To completely neutralise 1 mole of HCl(aq), the number of moles of NH_3(aq) needed is more than the number of moles of KOH(aq) needed.

2nd statement

NH_3(aq) is a weaker alkali than KOH(aq).

(HKDSE, Paper 1A, 2018, 24)

Answer: C

Topic Exercise (p.150)

15 1st statement

All acidic gases can react with $CaO(s)$ to form salt and water only.

2nd statement

All acidic gases contain hydrogen as one of their constituent atoms.

(HKDSE, Paper 1A, 2014, 24)

Answer: D

Topic Exercise (p.150)

PART II STRUCTURED QUESTIONS

16 A student proposed the following methods to accomplish three tasks. The proposed methods were all considered inappropriate.

	Task	Proposed method
1	To neutralise acidic soil in a flower bed.	Add solid sodium hydroxide to the soil.
2	To prepare potassium chloride.	Add excess potassium to dilute hydrochloric acid.
3	To dry a sample of ammonia gas.	Pass the sample of ammonia gas through concentrated sulphuric acid.

For each task,

a) state ONE reason why the method is inappropriate; and

b) suggest an appropriate method to accomplish the task.

Task 1

a) Sodium hydroxide is corrosive. (1)

b) Use calcium hydroxide instead. (1)

Task 2

a) An explosive reaction occurs between potassium and dilute hydrochloric acid. (1)

b) Use potassium hydroxide solution and dilute hydrochloric acid via the titration method. (1)

Task 3

a) Reaction occurs between ammonia and concentrated sulphuric acid. (1)

b) Use calcium oxide. (1)

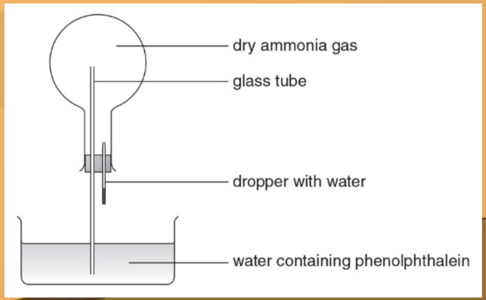
Topic Exercise (p.150)

17 This question involves the preparation of ammonia gas and the investigation of the properties of ammonia gas in a laboratory.

a) Solid calcium hydroxide reacts with solid ammonium chloride to form ammonia gas. Draw a labelled diagram to show the set-up involved and how ammonia gas is collected.

b) An experiment was performed to investigate the properties of ammonia gas with the set-up shown below:

The round-bottomed flask was initially full of dry ammonia gas. Several drops of water were injected into the flask from the dropper. The water containing phenolphthalein was then automatically sucked into the flask through the glass tube.



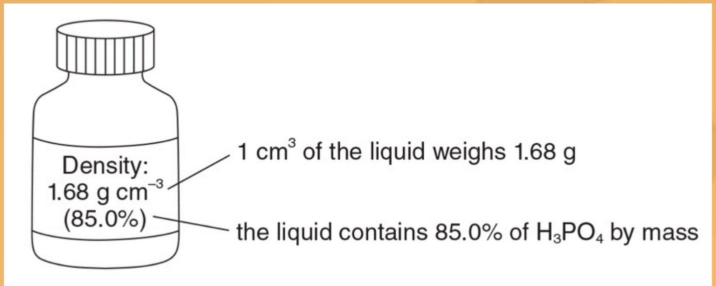
i) Briefly explain why the water containing phenolphthalein was sucked into the flask.

ii) State, with explanation, an observation related to phenolphthalein in the flask.

(HKDSE, Paper 1B, 2018, 2)

Topic Exercise (p.150)

18 A bottle of concentrated phosphoric acid $H_3PO_4(aq)$ is shown below:



a) Circle a hazard warning label that should be displayed on a bottle of concentrated phosphoric acid.

(1)

b) State a safety measure in handling concentrated phosphoric acid in laboratories.

Wear safety glasses / wear protective gloves / handle in fume cupboard. (1)

Topic Exercise (p.150)

18 (continued)

c) According to the information on the label, calculate the concentration of the concentrated phosphoric acid in mol dm^{-3}.
(Relative atomic masses: H = 1.0, O = 16.0, P = 31.0)

Mass of 1 000 cm^3 of acid
= 1.68 g cm^{-3} x 1 000 cm^3
= 1 680 g
Mass of H_3PO_4 in 1 000 cm^3 of acid
= 1 680 g x 85.0%
= 1 430 g
Molar mass of H_3PO_4
= (3 x 1.0 + 31.0 + 4 x 16.0) g mol^{-1}
= 98.0 g mol^{-1}
Number of moles of H_3PO_4 in 1 000 cm^3

$$= \frac{\text{mass}}{\text{molar mass}}$$

$$= \frac{1\,430\text{ g}}{98.0\text{ g mol}^{-3}}$$

= 14.6 mol

Concentration of phosphoric acid

$$= \frac{\text{number of moles of } H_3PO_4}{\text{volume of acid}}$$

$$= \frac{14.6\text{ mol}}{\frac{1\,000}{1\,000}\text{ dm}^{-3}}$$

= 14.6 mol dm^{-3}
∴ the concentration of the phosphoric acid is 14.6 mol dm^{-3}.

Topic Exercise (p.150)

19 Methanoic acid (HCOOH) can be used to dissolve 'lime scale' in kettles. The concentration of a sample of methanoic acid used for this purpose can be found by a titration using sodium hydroxide solution.

For this purpose, 25.00 cm^3 of methanoic acid were diluted to 250.0 cm^3. 25.00 cm^3 portions of the diluted methanoic acid was titrated with 0.224 mol dm^{-1} NaOH(aq). An average of 29.90 cm^3 of NaOH(aq) was needed to reach the titration end point.

a) Describe how the titration should be carried out.

- Fill a burette with NaOH(aq). Record the initial burette reading. (1)
- Use a pipette to measure out 25.00 cm^3 of the diluted methanoic acid and carefully transfer it into a conical flask. (1)
- Add a few drops of indicator to the conical flask. Put the flask on a white tile under the burette. (1)
- Run NaOH(aq) from the burette into the diluted methanoic acid until the indicator changes colour, showing that the acid is neutralised. Record the final burette reading. (1)

Topic Exercise (p.150)

19 (continued)

b) Suggest a suitable indicator for the titration and state the expected colour change at the end point.

Phenolphthalein (1)

From colourless to just pink (1)

c) Methanoic acid reacts with NaOH(aq) according to the equation below.

$HCOOH(aq) + NaOH(aq) \longrightarrow HCOONa(aq) + H_2O(l)$

i) Based on the titration result, calculate the number of moles of NaOH used for complete neutralisation of 25.00 cm^3 of the diluted methanoic acid.

$HCOOH(aq) + NaOH(aq) \longrightarrow HCOONa(aq) + H_2O(l)$

25.00 cm^3 0.224 mol dm^{-3}

↓ 29.90 cm^3

250.0 cm^3

↓

(used) 25.00 cm^3

Number of moles of NaOH for complete neutralisation of 25.00 cm^3 of diluted methanoic acid

= molarity of solution x volume of solution

= 0.224 mol dm^{-3} x $\frac{29.90}{1\ 000}$ dm^3

= 6.70 x 10^{-3} mol (1)

Topic Exercise (p.150)

19 (continued)

c) ii) Calculate the concentration of the original methanoic acid in mol dm^{-3}.

According to the equation, 1 mole of HCOOH requires 1 mole of NaOH for complete neutralisation. i.e. number of moles of HCOOH in 25.00 cm^3 diluted methanoic acid
= 6.70×10^{-3} mol
Number of moles of HCOOH in 250.0 cm^3 of diluted methanoic acid
= $10 \times 6.70 \times 10^{-3}$ mol
= 6.70×10^{-2} mol
= number of moles of HCOOH in 25.00 cm^3 of original methanoic acid

$$\text{Concentration of original methanoic acid} = \frac{\text{number of moles of HCOOH}}{\text{volume of solution}}$$

$$= \frac{6.70 \times 10^{-2}\ \text{mol}}{\frac{25.00}{1\,000}\ \text{dm}^3}$$

$$= 2.68\ \text{mol dm}^{-3}$$

∴ the concentration of the original methanoic acid is 2.68 mol dm^{-3}.

Topic Exercise (p.150)

*20 Explain, with the aid of a chemical equation, why NH_3(aq) is regarded as a weak alkali. Suggest how you would show that NH_3(aq) is a weaker alkali than NaOH(aq) through an experiment.

(HKDSE, Paper 1B, 2015, 5)

Answers for the questions of the public examinations in Hong Kong are not provided (if applicable).

Topic Exercise (p.150)

*21 Outline the steps in preparing zinc nitrate from zinc carbonate. You have state the additional chemical reagents that are required, but you need NOT mention the apparatus involved.

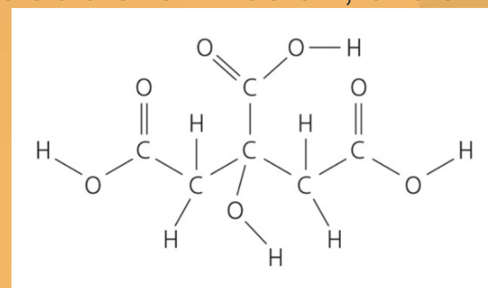
- Add an excess of zinc carbonate to dilute nitric acid. Allow to react. (1)
- Filter off the remaining solid. Collect the filtrate. (1)
- Heat the filtrate gently to evaporate the water and concentrate the zinc nitrate solution. (1)
- Allow the concentrated zinc nitrate solution to cool to room temperature to let the crystals form. (1)
- Filter off the crystals. Wash with a small amount of cold deionised water. Dry the crystals between two pieces of filter paper. (1)

Communication mark (1)

Topic Exercise (p.150)

22 Citric acid is a tribasic acid found in lemon. It is a white solid and soluble in water.

a) In the structure of citric acid shown below, circle ALL ionisable hydrogen atom(s) making it a tribasic acid.



b) A solid sample contained citric acid and other soluble inert substances. 1.65 g of the sample was dissolved in deionised water and diluted to 250.0 cm^3 in apparatus X. After that, 25.00 cm^3 of the diluted solution was withdrawn and titrated with 0.123 M NaOH(aq) using phenolphthalein as an indicator. 18.45 cm^3 of the NaOH(aq) was required to reach the end point.

(Molar mass of citric acid = 192.0 g)

i) What is apparatus X?

ii) Calculate the percentage by mass of citric acid in the solid sample.

c) A few drops of lemon juice are added to sodium hydrogencarbonate powder.

i) State the expected observation.

ii) Write the ionic equation for the reaction involved.

(HKDSE, Paper 1B, 2016, 6)

Answers for the questions of the public examinations in Hong Kong are not provided (if applicable).

Topic Exercise (p.150)

23 Concentrated sulphuric acid is a reagent commonly found in laboratories. In order to determine the concentration of a sample of concentrated sulphuric acid, 5.00 cm^3 of the sample was diluted to 1 000.0 cm^3 with deionised water. Portions of 25.00 cm^3 of the diluted sample were titrated with 0.189 mol dm^{-3} NaOH(aq) using methyl orange as an indicator. An average of 22.20 cm^3 of NaOH(aq) was used to reach the end point.

a) Explain why concentrated sulphuric acid should NOT be titrated directly with NaOH(aq).

b) State the colour change at the end point of the titration.

c) Calculate the concentration of the sample of concentrated sulphuric acid, in mol dm^{-3}.

Answers for the questions of the public examinations in Hong Kong are not provided (if applicable).

(HKDSE, Paper 1B, 2017, 6(b))

Topic Exercise (p.150)

24 A student carried out an experiment to identify an unknown carbonate. For this purpose, the student prepared a solution of the unknown carbonate using the procedure below.

- The student weighed a sample of the solid carbonate in a weighing bottle.
- The student tipped the carbonate into a beaker and then weighed the empty weighing bottle.
- The student dissolved the carbonate in approximately 50 cm^3 of deionised water in a beaker and transferred the solution to a volumetric flask. The volume of the solution was made up to 100.0 cm^3 with deionised water.

a) Another student suggested two possible sources of error:
- A small amount of solid remained in the weighing bottle.
- A small amount of solution remained in the beaker.

i) State whether the other student's statements were correct.

NOT correct about the solid remaining in the weighing bottle (weighed by difference).(1)
Correct about the solution remaining in the beaker. (1)

Topic Exercise (p.150)

24 (continued)

a) i) How could the procedure be improved?

Rinse the beaker with deionised water. Pour all the washings into the volumetric flask before making up to 100.0 cm. (1)

The student titrated portions of 10.00 cm^3 of the diluted carbonate solution with 0.108 mol dm^{-3} hydrochloric acid. The titration results are shown in the table below.

Reading (cm^3)	Titration number			
	1 (trial)	2	3	4
Final burette reading	30.55	28.75	28.75	28.75
Initial burette reading	0.00	0.05	0.00	0.00
Titre	30.55	28.70	28.75	28.75

b) Suggest a suitable indicator for the titration and state the expected colour change at the end point.

Methyl orange (1)
From yellow to orange (1)

Topic Exercise (p.150)

24 (continued)

c) Suggest why the student carried out a trial (a rough titration).

Any one of the following:

- So that in accurate titration, a certain volume of HCl(aq) could be added quickly before adding drop by drop. (1)
- To save time before doing accurate titrations. (1)
- To give a rough idea of what the titre is. (1)

d) Calculate the mean titre.

$$\text{Mean titre} = \frac{28.70 + 28.75 + 28.75}{3} \text{ cm}^3$$

$$= 28.73 \text{ cm}^3 \quad (1)$$

Topic Exercise (p.150)

24 (continued)

e) The equation below represents the reaction between the carbonate and hydrochloric acid.

$M_2CO_3(aq) + 2HCl(aq) \longrightarrow 2MCl(aq) + H_2O(l) + CO_2(g)$

i) Calculate the number of moles of M_2CO_3 used in the titration.

$M_2CO_3(aq) + 2HCl(aq) \longrightarrow 2MCl(aq) + H_2O(l) + CO_2(g)$

100.0 cm^3 0.108 mol dm^{-3}

↓ 28.73 cm^3

(used) 10.00 cm^3

Number of moles of HCl in 28.73 cm^3 solution

= molarity of solution x volume of solution

$= 0.108 \text{ mol dm}^{-3} \times \frac{28.73}{1\,000} \text{ dm}^3$

$= 3.10 \times 10^{-3}$ mol (1)

According to the equation, 1 mole of M2CO3 requires 2 moles of HCl for complete reaction.

i.e. number of moles of M_2CO_3 used in titration = $\frac{3.10 \times 10–3}{2}$ mol

$= 1.55 \times 10^{-3}$ mol (1)

Topic Exercise (p.150)

24 (continued)

ii) The student's mass readings are recorded below.

Mass of weighing bottle + carbonate (g)	16.92
Mass of weighing bottle + any traces of carbonate (g)	14.78

Use the student's results to identify the carbonate, M_2CO_3. (Refer to the Periodic Table.)

(Relative atomic masses: C = 12.0, O = 16.0)

Mass of M_2CO_3 used = (16.92 – 14.78) g = 2.14 g

Number of moles of M_2CO_3 in 100.0 cm^3 solution

= 10 x 1.55 x 10^{-3} mol = 1.55 x 10^{-2} mol

= number of moles of M_2CO_3 in 2.14 g sample

Let *m* be the relative atomic mass of M.

Molar mass of M_2CO_3 = (2*m* + 12.0 + 3 x 16.0) g mol^{-1}

= (2*m* + 60.0) g mol^{-1}

Number of moles of M_2CO_3 in 2.14 g sample =

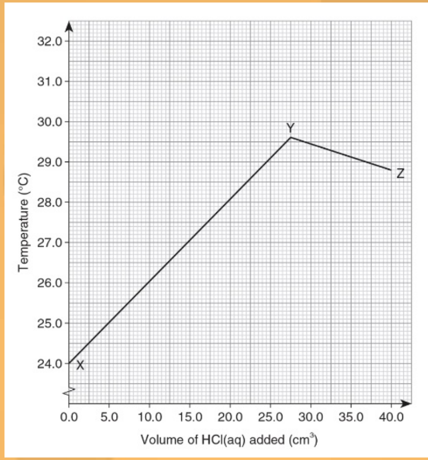
$$1.55 \times 10^{-2} \text{ mol} = \frac{2.14 \text{ g}}{(2m + 60.0) \text{ g mol}^{-1}} \quad (1)$$

m = 39.0 (1)

∴ M is potassium. (1)

Topic Exercise (p.150)

25 In an experiment, 40.0 cm^3 of 1.20 mol dm^{-3} hydrochloric acid were added, 5.0 cm^3 at a time, to 50.0 cm^3 of sodium hydroxide solution in a polystyrene cup. The temperature of the solution mixture was recorded after each addition. The graph below shows the experimental results:



a) Explain the change in temperature in the following stages:

i) From X to Y

Neutralisation is exothermic. Temperature of the solution mixture rose when hydrochloric acid was added to the sodium hydroxide solution. (1)
When the sodium hydroxide was just completely reacted, the temperature reached a maximum value. No more heat was produced. (1)

ii) From Y to Z

After complete neutralisation of the alkali, the addition of excess cold hydrochloric acid lowered the temperature of the solution mixture. (1)

Topic Exercise (p.150)

25 b) Calculate the molarity of the sodium hydroxide solution used.

$NaOH(aq) + HCl(aq) \longrightarrow NaCl(aq) + H_2O(l)$

? mol dm^{-3} 1.20 mol dm^{-3}

50.0 cm^3 27.50 cm^3

Number of moles of HCl in 27.50 cm^3 solution = molarity of solution x volume of solution

$= 1.20 \text{ mol dm}^{-3} \times \frac{27.50}{1\,000} \text{ dm}^3$

$= 0.0330 \text{ mol}$

According to the equation, 1 mole of NaOH requires 1 mole of HCl for complete neutralisation.

i.e. number of moles of NaOH in 50.0 cm^3 solution = 0.0330 mol

$$\text{Molarity of sodium hydroxide solution} = \frac{\text{number of moles of NaOH}}{\text{volume of solution}}$$

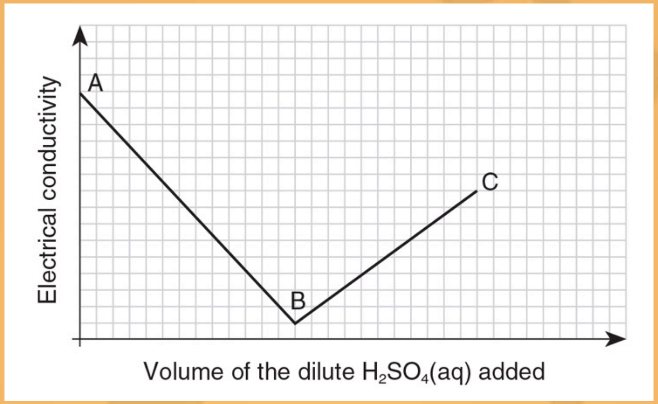
$$= \frac{0.0330 \text{ mol}}{\frac{50.0}{1\,000} \text{ dm}^3}$$

$$= 0.660 \text{ mol dm}^{-3}$$

∴ the molarity of the sodium hydroxide solution is 0.660 mol dm^{-3}.

Topic Exercise (p.150)

26 An experiment was carried out to study the change in electrical conductivity of the mixture formed when a dilute H_2SO_4(aq) was added gradually to a fixed volume of a dilute $Ba(OH)_2$(aq). The graph below shows the results of the experiment.



a) State the expected observation when dilute H_2SO_4(aq) is added to dilute $Ba(OH)_2$(aq).

b) Explain the change of electrical conductivity in the following stages:

i) From A to B

ii) From B to C

(HKDSE, Paper 1B, 2017, 1(c))

Answers for the questions of the public examinations in Hong Kong are not provided (if applicable).

Topic Exercise (p.150)

27 The following experiment was carried out to determine the percentage by mass of calcium carbonate in a brand of toothpaste.

Step 1 0.170 g of toothpaste was placed in a conical flask.
Step 2 10.0 cm^3 of 0.160 mol dm^{-3} hydrochloric acid were added to the conical flask.
Step 3 The contents of the conical flask were heated gently on a hot plate for 5 minutes.
Step 4 The contents of the conical flask were cooled to room temperature. Two drops of methyl orange were added.
Step 5 Excess hydrochloric acid in the conical flask was titrated with 0.0800 mol dm^{-3} NaOH(aq). 11.75 cm^3 of NaOH(aq) were required to reach the end point.

a) Name a suitable apparatus for transferring 10.0 cm^3 of the hydrochloric acid in *Step 2*.
Pipette (1)

b) State the colour change of the indicator at the titration end point.
From red to orange (1)

Topic Exercise (p.150)

27 (continued)

c) Calculate the number of moles of excess HCl in the conical flask from the data obtained in the titration.

$NaOH(aq) + HCl(aq) \longrightarrow NaCl(aq) + H2O(l)$

$0.0800 \text{ mol dm}^{-3}$

11.75 cm^3

Number of moles of NaOH in 11.75 cm^3 solution = molarity of solution x volume of solution

$$= 0.0800 \text{ mol dm}^{-3} \times \frac{11.75}{1\,000} \text{ dm}^3$$

$$= 9.40 \times 10^{-4} \text{ mol} \quad (1)$$

According to the equation, 1 mole of HCl requires 1 mole of NaOH for complete neutralisation.

i.e. number of moles of excess HCl in conical flask = 9.40×10^{-4} mol (1)

Topic Exercise (p.150)

27 (continued)

d) Assuming other substances in the toothpaste are inert to acid and alkali, calculate the percentage by mass of calcium carbonate in the toothpaste.
(Relative atomic masses: C = 12.0, O = 16.0, Ca = 40.1)

Number of moles of HCl added in *Step 2* = molarity of solution x volume of solution

$= 0.160 \text{ mol dm}^{-3} \times \frac{10.0}{1\,000} \text{ dm}^3$

$= 1.60 \times 10^{-3}$ mol

Number of moles of HCl reacted with $CaCO_3$ in toothpaste

$= (1.60 \times 10^{-3} - 9.40 \times 10^{-4})$ mol

$= 6.60 \times 10^{-4}$ mol (1)

$CaCO_3(s) + 2HCl(aq) \longrightarrow CaCl_2(aq) + H_2O(l) + CO_2(g)$

According to the equation, 1 mole of $CaCO_3$ requires 2 moles of HCl for complete reaction.

i.e. number of moles of $CaCO_3$ in toothpaste $= \frac{6.60 \times 10–4}{2}$ mol

$= 3.30 \times 10^{-4}$ mol (1)

Molar mass of $CaCO_3$ = (40.1 + 12.0 + 3 x 16.0) g mol^{-1} = 100.1 g mol^{-1}

Mass of $CaCO_3$ in toothpaste = number of moles x molar mass

$= 3.30 \times 10^{-4} \text{ mol} \times 100.1 \text{ g mol}^{-1} = 0.0330$ g

Percentage by mass of $CaCO_3$ in toothpaste $= \frac{0.0330 \text{ g}}{0.170 \text{ g}} \times 100\%$

= 19.4% (1)

∴ the percentage by mass of calcium carbonate in the sample of toothpaste is 19.4%.

Topic Exercise (p.150)

*28 Three unlabelled reagent bottles each contains one of the white solids listed below:

$ZnSO_4$ $MgSO_4$ $MgSO_4 \cdot 7H_2O$

Outline how you would carry out tests to distinguish these three solids.

Answers for the questions of the public examinations in Hong Kong are not provided (if applicable).

(HKDSE, Paper 1B, 2016, 9)

Topic Exercise (p.150)

*29 Students work together in groups to identify four different solutions. Each solution contains one of the following compounds:

- ammonium sulphate, $(NH_4)_2SO_4$;
- sodium sulphate, Na_2SO_4;
- sodium carbonate, Na_2CO_3;
- potassium chloride, KCl.

Your group has been provided with red litmus paper and the following test reagents:

- barium chloride solution;
- silver nitrate solution;
- dilute hydrochloric acid;
- dilute sodium hydroxide solution.

Describe how you could distinguish the four solutions. Your tests should produce at least one positive result for each solution.

Topic Exercise (p.150)

*29 (continued)

To identify ammonium sulphate solution

Warm each solution with dilute sodium hydroxide solution separately. (1)

Ammonium sulphate solution gives a gas that turns moist red litmus paper blue.
The other three solutions give no observable change. (1)

To identify sodium carbonate solution (1)

Add dilute hydrochloric acid to each of the three remaining solutions separately.
Sodium carbonate solution gives effervescence.
The other two solutions give no observable change. (1)

To identify potassium chloride solution (1)

Add silver nitrate solution to each of the two remaining solutions separately.
Potassium chloride solution gives a white precipitate.
Sodium sulphate solution gives no observable change. (1)

To identify sodium sulphate solution (1)

Add barium chloride solution to the remaining solution. (1)

Sodium sulphate solution gives a white precipitate. (1)

Communication mark (1)