Chapter 1: Masses, moles and atoms

Chapter outline

This chapter relates to Chapter 1: Moles and equations, Chapter 2: Atomic structure and Chapter 3: Electrons in atoms in the coursebook.

In this chapter learners will complete practical investigations on:

- 1.1 Empirical formula of hydrated copper(II) sulfate crystals
- 1.2 Relative atomic mass of magnesium using molar volumes
- 1.3 Percentage composition of a mixture of sodium hydrogen carbonate and sodium chloride
- 1.4 Relative atomic mass of calcium by two different methods: molar volume and titration

Practical investigation 1.1: Empirical formula of hydrated copper(II) sulfate crystals

Introduction

In this investigation learners determine the empirical formula (see Chapter 1 of the coursebook) of hydrated copper(II) sulfate by finding the value of **x** in $CuSO_4.\mathbf{x}H_2O$. They weigh out some hydrated copper(II) sulfate in an evaporating basin, heat it to constant mass, determine the mass of water present in their sample and then find the molar ratio: $CuSO_4 : H_2O$.

Skills focus

The following skill areas are developed and practised (see the skills grids at the front of this guide for codes):

MMO	Collection of data and observations: (a), (b), (c), (d) and (e) Decisions relating to measurements of observations: (a), (b) (c) and (d)
PDO	Recording data and observations: (e) Display of calculations and reasoning: (a) and (b) Data layout: (b), (c), (d), (e) and (f)
ACE	Data interpretation and sources of error: (c) and (d) Drawing conclusions: (c) Suggesting improvements: (a)

Duration

This investigation should take no more than 1 h to complete. However, as it is the first time learners will have completed error calculations you may need another hour to go through the errors involved.

Preparing for the investigation

- Learners should be made aware of the 'Skills Chapter' and how it informs them about the techniques they will be using.
- They will also need to have an awareness of the sources of errors.
- Learners will need to understand the concept of an empirical formula and be able to calculate the number of moles present.
- They should revise the concepts of moles and molar ratios.

Equipment

Each learner or group will need:

- a pipe-clay triangle
- an evaporating basin
- Bunsen burner and tripod
- tongs
- glass stirring rod
- two heat-resistant pads
- spatula

Access to:

- a supply of gas
- a top-pan balance that reads to at least two decimal places

Safety considerations

- Learners must wear eye protection at all times in this experiment and tie back long hair.
- When weighing the evaporating basin and copper sulfate the learners should place it on the extra heat-resistant mat and then carry it across to the top-pan balance.
- The copper(II) sulfate is an environmental hazard and should be recycled. It can be used as a test for water or dissolved in water and recrystallised. It could also be used in a Hess' Law determination.

Carrying out the investigation

- They may need help to understand what is meant by 'water of crystallisation' and how it is loosely bound to the copper(II) sulfate and that the number of water molecules per formula is a whole number.
- Assuming that the length of the practical time available is about 1 h then this is sufficient time for each group to do one determination.
- Allocate a given mass to each group. It is a good idea to give the larger masses of copper sulfate to the more able learners or more patient ones because they will obviously need more time in heating the copper(II) sulfate to give the anhydrous form.
- If they heat the copper sulfate properly there will be some at the beginning that will stick to the stirring rod and the basin and when this ceases to happen it shows that they are removing the water from the salt.
- The anhydrous salt should be as near white as possible but may have a greyish tinge after the heating is finished and constant mass is obtained.
- Ensure that if more than one balance is used, the learners should use the same balance throughout. By doing this any errors in the balances are reproducible.

  Some learners will need help on why some points on their graph lie above and below the line.
- Some will also need help on heating the copper(II) sulfate as gently as possible (see above) so will need to be trained on how to adjust the Bunsen flame to a very low level.
- Learners who struggle with the practical, especially the theoretical part, should be given the lowest value masses so that their heating is over quickly and they can start processing their results.

  More able learners should, if possible, be allowed to work on their own.

Common learner misconceptions

- When instructed to 'heat gently' some learners will still use a yellow flame.

Sample results

Mass of crystals/g	Mass of anhydrous copper(II) sulfate/g
0.20	0.12
0.50	0.32
0.80	0.51
2.50	1.60

Table 1.1

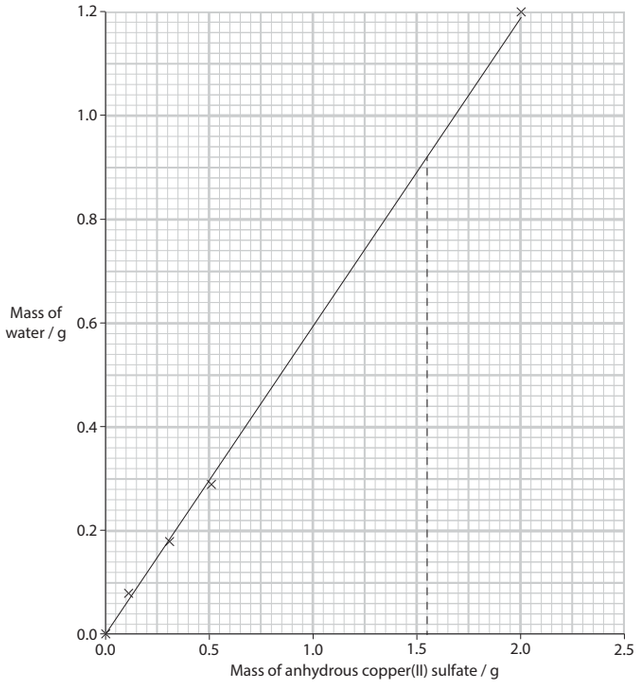

Figure 1.1

Answers to the workbook questions (using the sample results)

a & b It is quite easy to get a set of results that give the ideal answer for this practical (see Table 1.1 and Figure 1.1).

c As can be seen from the graph, the mass of water that combines with 1.60 g of copper(II) sulfate is 0.90 g

d Results shown in Table 1.2

	Copper(II) sulfate ($CuSO_4$)	Water (H_2O)
Mass/g	1.60	0.90
Number of moles	$\frac{1.60}{159.6} = 0.0100$	$\frac{0.90}{18} = 0.0500$
Simplest ratio (divide by lowest number)	$\frac{0.0100}{0.0100} = 1$	$\frac{0.0500}{0.0100} = 5$

Table 1.2

e This means that the formula for the hydrated copper(II) sulfate is $CuSO_4.5H_2O$

f 0, 0 because if there is no copper(II) sulfate then there will be no water attached to it.

g **i** If a point lies **above the line** then it could have been heated too much and the copper (II) sulphate has decomposed to some extent.

ii If a point lies **below the line** there has been insufficient heating of the crystals and the water of crystallisation is still attached to them. However, it could be that the heated solid has been left to cool and absorbed water from the atmosphere.

h The best alternative is to use an oven. The temperature of the oven can be adjusted to one where the water of crystallisation will be removed but it will not be hot enough to decompose the copper(II) sulfate. Using a Bunsen burner cannot be sufficiently accurate. A possible way of determining the Bunsen burner temperature is to use a thermocouple to give a reading of the temperature. Even using this method is inaccurate because any slight change in the extent to which the air hole is opened will lead to a change in temperature.

Practical Investigation 1.2:
Relative atomic mass of magnesium using molar volumes

Skills focus

The following skill areas are developed and practised (see the skills grids at the front of this guide for codes):

MMO	Collection of data and observations (a), (b), (c), (d) and (e) Decisions relating to measurements of observations (c) and (d)
PDO	Recording data and observations (a) and (e) Display of calculations and reasoning (a) and (b) Data layout (b), (c), (d), (e) and (f)
ACE	Data interpretation and sources of error (c), (d), (h), (i) and (j) Drawing conclusions (a) and (c)

Duration

This investigation should take approximately 1.5 h to complete.

Preparing for the investigation

- Learners should, ideally, have a good understanding of moles and molar volumes. The crucial relationships are:

$$A_r = \frac{\text{mass } (m)}{\text{number of moles } (n)} \text{ and } n = \frac{\text{Volume of gas in cm}^3}{24\,000}$$

Equipment

Each learner or group will need:

- either a trough;
  a selection of measuring cylinders (10 cm^3; 25 cm^3 and 50 cm^3); OR a 100 cm^3 gas syringe
- 150 cm^3 conical flask with retort stand, boss and clamp
- small piece of steel wool
- 25 cm^3 measuring cylinder for acid
- one 10.0 cm length of magnesium ribbon
- 30 cm ruler
- plastic gloves (see safety considerations)

Access to:

- a top-pan balance reading to **at least** two decimal places
- 2 mol dm^{-3} hydrochloric acid

Alternative equipment

- Of the two sets of apparatus suggested, the easiest to set up is the one using the gas syringe. However, if gas syringes are not available, then the displacement of water in a measuring cylinder works very well.

Safety considerations

- Learners must wear eye protection at all times and tie hair back if it is long.
- Magnesium is highly flammable.
- Hydrogen is a flammable gas.
- 2 mol dm^{-3} hydrochloric acid is an irritant.
- Steel wool sometimes splinters and some learners could be quite sensitive to this. To lower the risk plastic gloves should be worn when using the steel wool to clean the magnesium.

Carrying out the investigation

- The point of weighing out 10 cm lengths of magnesium ribbon is that 10 cm will give a valid reading on the top-pan balance, especially if the balance reads to only two decimal places. The masses of the shorter lengths are then calculated using the relationship:
  $\text{mass} = \frac{\text{length}}{10} \times \text{mass of 10 cm length.}$
- Please note that if learners are measuring the gas volume by displacement of water, the first problem to overcome is making sure that the measuring cylinder is full of water when it is put in the trough and that none or very little escapes. This can be done by either learners holding their hands over the end of the measuring cylinder or placing a piece of plastic wrap over the open end and then turn the measuring cylinder upside down when it is in the trough. Remember to remove the film before starting the actual measurement. A boiling tube will do as well as a conical flask for the reaction vessel.
- The main problem with the practical is the purity of the magnesium ribbon. If you have fresh ribbon then omit the cleaning. If it is visibly oxidised then it will need cleaning and that is done using the steel wool. This should be done by holding the ribbon using the wool and then drawing it through. Once should be enough. Any more than that will lead to irregularities in the thickness of the ribbon and inaccuracy when estimating the masses of the individual lengths.

  Evaluation of a practical method always presents problems to learners and they will need help when estimating the percentage error due to using different apparatus.
- Before the practical, a short demonstration will give learners some idea of the volumes of gas that they will be dealing with. This can be their trial run but more able learners can be asked to do this for themselves. If the volume of gas for a 1 cm length of ribbon is found then they should be able to estimate the volumes for the other lengths and adjust their choice of measuring cylinder (if these are used) accordingly.

  If learners are measuring the gas volume by displacement of water then they can be marked on which measuring cylinder they use for the most accurate measurements of gas volumes.
- Learners can be asked to analyse their results in Microsoft Excel or a similar data-handling application.

Sample results

Mass of 10 cm length of magnesium ribbon = 0.160 g

The results from one set of measurements are shown in Table 1.3

Length of Mg ribbon/cm	Mass of Mg/g	Expt. 1	Expt. 2	Average
0.00	0	0	0	0
0.50	0.008	8	8	8.0
1.00	0.016	16	17	16.5
1.50	0.024	23	25	24.0
2.00	0/032	30	31	30.5

Table 1.3

Answers to the workbook questions (using the sample results)

a Please see Figure 1.2

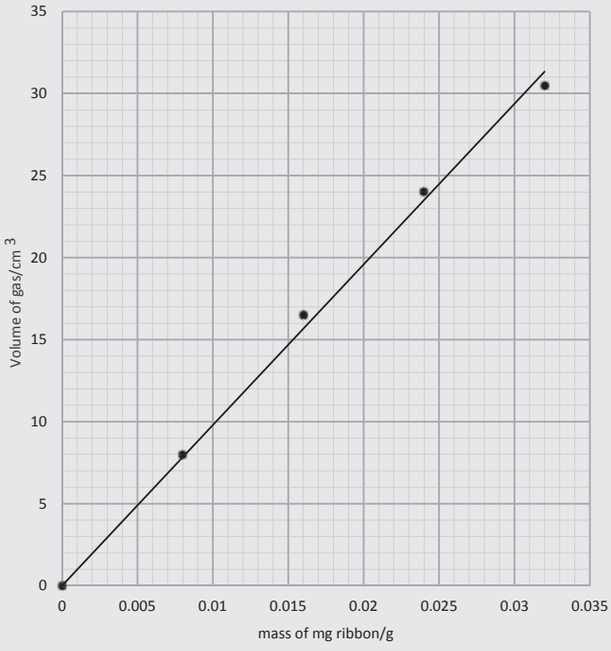

Figure 1.2

b Using Figure 1.2: 24.0 cm^3 of H_2 is produced from 0.0245 g of magnesium

c 24.0 cm^3 = $\frac{24}{24{,}000}$ mol = 0.001 mol of H_2= number of mol of magnesium

Therefore, mass of 1 mol

= $\frac{m}{n} = \frac{0.0245}{0.001}$ = 24.5 g mol^{-1}

d Percentage error = $\frac{|\text{Actual value} - \text{experimental value}|}{\text{Actual value}} \times 100$

= $\frac{24.5 - 24.3}{24.3} \times 100\% = 0.823\%$

The mass of 10 cm of magnesium ribbon is around 0.15–0.17 g.

In this experiment, the systematic errors come from the top-pan balance, the ruler and the measuring cylinder (or gas syringe).

e Maximum error from the top-pan balance

If the top-pan balance reads to 0.01 g then the maximum error can be estimated to be ±0.005 g. If we think our 10 cm length of magnesium will weigh in the region of 0.15 g then the percentage error = $2 \times \frac{0.005}{0.15} \times 100\% = 6.67\%$

f Percentage error from measurements of lengths

For example, if the length is 1 cm then the maximum percentage error is equal to $\frac{0.05}{1.0} \times 100\% = 5\%$

g Total error from length measurements

i The measurement of the lengths of magnesium ribbon. If we go by the rules that the maximum error or uncertainty is half the smallest possible measurement then the ruler reads to ±0.5 mm. The length measurements will give the greatest error.

ii If they use measuring cylinders, learners should be marked on their choice. For example, if they estimate from their trial run that they will obtain around 20 cm^3 from the reaction, then choosing a 50 cm^3 measuring cylinder that is graduated in 2.0 cm^3 divisions will give a maximum error of ±1.0 cm^3 (half the graduation's reading).

iii Total possible percentage error from apparatus readings. In this case, the maximum percentage error is $\frac{1}{20} \times 100\% = 5\%$. This error is halved if a 25 cm^3 measuring cylinder is used.

h Other factors that limit accuracy and contribute to the error

- Because of the cleaning by the steel wool, the thickness of the magnesium ribbon is not the same along its whole length.
- There may still be some oxide present even after cleaning.

Practical Investigation 1.3:
Percentage composition of a mixture of sodium hydrogen carbonate and sodium chloride

Introduction

In this investigation, learners will find the percentage composition of a mixture of sodium hydrogen carbonate and sodium chloride. They will do this by titrating the sodium hydrogen carbonate against standard hydrochloric acid.

Skills focus

The following skill areas are developed and practised (see the skills grids at the front of this guide for codes):

MMO	Collection of data and observations (a), (b), (c), (d) and (e) Decisions relating to measurements of observations: (a), (b) (d) and (e)
PDO	Recording data and observations (a), (c) and (e) Display of calculations and reasoning (a) and (b)
ACE	Data interpretation and sources of error (d) Drawing conclusions (a), (c) and (d) Suggesting improvements (a)

Duration

This investigation requires 1 h of preparation, including making up the solution of the mixture, then 1 h for the titrations and calculations.

Preparing for the investigation

- The volume of hydrochloric acid required can be calculated from the projected titre values. For example, if you calculate that the sodium hydrogen carbonate would require 17.00 cm^3 of acid for complete reaction, then if each learner or group does five titrations, 85 cm^3 is required and 100 cm^3 per learner/group would be an adequate allocation.

Equipment

Each learner or group will need:

- 150 cm^3 conical flask
- 250 cm^3 volumetric flask
- wash bottle of distilled water
- burette stand
- 25.0 cm^3 pipette
- white tile
- 250 cm^3 beaker and 100 cm^3 beaker
- stirring rod and small dropper
- small filter funnel for burette and larger one for volumetric flask
- weighing boat
- 50 cm^3 burette

Access to:

- a mixture of sodium hydrogen carbonate and sodium chloride. You can decide on the composition. If different classes are doing the same practical they can be given different mixtures to investigate.
- 0.100 mol dm^{-3} hydrochloric acid
- The volume of hydrochloric acid required can be calculated from the projected titre values. For example, calculations might show that the sodium hydrogen carbonate would require 17.00 cm^3 of acid for a complete reaction. Therefore, if each student or group does five titrations, 85 cm^3 is required and 100 cm^3 per student/group would be an adequate allocation.
- methyl orange indicator and dropper
- either a two or three place top-pan balance
- distilled water

Safety considerations

- They must wear eye protection and tie hair back if it is long.
- The acid is an irritant at the concentration used in the experiment.
- Methyl orange is poisonous. Wash off skin immediately.

Carrying out the investigation

- As far as the mixture is concerned, a typical calculation is as follows:

  i Let us suppose we want the titre to be 17.20 cm^3. Such a volume requires the learner to fill up their burette twice at most.

  ii The number of moles of sodium hydrogen carbonate present in 25.00 cm^3 is: $17.20 \times 10^{-3} \times 0.1 = 1.72 \times 10^{-3}$ mol

iii Therefore, in 250 cm^3 the learner has 1.72×10^{-2} mol or $1.72 \times 10^{-2} \times 84.1$ g = 1.445 g

iv If each learner requires 2.00 g of mixture, then the sodium chloride should contribute 2.00–1.45 g = 0.55 g.

v The percentage composition of the mixture = 72.5% $NaHCO_3$ and 27.5% NaCl. If you have 20 learners then you will need 20 x 2.00 g of mixture but allow for more because learners are still in the early stages of learning in detail about quantitative investigations and their technique may not yet be up to scratch.

vi Whatever is decided, there could be differences in the results obtained because the solid mixture may not be homogeneous. The only way to ensure complete homogeneity is to make up a solution of the mixture. This makes a very good discussion point at the end.

vii It is important that learners express the burette readings to ±0.05 cm^3. For example, if they get two readings such as 17.00 and 17.10, then the average is 17.05 because burettes usually read to 0.05 cm^3, which is one drop.

- Please be aware that learners tend to 'blow out' or expel the last drop of solution from their pipette. The pipette is calibrated so that this last remaining drop is not in the 25.00 cm^3 used.
- The end-point of the methyl orange is in fact an orange colour. If a red colour is obtained, then they have overshot.
- The biggest problem is how well you have mixed the sodium hydrogen carbonate and sodium chloride. It is not that big a problem because the apparatus used is overall very accurate and therefore the systematic errors are small. It is a random source of error and a source of an 'open question' at the end of the practical. A systematic error could be the learner who does the same thing wrong for every titration.

  As already mentioned, making the whole mixture into a solution would remove the possibility of random distribution of the solids. Ask them to put forward one way to overcome the problem and see if they come up with a plausible method.

Common learner misconceptions

- The most common error is that learners forget that 25 cm^3 is only $\frac{1}{10}$ th of the total amount of solution they have prepared.

Sample results

	Rough titration/cm^3	First accurate titration/cm^3	Second accurate titration/cm^3	Third accurate titration/cm^3
Final burette reading/cm^3	18.00	35.20	19.80	37.00
Starting burette reading/cm^3	0.00	18.00	2.20	19.80
Titre/cm^3	18.00	17.20	17.60	17.20

Table 1.4

Answers to workbook questions (using the sample results)

a Change in enthalpy of hydration of copper (II) sulfate

b i Volume of 0.100 mol dm^{-3} hydrochloric acid needed to react completely with the sodium hydrogen carbonate present in 25 cm^3 of the mixture = 17.20 cm^3

ii Number of moles of hydrochloric acid reacting = number of moles of sodium hydrogen carbonate present in 25.00 cm^3 = $17.20 \times 10^{-3} \times 0.100 = 1.72 \times 10^{-3}$ = number of moles of sodium hydrogen carbonate present in 25.00 cm^3 of solution.

Therefore, in 250 cm^3 of solution the number of moles of sodium hydrogen carbonate present = $1.72 \times 10^{-3} \times 10 = 1.72 \times 10^{-2}$ mol

iii Mass of sodium hydrogen carbonate present ($m = n \times M_r$) = $1.72 \times 10^{-2} \times 84.1 = 1.45$ g

iv Total mass of mixture = 2.00 g

v Mass of sodium chloride present in mixture = 2.00–1.45 = 0.55 g

vi Percentage of sodium hydrogen carbonate present mixture = $\frac{1.45}{2.00} \times 100\% = 72.5\%$

vii What is the actual percentage composition of the mixture? = 72.5% $NaHCO_3$ and 27.5% NaCl

If you have 20 students then you will need 20 x 2.00 g of mixture but allow for more because students are still in the early stages of learning in detail about quantitative investigations and their technique may not yet be up to scratch.

c Percentage error = $\frac{|\text{Actual value} - \text{experimental value}|}{\text{Actual value}} \times 100$

d The systematic errors:

i The top pan balance: if 2 readings are taken and the balance reads to 0.01 g then the percentage error for a mass of 2.00 g the percentage error = $2 \times \frac{0.005}{2.00} \times 100\% = 0.5\%$

ii The pipette: if this reads to ± 0.05 cm^3 then the percentage error = $\frac{0.05}{25.00} \times 100\% = 0.200\%$

iii The burette readings

It is important that the students express the burette readings to ± 0.05 cm^3. For example, if they get two readings such as 17.00 and 17.10 then the average is 17.05 because burettes usually read to 0.05 cm^3, which is approximately one drop of solution.

The uncertainty for a burette is ±0.05 cm^3 for each reading. Therefore, the uncertainty associated with the difference between two burette readings (a titre)

$= 2 \times 0.05 = \pm 0.10\ cm^3$

Therefore, the error = $\frac{0.10}{17.20} \times 100\% = 0.58\%$

e The main random error depends on the homogeneity of the mixture. Another possible error is in the purity of the sodium hydrogen carbonate. Over time it can decompose to give sodium carbonate.

f The main contribution to any percentage error is due to the solid mixture not being homogeneous.

g The only way to ensure complete homogeneity is to make up a solution of the mixture. This makes a very good discussion point at the end.

Practical investigation 1.4:
Relative atomic mass of calcium by two different methods: molar volume and titration

Introduction

In this investigation, learners will react calcium with water to give hydrogen. The volume of hydrogen given by a known mass of calcium is measured and, using molar ratios, the number of moles of calcium is found and from this the relative atomic mass. The reaction of calcium with water also gives the alkali calcium hydroxide, which is titrated against standard hydrochloric acid. Again, the number of moles of calcium hydroxide (and therefore calcium) is determined and this will give another value for the relative atomic mass.

Skills focus

The following skill areas are developed and practised (see the skills grids at the front of this guide for codes):

MMO Collection of data and observations: (a), (b), (c), (d) and (e)
Decisions relating to measurements of observations: (a), (b) (c) and (d)

PDO Recording data and observations: (c) and (e)
Display of calculations and reasoning: (a) and (b)

ACE Data interpretation and sources of error: (g) (h), (i) and (j)
Drawing conclusions: (c) and (d)
Suggesting improvements: (a) and (c)

Duration

This investigation is a summative exercise as it uses techniques from Investigations 1.2 and 1.3 and requires the learners to use several formulae and relationships.

Preparing for the investigation

- Of the two sets of apparatus suggested for collecting the gas, the easiest to set up is the one using the gas syringe. However, if gas syringes are not available, then the displacement of water in a measuring cylinder works very well.

Equipment

Each learner or group will need:

- apparatus for measuring gas volumes as used in Investigation 1.2

- small filter funnel for burette
- 50 cm^3 burette
- weighing boat
- 150 cm^3 conical flask
- wash bottle of distilled water
- burette stand
- 25 cm^3 pipette
- white tile
- 250 cm^3 beaker
- 25 cm^3 measuring cylinder (for water)
- methyl orange indicator in dropper bottle

Access to:

- top-pan balance reading to **at least** two decimal places. A top-pan balance reading to three decimal places is preferable.
- 0.200 mol dm^{-3} hydrochloric acid
- access to **fresh** calcium granules
- distilled water

Safety considerations

- Learners must wear eye protection and tie their hair back if it is long.
- Calcium reacts vigorously with water. Emphasise that learners should not handle it with wet hands.
- Hydrogen is a flammable gas.
- 0.2 mol dm^{-3} hydrochloric acid is an irritant.
- It is important that if learners are using gas syringes they do not clamp the syringe too tightly. Firstly, they could crack the glass and it may also hinder the movement of the piston.
- The calcium hydroxide is an alkali and should be regarded as being corrosive. It should be washed off immediately if spilt on the skin.
- Methyl orange indicator is poisonous. If any is splashed onto skin it should be washed off immediately.

Carrying out the investigation

- One problem that needs to be overcome first is making sure that the measuring cylinder is full of water when it is put in the trough and that none or very little escapes. This can be done by either learners holding their hands over the end of the measuring cylinder or placing a piece of plastic wrap over the open end and then turn the measuring cylinder upside down when it is in the trough. Remember to remove the film before starting the actual measurement.
- The main problem with the practical is the freshness of the calcium. If it is visibly oxidised, then the results will be inaccurate and this is one of the random errors encountered. If the top portion of your calcium looks to be oxidised then use the lower portions. An alternative is that if you know you are going to use calcium for Group II experiments, then as soon as it is bought, divide it up into smaller portions and store in small containers until ready to use. It is the constant exposure to air that leads in the end to its oxidation.

  Make sure that learners have at least two sets of results to analyse. They may struggle on the first set but will get better the more practice they have.
- Once learners have started, then one of the group can do the determination of gas volumes while the other can do the titration. After they have done this once they can swap over.
- Before the practical, a short demonstration with an approximate mass of calcium will give learners some idea of the volumes of gas that they will be dealing with.
- Also, unless there is time for a trial run, learners could be given an idea of the volume of acid required for the titration.
- Evaluation of a practical method always presents problems to learners and they will need help when estimating the percentage error due to using different apparatus.

  If you want to extend the more able learners, you can state that they know what the answer should be and they can work back to see what readings they should get. However, in this case it should be emphasised that the methods are not perfect and therefore cheating will give them fewer marks.

Common learner misconceptions

- Learners may need to be reminded that the calcium hydroxide is formed from the same mass of calcium as in the first method. This fact sometimes becomes lost when learners are doing their calculations.

Sample results

Part 1: Determination by molar volume

Example measurements shown in Table 1.5.

Learner	Mass of Ca/g	Volume of H_2/cm³	At mass of Ca/g mol⁻¹	Burette readings		Vol of HCl/cm³	At mass of Ca/g mol⁻¹
1	0.050	30.00	40.00	2nd 1st	12.50 0.00	12.50	40.00
	0.048	28.0	41.10	2nd 1st	23.90 12.50	11.40	42.30
2	0.040	24.0	40.0	2nd 1st	10.00 0.00	10.00	40.00
	0.055	31.0	42.5	2nd 1st	24.50 10.00	14.50	37.70
3	0.060	37.0	38.9	2nd 1st	17.20 2.00	15.20	39.50
	0.071	42.0	40.57	2nd 1st	36.20 18.00	18.20	39.01

Table 1.5

Answers to the workbook questions (using the sample results)

Weight of calcium = 0.048 g

a i Number of moles of hydrogen formed in first experiment:

$$n_{hydrogen} = \frac{28}{24\,000} = 1.17 \times 10^{-3}\ mol$$

ii Number of moles of calcium:

$$n_{calcium} = n_{hydrogen} = 1.17 \times 10^{-3}\ mol$$

iii Relative atomic mass of calcium:

$$A_r(Ca) = \frac{0.048}{1.17 \times 10^{-3}} = 41.0\ g\ mol^{-1}$$

b The percentage error in your result

$$\text{Percentage error} = \frac{|\text{Actual value} - \text{experimental value}|}{\text{Actual value}} \times 100$$

The relative atomic mass result for this experiment is 41.0 which should be 40.1.

This gives a percentage error of $\frac{41.0 - 40.1}{40.1} \times 100\% = 2.24\%$

c Systematic errors in the apparatus:

i The weighing out of the calcium: If you use a top-pan balance reading to ± 0.001 g then the possible error is ½ x 0.001 = 0.0005.

A mass of 0.048 g has a possible error of $\frac{0.0005}{0.048} \times 100\% = 1.04\%$. This will rise to 10.4% if you use a top-pan balance that measures to two decimal places.

ii The measurement of gas volume

A 100 cm³ measuring cylinder reads to ±2.00 cm³ and therefore has a maximum error of ±1.00 cm³. A volume of 28.0 cm³ has a possible error of $\frac{1}{28.0} \times 100\% = 3.60\%$.

iii Random errors in the method:

The calcium is possibly oxidised. In this case, the volume of hydrogen will be less than ideal and the value of n will be lower than expected. Therefore $\frac{m}{n}$ will give a value of the relative atomic mass higher than the published value. This method also assumes that the hydrogen is collected at R.T.P.

iv Improvements to Method 1:

If the calcium is oxidised than some of the mass weighed out is not calcium. The best way round this is to not use the calcium at the top of the container but use the calcium below it because it is less exposed to air.