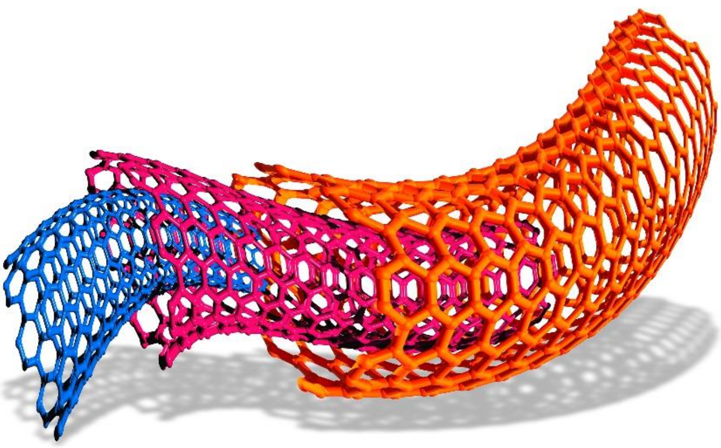
Cambridge Assessment International Education

Teaching Pack
Finding the empirical formula by displacement

Cambridge O Level
Chemistry 5070



Version 2.0

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Introduction

This pack will help you to develop your learners' experimental skills as defined by assessment objective 3 (AO3 Experimental skills and investigations) in the course syllabus.

Important note
Our *Teaching Packs* have been written by **classroom teachers** to help you deliver topics and skills that can be challenging. Use these materials to supplement your teaching and engage your learners. You can also use them to help you create lesson plans for other experiments.

This content is designed to give you and your learners the chance to explore practical skills. It is not intended as specific practice for Paper 5 (Practical Test) or Paper 6 (Alternative to the Practical Test).

There are two options for practising experimental skills. If you have laboratory facilities this pack will support you with the logistics of running the experiment. If you have limited access to experimental equipment and/or chemicals, this pack will help you to deliver a virtual experiment.

This is one of a range of *Teaching Packs*. Each pack is based on one experiment with a focus on specific experimental techniques. The packs can be used in any order to suit your teaching sequence.

The structure is as follows:

Briefing lesson (1 hour*)
This lesson introduces the focus experimental skills to be developed. It also introduces any content needed for your learners to understand the experiment being carried out in the *Lab lesson*.

Lab lesson (1 hour*)	
Option 1 – run the experiment	**Option 2 – virtual experiment**
This lesson allows the experiment to be run with your learners, providing an opportunity to practise the experiment skills introduced in the *Briefing lesson*.	This lesson allows your learners to complete a virtual experiment, providing an opportunity to practise the experiment skills introduced in the *Briefing lesson*.

Debriefing lesson (1 hour*)
This lesson consolidates and builds on the progress learners have made. In some cases this also includes the opportunity to practise extended writing skills.

** the timings are a guide only; you may need to adapt the lessons to suit your circumstances.*

In this *Teaching Pack* you will find the lesson plans, worksheets for learners and teacher resource sheets you will need to successfully complete this experiment.

Experiment: Finding the empirical formula by displacement

This *Teaching Pack* focuses on calculating the empirical formula of a compound (copper chloride) using a chemical displacement reaction.

Copper is displaced from a solution of its salts by the more reactive metal zinc. A known mass of the copper salt produces copper metal, which is dried and its mass measured. From this the empirical formula and hence the chemical formula of the salt is determined.

The syllabus reference for this experiment is:

- 3 Formulae, stoichiometry and the mole concept

The experiment covers the following experimental skills, adapted from **AO3: Experimental skills and investigations**:

- demonstrate knowledge of how to safely use techniques, apparatus and materials, including following a sequence of instructions
- make and record observations, measurements and estimates
- interpret and evaluate experimental observations and data.

Prior knowledge

Knowledge from the following syllabus topics is required for this experiment.

- 3 Formulae, stoichiometry and the mole concept
- 9.2 Reactivity series

Going forward

The knowledge and skills gained from this experiment will be useful for when learners undertake other calculations based on the mole concept and evaluate experimental work of a quantitative nature.

Briefing lesson: Simplest ratios

Resources	• Worksheets A and B • a strip of magnesium (if available) • images of magnesium burning

Learning objectives	By the end of the lesson: • ***all*** learners should be able to calculate the empirical formula for magnesium oxide • ***most*** learners should be able to calculate the empirical formula for magnesium oxide and magnesium nitride • ***some*** learners will additionally be able to justify the formulae for MgO and Mg_3N_2 using 'dot and cross' diagrams.

Timings	Activity
10 min	**Starter/Introduction** Ask learners what the chemical formulae of water, carbon dioxide, sodium chloride and ethanol are: *H_2O, CO_2, NaCl, C_2H_5OH* Write the names and formulae for benzene (C_6H_6) and glucose ($C_6H_{12}O_6$) on the board. Then ask learners what the simplest ratio of the elements is in these compounds? *For benzene, C : H = 1 : 1 and for glucose, C : H : O = 1 : 2 : 1.* On the board, re-write these ratios as empirical formulae: *CH and CH_2O* Define empirical formula as the smallest whole number ratio of moles of each element in a compound. The formula may or may not correspond to the molecular formula of a compound. You should explain that 'CH' does not exist but 'CH_2O' is the molecular formula for methanal, which is different from glucose.
10 min	**Main lesson** Give Worksheet A and Worksheet B to each pair of learners. **Worksheet A** explains a simplified practical procedure for determining the empirical formula of magnesium oxide and Worksheet B is for data processing. The purpose of this lesson is to work through each step of the determination of the empirical formula of magnesium oxide so that learners can better understand the main experiment or virtual experiment lesson. (You could also run this as an experiment if resources are available.) Explain that 'empirical' means 'by experiment', and that to find an empirical formula, experiments must be conducted. One common method of doing this is by combustion analysis. If a strip of magnesium is available to demonstrate/remind learners how it burns, this would be advantageous. (Warn learners not to look directly at the brilliant white flame emitted.) If you cannot do the demonstration, explain that magnesium is a reactive metal and burns with a bright white flame. (Alternatively, show an image from the internet.) Next, ask learners for the name of the product that is formed in the reaction. *magnesium oxide* *Continues on next page …*

Timings	Activity
30 min	Now ask learners to look at the raw data on Worksheet A and to complete the calculations on Worksheet B. Once again, ask learners to think about the definition of empirical formula. The initial goal is to find the mole ratio of the individual elements, in this case magnesium and oxygen. Here are the steps learners need to follow (further teacher information can be found in the teacher notes section): 1. Find the mass of the magnesium by subtraction from the mass of the crucible (plus lid). 2. Look up the relative atomic masses of the elements in the Periodic Table. 3. Calculate the number of moles of each element. 4. Identify which of the elements has the smallest number of moles, which in this case is for oxygen. Learners should arrive at an empirical formula of MgO. Learners should now repeat this with the second example on Worksheet B. Once finished, ask learners to swap their sheets and check that their answers are correct. It is important that learners have shown their working for all calculations. Finally, explain to the learners that whichever type of chemical reaction is used to determine the empirical formula, the basic principles remain the same.
10 min	**Plenary** Working in pairs, learners are requested to justify that the formulae calculated, MgO and Mg_3N_2, are sensible, based on their knowledge of valences and ionic bonding. Explain that they need to refer to the Periodic Table for this exercise. MgO – magnesium is in Group II and oxygen in Group VI. Therefore, magnesium transfers two electrons to oxygen, which needs two electrons to complete a stable octet. Mg_3N_2 – as nitrogen is in Group V it requires three electrons whereas magnesium only has two electrons available to transfer. Therefore, two nitrogen atoms are needed so that three magnesium atoms can donate a total of six electrons. Encourage learners to draw 'dot and cross' diagrams to exemplify the bonding process. Check that learners have included the correct charges on the ions. Some learners may need assistance in writing the correct charge for the nitride ion, N^{3-}.

Lab lesson: Option 1 – run the experiment

Resources	• Teacher notes • *Teacher walkthrough* video • Worksheets C, D, F, G, J, K, L and M • Equipment as outlined in the notes
Learning objectives	By the end of the lesson: • **all** learners should be able to calculate an empirical formula based on their results • **most** learners should be able to calculate an empirical formula based on their results and evaluate them • ***some*** learners should be able to calculate an empirical formula based on their results and evaluate them and be able to suggest improvements to the method.

Timings	Activity
5 min	**Starter/Introduction** Before starting in the lab, give learners Worksheet C, which depicts common hazards associated with lab work. In pairs, can learners find all the hazards on the sheet? (There are 18.) Encourage learners to think about the hazards found and how they could avoid them.
20 min 20 min	**Main lesson** **Safety** Circulate the classroom at all times during the experiment so that you can make sure your learners are safe and that the data they are collecting is accurate. Inform learners that they are going to do an experiment to find the empirical formula of copper chloride. Unlike the examples in the briefing lesson, more than one possible formula exists for copper chloride. Ask the learners why this is possible. *Because copper is a transition metal and has more than one oxidation state, +1 and +2, meaning that copper chlorides containing Cu(I) and Cu(II) exist.* Ask learners what the two possible formulae for copper chloride are. Learners should either work in pairs or in threes. Give them Worksheet D and Worksheet F. The practical procedure is straightforward but contains many steps. Therefore, learners should read Worksheet D very carefully and check-off each completed stage as the work through it. Each learner in the group should ensure that they record all masses and colours of solids and solutions on Worksheet F as instructed in Worksheet D. **Safety** Ensure that the Bunsen burner flame used is small and that the part of the experiment involving heating propan-2-ol is done in a well-ventilated area. Also, ensure that the bottle of propan-2-ol and the waste organic solvent bottle tops are secured and are stored away before starting this step. *Continues on next page …*

Timings	Activity
	After the experiment, learners should calculate the empirical formula of the compound on Worksheet F. They should refer to the briefing lesson, where each step for calculating an empirical formula was explained. Ensure that learners show all their working on Worksheet F. Ask for the empirical formula from each group of learners and write it on the board. If the experiment has been performed carefully (and correctly) the empirical formula should be: $CuCl_2$, which is of course the actual formula for copper(II) chloride.
	**Plenary** Give each pair of group of learners Worksheet G, which allows them to evaluate their experiment. Worksheet J, Worksheet K, Worksheet L and Worksheet M can be used to support lower ability learners with Worksheet G. Answers can be displayed and checked just before the end of the lesson.

Teacher notes

Watch the *Teacher walkthrough* video for empirical formula by displacement and read these notes.

Each pair or group of learners will require:

- anhydrous copper(II) chloride (supply this in a vial labelled as 'Cu_xCl_y')
- a thin piece of zinc metal having a mass of approx. 5 g (thin sheets with large surface areas are preferred)
- dilute hydrochloric acid (2 mol/dm^3, 5–10 drops)
- distilled water (25 cm^3)
- 50 cm^3 measuring cylinder
- 100 cm^3 and 250 cm^3 beakers
- metal tweezers
- glass rod
- balance (preferably to 2 d.p.)
- wash bottle containing distilled water
- propan-2-ol [*iso*-propanol] (30 cm^3)
- evaporating dish
- tripod and gauze
- Bunsen burner
- paper towel
- access to aqueous waste disposal container and organic waste disposal container

Safety

The information in the table below is a summary of the key points you should consider before undertaking this experiment with your learners.

It is your responsibility to carry out an appropriate risk assessment for this experiment.

Substance	Hazard	First aid
Copper(II) chloride (solid, anhydrous)	 GHS07 (*moderate hazard* **MH**)  GHS09 (*hazardous to the aquatic environment* **N**)	**In the eye:** flood the eye with gently-running tap water for at least 10 min. See a doctor. **Swallowed:** do no more than wash out the mouth with water. Do not induce vomiting. Sips of water may help cool the throat and help keep the airway open. See a doctor. **Dust breathed in:** remove to fresh air. See a doctor if breathing is difficult. **Spilt on the skin or clothing:** remove contaminated clothing and rinse it. Wash off the skin with plenty of water. **Spilt on the floor, bench, etc.:** scoop up solid (take care not to raise dust). Wipe up small solution spills or any traces of solid with cloth; for larger spills use mineral absorbent.

Substance	Hazard	First aid
Propan-2-ol (*iso*-propanol)	 GHS02 (*flammable* **F**)  GHS07 (*moderate hazard* **MH**)	**In the eye:** flood the eye with gently-running tap water for 10 min. See a doctor. **Vapour breathed in:** remove to fresh air. Keep them warm. See a doctor if breathing is difficult. **Swallowed**: do no more than wash out the mouth with water. Do not induce vomiting. Sips of water may help cool the throat and help keep the airway open. See a doctor. **Clothing catches fire:** smother flames on clothing or the skin with a fire blanket or other material. Cool any burnt skin with gently-running tap water for 10 min. **Other fires:** allow fires in sinks, etc. to burn out. Fires at the top of test-tubes, beakers, etc. should be smothered with a damp cloth or heat-resistant mat. **Spilt on the skin or clothing: r**emove contaminated clothing. If more than a test-tube amount was involved, wash the affected area and clothing with plenty of water. **Spilt on the floor, bench**, **etc.:** put out all Bunsen-burner flames. Wipe up small amounts with a cloth and rinse it well. For larger amounts, open all windows, cover with mineral absorbent (e.g. cat litter), and scoop into a bucket and add water.
Dilute hydrochloric acid [2 mol/dm^3]	 GHS07 (*moderate hazard* **MH**)	**In the eye:** flood the eye with gently-running tap water for 10 min. See a doctor. **Vapour breathed in:** remove to fresh air. Call a doctor if breathing is difficult. **Swallowed:** do no more than wash out the mouth with water. Do not induce vomiting. Sips of water may help cool the throat and help keep the airway open. See a doctor. **Spilt on the skin or clothing**: remove contaminated clothing. Then drench the skin with plenty of water. If a large area is affected or blistering occurs, see a doctor. **Spilt on the floor, bench, etc.:** for release of gas, consider the need to evacuate the laboratory and open all windows. For large spills, and especially for (moderately) concentrated acid, cover with mineral absorbent (e.g. cat litter) and scoop into a bucket. Neutralise with sodium carbonate. Rinse with plenty of water. Wipe up small amounts with a damp cloth and rinse it well.

Procedure for *Briefing* lesson

1. **Find the mass of the magnesium by subtraction from the mass of the crucible and lid.**

   The mass of oxygen, which represents the mass gained in the experiment, is the difference between the mass of the crucible + lid + magnesium and the mass of the crucible + lid + magnesium oxide.

   In the given example:

mass Mg	=	37.95 g – 37.73 g	=	0.22 g Mg
mass O	=	38.08 g – 37.95 g	=	0.13 g O

2. **Look up the relative atomic masses of the elements in the Periodic Table.**

   A_r Mg = 24 A_r O = 16

3. **Calculate the number of moles of each element.**

$$\text{moles} = \frac{\text{mass of element}}{\text{relative atomic mass}}$$

$$\text{mol}_{Mg} = \frac{0.22\text{ g}}{24} = 0.009167\text{ mol}$$

$$\text{mol}_{O} = \frac{0.13\text{ g}}{16} = \mathbf{0.008125\ mol\ [smallest]}$$

   Learners should not round up at this stage. They now have the ratio of moles of each element. However, it is most unlikely at this stage that either amount will be in whole numbers.

   $Mg_{0.009167} : O_{0.008125}$

4. **Identify which of the elements has the smallest number of moles.**

   In this case it is oxygen with the smallest number of moles.

   The mole values for the other elements are divided by the smallest. Learners should now have whole number mole ratios.

Continues on next page …

$$mol_O = \frac{0.008125}{0.008125} = 1.0$$

$$mol_{Mg} = \frac{0.009167}{0.008125} = 1.1$$

This gives $Mg_{1.1} : O_{1.0}$

This approximates to Mg_1O_1. Therefore, the empirical formula is MgO.

This empirical formula is in accordance with the expected formula for magnesium oxide.

Sometimes a multiplication factor may need to be applied to all the molar quantities to give a whole number ratio for all the elements present and hence the empirical formula.

Teacher method

This is your version of the method for this experiment that accompanies the *Teacher walkthrough* video.

Do not share this method with learners. Give them Worksheet D.

Before you begin
Plan how you will group your learners during the experiment session.

Think about:
- the number of groups you will need (group size 2–3 learners)
- the amount of equipment/chemicals required
- how to minimise the risk of fire by ventilating the room adequately and keeping the stock bottle of propan-2-ol in the solvent cupboard when not needed.

Experiment
Walk around the learners during the experiment in case they encounter any difficulties.

Steps	Notes
1. Check that learners have the chemicals and equipment they need in front of them.	*Ensure that the label of the copper(II) chloride is obscured or hand out in small vials with approximately the right amount of reagent inside and labelled Cu_xCl_y.*
2. Check that the learners have Worksheet D and Worksheet F.	
3. Before they start, warn the learners about safety and good practice for this experiment.	*It is essential that the room is well-ventilated and that the learners are aware of the risk of fire with the propan-2-ol unless strict safety instructions are followed.*
4. Record the mass of an empty 100 cm^3 beaker.	
5. Accurately measure out and record the mass of approximately 1.00 g of the copper chloride salt. Also record its colour.	*Learners may get confused by this. They need to be aware that the mass measured out might not be exactly 1.00 g, in fact the learners should not waste time trying to get it exactly so. Learners must accurately record the mass they measure out e.g. 1.02 g.*
6. Using a measuring cylinder, measure out 25 cm^3 of water and add it to the beaker.	
7. Stir the contents of the beaker using a glass rod, until all the solid dissolves.	*Learners should record the colour of the solution produced.*

8. Accurately measure the mass of a pre-cut piece of zinc sheet.

The shape of the zinc sheet does not matter, but it should not be very thick with a small surface area.

9. Using tweezers carefully place the zinc into the beaker and rinse the tweezers with distilled water.

Introducing the zinc should not cause the solution to splash out of the beaker.

10. As copper is produced it will be necessary to scrape the piece of zinc with the glass rod and rinse again with distilled water as above. Continue doing this until no more copper is formed on the zinc.

Once the scraping process has finished, learners should not forget to record the colour of the solution.

11. Once the reaction has stopped, hydrochloric acid (5–10 drops, 2 mol/dm^3) is added to the beaker and stirred.

12. Take the piece of zinc out of the beaker and hold it above the mixture. At the same time scrape as much of the remaining copper off the zinc plate with a glass rod, allowing any pieces to fall into the beaker. When this is done, dip the glass rod into the solution to ensure that remaining pieces of copper are not stuck to the glass rod.

13. Dry the piece of zinc between a paper towel and record its new mass.

Inevitably traces of copper may remain on the zinc sheet and be left on the paper towel.

14. Decant the liquid slowly from the beaker containing the copper into an aqueous waste bottle. Be careful that none of the copper falls into this bottle.

It would be good to ask the learners what the solution is, explaining that any zinc salts should not be thrown down the sink, hence the need for an aqueous waste bottle.

15. The copper is now rinsed with distilled water (approx.10 cm^3) and stirred. These are decanted off carefully into the aqueous waste bottle.

16. Next, the copper is rinsed with propan-2-ol (isopropyl alcohol) (approx.10 cm^3) to remove water from the copper, and the washings poured carefully into a waste solvent bottle. Repeat this procedure two more times.

It may be worth pointing out that propan-2-ol is one of many alcohols used in chemistry. Stress that it is highly flammable and the bottle top should be immediately replaced after use. Learners who are waiting can get on with the next step of the experiment and also set up their hot water bath.

17. Record the mass of an empty, clean evaporating dish.

18. The copper is carefully transferred into the evaporating dish using a glass rod. A small amount of propan-2-ol is used to ensure that all the copper is transferred.

19. Take a 250 cm^3 beaker and add approximately 100 cm^3 of water into it. Set this up with a tripod, gauze and heatproof mat. Place the evaporating dish on top of the beaker and boil the water gently with a Bunsen burner. When the copper appears almost 'dry' it is stirred with a glass rod.

Take great care that the Bunsen burner flame used is small and that this operation is done in a well-ventilated area. It would be advisable to wait for all learners to complete the rinsing stages with propan-2-ol and then collect the organic waste solvent bottles, before proceeding to the next stage of the experiment.

20. When the copper in the evaporating dish appears completely dry, the dish is removed from the water bath and left to cool. Once cooled, ensure that the bottom of the evaporating dish is wiped dry with a tissue. Then, the mass of the evaporating dish containing the copper is recorded.

21. The evaporating dish is placed back on the hot water bath for another 5 min. Once again, the dish is removed from the heat, dried, and left to cool, and its mass recorded again.

Continue to monitor that learners are using a small Bunsen flame and as soon as they are finished, make sure that they turn off their Bunsen burners.

22. This process is repeated until a constant mass within the range of 0.04 g is reached. The lowest of these masses in the range is used for the calculations.

Clean-up

After the experiment learners should:

- clean all glassware
- tidy up their work space
- ensure any spillages have been mopped up
- return all equipment and any unused chemicals to you.

Lab lesson: Option 2 – virtual experiment

Resources	• *Virtual experiment* video for finding the empirical formula by displacement • Worksheets C, E, F, G, J, K, L and M

Learning objectives	By the end of the lesson, • **all** learners should be able to calculate an empirical formula based on their results • **most** learners should be able to calculate an empirical formula based on their results and evaluate them • ***some*** learners should be able to calculate an empirical formula based on their results and evaluate them and be able to suggest improvements to the method.

Timings	Activity
5 min	**Starter/introduction** Before starting in the lab, give learners Worksheet C, which depicts common hazards associated with lab work. In pairs, can learners find all the hazards on the sheet? (There are 18.) Encourage learners to think about the hazards found and how they could avoid them.
20 min 20 min	**Main lesson** Inform learners that they are going to do an experiment to find the empirical formula of copper chloride. Unlike the examples in the briefing lesson, more than one possible formula exists for copper chloride. Ask the learners why this is possible. Ask learners what the two possible formulae for copper chloride are. Give each pair of learners Worksheet E and Worksheet F. You will need to show the video and be able to pause it at regular intervals. Learners will need to record data and observations on Worksheet F. The experimental procedure is straightforward but contains many steps. Therefore, it may be necessary to play the video more than once. Each learner should ensure that they record all masses and colours of solids and solutions on Worksheet F. It is an important skill to be able to draw fully annotated diagrams of practical procedures. Worksheet E has a space for learners to draw their diagrams. It may be preferable to do this in a sequence of drawings. Learners should be encouraged to use a pencil and ruler where appropriate and draw apparatus as simple 2D objects. After watching the video learners can continue to work in pairs for calculating the empirical formula of copper chloride on Worksheet F. Ensure that learners show all their working on Worksheet F. Ask for the empirical formula from each group and write it on the board. It should be $CuCl_2$, which is of course the actual formula for copper(II) chloride.
15 min	**Plenary** Give each pair of learners Worksheet G to work through. Worksheet J, Worksheet K, Worksheet L and Worksheet M can be used to support lower ability learners with Worksheet G. Answers can be displayed and checked together just before the end of the lesson.

Debriefing lesson: Stoichiometric evaluation

Resources	• Worksheets F, H, I, J, K, L and M

Learning objectives	By the end of the lesson: • ***all*** learners should be able to identify the limiting and excess reagents, write an equation for the reaction and correctly solve some of the empirical formula calculations • ***most*** learners should be able to complete many of the quantitative calculations correctly on both sheets • ***some*** learners may be able to answer all of the quantitative calculations on both sheets accurately.

Timings	Activity
5 min	**Starter/Introduction** Ask the following question about the experiment the learners have just performed. 'From the qualitative observations you recorded in Worksheet F, how can you tell that the reaction went to completion?' Learners should mention that: • the blue colour of the solution at the beginning was due to the copper ions; • at the end of the reaction the solution was colourless, meaning that all the copper ions had reacted; • also, no more copper was formed on the zinc plate after repeated scraping exposing fresh zinc to the copper solution.
25 min 25 min	**Main lesson** Give learners (in pairs) Worksheet H. The aim of this sheet is to allow the learners to evaluate their experiment in a quantitative manner. Questions 3(a) and (b) might be challenging for some learners so go through the answers, step-by-step on the board. Worksheet J, Worksheet K, Worksheet L and Worksheet M can be used to support lower ability learners with Worksheet H. Next, give learners (again in pairs) Worksheet I. The object of this worksheet is to extend ideas about empirical formula and provide further practise to consolidate learning. Explain the following about each question: **1.** Empirical formula can be calculated in the manner used in the experiment, but with more than two elements. Emphasise that for ionic compounds, the empirical formula is also the chemical formula. **2.** This is the other common kind of problem the learners are likely to encounter, where percentages of the elements in the compound are given instead of masses. Learners need to know that it is necessary to consider 100 g of the substance, in which case masses are effectively the same as their percentages. *Continues on next page …*

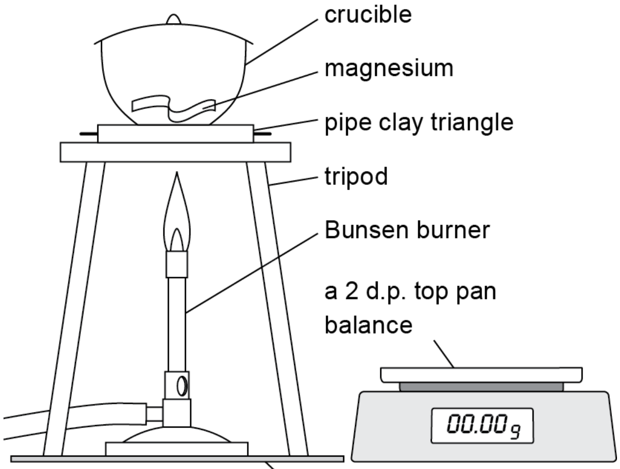
Timings	Activity
	3. For ionic compounds, the actual formula is always the same as the empirical formula. This is not necessarily the case for covalent compounds. In the Briefing lesson, we saw that Benzene has molecular formula C_6H_6, and glucose $C_6H_{12}O_6$. However, their respective empirical formulae are CH and CH_2O. To find out the molecular formula for covalently bonded substances, we also need to know the relative molecular mass. If this is given, the molecular formula can be calculated from the empirical formula. In this question, we see that the empirical formula calculated for propan-2-ol is the same as the molecular formula. **4.** In the final question, it transpires that the molecular formula is twice that of the empirical formula. Ensure that at each stage all learners have completed the question tables.
	**Plenary** Write the following on the board: 'CH' and 'C_2H_4' Ask the learners: 'Which is the molecular formula and which is the empirical formula?' *'CH' is the empirical formula and 'C_2H_4' is the molecular formula.* Then ask the learners: 'Justify why 'CH' does not exist'. *Carbon is in group 4 and must form 4 covalent bonds. It cannot do this with one hydrogen atom alone, since hydrogen only has one electron to share*

Worksheets and answers

	Worksheets	Answers
For use in the *Briefing lesson*:		
A: Magnesium oxide – empirical formula	**21**	—
B: Empirical formula – evaluation	**22–23**	**41**
For use in *Lab lesson: Option 1*:		
C: Safety	**24**	**42**
D: Method	**25–26**	—
F: Raw data and processing	**29–30**	—
G: Evaluation of the experiment	**31–32**	**43**
J: Interpretation and evaluation	**37**	—
K: Writing up experiments	**38**	—
L: Using connectives	**39**	—
M: Sentence starters	**40**	—
For use in *Lab lesson: Option 2*:		
C: Safety	**24**	**42**
E: Method – virtual experiment	**27–28**	—
F: Raw data and processing	**29–30**	—
G: Evaluation of the experiment	**31–32**	**43**
J: Interpretation and evaluation	**37**	—
K: Writing up experiments	**38**	—
L: Using connectives	**39**	—
M: Sentence starters	**40**	—
For use in the *Debriefing lesson*:		
H: Quantitative evaluation	**33–34**	**44**
I: Extension on empirical formula	**35–36**	**45–46**
J: Interpretation and evaluation	**37**	—
K: Writing up experiments	**38**	—
L: Using connectives	**39**	—
M: Sentence starters	**40**	—

Worksheet A: Magnesium oxide – empirical formula

Consider the following experimental procedure to determine the empirical formula of magnesium oxide.



Method

1. The mass of a clean, dry, empty crucible (plus lid) is accurately measured using a mass balance.
2. A piece of magnesium strip (approx.10 cm in length) is added to the crucible and the mass of the crucible (plus lid and magnesium) is measured.
3. The Bunsen burner is lit and the crucible is heated intensely with a roaring blue flame.
4. Once the crucible is hot, carefully lift the lid with a pair of metal crucible tongs to allow oxygen into the crucible. When the magnesium starts to burn, it will do so with an intense white flame. Do not look directly at this flame. Keep heating until no further reaction is seen to take place.
5. Turn off the Bunsen burner and let the apparatus cool.
6. Measure the new mass of the crucible (plus lid and product).

Raw data

A learner performed the above experiment and obtained the following data.
Use it to find the empirical formula for magnesium oxide.

Description	Mass recorded / g
Mass of empty crucible + lid	37.73
Mass of empty crucible + lid + strip of magnesium	37.95
Mass of empty crucible + lid + Mg_xO_y	38.08

Worksheet B: Empirical formula – evaluation

Data processing

Element	Magnesium	Oxygen
Mass		
Relative atomic mass		
Moles of each element		
Mole ratio		
Empirical formula		

Worksheet B: Empirical formula – evaluation

The empirical formula of magnesium nitride

When nitrogen is passed over magnesium (0.91 g) at 800 °C; magnesium nitride (1.26 g) forms.

Calculate the formula of magnesium nitride.

Element	Magnesium	Nitrogen
Mass		
Relative atomic mass		
Moles of each element		
Mole ratio		
Empirical formula		

Worksheet C: Safety

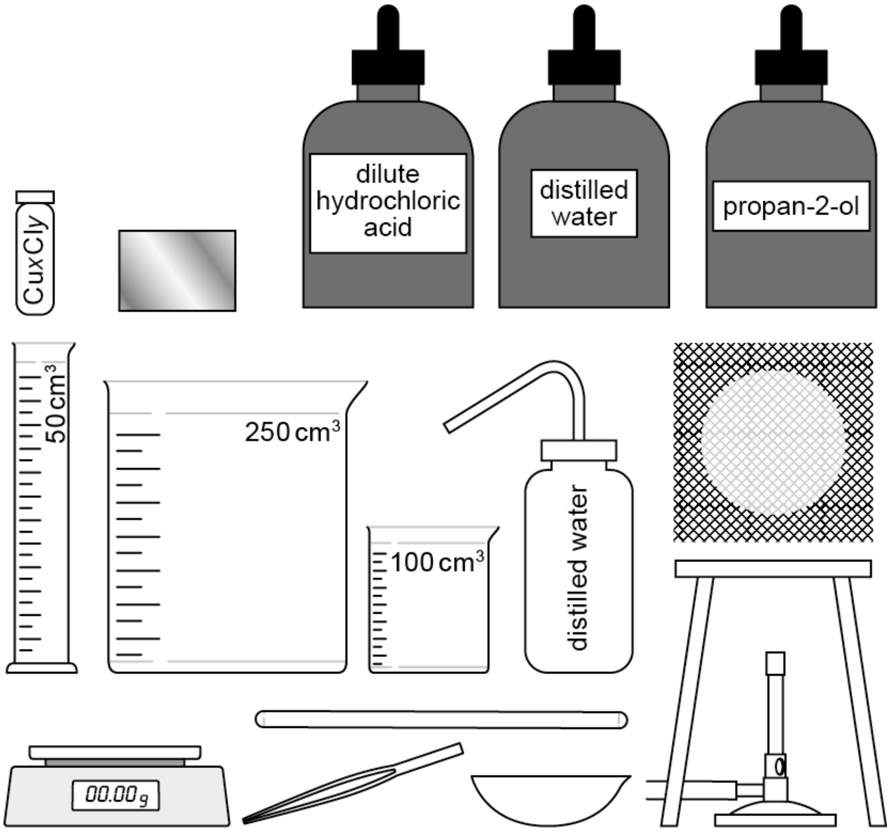
Look closely at the picture. Circle all the safety hazards you can see.

Worksheet D: Method

Follow the method below very carefully.

Make sure that you record your readings as you go using **Worksheet F**.

The diagram of the experimental equipment below should help you.



Method

1. Record the mass of an empty 100 cm^3 beaker.

2. Into the beaker, accurately measure out and record the mass of approximately 1.00 g of the copper chloride salt. Also record its colour.

3. Using a measuring cylinder, measure out 25 cm^3 of water and add it to the beaker.

4. Stir the contents of the beaker using a glass rod, until all of the solid dissolves. Record its colour.

5. Accurately measure the mass of a pre-cut piece of zinc sheet.

6. Using tweezers carefully place the zinc into the beaker and rinse the tweezers with distilled water.

Continues on next page …

Worksheet D: Method

7. As copper is produced it will be necessary to scrape the piece of zinc with the glass rod and rinse again with distilled water as above. Continue doing this until no more copper is formed on the zinc. At this point, record the colour of the solution above the copper.

8. Once the reaction has stopped, add hydrochloric acid (5–10 drops, 2 mol/dm^3) are added to the beaker and stirred.

9. Take the piece of zinc out of the beaker and hold it above the mixture. At the same time scrape as much of the remaining copper off the zinc plate with a glass rod, allowing any pieces to fall into the beaker. When this is done, dip the glass rod into the solution to ensure that remaining pieces of copper are not stuck to the glass rod.

10. Dry the piece of zinc using a paper towel and record its mass.

11. Decant the liquid slowly from the beaker containing the copper into an aqueous waste bottle. Be careful that none of the copper falls into this bottle.

12. The copper is now rinsed with distilled water (approx.10 cm^3) and stirred. These are once again decanted off carefully into the aqueous waste bottle.

13. Next, the copper is rinsed with propan-2-ol (isopropyl alcohol) (approx.10 cm^3) to remove water from the copper, and the washings poured carefully into a waste solvent bottle. Repeat this procedure two more times.

14. Record the mass of an empty, clean evaporating dish.

15. The copper is carefully transferred into the evaporating dish using a glass rod. A small amount of propan-2-ol is used to ensure that all the copper is transferred.

16. Take a 250 cm^3 beaker and add approximately 100 cm^3 of water into it. Set this up with a tripod, gauze and heatproof mat. Place the evaporating dish on top of the beaker and boil the water gently with a Bunsen burner. When the copper appears almost ‘dry’ it is stirred with a glass rod.

Take great care that the Bunsen burner flame used is small and that this operation is done in a well-ventilated area. Also ensure that the bottle of propan-2-ol used and the waste organic solvent bottle tops are secured and the bottles stored away before starting this step of the procedure.

17. When the copper in the evaporating dish appears completely dry, the dish is removed from the water bath and left to cool. Once cooled, ensure that the bottom of the evaporating dish is wiped dry with a tissue. Then, the mass of the evaporating dish containing the copper is recorded.

18. The evaporating dish is placed back on the hot water bath for another 5 min. Once again, the dish is removed from the heat, dried, and left to cool, and its mass recorded again.

19. This process is repeated until a constant mass within the range of 0.04 g is reached. The lowest of these masses in the range is used for the calculations.

Worksheet E: Method – virtual experiment

Together with the *Virtual experiment* video and the procedure detailed below, record the required data in **Worksheet F** as instructed.

First, draw a fully-labelled diagram below of the set-up used in this experiment.

2. Record the mass of the copper chloride salt used and write down its colour.

3. Using a measuring cylinder, 25 cm^3 of water is added to the beaker.

4. The contents of the beaker are stirred using a glass rod, until all the solid dissolves. Record the colour of the solution formed.

5. Record the mass of the pre-cut piece of zinc sheet used.

Continues on next page …

Worksheet E: Method – virtual experiment

6. Using tweezers, the zinc was carefully placed into the beaker and then the tweezers were rinsed with distilled water.

7. As copper is produced, the piece of zinc is scraped with the glass rod and rinsed again with distilled water as above. This process is repeated until no more copper is formed on the zinc. At this point, record the colour of the solution above the copper.

8. Once the reaction stops, hydrochloric acid (5–10 drops, 2 mol/dm^3) is added to the beaker and stirred.

9. The piece of zinc is then taken out of the beaker and held above the mixture. As much of the remaining copper as possible is scraped off the zinc plate with a glass rod, allowing any pieces to fall into the beaker. Then the glass rod is dipped into the solution to ensure that remaining pieces of copper are not stuck to the glass rod.

10. The piece of zinc is dried between a paper towel and its new mass recorded.

11. The supernatant liquid was slowly decanted from the beaker containing the copper into an aqueous waste bottle. Care is taken that none of the copper falls into this bottle.

12. The copper is now rinsed with distilled water (approx. 10 cm^3) and stirred. The residues are once again decanted off carefully into the aqueous waste bottle.

13. Next, the copper is rinsed with propan-2-ol (isopropyl alcohol) (approx. 10 cm^3) to remove water from the copper, and the washings poured carefully into a waste solvent bottle. This procedure is repeated two more times.

14. Record the mass of an empty, clean evaporating dish.

15. The copper is carefully transferred into the evaporating dish using a glass rod. A small amount of propan-2-ol is used to ensure that all the copper is transferred.

16. A 250 cm^3 beaker containing about 100 cm^3 of water is set up on a tripod with gauze and a heatproof mat. The evaporating dish is placed on the top of the beaker and the water is boiled gently. When the copper appears almost ‘dry’ it is stirred with a glass rod.

17. When the copper in the evaporating dish appears completely dry, the dish is removed from the water bath and left to cool. Once cooled, ensure that the bottom of the evaporating dish is wiped dry with a tissue. Then, the mass of the evaporating dish containing the copper is recorded.

18. The evaporating dish is placed back on the hot water bath for another 5 min. Once again, the dish is removed from the heat, dried, and left to cool, and its mass recorded again.

19. This process is repeated until a constant mass within the range of 0.04 g is reached. The lowest of these masses in the range is used for the calculations.

Worksheet F: Raw data and data processing

Record your raw data and results in the table below.

The copper salt	
Mass of empty beaker	g
Mass of empty beaker and copper chloride salt	g
Mass of copper chloride salt (*mass of the empty beaker and copper chloride salt minus the mass of the empty beaker*)	g
Colour of the salt	
Colour of the solution of the salt	
Mass of zinc consumed	
Mass of zinc plate consumed	g
Colour of the solution at the end of the reaction	
Mass of copper produced	
Mass of clean, empty evaporating dish	g
Mass of evaporating dish and copper	
Measurement 1	g

Worksheet F: Raw data and data processing

Mass of evaporating dish and copper (continued)	
Measurement 2	g
Measurement 3	g
Mass of copper (*mass of evaporating dish and copper minus the mass of copper*)	g
Mass of chloride	
Mass of chloride (*mass of copper chloride minus the mass of copper produced*)	g

Processing your results

Element	**copper**	**chlorine**
Mass		
Relative atomic mass		
Moles of each element		
Moles ratio		
Empirical formula		

Worksheet G: Evaluation of the experiment

Answer the following questions to focus more deeply on the experiment you have just performed/seen.

1. (a) Why is zinc able to displace copper from copper chloride?

……

……

……

(b) Name a metal that would not be able to displace copper in this experiment?

……

(c) Suggest a solution of a different salt that would cause a different metal to be displaced using zinc?

……

2. In steps 6 and 7 of the method, why was it necessary to rinse the tweezers with distilled water?

……

……

……

……

……

Worksheet G: Evaluation of the experiment

3. (a) Why would the reaction not go to completion if the copper formed was not scraped off the zinc sheet in step 7?

....

....

....

....

....

....

4. (a) What is the greatest danger posed by doing the experiment in this way?

....

....

....

(b) How could the experiment be modified to reduce this risk?

....

....

....

Worksheet H: Quantitative evaluation

Answer the following questions which will help you evaluate your experiment quantitatively.

1. What was the limiting reagent and excess reagent in the experiment?

....

2. For ionic compounds like copper(II) chloride, the empirical formula is also the same as the actual formula. Given this, write an equation for the reaction including state symbols.

.... $\longrightarrow$ ....

3. (a) Based on the amount of copper salt you used (recorded in **Worksheet F**), what is the theoretical maximum amount of copper that could have been produced in this experiment?

....

....

....

....

....

....

Worksheet H: Quantitative evaluation

3. (b) What is the percentage yield of copper you obtained?

………

………

………

………

3. (c) Can you think of any reasons why this theoretical amount was not measured?

………

………

………

………

………

………

Worksheet I: Extension on empirical formula

Answer the following questions to further your understanding of empirical formulae

1. What is the empirical formula for a compound which contains 0.0134 g of iron, 0.00769 g of sulfur and 0.0115 g of oxygen?

Element	Iron	Sulfur	Oxygen
Mass			
Relative atomic mass			
Moles of each element			
Moles ratio			
Empirical formula			

2. Find the empirical formula of a compound which contains nitrogen 26.2%, chlorine 66.4% and hydrogen 7.4%.

Element	Nitrogen	Chlorine	Hydrogen
%			
Mass			
Relative atomic mass			
Moles of each element			
Moles ratio			
Empirical formula			

Worksheet I: Extension on empirical formula

3. Rubbing alcohol (which is another name for the propan-2-ol used in this experiment) was found to contain 60.0% carbon, 13.4% hydrogen and the remaining mass was oxygen. It has a molecular formula mass (M_r) of 60 g/mol. What is the empirical formula and molecular formula of rubbing alcohol?

Element	Carbon	Hydrogen	Oxygen
%			
Mass			
Relative atomic mass			
Moles of each element			
Moles ratio			
Empirical formula			
Molecular formula			

4. A compound contains 63.11% carbon, 12.36% hydrogen and 24.53% nitrogen.
The experimental molar mass is found to be 114 g/mol. Find the empirical formula and molecular formula.

Element	Carbon	Hydrogen	Nitrogen
%			
Mass			
Relative atomic mass			
Moles of each element			
Moles ratio			
Empirical formula			
Molecular formula			

Worksheet J: Interpretation and evaluation

Use this worksheet to help you to write up your interpretations and evaluation for the experiment.

Interpretation

Use this section to explain each the measurements you made. Make sure you support this with the data collected. You should refer to:

- the mass of Cu_xCl_y used
- the mass of zinc used
- the observations noticed throughout the experiment.

Evaluation

Use this section to describe the strengths of the experiment and what you could do to make it better. You should refer to:

- what went well and the reasons for this
- what problems you experienced and why
- how you could solve the problems if you did the experiment again.

Writing check

1. Have you explained each of your deductions, supported by data collected?

2. Have you identified what worked well and where improvements were needed?

3. Have you used a range of linking words (e.g. next, because) to extend your writing?

Check it

Read your partner's work and look back at the success criteria.

Record **three** things they have done well and **one** thing they need to improve.

Cut along the dashed line and give this back to your partner.

The three things you have done well are:

1. ……………………………………………………………………………………………………

……………………………………………………………………………………………………

2. ……………………………………………………………………………………………………

……………………………………………………………………………………………………

3. ……………………………………………………………………………………………………

……………………………………………………………………………………………………

To improve, you need to:

……………………………………………………………………………………………………

……………………………………………………………………………………………………

Worksheet K: Writing up experiments

This worksheet shows some ideas and techniques you might want to use when writing up your experiments.

Section	What to include
Plan	This section should explain the processes involved in your experiment. You might also need to explain a theory or concept linked to your experiment. • Begin with general statements to introduce the background, e.g. 'Empirical formula is the simplest possible ration of the elements in a compound …' • Your vocabulary should be precise and you should use relevant technical words. • Your language should be impersonal. Do not use words like 'I' or 'we'.
Instructions or method	This section should have a sequence of steps that show how a task should be carried out. • State what you want to achieve, e.g. 'Finding the empirical formula of compound *x*'. • Make sure you explain (or draw) the equipment and materials needed. • Explain clearly what steps should be taken to achieve the goal, e.g. 'Measure out accurately a known mass of Cu_xCl_y'. • You should use imperatives like 'Zero the top pan balance and weigh the dry, empty crucible.' Your instructions should be like a series of commands. • Use numbers or temporal connectives to show the stages involved. • Your language should be clear so that someone could repeat the experiment without mistakes.
Observations	This section should be made up of what you have been able to measure or observe. • Only record what can be seen or measured – do not make guesses about what the products of an experiment are without testing them, e.g. if you see bubbles, this is all you can say (unless you have tested the gas produced). • Your observations need to be as accurate as possible. Make sure you record them using the correct units. You may need to repeat observations.
Interpretations	This is where you need to make sense of the observations you have collected. • Now you can use your scientific knowledge to explain your observations. • Support points made with evidence from your observations or measurements, e.g. 'The bubbles observed turned the limewater cloudy, therefore it is clear these were carbon dioxide.'
Evaluation	The evaluation is an opportunity to discuss both the strengths and weaknesses of an experiment. • Identify both the strengths and weaknesses of the experiment. • Avoid meaningless comments like 'It did not work very well.' Be specific and explain why the experiment did not work well and how you could improve it. • Use connectives to balance the strengths and weaknesses, e.g. 'although' or 'however'; or to give evidence, e.g. 'This is because …' or 'this shows that'.

Worksheet L: Using connectives

Connectives help to develop your extended writing by allowing you to link ideas. This means that you can show how parts of the experiment link or how your observations might be supported by evidence.

In the table below there are examples of connectives you could use in your writing.

Useful connectives and where you might use them	
These connectives help you to show how time progresses. They are very useful in the planning and instruction sections.	• next • after • first, second, third etc. • 20 minutes later • meanwhile
These connectives help you to show cause and effect. They are very useful in the interpretation and evaluation sections.	• because • so • since • therefore • as a result
These connectives help you to show links and connections. They are very useful in the interpretation and evaluation sections.	• therefore • this shows • because • in fact • for example • furthermore • in conclusion
These help you to give comparisons, or to show differences. They are very useful in the interpretation and evaluation sections.	• although • while • similarly • equally • unless • whereas
These connectives help you to add evidence in your writing. They are very useful in the interpretation section.	• this shows that • as can be seen • as suggested by

Worksheet M: Sentence starters

Below are sentence starters for each of the points that should be addressed in the interpretation and method sections.

Interpretations

This section should include:

- the mass of Cu_xCl_y used
- the mass of zinc used
- the observations noticed throughout the experiment

The mass of Cu_xCl_y was measured. It was …

Next, the mass of zinc was recorded as …

When distilled water was added to the solid Cu_xCl_y, the brown solid became …

This method could be used for finding the empirical formulae of …

Evaluation

This section should include:

- what went well and the reasons for this
- what problems you experienced and why
- how you could solve the problems if you did the experiment again.

The method that worked particularly well was …

It worked well because …

There was a problem with …

This problem affected the results by …

To improve the experiment …

Worksheet B: suggested answers

Data processing

Element	Magnesium	Oxygen
Mass	37.95g – 37.73g = 0.22 g	38.08g – 37.95g = 0.13 g
Relative atomic mass	24	16
Moles of each element	= 0.22g/24 = 0.009167 mol	= 0.13g/16 = 0.008125 mol (smallest)
Moles ratio	0.009167/0.008125 = 1.1	0.008125/0.008125 = 1.0
Empirical formula	Mg : O = 1.1 : 1.0 Therefore, the empirical formula is MgO.	

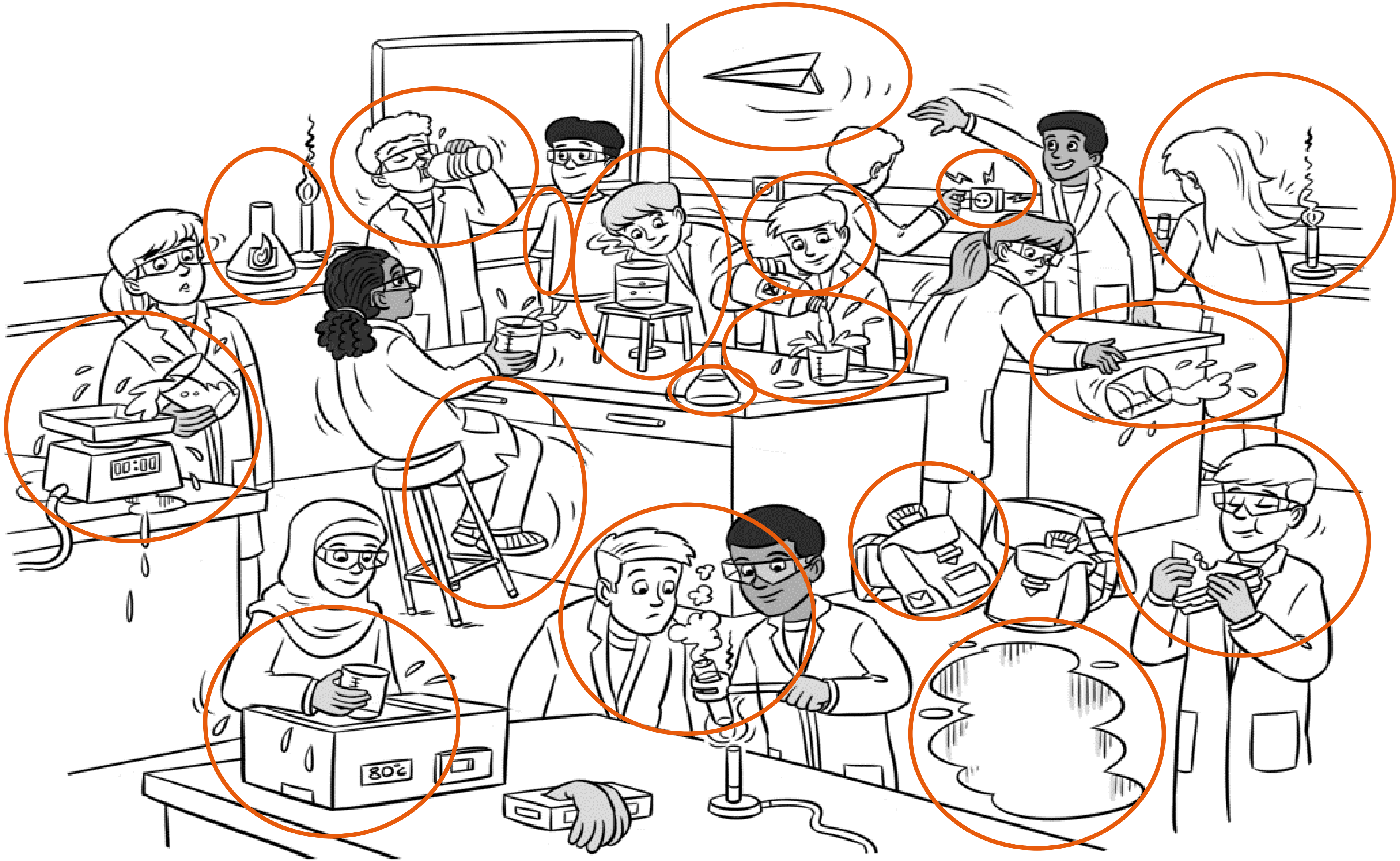
The empirical formula of magnesium nitride

When nitrogen is passed over magnesium (0.91 g) at 800 °C, magnesium nitride (1.26 g) is formed.

Calculate the formula of magnesium nitride, based on the following data.

Element	Magnesium	Nitrogen
Mass	0.91 g	1.26-0.91g = 0.35 g
Relative atomic mass	24	14
Moles of each element	0.91/24 = 0.037916 mol	0.35/14 = 0.025 mol (smallest)
Moles ratio	0.037916/0.025 = 1.5	0.025/0.025 = 1.0
Empirical formula	Mg : N = 1.5 : 1 (since you cannot have fractional numbers of atoms in the formula, it is necessary to multiply both numbers in the ratio by two) Mg : N = 3 : 2 Therefore, the empirical formula is Mg_3N_2.	

Worksheet C: suggested answers



Worksheet G: suggested answers

1 **(a)** *This is because zinc is more reactive. It is higher up in the reactivity series than copper.*

(b) *Any named metal below copper, for example, gold or silver.*

(c) *Example: silver chloride or iron(III) chloride*

2 *This was to ensure that none of the copper chloride salt was lost. It was measured accurately and the calculations of the empirical formula depend on this salt.*

3 *Once the zinc becomes completely coated with copper, the zinc is no longer in contact with the copper chloride solution and cannot react with it. By scraping the copper off the zinc periodically, a fresh surface of zinc becomes exposed.*

4 **(a)** *If the experiment is not conducted in a well-ventilated room and if a small Bunsen flame is not used, there is a risk that the propan-2-ol could ignite.*

(b) *A thermostatically-controlled hot water bath could be used to evaporate off the propan-2-ol*

Worksheet H: suggested answers

1. The copper chloride solution was the limiting reagent and the zinc was the excess reagent.

2. $Zn(s) + CuCl_2(aq) \longrightarrow ZnCl_2(aq) + Cu(s)$

3 (a)

A sample calculation (based on the video in this case):

The mass of copper(II) chloride used was 1.01 g (limiting reagent)

Moles of copper(II) chloride used = mass of $CuCl_2$/RFM

= 1.01g/(64 + (2 x 35.5)) = 1.03/135 = 0.0075 mol

From the balanced equation 0.0075 mol $CuCl_2$ produces 0.0075 mol Cu

Therefore, the theoretical maximum amount of copper produced = 64 x 0.0075

= <u>0.48g Cu</u>

(b)

A sample calculation (based on the video in this case) is:

Mass of copper obtained = 0.45g

% yield = 0.45g/0.48g x 100% = <u>93.8%</u>

(c)

Suggestions include:

- Some of the copper remained on the zinc or was lost on the paper towel.
- The copper chloride used was not pure.

Worksheet I: suggested answers

1.

Element	Iron (Fe)	Sulfur (S)	Oxygen (O)
Mass	0.0134 g	0.00769 g	0.0115 g
Relative atomic mass	56	32	16
Moles of each element	0.0134 g/56 = 0.000240 mol (smallest)	0.00769 g/32 = 0.000240 mol (smallest)	0.0115 g/16 = 0.000719 mol
Moles ratio	0.000240/0.000240 = 1	0.000240/0.000240 = 1	0.000719/0.000240 = 3
Empirical formula	$FeSO_3$ (which is called iron(II) sulfite)		

2.

Element	Nitrogen (N)	Chlorine (Cl)	Hydrogen (H)
%	26.2	66.4	7.4
Mass	26.2 g	66.4 g	7.4 g
Relative atomic mass	14	35.5	1
Moles of each element	26.2 g/14 = 1.87mol (smallest)	66.4 g/35.5 = 1.87 mol (smallest)	7.4 g/1 = 7.40 mol
Moles ratio	1.87/1.87 = 1	1.87/1.87 = 1	7.40/1.87 = 4
Empirical formula	$NClH_4$		

Worksheet I: suggested answers

3.

Element	Carbon (C)	Hydrogen (H)	Oxygen (O)
%	60.0	13.4	100 – (60.0 + 13.4) = 26.6
Mass	60.0 g	13.4 g	26.6 g
Relative atomic mass	12	1	16
Moles of each element	60.0 g/12 = 5.0 mol	13.4 g/1 = 13.4 mol	26.6 g/16 = 1.66 mol (smallest)
Moles ratio	5.0/1.66 = 3	13.4/1.66 = 8	1.66/1.66 = 1
Empirical formula	C_3H_8O The empirical formula mass = (3x12) + (8x1) + (1x 16) = 60 g/mol		
Molecular formula	The question gives the molecular formula = 60 g/mol. Therefore, in this case the molecular formula is the same as the empirical formula.		

4.

Element	Carbon (C)	Hydrogen (H)	Nitrogen (N)
%	63.11	12.36	24.53
Mass	63.11 g	12.36 g	24.53 g
Relative atomic mass	12	1	14
Moles of each element	63.11 g/12 = 5.26 mol	12.36 g/1 =12.36 mol	24.53 g/14 = 1.75 mol (smallest)
Moles ratio	= 5.26/1.75 = 3	= 12.36/1.75 = 7	1.75/1.75 = 1
Empirical formula	C_3H_7N The empirical formula mass = (3x12) + (7x1) + (1x 14) = 57 g/mol		
Molecular formula	The question gives the molecular formula as 114 g/mol. Therefore, the molecular formula = 114/57 = 2. So the molecular formula is twice the empirical formula. Thus, the molecular formula is $C_6H_{14}N_2$.		

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