Cambridge Assessment International Education

Skills for science

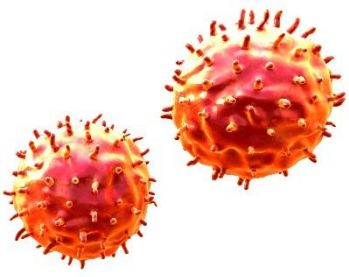
Planning experiments and investigations

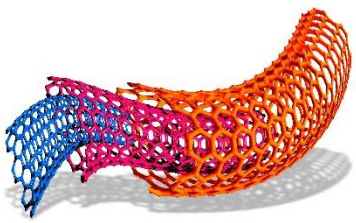
Cambridge International O Level

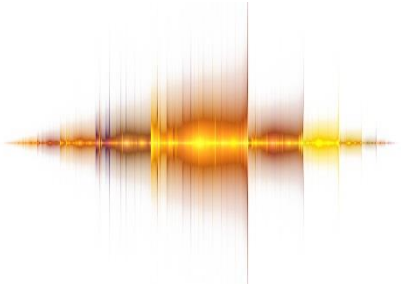
Biology 5090

Chemistry 5070

Physics 5054







Version 1.0

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Contents

About this document

This document has been designed to help you to develop your learners' planning skills as defined by assessment objective 3 (AO3) in the science syllabuses.

AO3 Experimental skills and investigations

Candidates should be able to:

- demonstrate knowledge of how to safely use techniques, apparatus and materials (including following a sequence of instructions where appropriate)
- plan experiments and investigations
- **make and record observations, measurements and estimates**
- interpret and evaluate experimental observations and data
- evaluate methods and suggest possible improvements.

In AO3, learners are expected to be able to plan experiments and investigations. In this document, we will use the term 'experiments', but all of the skills, information and activities also apply to investigations.

The document is divided into **three** main sections:

1. Introduction

This describes how to write a good plan within the context of our science syllabuses. It includes suggested questions that learners should ask themselves while planning, along with guidance on the use of appropriate language. Help with starting classroom discussions on planning in general terms is also provided.

2. Classroom activities

A set of generic worksheets are provided that can be used to increase learner confidence in planning experiments.

3. Example responses

Planning questions from past papers and the associated mark schemes are provided along with example responses. There is one example for each of the three IGCSE science subjects (biology, chemistry and physics). A middle-level response is annotated with what was done well, what could be improved, and useful terminology. An improved response to the question is then annotated for comparison.

Introduction

Candidates may be required to do the following in either Paper 5 or Paper 6: *Plan an experiment or investigation, including making reasoned predictions of expected results and suggesting suitable apparatus and techniques.*

A plan for an experiment consist of a **sequence of steps** that describe how the experiment should be carried out. The key to a good plan is that anyone should be able to repeat the experiment by following the steps given.

Learners should be encouraged to:

- draw detailed diagrams of the experimental set-up (where required/helpful)
- use precise vocabulary and relevant technical words, such as **independent variable**, **dependent variable** and **control variable(s)**
- use language that is impersonal, avoiding the use of words like 'I' and 'we'.

A good plan should focus on 'what' will be investigated and 'how' this will be achieved. Your learners should ask themselves the following questions when planning an experiment.

What…	**How…**
is the experiment/investigation about?	will the experiment support the theory?
is expected to happen (prediction)?	will I test my prediction?
are the variables in the experiment?	will I make it fair?
data should I collect?	will I collect the data accurately?
apparatus should I use?	should the apparatus be used/arranged?
techniques should I use?	will the technique be used?
what sequence of steps should I take?	will I order each step?
risks are involved?	will I keep safe?

Getting started

Before asking learners to plan experiments, introduce the concept of planning using the activities below.

The purpose of a plan

Discuss what the purpose of a plan is by asking question such as:

- What different types of planning in your everyday life can you think of?
- Why do we plan?
- When are plans useful?

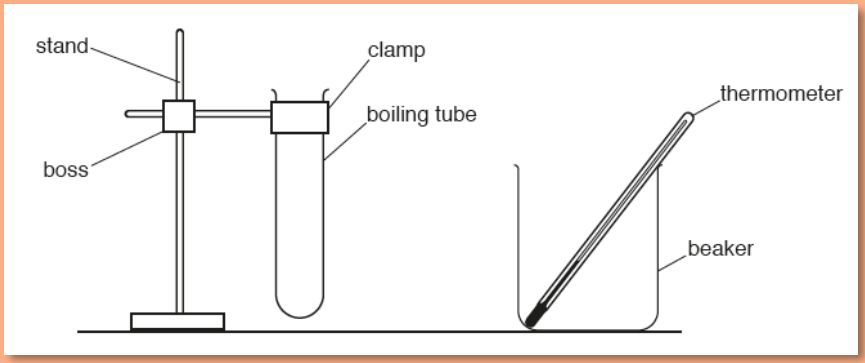
Then discuss the specific reasons we need to plan experiments, for example:

- to ensure accuracy and reliability by using repeats
- to make sure we collect the correct data
- to make the experiment as safe as possible.

Using diagrams to exemplify plans

Diagrams help us to communicate complex thoughts and ideas. A clear diagram in an experimental plan will help whoever is following the plan.

Discuss with learners the set-up below. What makes this a good diagram? Is there anything missing that they would want to include?



Plans help to make the complex simple

Plans help us to break down complex processes into simple steps. Ask learners to produce a plan for baking and decorating this cake. Encourage them to think about:

- how to achieve the structure shown
- how to order the addition of ingredients
- how to order the construction of the cake
- any key points to be aware of, such as: apparatus needed, timings etc.

Planning checklist

When planning, learners could use the checklist below:

Criteria	✓ or ✗
Have you described what the plan is for?	
Have you included a prediction?	
Have you identified the variables?	
Have you identified the data you want to collect?	
Have you listed all the apparatus required?	
Have you listed all the techniques you will use?	
Have you set out your plan as a sequence of steps?	
Have you identified the risks involved?	
Have you explained how the experiment supports the theory?	
Have you explained how you will test the prediction?	
Have you explained how to make the test fair?	
Have you explained how you will collect the data accurately?	
Have you shown how the apparatus should be used/arranged?	
Have you discussed any hazards and safety issues related to the experiment?	
Would someone else be able to follow your plan?	

Classroom activities

The following worksheet activities can be used with your learners to help them improve their ability to plan experiments. These worksheets are generic and can be used to develop planning skills in general, not just for experiments.

- **Worksheet 1:** Match the statements
- **Worksheet 2:** Writing a good plan
- **Worksheet 3:** Planning scenario – biology
- **Worksheet 4:** Planning scenario – biology
- **Worksheet 5:** Planning scenario – chemistry
- **Worksheet 6:** Planning scenario – chemistry
- **Worksheet 7:** Planning scenario – physics
- **Worksheet 8:** Planning scenario – physics
- **Worksheet 9:** Planning sheet
- **Worksheet 10:** How good is your plan?

Worksheet 1: Match the statements

The list of statements in column **A** are important steps when planning an effective experiment. Cut out the statements and order them on page 2 of the worksheet to create a good plan.

The statements in column **B** are definitions or examples of each step in the plan. Cut out the statements and match these to the appropriate steps in **A**, on page 2.

A	**B**
Identify which variable(s) you will change	The number of times a sample is tested and results recorded; at least three is best
Decide how many repeats to make	Draw a results table, then decide if a graph will help show any trends in the data
List any variable(s) that need to be controlled	Factors that should be kept the same so that they do not make the results invalid
Write down required safety precautions	For example, count the number of bubbles of gas given off in 1 minute
Identify the variables	A picture that shows how to arrange the apparatus during the experiment
Draw a diagram of the apparatus set-up	For example, observing a colour change or measuring the volume of gas produced
Decide how you will take measurements	This is the independent variable; for example, how often a measurement will be taken
Decide how you will control variables	Choose apparatus that allows the most efficient and accurate measurement of data
Describe how you will present your data	The suggested explanation/prediction/theory that is to be tested
State a prediction	The factors that can change during an experiment
List suitable apparatus to use	For example, wear safety goggles and a lab coat
Decide what you will measure	For example, use the same volume of solution each time

Worksheet 1: Match the statements, continued

Put the statements in the correct order in column **A**, then add the correct definitions/examples of each into column **B**.

A	**B**

Worksheet 2: Writing a good plan

Here are some ideas and techniques you might want to use when writing a good plan.

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. 'Unstable elements undergo radioactive decay.' • Your vocabulary should be precise and you should use relevant technical/scientific 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. 'Model the process of radioactive decay'. • Make sure you explain (or draw) the apparatus and materials needed. • Explain clearly what steps should be taken to achieve the goal, e.g. 'After each throw, remove the items which fell in the decayed state'. • Your instructions should be a series of commands, for example 'Count the undecayed items and place them back in your beaker'. Your instructions should be like a series of commands. • Use numbers or temporal connectives to show the stages involved, such as 'next', 'then', etc. • Your language should be clear so that someone could repeat the experiment without mistakes.

Worksheet 3: Planning scenario – biology

Plan an experiment to investigate the effect of leaf area on the rate of water uptake by a celery stick.

What could be investigated?	How could this be measured? Include the type of variable and data involved.	What apparatus would be needed?

Worksheet 4: Planning scenario – biology

When running your heart rate increases. After running your heart rate returns to normal.

Plan an investigation to compare the increase in heart rate as a result of exercise for leaners who take regular exercise with those who do not.

What could be investigated?	How could this be measured? Include the type of variable and data involved.	What apparatus would be needed?

Worksheet 5: Planning scenario – chemistry

Nickel sulfate-6-water, $NiSO_4 \cdot 6H_2O$, is a blue crystalline salt.

Plan an experiment to obtain a sample of pure water from this salt. Include a diagram in your response.

What could be investigated?	How could this be measured? Include the type of variable and data involved.	What apparatus would be needed?

Worksheet 6: Planning scenario – chemistry

Agri Limes are mixtures of calcium carbonate and calcium oxide. Farmers use Agri Limes on fields to neutralise acidity.

Plan an investigation to find out which of **two** different Agri Limes, **Q** or **R**, will neutralise more acid.

What could be investigated?	How could this be measured? Include the type of variable and data involved.	What apparatus would be needed?

Worksheet 7: Planning scenario – physics

A learner notices that the size of the image produced by a converging lens changes when the lens is moved further away from an object.

Plan an experiment to investigate how the size of the image varies with the object distance for a converging lens suitable for school experiments.

What could be investigated?	How could this be measured? Include the type of variable and data involved.	What apparatus would be needed?

Worksheet 8: Planning scenario – physics

A learner is investigating whether using a lid reduces the time taken to heat a beaker of water to boiling point.

Plan an experiment to investigate whether using a lid reduces heating time.

What could be investigated?	How could this be measured? Include the type of variable and data involved.	What apparatus would be needed?

Worksheet 9: Planning sheet

Use the space below to plan your experiment.

Diagram	Independent and dependent variables: …… …… …… …… ……	Safety considerations …… …… …… …… ……
Brief outline of how the experiment will be carried out: …… …… …… ……		

Worksheet 10: How good is your plan?

Use this worksheet to help you to write up your plan and method for an experiment.

Plan

Use this section to explain the scientific principles shown by this experiment. You should refer to:

- what the investigation is about
- how the investigation helps to understand/support the theory
- what data you would expect to collect from this experiment – these are your predictions.

Method

Use this section to explain how the experiment is carried out. You should refer to:

- the apparatus needed and how it should be used
- the exact steps that should be taken to complete the experiment
- the steps taken to make this a fair test.

Writing check

1. Have you explained the background to this experiment and supported this with relevant examples and diagrams?

2. Is it clear what data will be collected and how this can be used to support your investigation?

3. Are the steps in the method clear enough so that the experiment can be repeated?

4. Has it been explained how this will be made a fair test?

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:

……

……

Example responses

This section includes a past paper question for each of the sciences. Example responses are shown with information on how the answers could be improved. Useful terminology and examples of improved answers are included to show how learner responses could be developed.

Planning question – biology

In this question, learners are required to plan an experiment for finding the position of the vascular bundles in a stem using the information provided. Learners should describe how they would do this in their response. As with all planning questions, recording a series of steps to be taken to achieve the required outcome is the best way for your learners to answer this type of question.

(b) The walls of xylem vessels are supported by a chemical called lignin, which can be stained by a red dye. This makes the xylem vessel walls easily seen when using a microscope.

Use this information to plan how you could find the position of the vascular bundles in a stem.

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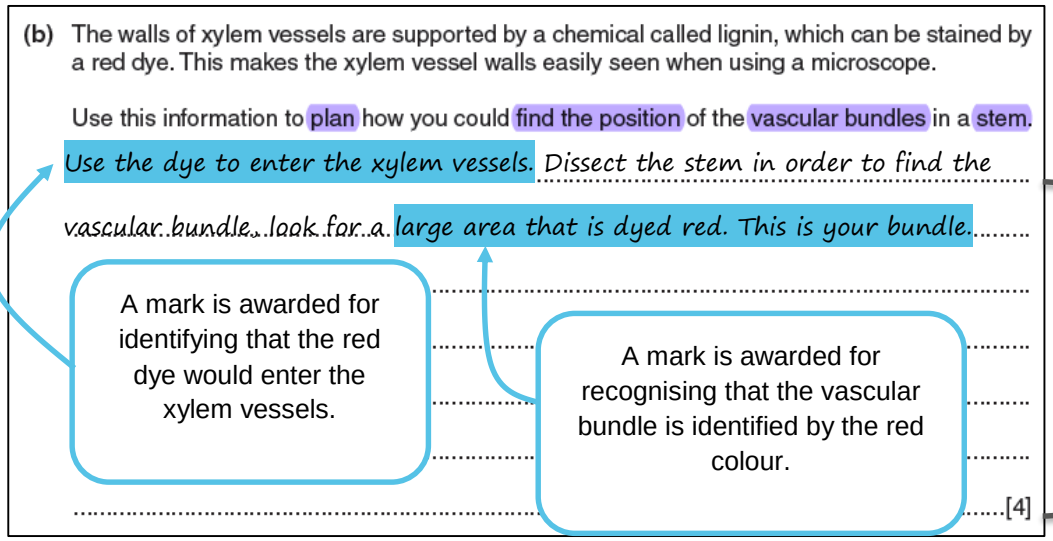
.....[4]

The mark scheme for this question is as follows:

Question	Mark scheme	Mark	Guidance
2 (b)	1 use of any suitable plant material; 2 put stem / material chosen in (red) dye / add dye to cut (stem) surface; 3 time for absorption of dye; 4 cut (sections) of stem or material chosen; 5 (red stained xylem) will indicate position of vascular bundle	[max 4]	 **Ignore** stain it red **Ignore** xylem alone

Example response

This response would earn a mid-range score as it only includes reference to the dye being used to stain the xylem vessels and that this is used to locate the vascular bundle. The blue highlight shows where marks were awarded. The response lacks the detail required for someone to be able to repeat the procedure.



(b) The walls of xylem vessels are supported by a chemical called lignin, which can be stained by a red dye. This makes the xylem vessel walls easily seen when using a microscope.

Use this information to plan how you could find the position of the vascular bundles in a stem.

Use the dye to enter the xylem vessels. Dissect the stem in order to find the vascular bundle, look for a large area that is dyed red. This is your bundle.

[4]

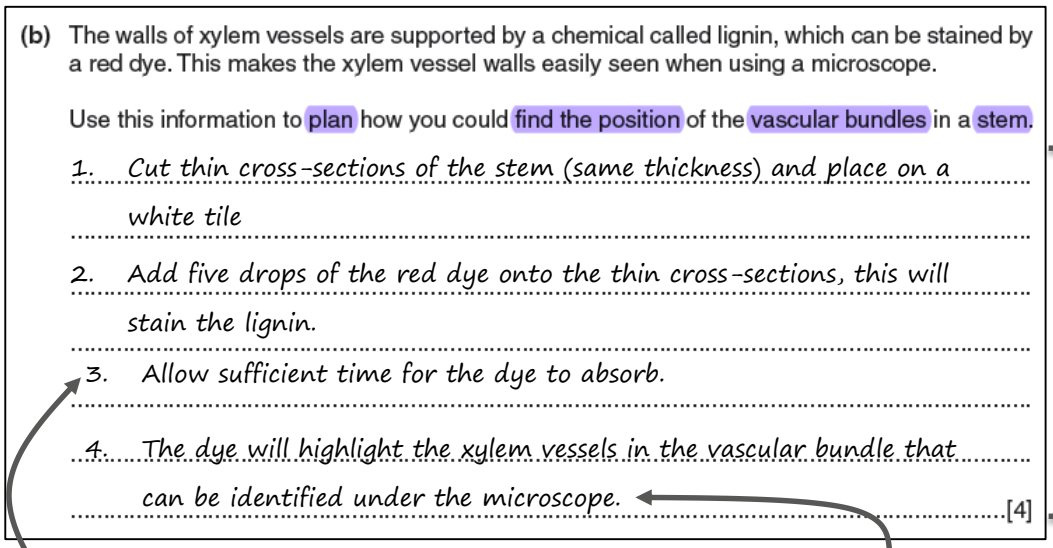
A mark is awarded for identifying that the red dye would enter the xylem vessels.

A mark is awarded for recognising that the vascular bundle is identified by the red colour.

The comment about dissecting the stem is correct, but needs to be more specific.

The learner has been given seven lines – if these are not full it is likely their answer lacks sufficient detail.

Improved response



(b) The walls of xylem vessels are supported by a chemical called lignin, which can be stained by a red dye. This makes the xylem vessel walls easily seen when using a microscope.

Use this information to plan how you could find the position of the vascular bundles in a stem.

1. Cut thin cross-sections of the stem (same thickness) and place on a white tile
2. Add five drops of the red dye onto the thin cross-sections, this will stain the lignin.
3. Allow sufficient time for the dye to absorb.
4. The dye will highlight the xylem vessels in the vascular bundle that can be identified under the microscope.

[4]

The specificity means that this plan could be used to conduct the experiment.

The learner has made excellent use of key terms.

This response is better as each step is clearly shown and explained in detail.

Planning question – chemistry

In this question learners are required to plan three experiments for separating a liquid cleaner (a mixture). Learners should provide details of how they would separate each substance. A series of steps would be a logical way of writing the response.

3 A liquid cleaner is a mixture of three substances. These substances are shown in the table.

name of substance	properties of substance
water	liquid, boiling point 100 °C
sodium carbonate	solid, soluble in water
silica	solid, insoluble in water

Plan experiments to obtain separate pure samples of each substance from the mixture in the liquid cleaner. You are provided with common laboratory apparatus.

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..... [6]

[Total: 6]

The mark scheme for this question is as follows:

Question	Answer	Mark
3	**silica** filter (the cleaner) wash the residue dry the residue **water** heat (the filtrate/cleaner) condense the vapour **sodium carbonate** heat to dryness/no liquid left (then solid) sodium carbonate is left OR heat until saturated then cool to crystallise/leave to crystallise	6

Example response

This response would earn a mid-range mark. The blue highlight shows where marks would be scored.

3 A liquid cleaner is a mixture of three substances. These substances are shown in the table.

name of substance	properties of substance
water	liquid, boiling point 100 °C
sodium carbonate	solid, soluble in water
silica	solid, insoluble in water

Plan experiments to obtain separate pure samples of each substance from the mixture in the liquid cleaner. You are provided with common laboratory apparatus.

1) Measure 30 cm³ of the liquid cleaner using a measuring cylinder.

2) Filter this liquid using a funnel and filter paper. Keep both the liquid and the solid.

3) Remove the solid from the filter paper. This is the silica.

4) Use distillation to separate the water from the soluble sodium carbonate.

[6]

[Total: 6]

The learner correctly identifies that the liquid cleaner should be filtered to obtain the silica

Distillation is correctly explained for separating the water from the mixture.

The response only deals with the separation of two of the three substances. Detail of the purification of silica and how sodium carbonate (the third substance) is collected is missing.

Improved response

3 A liquid cleaner is a mixture of three substances. These substances are shown in the table.

name of substance	properties of substance
water	liquid, boiling point 100 °C
sodium carbonate	solid, soluble in water
silica	solid, insoluble in water

Plan experiments to obtain separate pure samples of each substance from the mixture in the liquid cleaner. You are provided with common laboratory apparatus.

1) Measure 30 cm³ of the liquid cleaner using a measuring cylinder.

2) Filter this liquid using a funnel and filter paper. Keep both the filtrate and the residue.

3) Remove the residue from the filter paper. This is the silica.

4) Purify the silica by washing with water and drying.

5) Use distillation to separate the water from the soluble sodium carbonate.

6) Continue to boil the liquid cleaner in the flask until dry – the solid left over is sodium carbonate.

[6]

[Total: 6]

The learner has made excellent use of key terms, such as **residue** and **filtrate**.

The silica should be washed and dried (purification).

The content of the flask should be boiled until dry. What is left over is sodium carbonate.

Planning question – physics

In this question learners are required to plan an experiment to investigate how the combined resistance of resistors, connected in parallel, depends on the number of resistors.

4 A student is investigating resistors connected in parallel.

The following apparatus is available to the student:

ammeter
voltmeter
power supply
variable resistor
switch
connecting leads
a box of identical resistors.

Plan an experiment to investigate how the combined resistance of the resistors, connected in parallel, depends on the number of resistors. You are **not** required to carry out this investigation.

You should:

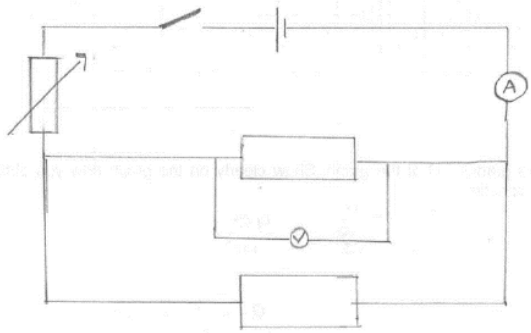
- draw a diagram of the circuit you could use to determine the resistance of resistors connected in parallel (show only two resistors in your diagram)
- explain briefly how you would carry out the investigation
- draw a table or tables, with column headings, to show how you would display your readings. You are **not** required to enter any readings into the table.

The mark scheme for this question is as follows:

Question	Answer	Mark
4	**MP1** On circuit diagram: one voltmeter in parallel with any component	1
	MP2 Circuit diagram correctly shows power supply, ammeter, unless in a branch, two or more resistors in parallel	1
	MP3 Circuit diagram: Correct symbols for ammeter, voltmeter and fixed resistor	1
	MP4 Repeat with a different number of resistors (in parallel)	
	MP5 Table that includes columns for number of resistors, voltage/V and current/A	1
	MP6 & MP7 Then any two from:	1
	Resistance calculated (may be shown in table)	
	Use low current (to stop resistors getting too hot)/switch off between readings	2
	Use at least 5 different combinations	
	Repeat with different current or voltage or variable resistor setting	
	Drawing a graph of number of resistors against combined resistance	
	Total:	7

Example response

The blue highlight shows where marks would be scored.



Set up the apparatus as shown.

Use the variable resistor to control the amount of current and use a voltmeter to measure voltage. Use 2 resistors. Switch on. Measure the current using the ammeter and voltage using the voltmeter. Record these values.

V / V	I / A	R / Ω

Then repeat using 3, 4 and 5 resistors. Values should be recorded and the equation R = V/I is used to measure the resistance. Then plot a graph of voltage (x axis) and current (y axis).

The highest resistance will have the lowest current and the highest voltage.

[7]

[Total: 7]

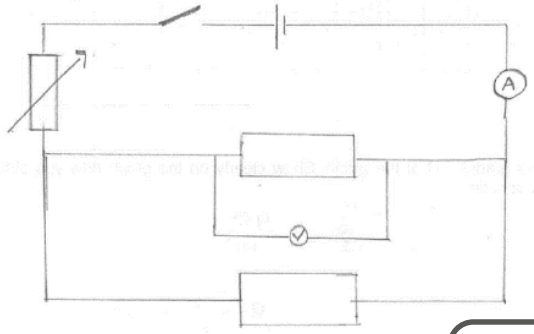
The response is clear and has a well-drawn diagram.

The response also clearly indicates that the readings are used to calculate the combined resistance of the resistors.

The method includes reference to repeating measurements with different numbers of resistors.

The learner has been given 26 lines in total and a lot of them have not been used here – it is likely their response lacks sufficient detail.

Improved response



Set up the apparatus as shown.

Method

1. Use the variable resistor to control the amount of current.
2. Use a voltmeter to measure voltage (V).
3. Use 2 resistors.
4. Switch on.
5. Measure the current using the ammeter and voltage using the voltmeter. Record these values.
6. Repeat steps 3–5 using 3, 4 and 5 resistors (in parallel).
7. Record your values and use the equation $R = V/I$ to measure the resistance.
8. Plot a graph of voltage, V (*x* axis) and current, A (*y* axis).

Remember: Use a low current to prevent the resistors form becoming too hot.

Table

Number of resistors	V / V	I / A	R / Ω

Conclusion

The highest resistance will have the lowest current and the highest voltage.

[7]

[Total: 7]

A clearer response given as a series of steps

The response makes good use of key terms such as resistor, resistance, ammeter, voltmeter, voltage and current

The learner recognises that the resistors need to be added in parallel.

A valid suggestion relating to precautions.

Good use of symbols ***V***, ***I*** and ***R*** and the units of each, **V**, **A** and **Ω**.

Addition to the table to show the 'Number of resistors'.

Worksheet 1: suggested answers

The following is a suggested order for a good plan, along with the correct definitions/examples.

A	B
State a prediction	The suggested explanation/prediction/theory that is to be tested
Identify the variables	The factors that can change during an experiment
List any variable(s) that need to be controlled	Factors that should be kept the same so that they do not make the results invalid
Decide how you will control variables	For example, use the same volume of solution each time
Identify which variable(s) you will change	This is the independent variable; for example, how often a measurement will be taken
Decide what you will measure	For example, observing a colour change or measuring the volume of gas produced
Decide how you will take measurements	For example, count the number of bubbles of gas given off in 1 minute
Decide how many repeats to make	The number of times a sample is tested and results recorded; at least three is best
List suitable apparatus to use	Choose apparatus that allows most efficient and accurate measurement of data
Draw a diagram of the apparatus set-up	A picture that shows how to arrange the apparatus during the experiment
Describe how you will present your data	Draw a results table and decide if a graph will help show any trends in the data
Write down required safety precautions	For example, wear safety goggles and a lab coat

Worksheet 3: suggested answers

- measure distance travelled up the stick
- add dye to water
- time stated
- change the number of leaves on the celery
- measure the area of leaves
- need to control temperature / humidity / wind speed
- repeats
- prediction

Worksheet 4: suggested answers

- heart / pulse rate taken before and after exercise
- heart / pulse rate taken immediately after exercise
- exercise – same type / same length of time
- learners – same age / gender / clothing
- repeat for each type of learner / use groups of learners

Worksheet 5: suggested answers

- method
- heat the salt
- condenser shown on diagram
- drops of water / condensation
- colour change / blue solid becomes paler
- test pure water
- boiling point
- 100 °C

Worksheet 6: suggested answers

- **method adding Agri Lime to acid**
- add weighed amount / known mass of Agri Lime **Q**
- to a known volume of acid
- with a named indicator added to the acid
- until the indicator changes colour
- note the mass of Agri Lime **Q** added
- repeat with Agri Lime **R**
- conclusion, e.g. 'the experiment using the smaller amount of Agri Lime is better'

OR

- **method adding acid to Agri Lime**
- use weighed amount / known mass of Agri Lime **Q**
- add acid to it gradually / from a burette
- with a named indicator added to the acid
- until the indicator changes colour
- note volume of acid added
- repeat with Agri Lime **R**
- conclusion, e.g. 'the experiment using the larger volume of acid is better'

Worksheet 7: suggested answers

- diagram – lens, (illuminated) object, screen in suitable order for experiment
- in line on flat surface
- instructions:
- set / measure object distance, move screen to get image, measure image height
- repeat for different object distances
- limiting factor for range of object distances – one from:
- image virtual / too big for screen
- image too dim / too small to measure
- must be greater than focal length
- for the graph, image size / magnification against object distance
- any one suitable precaution and consequence of not taking it, e.g.
    - dark room / bright light – image might not be distinct
    - lens and object at same height – image might not appear on screen
    - lens, object and screen perpendicular – image might be distorted
    - fix rule – may move and give incorrect distances
    - mark position of lens on holder – cannot judge correct measurements
    - detailed means of obtaining a sharp image – might not be correctly focused
    - means of measuring image height accurately – might be obscured

Worksheet 8: suggested answers

- clock / stopwatch and source of heat
- heat to boiling with and without lid
- measure time taken to reach boiling point / boil
- same volume / mass / amount of water
- same starting temperature
- suitable table with column headings and units (seconds or minutes)
- conclusion drawn

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