Cambridge Assessment International Education

Teaching Pack

Measuring refraction and total internal reflection

Cambridge O Level

Physics 5054

This *Teaching Pack* can also be used with the following syllabuses:
- Cambridge IGCSE™ Physics **0625**
- Cambridge IGCSE™ (9–1) Physics **0972**
- Cambridge IGCSE™ (9–1) Co-ordinated Sciences (Double Award) **0973**
- Cambridge IGCSE™ Combined Science **0653**
- Cambridge IGCSE™ Physical Science **0652**

Version 0.1

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Briefing lesson

Lab lesson: Option 1 – run the experiment

Lab lesson: Option 2 – virtual experiment

Debriefing lesson

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 experimental skills introduced in the *Briefing lesson*.	This lesson allows your learners to complete a virtual experiment, providing an opportunity to practise the experimental skills introduced in the *Briefing lesson*.

↓

Debriefing lesson (1 hour*)
This lesson consolidates and builds on the progress learners have made. In some cases, it will also provide 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 pack you will find the lesson plans, worksheets for learners and teacher resource sheets you will need to successfully complete this experiment.

Experiment: Refraction and total internal reflection

This *Teaching Pack* focuses on an experiment to measure refraction and total internal reflection.

Refraction is observed when light is transmitted across a boundary and changes speed. In this experiment, a ray of light will be passed between air and a transparent material. The refractive index and critical angle of the material will be determined.

This experiment has links to the following syllabus content (see syllabus for detail):

- 14.2 Refraction of light

The experiment covers the following experimental skills, adapted from **AO3: Experimental skills and investigations** (see syllabus for assessment objectives):

- Make and record observations
- Interpret and evaluate experimental observations and data
- Demonstrate knowledge of how to safely use techniques, apparatus and materials

Prior knowledge

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

- 13 General wave properties
- 14.1 Reflection of light

Going forward

The knowledge and skills developed in this experiment are applicable to other parts of the topic of light. The understanding of refraction and ray diagrams gained from this experiment will be useful when you teach learners about converging lenses.

Briefing lesson: Interpreting data

Resources	• Access to the Internet and a projector • Worksheets A, B and C

Learning objectives	By the end of the lesson: • ***all*** learners should know what an observation is and be able to draw ray diagrams. • ***most*** learners should be able to describe how to collect data and describe the reflection of light. • ***some*** learners should be able to interpret observations and evaluate the quality of experimental data.

Timings	Activity
5 min	**Starter / Introduction** Show a picture of a pencil in a glass of water. Alternatively, this can be demonstrated. Discuss the appearance of the pencil, in terms of rays of light. Although there appears to be a break in the pencil, this is due to the light changing direction as it leaves the water.
10 min	**Main lesson** Learners should use Worksheet A to demonstrate their understanding of reflection. This is an opportunity for you to address any misconceptions regarding ray diagrams.
10 min	Show a picture of a ray box, slit plate and mirror. Use questioning to establish how accurate experimental data could be collected to support the Law of Reflection. Learners should then discuss what measurements must be taken and how sources of uncertainty can be minimised. They should be aware of: • Correct use of protractor to measure angles • Measuring from the centre of the ray of light • Multiple readings • Anomalies • Calculations of averages • Reliability • Significant figures and decimal places
25 min	Provide learners with Worksheet B. As learners complete Worksheet B they can move straight onto Worksheet C.
5 min	Provide answers to the worksheet questions while learners self-assess their work. Lead a discussion of the likely sources of uncertainty and how data could be collected more effectively.

Briefing lesson: *continued*

Timings	Activity
5 min	**Plenary** Show a picture of a squash player hitting a ball off a wall. Learners should discuss how the picture is relevant to the Law of Reflection and whether it is reasonable to compare this to the reflection of light.

Lab lesson: Option 1 – run the experiment

Resources	• Teacher notes • Teacher walkthrough video • Worksheets D, E and F • Equipment as outlined in the notes

Learning objectives	By the end of the lesson: • ***all*** learners should be able describe how rays of light pass through a Perspex block. • ***most*** learners should be able to calculate the refractive index of a material. • ***some*** learners will be able to determine the critical angle of a material and relate this to the refractive index.

Timings	Activity
5 min	**Starter / Introduction** Set up a ray box and rectangular Perspex block but do not turn the ray box on. Alternatively, show an image of the equipment. Ask your learners to discuss what will happen to the ray of light when it reaches the block. They should annotate Worksheet D in pencil showing their prediction. Extend learners by asking whether the same thing would happen if the block were made of a different material.
5 min	**Main lesson** Learners should collect the equipment and set up the experiment to test their prediction. Lights may be switched off once equipment is set up. Learners should make corrections to their predictions on Worksheet D.
5 min	Discuss the results and ensure learners can identify the angle of incidence and angle of refraction on Worksheet D. Suggest that there may be a relationship between the angle of incidence and angle of refraction. Discuss how this relationship could be investigated using the equipment available.
25 min	Most learners would benefit from a brief demonstration before beginning the experiment although the most able could start and refer to the method on Worksheet E. During the demonstration, show learners the table of results on Worksheet F. Introduce the concept of refractive index and the equation $n = \sin i / \sin r$.
10 min	Encourage learners to move straight onto the investigation of the critical angle after determining the refractive index. **Safety** Circulate the classroom at all times during the experiment so that you can make sure that your learners are safe and that the data they are collecting is accurate.

Lab lesson: *continued*

Timings	Activity
10 min	**Plenary** List the values of refractive index and critical angle determined by different groups. Ask learners to find a mean value for refractive index and critical angle and compare these to the expected values of 1.5 (refractive index) and 43° (critical angle). Discuss why different groups recorded different results.

Teacher notes

Watch the video on measuring refraction and total internal reflection (teacher version) and read these notes.

Each group will require:
- Ray boxes (a separate power supply and leads may be required)
- Slit plate
- Rectangular Perspex block
- Semi-circular Perspex block
- Fibre board mat (the experiment can be completed without a fibre board mat or optical pins)
- Optical pins
- Paper
- Pencil
- Protractor
- Ruler
- Calculator

Safety

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

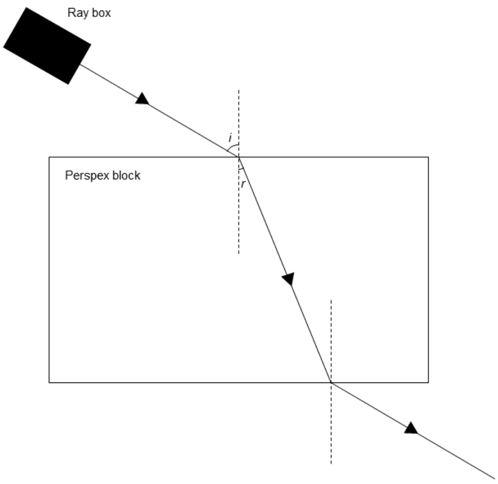
Equipment should be set up and trip hazards removed before turning off lights.
Ray boxes can become very hot and should be turned off and allowed to cool before handling.

Ray boxes should only be used at the recommended voltage setting.

Perspex blocks can become chipped or smashed if dropped.

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

Experiment set-up



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 E**.

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 required

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

Experiment: Part 1 Refractive index

Step	Notes
1. Learners should collect all the equipment they need.	
2. A piece of white paper should be placed on a soft fibre board mat. A rectangular Perspex block should be placed on the paper.	*The fibre board mat allows the use of optical pins. It is not essential.*
3. Learners should draw a line around the block in pencil and draw the normal line at the centre of the long edge of the block.	*Remind learners that the normal line is perpendicular to the surface of the block at the point where the ray of light enters the block.*
4. A protractor should be placed against the Perspex block so that the 90° mark overlays the normal line.	
5. Learners should insert a slit plate into a ray box.	
6. The ray box should be turned on and directed towards the block, along the normal line.	*This is the first data point. The angle of incidence is 0° and the angle of refraction is also 0°.*
7. Learners should move the ray box to increase the angle of incidence in intervals of 10° up to 60°. Each time they should use an optical pin to mark the point where the ray of light meets the protractor and where it leaves the block.	*Care must be taken not to touch the part of the ray box holding the lamp, which will have heated up.*

8. The Perspex block should be removed and the points should be joined using a pencil and ruler, to show the path of the ray of light.
9. A protractor should be used to measure the angle of refraction for each angle of incidence. Values are added to **Worksheet F**.
10. **Worksheet F** should be completed using a calculator to calculate values of sin *i*, sin *r* and refractive index, *n*.

Learners should use the formula: $n = \sin i / \sin r$

Experiment: Part 2 Total internal reflection

Step | **Notes**

1. Another piece of white paper should be placed on the soft fibre board mat. A semi-circular Perspex block should be placed on the paper.
2. Learners should draw a line around the block in pencil and draw the normal line at the centre of the straight edge of the block.
3. A ray of light should be directed through the curved side of the block so it passes out of the straight side of the block along the normal line.
4. Learners should move the ray box to increase the angle of incidence, while continuing to direct the ray of light at the middle of the straight edge. The critical angle is identified when the ray travels along the straight edge of the block.
5. An optical pin should be placed at the point where the ray of light enters the block.
6. The block should be removed and a pencil and ruler used to mark the path of the ray of light.
7. The critical angle should be measured using a protractor.

Remind learners that the critical angle is measured from the normal line, i.e. the angle of incidence.

Clean-up

After the experiment learners should:

- turn off ray boxes and allow them to cool
- tidy up their work space
- return all equipment to you.

Lab lesson: Option 2 – virtual experiment

Resources	• Virtual experiment video • Worksheets D, F and G.
Learning objectives	By the end of the lesson: • ***all*** learners should be able describe how rays of light pass through a Perspex block. • ***most*** learners should be able to calculate the refractive index of a material. • ***some*** learners will be able to determine the critical angle of a material and relate this to the refractive index.

Timings	Activity
5 min	**Starter / Introduction** Remind learners of the previous lesson where they used ray diagrams to show the reflection of a ray of light incident upon a plane mirror. Provide your learners with Worksheet D. Ask your learners to discuss what will happen to the ray of light when it reaches the block. They should annotate Worksheet D showing their prediction. Extend learners by asking whether the same thing would happen if the block were made of a different material.
5 min	**Main lesson** Watch the first part of the virtual experiment video and ask your learners to make corrections to their predictions on Worksheet D (the video will stop at the appropriate place).
5 min	Discuss the results and ensure learners can identify the angle of incidence and angle of refraction on Worksheet D. Suggest that there may be a relationship between the angle of incidence and angle of refraction. Play the video to show the equipment. Discuss how this relationship could be investigated using the equipment available.
25 min	Introduce the concept of refractive index then play the next section of the video. Your learners should collect data from Worksheet G and use this to complete Worksheet F. Weaker learners may need support using the formula $n = \sin i / \sin r$.
10 min	Watch the final section of the video. Learners should complete the rest of Worksheet F.
10 min	**Plenary** List the values of refractive index and critical angle determined by different groups. Ask learners to find a mean value for refractive index and critical angle and compare these to the expected values of 1.5 (refractive index) and 43° (critical angle). Discuss why different groups recorded different results.

Debriefing lesson: Collecting data

Resources	• Access to the Internet and speakers • Worksheets H, I and J.

Learning objectives	By the end of the lesson: • ***all*** learners should be able to select suitable equipment to make observations. • ***most*** learners should be able to describe how to record data, and calculate the refractive index and critical angle of a material. • ***some*** learners will be able to evaluate data and relate critical angle to refractive index.

Timings	Activity
5 min	**Starter / Introduction** Show an image of a spear-fisherman. Explain that if they aim at the fish they will miss, instead they must aim lower. Ask your learners to discuss why this is the case. You may need to clarify that the arrow travels in a straight line. Illustrate that it is the light that changes direction on its path from the fish to the spear-fisherman's eyes.
10 min	**Main lesson** Ask your learners how they would calculate the area of a rectangular desk or table. Alternatively, a rectangular section of the floor could be marked out with tape. Learners should discuss the following questions. The challenge of these increases progressively: 1. What equipment would you use? 2. What units of measurement are most suitable? 3. How could accuracy be improved? 4. How can precision be improved? 5. How many significant figures would you state in measurements? Discuss the importance of collecting suitable data and evaluating the quality of data you are given.
15 min	Provide learners with Worksheet H. Use questioning to determine which approach on the worksheet is favoured by learners. Discuss the flaws in each statement.
25 min	Provide learners with Worksheet I. Learners who require additional support can be given Worksheet J. Provide answers to the worksheet questions while learners self-assess their work.
5 min	**Plenary** Show a picture of an observer on the Earth looking at stars in the night sky. Inform your learners that light travels faster in a vacuum than it does in the Earth's atmosphere. Ask your learners to discuss whether the position where a star appears to an observer on Earth is actually lower or higher than its true position.

Worksheets and answers

	Worksheets	Answers
For use in the *Briefing lesson:*		
A: Ray diagrams and reflection	**16**	**29**
B: The Law of Reflection 1	**17**	**30**
C: The Law of Reflection 2	**18**	**31**
For use in *Lab lesson: Option 1:*		
D: Refraction of light	**19**	**32**
E: Method	**20**	**–**
F: Analysing Results	**21-22**	**33**
For use in *Lab lesson: Option 2:*		
D: Refraction of light	**19**	**32**
F: Analysing Results	**21-22**	**33**
G: Results	**23-24**	**–**
For use in the *Debriefing lesson:*		
H: Appropriate measurements	**25-26**	**34**
I: Using data	**27**	**35**
J: Using data (extra support)	**28**	**35**

Worksheet A: Ray diagrams and reflection

1. Describe how each of the following objects uses light and explain which is the odd one out.

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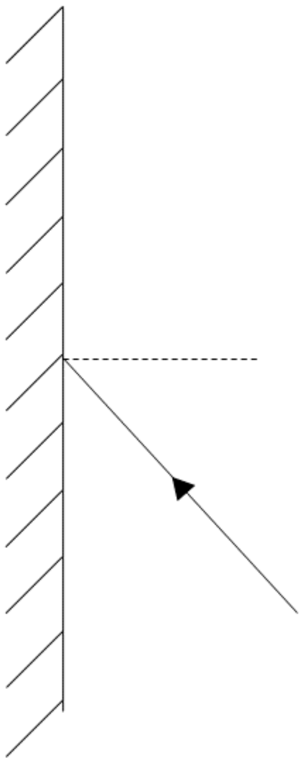
2. The diagram shows a ray of light being reflected from a mirror.
   a. Use a pencil and ruler to complete the diagram.
   b. Add the following labels:
      i. normal
      ii. angle of incidence
      iii. angle of reflection.



Worksheet B: The Law of Reflection 1

A group of learners investigated the Law of Reflection using a ray box and a plane mirror. The table below shows their results.

Angle of incidence / °	**Angle of reflection / °**
10	11
15	15
30	29
44	42
50	50
52	51
55	56
60	60
75	75
80	81

1. State the Law of Reflection.

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2. State the variables in this experiment

Independent variable: ....

Dependent variable: ....

3. Explain whether the data supports the Law of Reflection.

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4. Suggest improvements to the experiment.

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Worksheet C: The Law of Reflection 2

The learners made some improvements and decided to repeat the experiment. The table below shows their results.

Angle of incidence / °	**Angle of reflection / °**			
	Trial 1	Trial 2	Trial 3	Average
10	12	10.5	9.0	9.5
20	18.5	21	20	19.83
30	30	No data recorded	No data recorded	30
40	28	40	42.5	37.57
50	48.5	51.5	41	48.33
60	62.5	60	59.5	62.67
70	69	70.5	79	69.25
80	77.5	80	88.5	82

1. A protractor was used to measure the angles. Explain why the learners should not have included decimal places in their measurements, or their average.

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2. At an angle of incidence of 30° the group measured an angle of reflection of 30°. This was the result they expected so they did not repeat the measurement. Explain whether this was a good decision.

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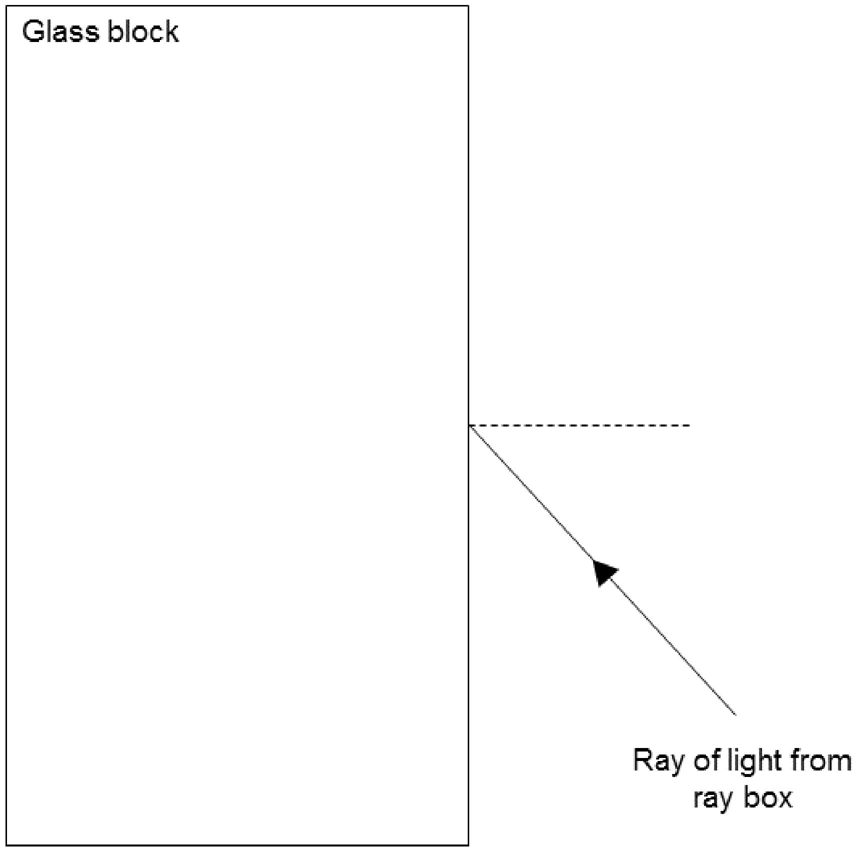
3. Identify any anomalies in the data and draw a circle around them.

4. Check the average values and make corrections in the table. Remember to ignore anomalies. Do not add decimal places to the average values.

Worksheet D: Refraction of light

The diagram shows a ray of light from a ray box being directed towards a glass block.

- Use a pencil and ruler to show the path of the ray of light through the block.
- Add the following labels:
    - normal
    - angle of incidence
    - angle of refraction.



Worksheet E: Method

Experiment: Part 1 Refractive index

1. Collect all your equipment.
2. Place a piece of white paper on a soft fibre board mat.
3. Place a rectangular Perspex block on the paper.
4. Draw a line around the block in pencil.
5. Draw the normal line at the centre of the long edge of the block.
6. Place a protractor against the Perspex block so that the 90° mark overlays the normal line.
7. Insert a slit plate into a ray box.
8. Turn the ray box on and direct it towards the block along the normal line, so the angle of incidence is 0°.
9. Move the ray box to increase the angle of incidence to 10°.
10. Use an optical pin to mark the point where the ray of light meets the protractor and where it leaves the block.
11. Move the ray box to increase the angle of incidence in intervals of 10°, up to 60°. Each time use an optical pin to mark where the ray of light meets the protractor and where it leaves the block.
12. Turn off the ray box and remove the Perspex block.
13. Use a pencil and ruler to join the points and show the paths of each ray of light.
14. Use a protractor to measure the angle of refraction (r) for each angle of incidence (i). Add the values to the table in **Worksheet F**.
15. Use a calculator to calculate sin i and sin r. Add the values to **Worksheet F**.
16. Complete the table on **Worksheet F** by calculating each value of refractive index (n), using the formula $n = \sin i / \sin r$.

Experiment: Part 2 Total internal reflection

1. Collect all your equipment.
2. Place a fresh piece of white paper on the soft fibre board mat.
3. Place a semi-circular Perspex block on the paper.
4. Draw a line around the block in pencil.
5. Draw the normal line at the centre of the straight edge of the block.
6. Turn the ray box on and direct it towards the curved edge of the block so it passes through, along the normal line. The angle of incidence is 0°.
7. Move the ray box to increase the angle of incidence until the ray of light passes along the straight edge of the block.
8. Place an optical pin at the point where the ray of light enters the block.
9. Removed the block and use a pencil and ruler to mark the path of the ray of light.
10. Use a protractor to measure the angle of incidence. This is the critical angle. Add the value to **Worksheet F**.
11. Complete Worksheet F

.

Worksheet F: Analysing results

Part 1: Refractive index

Angle of incidence *i* / °	**Angle of refraction *r* / °**	**sin *i***	**sin *r***	**Refractive index**
0				
10				
20				
30				
40				
50				
60				

1. Calculate a mean value of refractive index (*n*), using the values from the experiment:

....

....

....

Worksheet F: *continued*

Part 2: Total internal reflection

2. State the critical angle (c) determined in the experiment.

3. Refractive index (n) and critical angle (c) are related by the formula, $n = 1/\sin c$.

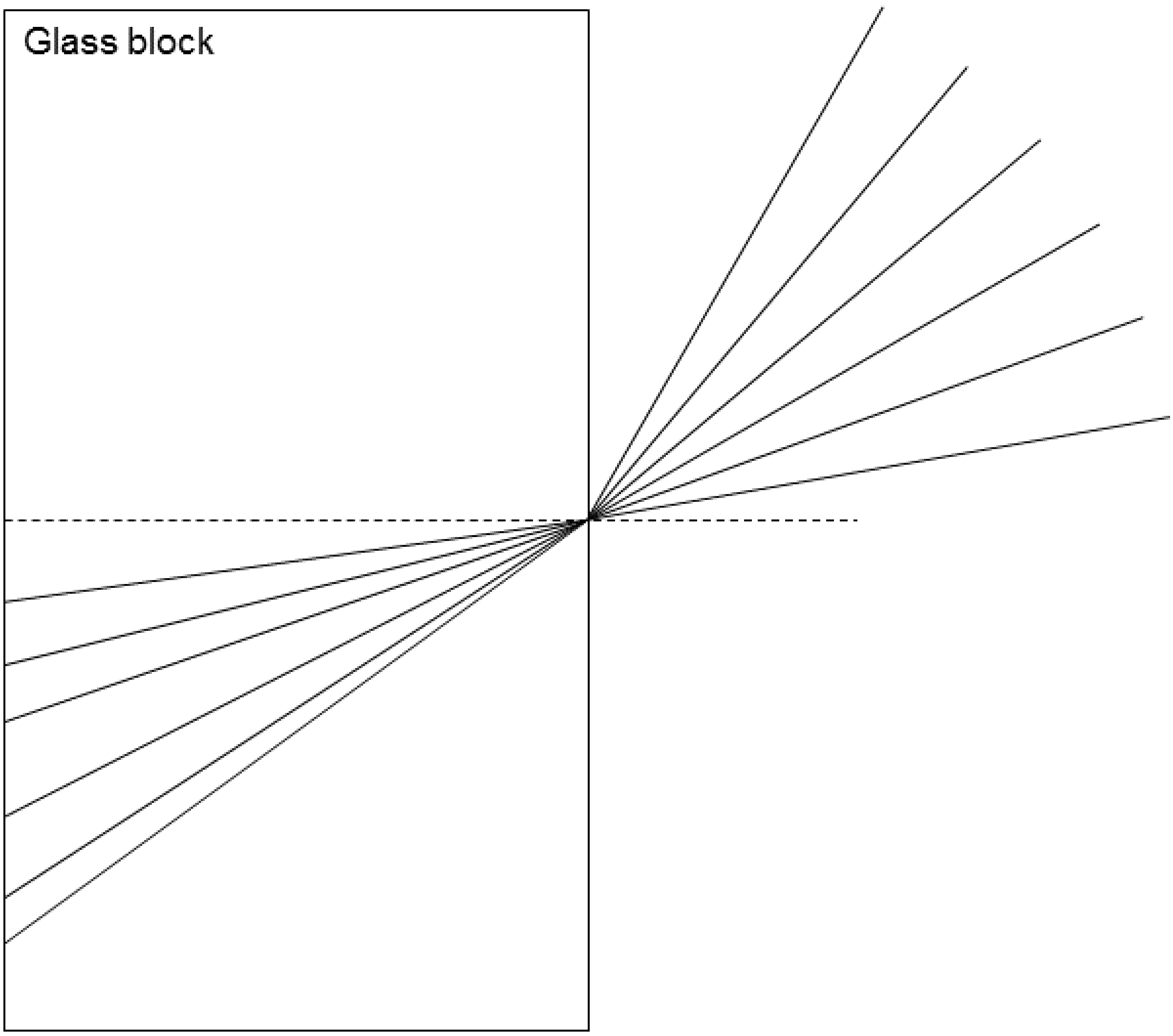
   a) Use this equation and the value of critical angle in Question 2 to calculate the refractive index of Perspex.

   b) Compare this value to the refractive index you calculated in Question 1.

Worksheet G: Results

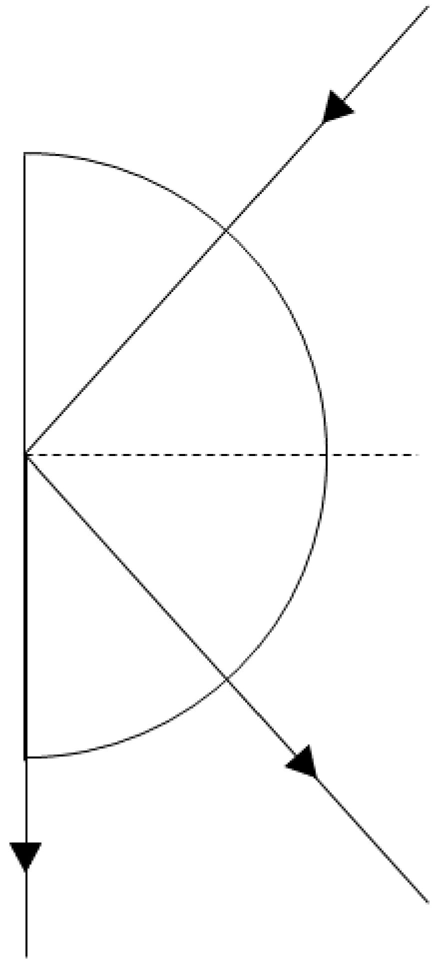
Use the diagrams below to complete **Worksheet F**.

Part 1: Refractive Index



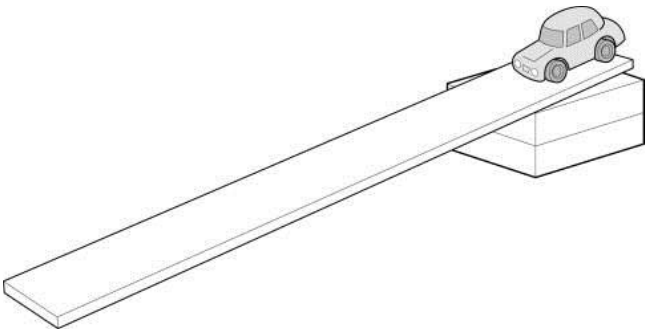
Worksheet G: *continued*

Part 2: Total internal reflection



Worksheet H: Appropriate measurements

Three learners are investigating the time it takes for a car to roll down a ramp. Each learner used a stop clock to make three measurements of time then calculated an average value.



Learner	Time 1 (s)	Time 2 (s)	Time 3 (s)	Average time (s)
1	2.32	2.25	2.29	2.2866667
2	2.4	2.2	2.3	2.3
3	2.18	2.28	2.41	2.29

The learners discussed their results and each made a statement:

Learner 1: My results were the most accurate because I used the most decimal places in my average value.

Learner 2: Reaction time is several tenths of a second so there is uncertainty in the measurement. I recorded values to one decimal place. My results are therefore the most precise.

Learner 3: I wrote down the values exactly as they were shown on the stop clock and calculator. My results must therefore be the most accurate.

Worksheet H: *continued*

Comment on the conclusions made by each learner.

Learner 1:...

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Learner 2:...

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Learner 3:...

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Worksheet I: Using data

A learner investigated the refraction of light through ice, glass and diamond. They planned to compare their results to the values in the table below.

Medium	**Critical angle / °**
Ice	50
Glass	41
Diamond	24

Unfortunately, the learner did not keep clear records of their observations.

Match each set of data to one of the materials.

Angle of incidence *i* / °	**Angle of refraction *r* / °**	**sin *i***	**sin *r***	**Refractive index**	**Critical angle / °**	**Material**
30	19					
40	15					
40	29					
20	13					
30	12					
40	25					
30	22					
20	8					
20	15					

Worksheet J: Using data (extra support)

A learner investigated the refraction of light through ice, glass and diamond. They planned to compare their results to the values in the table below.

Medium	**Critical angle / °**
Ice	50
Glass	41
Diamond	24

Unfortunately, the learner did not keep clear records of their observations.

Angle of incidence *i* / °	**Angle of refraction *r* / °**	**sin *i***	**sin *r***	**Refractive index**	**Critical angle / °**	**Material**
30	19					
40	15					
40	29					
20	13					
30	12					
40	25					
30	22					
20	8					
20	15					

1. Calculate values of sin *i* and sin *r*.
2. Calculate the refractive index, using the formula: $n = \sin i / \sin r$.
3. Calculate the critical angle, using the formula: $n = 1/\sin c$.
4. Identify each material based on the critical angle.

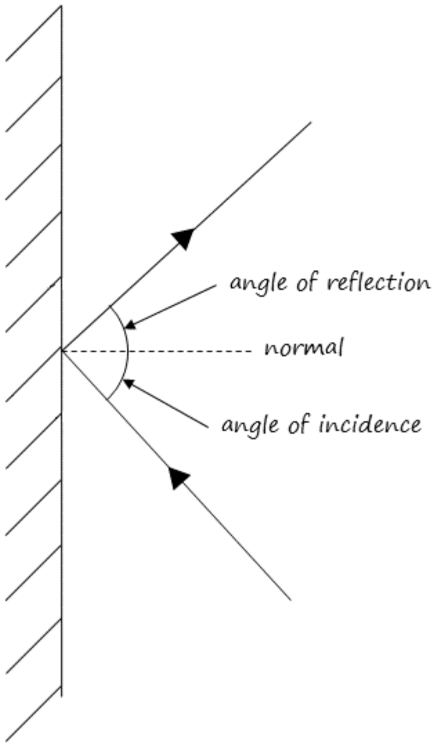
Worksheet A: Suggested Answers

1. Describe how each of the following objects uses light and explain which is the odd one out.




The wing mirror reflects light to allow a driver to see behind them.
The parabolic mirror reflects light from a curved surface allowing an observer to see around obstructions.
Light is emitted by the bulb in the torch. The bulb is surrounded by a silver material that reflects the light, increasing the brightness of the torch beam.
Light is magnified as it passes through the glasses. It is not reflected. The glasses are therefore the odd one out.

2. The diagram shows a ray of light being reflected from a mirror.
   a. Use a pencil and ruler to complete the diagram.
   b. Add the following labels:
      i. Normal
      ii. angle of incidence
      iii. angle of reflection.



Worksheet B: Suggested Answers

A group of learners investigated the Law of Reflection using a ray box and a plane mirror. The table below shows their results.

Angle of incidence / °	**Angle of reflection / °**
10	11
15	15
30	29
44	42
50	50
52	51
55	56
60	60
75	75
80	81

1. State the Law of Reflection.

   angle of incidence = angle of reflection

2. State the variables in this experiment:

Independent variable: *angle of incidence*

Dependent variable: *angle of reflection*

3. Explain whether the data supports the Law of Reflection.

   The data does support the Law of Reflection.

   Each angle of reflection is the same or almost the same as each angle of reflection.

   Any difference in the angles can be attributed to uncertainty in the measurements.

4. Suggest improvements to the experiment

   Regular intervals should be used for the angle of incidence.

   Multiple measurements should be taken for each angle of reflection.

   A mean value should be calculated for each angle of reflection.

Worksheet C: Suggested Answers

The learners made some improvements and decided to repeat the experiment. The table below shows their results.

Angle of incidence / °	**Angle of reflection / °**			
	Trial 1	Trial 2	Trial 3	Average
10	11	10.5	9.0	10
20	18.5	21	20	~~19.83~~ 20
30	30	No data recorded	No data recorded	30
40	28	40.5	41	~~36.5~~ 41
50	49.5	50.5	41	~~47~~ 50
60	61	60	59.5	~~60.2~~ 60
70	69	70.5	79	~~72.8~~ 70
80	79.5	79	88.5	~~82~~ 79

1. A protractor was used to measure the angles. Explain why the learners should not have included decimal places in their measurements, or their average.

   A protractor can only be used to measure each angle to the nearest degree.
   Each measurement should therefore be given to the nearest degree.
   The average should be given to the same number of decimal places as the measurements.

2. At an angle of incidence of 30° the group measured an angle of reflection of 30°. This was the result they expected so they did not repeat the measurement. Explain whether this was a good decision.

   This was not a good decision.
   A scientist should not deviate from their method due to their assumptions or expectations.
   Further measurements will improve the reliability of the results.

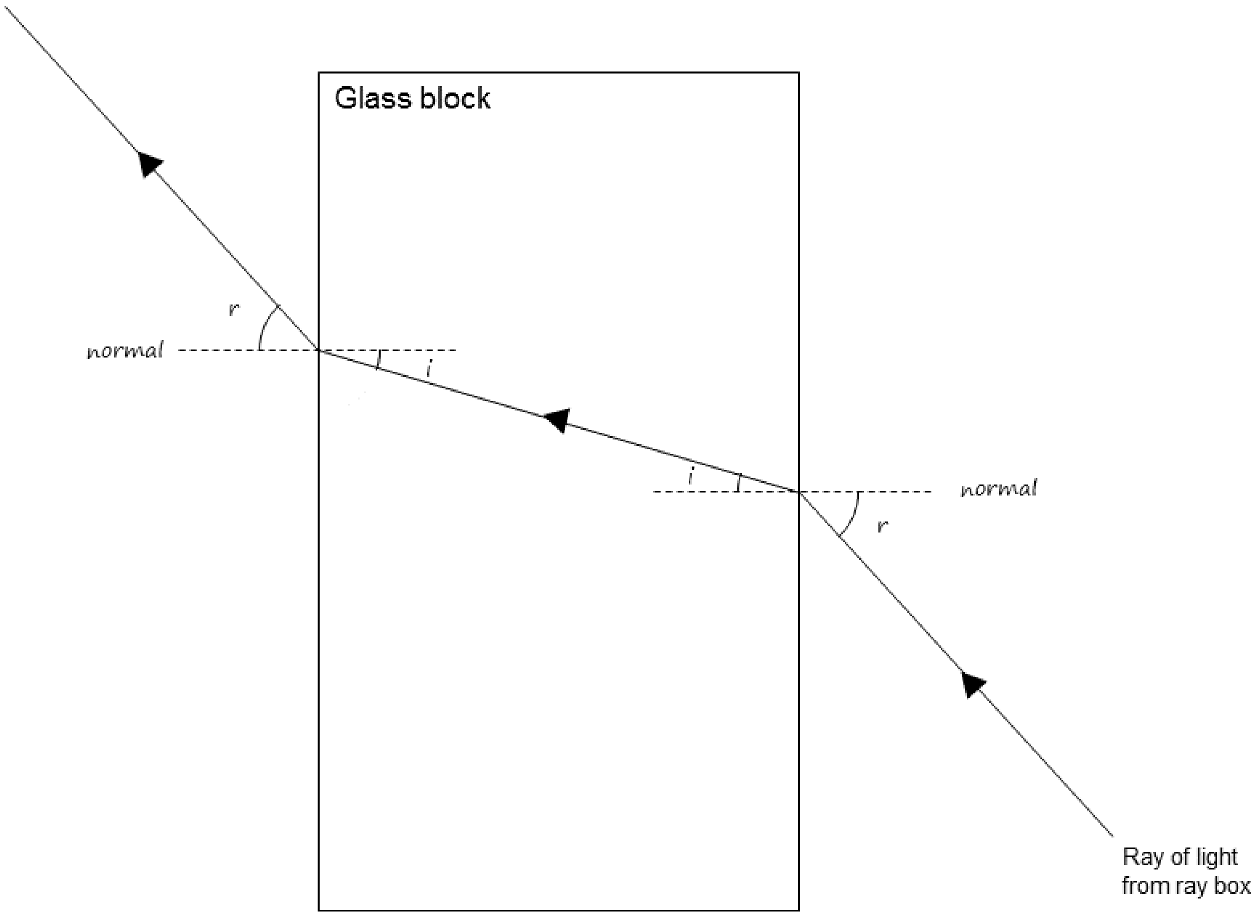
3. Identify any anomalies in the data and draw a circle around them.

4. Check the average values and make corrections in the table. Remember to ignore anomalies. Do not add decimal places to the average values.

Worksheet D: Suggested Answers

The diagram shows a ray of light from a ray box being directed towards a glass block.

- Use a pencil and ruler to show the path of the ray of light through the block.
- Add the following labels:
  - normal
  - angle of incidence
  - angle of refraction.



Worksheet F: Suggested Answers

Part 1 Refractive index

Your learners may calculate different values of refractive index, depending on how they round answers during previous steps of the calculation.

Angle of incidence *i* / °	Angle of refraction *r* / °	sin *i*	sin *r*	Refractive index
0	0			
10	8	0.17	0.14	1.21
20	14	0.34	0.24	1.42
30	19	0.50	0.33	1.52
40	27	0.64	0.45	1.42
50	33	0.77	0.54	1.43
60	36	0.87	0.59	1.47

1. Calculate a mean value of refractive index (n), using the values from the experiment:

   1.42 + 1.52 +1.42 + 1.43 + 1.47 = 7.26

   7.26 ÷ 5 = 1.45

Part 2 Total internal reflection

2. State the critical angle (c) determined in the experiment.
   48°

3. Refractive index (n) and critical angle (c) are related by the formula, $n = 1/\sin c$.
   a. Use this equation and the value of critical angle in Question 2 to calculate the refractive index of Perspex.

      n = 1 / sin c

      n = 1 / sin 48° = 1.35

   b. Compare this value to the refractive index you calculated in Question 1.

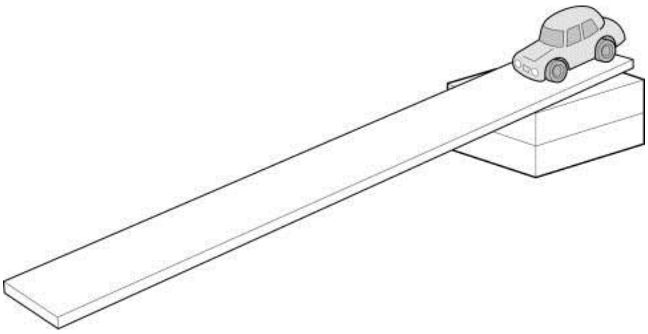
      The values of 1.45 and 1.35 are close but not the same.

      The difference between the values is 0.1.

      This difference can be attributed to uncertainties in the measurements.

Worksheet H: Suggested Answers

Three learners are investigating the time it takes for a car to roll down a ramp. Each learner used a stop clock to make three measurements of time then calculated an average value.



Learner	Time 1 (s)	Time 2 (s)	Time 3 (s)	Average time (s)
1	2.32	2.25	2.29	2.2866667
2	2.4	2.2	2.3	2.3
3	2.18	2.28	2.41	2.29

The learners discussed their results and each made a statement:

Learner 1: My results were the most accurate because I used the most decimal places in my average value.

Learner 2: Reaction time is several tenths of a second so there is uncertainty in the measurement. I recorded values to one decimal place. My results are therefore the most precise.

Learner 3: I wrote down the values exactly as they were shown on the stop clock and calculator. My results must therefore be the most accurate.

Comment on the conclusions made by each learner.

Learner 1: *This is incorrect. An appropriate number of decimal places should be used based on the measuring device. Using more decimal places does not make data more accurate.*

Learner 2: *One decimal place is suitable for this experiment, when reaction time is considered. However, using one decimal place does not make the results more precise.*

Learner 3: *It is not always appropriate to write values exactly as they are shown on a stop clock or calculator. It is important to use an appropriate number of decimal places for each measurement.*

Worksheets I & J: Suggested Answers

A learner investigated the refraction of light through ice, glass and diamond. They planned to compare their results to the values in the table below.

Medium	Critical angle / °
Ice	50
Glass	42
Diamond	24

Unfortunately, the learner did not keep clear records of their observations.

Match each set of data to one of the materials.

Your learners may calculate different values to these depending on how they round answers during previous steps of the calculation.

Angle of incidence *i* / °	Angle of refraction *r* / °	sin *i*	sin *r*	Refractive index	Critical angle / °	Material
30	19	0.50	0.33	1.52	41	Glass
40	15	0.64	0.26	2.46	24	Diamond
40	29	0.64	0.48	1.33	49	Ice
20	13	0.34	0.22	1.55	40	Glass
30	12	0.50	0.21	2.38	25	Diamond
40	25	0.64	0.42	1.52	41	Glass
30	22	0.50	0.37	1.35	48	Ice
20	8	0.34	0.14	2.43	24	Diamond
20	15	0.34	0.26	1.31	50	Ice

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