Index

Introduction
Investigating the acceleration of free fall
Investigating the relationship between velocity and the horizontal distance travelled by a projectile
Measuring the specific latent heat of vaporisation of water
Investigating an ideal gas law
Measuring the speed of sound
Determining refractive index
Investigating the resistivity of a conducting wire
Measuring the internal resistance of a cell
Determining the half-life of random processes as a simulation of radioactive decay
Investigating double-slit and double-source wave interference (HL)

Introduction

ITER is a large-scale nuclear fusion energy project that is underway in Saint Paul-lez-Durance, southern France. The ITER Members, China, the European Union, India, Japan, Korea, Russia and the United States, are all collaborating on this fusion experiment to try to find a way of making nuclear fusion an economically viable means of energy production.

Figure 1. Aerial view of the ITER facility in France.

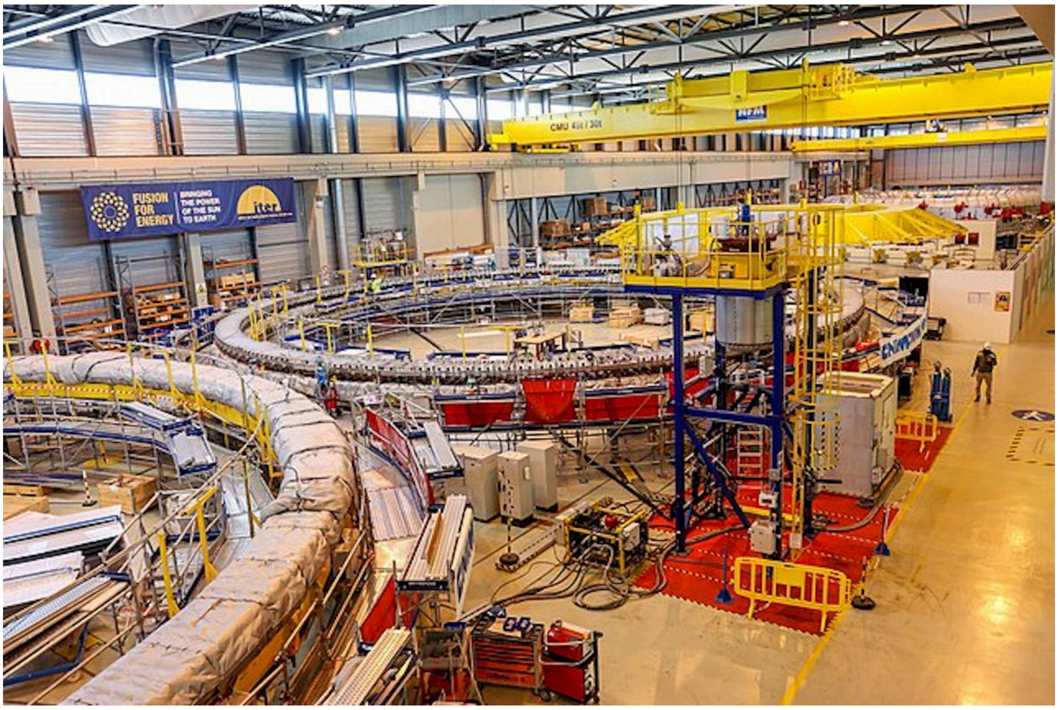


Figure 2. An inside look at the ITER facility.

The warmth that we feel from the Sun is the result of a fusion reaction that turns 600 million tonnes of hydrogen into helium every second.

$$H + H \rightarrow He + energy$$

This reaction releases vast amounts of carbon-free energy and scientists at ITER are trying to replicate the reaction. However, without the same magnitude of gravitational forces that are at work in the Sun, achieving fusion on Earth has proved to be difficult.

A total of 35 nations are collaborating to build the world's largest tokamak, a magnetic fusion device that has been designed to prove the feasibility of fusion.

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

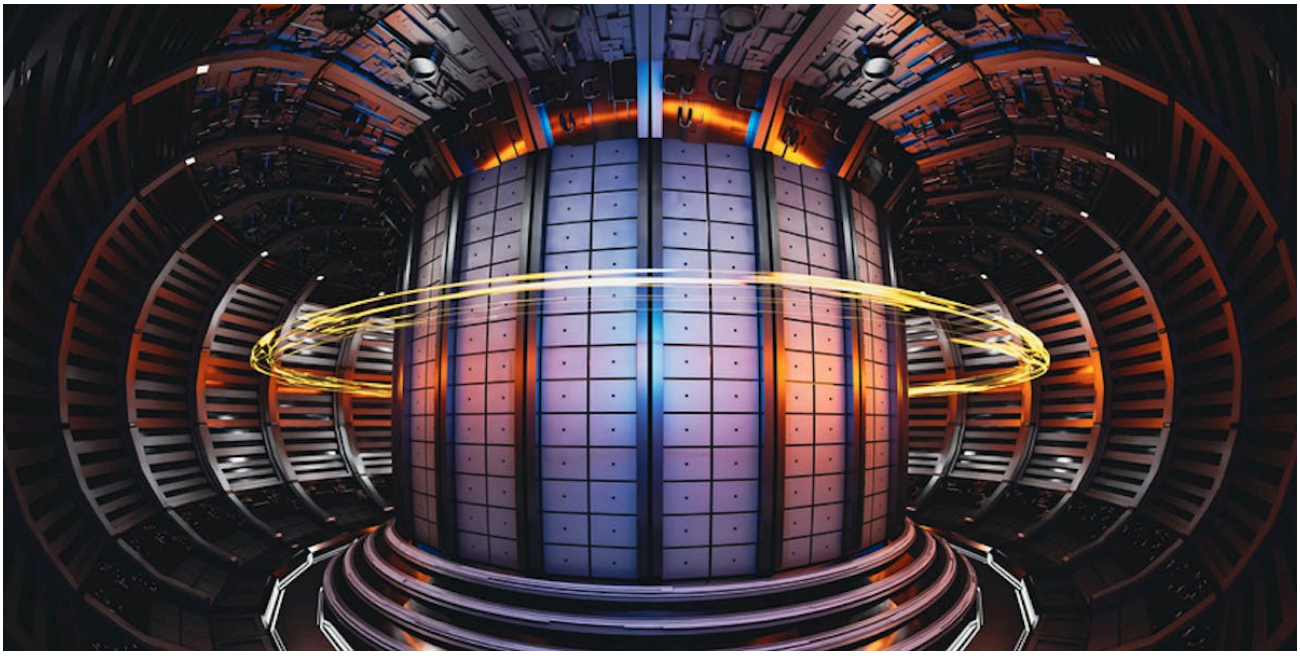


Figure 3. A tokamak is a machine that confines a plasma using magnetic fields in a donut shape that scientists call a torus.

Credit: mesh cube, Getty Images

For fusion to occur, an incredibly high pressure is required as well as absurdly large temperatures. The primary objective of this project is to use the energy of the helium nuclei, produced by the fusion reactions, to maintain the temperature of the plasma. This would reduce the need for external heating.

ITER is also testing the technology that is required for a fusion reactor such as superconducting magnets, remote maintenance, and systems to exhaust power from the plasma.

In previous projects, scientists have succeeded in producing energy from nuclear fusion, however, the problem with fusion power at the moment is that it is too inefficient. The record for fusion power is held by the European tokamak JET. In 1997, JET, from an input of 24 MW, produced a total of 16 MW of fusion power. ITER aims to produce 500 MW of fusion power from 50 MW of input heating power.

For more facts about ITER, check out [https://www.iter.org/factsfigures (https://www.iter.org/factsfigures)](https://www.iter.org/factsfigures).

ITER is not only a shining illustration of International Collaboration, it is also an example of the successes of the scientific method. Scientists and engineers conducted background research and calculations to create hypotheses and design methods that will be tested. Once the experimental data has been collected, conclusions will be drawn and improvements to the method and process will be suggested.

Student view

This is very similar to the process undertaken in the Internal Assessment and in practical work in the IBDP science curriculum.

Initially, you, the researcher, will come up with an idea of something that you would like to research. You will then conduct thorough background research with a variety of sources to inform your proposal. By selecting sufficient and relevant sources of information you will be able to formulate a hypothesis that will be tested in your research, just as the scientists in ITER did before the project began in 1985. This will be tested in your Internal Assessment in the Research Design criterion.

Once you have designed a method, you will collect, transform and analyse data. In this criterion, Data Analysis, you will need to consider uncertainties and the processing data. These skills are discussed in the practicals that follow.

Upon analysing the data, you (or any other scientist for that matter) will need to evaluate the research question in light of the collected data. The Conclusion criterion makes you question whether your data supports your research question. You will draw conclusions about your experiment and discuss them through relevant comparison to the accepted scientific context.

Having drawn conclusions, you will need to reflect on the experiment that was completed and identify ways of improving the data that was collected. In the Evaluation criterion you will need to consider the impact of methodological weakness and experimental limitations and suggest improvements to make this experiment more reliable or suggest extensions to this experiment for further research.

Scientists in ITER do not intend to create a nuclear fusion reactor that harvests enough energy to satisfy our energy needs. Instead, the facility is entirely for research. They aim to develop science and to make fusion a more realistic and efficient form of energy production for the future.

Through hypothesising, testing, analysing, concluding and evaluating, scientists are able to move the overall global knowledge base forward step by step to create a better future for everyone.

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

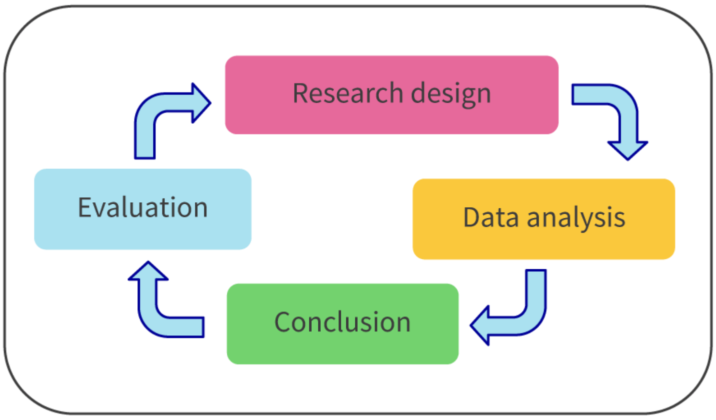


Figure 4. The four phases of the inquiry cycle.

More information for figure 4

The image is a flowchart illustrating the four phases of the inquiry cycle. It is arranged in a circular sequence with arrows indicating the flow from one phase to the next. The phases are labeled as follows: 'Research design', 'Data analysis', 'Conclusion', and 'Evaluation'. Each phase is represented by a colored box: pink for Research design, yellow for Data analysis, green for Conclusion, and blue for Evaluation. The arrows are blue and show a clockwise progression, connecting each phase to form a continuous loop. These phases represent a cyclical process in conducting research, emphasizing the iterative nature of inquiry where evaluation leads back into research design.

[Generated by AI]

This subtopic contains ten practicals. In all these practicals, you will develop your skills in one or more phases. As you develop skills, you will be preparing for your Internal Assessment (IA Guide) (/study/app/math-aa-hl/sid-423-cid-762593/book/introduction-id-46741/), where you will demonstrate your skills in all phases.

The new DP physics syllabus guide doesn't have prescribed practicals but a greater focus on specific tools and techniques (i.e. prescribed skills). The practicals in this Kognity resource are not to be seen as prescribed, but as a suggestion of practicals that will cover the prescribed tools and skills. Some of the practicals therefore have a series of steps for you to follow, while others are more open ended and require you to design an experiment to respond to a research question. Each of the practicals includes a 'Practical skills' box listing the particular experimental technique, technology and mathematical skills you require.

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Before you start, revisit the safety guidelines in the welcome topic (/study/app/math-aa-hl/sid-423-cid-762593/book/practical-activities-safety-id-43223/) and section 1.1.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/safety-of-self-others-and-the-environment-id-48941/) to refresh your memory. When performing these practicals, always follow your teacher's instructions.

Investigating the acceleration of free fall

? Guiding question(s)

- How can the acceleration due to gravity be measured experimentally?

Prior learning

Before attempting this practical, you should be familiar with the following concepts:

A.1 Kinematics

- Velocity is the rate of change of position, and acceleration is the rate of change of velocity (section A.1.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/describing-motion-id-44298/)).
- The change in position is the displacement (section A.1.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/describing-motion-id-44298/)).
- The difference between distance and displacement (section A.1.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/describing-motion-id-44298/)).
- The difference between instantaneous and average values of velocity, speed and acceleration, and how to determine them (section A.1.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/describing-motion-id-44298/)).
- The equations of motion for solving problems with uniformly accelerated motion (section A.1.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-equations-of-motion-id-44299/)).

Legend has it that when Galileo Galilei measured the acceleration of a falling object, he went up the Leaning Tower of Pisa and dropped objects to the ground (**Figure 1**).

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

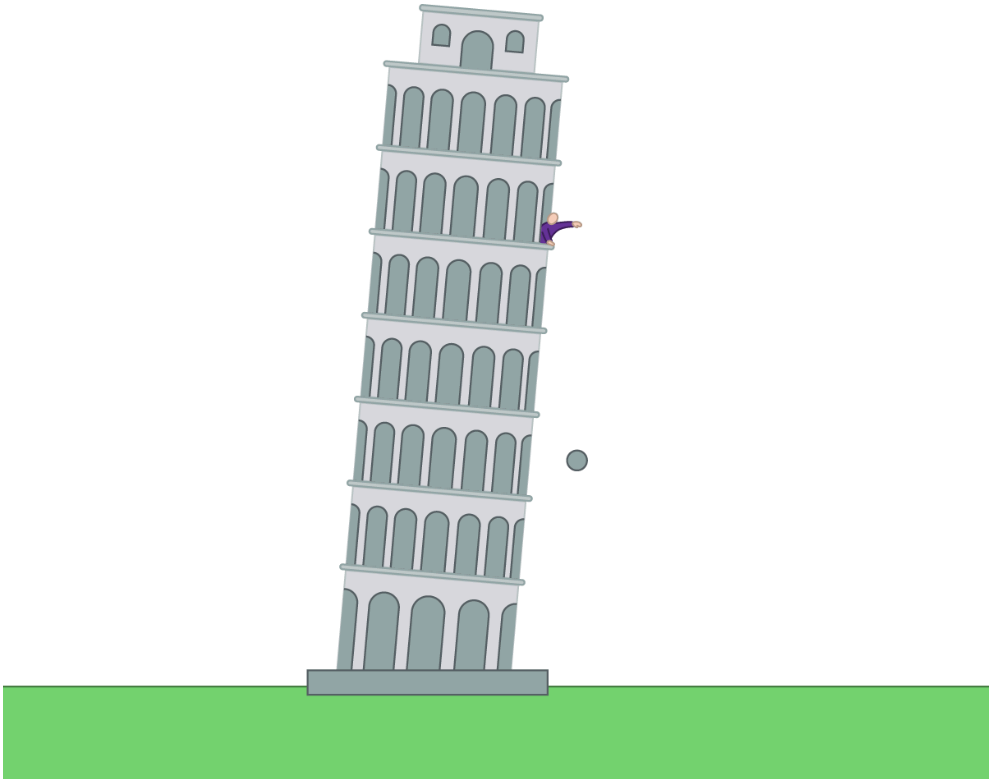


Figure 1. An object in freefall.

In truth, he probably used a more reliable, and safer method, in a controlled environment (a laboratory). He rolled heavy objects down steep inclines, and measured their acceleration as the incline became almost vertical. In this way, objects behaved as if they were in free fall.

In subtopic A.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43128/) you learned that objects in free fall will all have the same constant acceleration, the acceleration due to gravity (on the surface of Earth in the absence of air resistance), $g = 9.8\ \text{m s}^{-2}$. In this practical, you will measure the value of this acceleration, as Galileo did almost 400 years ago.

Study skills

Throughout the DP physics course you will study many constants, such as the acceleration due to gravity and the speed of light. You will not be required to memorise the value of any constants for exams, you can find them in section 1.6.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/fundamental-constants-id-45155/) of the DP physics data booklet, or they will be given in the exam itself.

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Practical skills

In this practical you will be using the following tools and skills:

Tool 1: Experimental techniques

- Understand how to accurately measure mass and length to an appropriate level of precision (see sections 1.1.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-variables-with-analogue-equipment-id-48813/) and 1.1.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-variables-with-digital-equipment-id-48814/)).

Tool 2: Technology

- Carry out image analysis and video analysis of motion (see section 1.2.5 (/study/app/math-aa-hl/sid-423-cid-762593/book/image-analysis-id-48946/)).
- Represent data in a graphical form (see section 1.2.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/manipulating-and-representing-data-id-48945/)).

Tool 3: Mathematics

- Select and manipulate equations (see section 1.3.6 (/study/app/math-aa-hl/sid-423-cid-762593/book/equations-id-48952/)).
- Distinguish between continuous and discrete variables (see section 1.3.7 (/study/app/math-aa-hl/sid-423-cid-762593/book/continuous-and-discrete-variables-id-48954/)).
- Understand direct and inverse proportionality, as well as positive and negative relationships or correlations between variables (see section 1.3.8 (/study/app/math-aa-hl/sid-423-cid-762593/book/proportionality-and-percentage-change-id-48955/)).
- Determine the effect of changes to variables on other variables in a relationship (see section 1.3.8 (/study/app/math-aa-hl/sid-423-cid-762593/book/proportionality-and-percentage-change-id-48955/))
- Understand the significance of uncertainties in raw and processed data (see section 1.3.9b (/study/app/math-aa-hl/sid-423-cid-762593/book/errors-and-uncertainties-id-49160/)).
- Record uncertainties in measurements as a range (±) to an appropriate precision (see section 1.3.9c (/study/app/math-aa-hl/sid-423-cid-762593/book/propagation-of-uncertainties-id-49161/)).
- Propagate uncertainties in processed data in calculations involving addition, subtraction, multiplication, division and (HL) exponents (see section 1.3.9c (/study/app/math-aa-hl/sid-423-cid-762593/book/propagation-of-uncertainties-id-49161/)).
- Express measurement and processed uncertainties, absolute, fractional (relative) and percentage, to an appropriate number of significant figures or level of

Student view

precision (see section 1.3.9c (/study/app/math-aa-hl/sid-423-cid-762593/book/propagation-of-uncertainties-id-49161/)).

Method

A simple experiment you can do could involve dropping objects vertically, and deducing the value of their acceleration as they fall.

Before starting your experiment, think through the following questions. Once you have had a think, click on the sample answers and compare your answers with the author's suggestions. Remember, there are often multiple correct answers, so do not be surprised if yours doesn't exactly match with those of the author.

1. Explain how you would calculate the value of the acceleration from your experiment.
2. Identify the independent and dependent variables of your investigation.
3. Describe the instruments you would need to measure these variables.
4. Explain which variables you will need to control.

1. You learned in subtopic A.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43128/) about the 'SUVAT' equations, the equations for uniformly accelerated motion. Since you are dealing with an object in free fall over short distances, these equations apply to this situation.
So, by measuring some of the object's parameters as it moves (its displacement, initial and final velocities, or time) the equations can be solved for acceleration.

Study skills

If you were measuring over larger distances, air resistance would have an effect and the acceleration would no longer be uniform.

As the distances are small, we make the assumption that air resistance is negligible.

In an Internal Assessment, it would be important to discuss this assumption in your background research section.

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

2. You probably cannot measure an object's acceleration directly, unless you have specialised equipment. This means that other values need to be measured, and then used to calculate the acceleration. Given the SUVAT equations, you can measure displacement, initial velocity, final velocity, or time.
It can be complicated to measure velocities directly, especially the velocity with which an object crashes into the ground. The best option is to set the independent variable as the time during which the object falls and the dependent variable as the object's displacement. For this, the SUVAT equation:

$$s = ut + \frac{1}{2}at^2$$

can be used to determine the acceleration.
If the object is dropped from a resting position, then initial velocity, $u = 0$.
This means ut gets removed from the equation making it:

$$s = \frac{1}{2}at^2$$

3. The displacement can be measured through the use of a measuring tape. Fix a measuring tape next to the object's path, so you can quickly measure the object's displacement without having to move the tape (**Figure 2**).

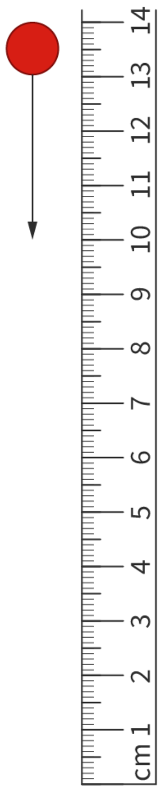


Figure 2. Measuring tape set next to a falling object.

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

To measure the time, you could consider using a stopwatch, but this will be inexact, given your reaction time. You can get a more precise measurement if you record the object's fall with a camera, and then get the time from your video. Make sure to set up the camera so that it is perpendicular to the object's trajectory, and do not move it while it is recording. Making a recording will also simplify your measurements, since you directly observe what distance the object covers over different periods of time.

4. The object needs to be in free fall, or as close to it as possible. Dense, compact objects will work best – for example, a tennis ball. Look for objects that are brightly coloured, so they are easier to observe in your video.
Another thing to consider is that, if the height is too big, air resistance will have a greater effect (but if it is too small, you might have trouble measuring the time).
The experiment will work best in a closed environment, so that the wind does not affect your work.
Finally, the use of the SUVAT equation will be simpler if the initial velocity of the object is zero. Make sure to drop it, rather than throwing it downwards.

Create a method that will allow you to measure the relationship between time and displacement. You may wish to use equipment available in the school lab, or perhaps simply use a ball, measuring tape/metre stick and your phone camera. To get an accurate measurement, you will need to carry out several repetitions. First, select seven time intervals. Then, you will need to collect three trials of each increment so that you can calculate an average.

Collecting and processing data

Internal assessment criteria

Data analysis

In this practical you will identify the amount of error provided by different devices and consider the uncertainty in a range of values. You will identify how to display these uncertainties graphically.

If for some reason you are unable to collect data yourself, a table of sample data has been provided below. If you have created your own data table, you should progress through the following material using your own original data.

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Time (s)	Displacement 1 (m)	Displacement 2 (m)	Displacement 3 (m)
0.30	0.50	0.40	0.50
0.40	0.90	0.80	0.85
0.50	1.20	1.22	1.22
0.60	1.60	1.80	1.60
0.70	2.30	2.30	2.40
0.80	3.00	3.10	3.20
0.90	3.90	4.00	3.90

Once you have your data, you need to calculate the uncertainties.

Error analysis

1. Analogue devices

Measuring tapes and metre sticks are examples of analogue measuring equipment. The absolute uncertainty of an analogue device is half of the smallest unit that can be measured with that equipment. For example, the smallest measurement that can be taken on a ruler is 1 mm. That means that the uncertainty in the ruler is ± 0.5 mm.

2. Digital devices

When you use a digital instrument to make a measurement, the uncertainty can be typically determined by the smallest amount the instrument can measure. For example, suppose you use a digital scale to measure an object’s mass, and you get a mass of 20.4 grams. In this case, since the scale gives the reading down to one decimal place, so in theory it could measure a value of mass as small as 0.1 grams. This would be your uncertainty on the mass.

Student view

Study skills

Uncertainty

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Very often, students feel like they should provide a report that gives almost perfect results and so, they underplay their uncertainties in their reports. This is best avoided.

Marks are awarded in the Internal Assessment for a realistic approach to uncertainties. If your report suggests uncertainties that are too small, it will look suspicious and the marker is sure to recognise it. This could cost you marks.

Uncertainty in time

Time will usually be measured with a stopwatch. This is a digital device and the uncertainty in most stopwatches is 0.1 seconds.

However, when taking measurements of time your reaction time is approximately 0.3 seconds. This is a form of uncertainty in your results.

The uncertainty in the reaction time is larger than the uncertainty in the measurement device. So, when quoting the uncertainty in the time value, we often quote that reaction time uncertainty instead.

Any time you have a choice of uncertainty values to choose from, always pick the larger of the two.

3. Uncertainty in a range of values

When carrying out an experiment it is important to carry out at least three trials so that you can get an average. The range of values that you collect can also be used to find the uncertainty.

Before calculating the uncertainty, inspect your data to identify if there might be an inconsistent measurement or result that does not fit with the rest of the data recorded. This is considered to be an outlier or anomalous result (see Data analysis (/study/app/math-aa-hl/sid-423-cid-762593/book/data-analysis-id-46745/) within the Internal assessment guide sections).

To find the uncertainty in the values, find the range (take the maximum of the three values and subtract the minimum of the three values) and divide it by two.

The formula for range uncertainty is:

$$\text{uncertainty} = \frac{(\text{maximum value} - \text{minimum value})}{2}$$

For the displacement, since we have several repetitions, we can work out the uncertainty by finding half of the range in the values.

Student view

Table 1. Calculation of uncertainty for the first measurements of displacement in the sample table.

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Displacement 1 (m)	Displacement 2 (m)	Displacement 3 (m)	Mean (average) displacement	Range uncertainty
0.50	0.40	0.50	0.47	0.05
0.88	0.80	0.85	0.85	0.04

Study skills

When presenting experimental data, always make sure to include its uncertainty. In a table, this is typically given at the top of the column (together with the descriptor, such as the variable name, and the units of measurement). In some cases, you might need to use different values of uncertainty for each row of measurements; in those cases, include the uncertainty to the right of the table, together with the average value.

Depending on the nature of your data, the uncertainty will be obtained in different ways — it might be determined by the instrument or by calculating the uncertainty from a range of values (such as when taking an average). In this case, you simply take

$$\frac{(\text{maximum value} - \text{minimum value})}{2}$$

We will use this method of finding uncertainty a number of times throughout these experiments.

If you have a choice (say, between range uncertainty and measurement device uncertainty) you should always use the larger of the two.

Do not be afraid to discuss this in your Internal Assessment. Let the marker know that you are aware that there are various ways of finding the uncertainty and that you have selected one and why you have made this decision.

Your processed data might look something like that shown in **Table 2**.

Table 2. Mean (average) displacement for each time interval.

Time (s) Uncertainty: 0.03 s	Mean displacement (m)
0.30	0.47
0.40	0.85
0.50	1.21

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Time (s) Uncertainty: 0.03 s	Mean displacement (m)
0.60	1.67
0.70	2.33
0.80	3.10
0.90	3.93

Study skills

When you write a report for a practical or your Internal Assessment, make sure you include evidence of all the work that you did, which includes carrying out the experiment and collecting data. When appropriate, you should include all your unprocessed data in an organised fashion, together with the average values and other calculations you carry out. If the data is too lengthy, you can include a sample.

Once you have your data, you can use it to calculate the value for the acceleration. The most common way of determining a variable is to measure it as the gradient of a line. If you plot a graph of displacement vs time, you will not get a straight line.

Determine what you should plot on each axis, so that the result is a straight line.

Go back to the SUVAT equation for displacement:

$$s = ut + \frac{1}{2}at^2$$

The initial velocity u is zero, so we do not have to worry about that term. That means that displacement depends on time squared.

$$s = \frac{1}{2} \times a \times t^2$$

To get a linear graph, rearrange the equation so that it follows the equation of a straight line,

Student view

$$y = mx + c$$

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

where m stands for the slope, c is the y-intercept, and y and x are the dependent and independent variables, respectively.

Using the SUVAT equation, each term of the equation can be related to its equivalent on the straight-line formula (**Figure 3**).

$$\underbrace{\boxed{s}}_{\text{“y”}} = \underbrace{\boxed{\frac{1}{2}a}}_{\text{“m”}}\underbrace{\boxed{t^2}}_{\text{“x”}}$$

Figure 3. Displacement equation with terms relating to the straight-line equation.

Therefore, in order to get a straight line, you should plot displacement s on the vertical axis, and time squared t^2 on the horizontal axis. The gradient will then be $\frac{1}{2} \times a$, or half the acceleration of free fall. The equation predicts that the line of best fit should go through the origin, since there is no y-intercept (it is zero).

Study skills

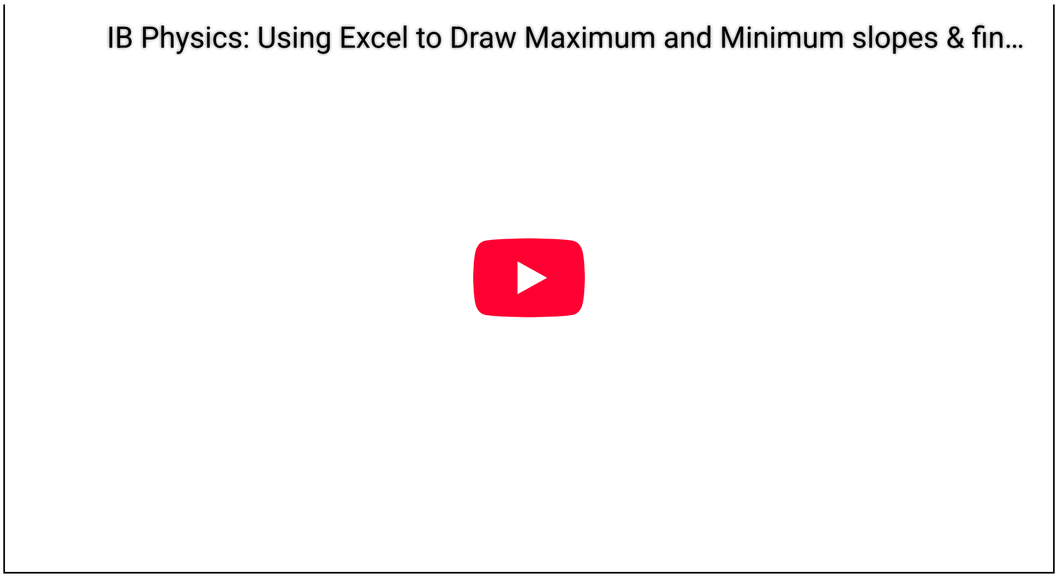
In practicals and in your Internal Assessment, you will often need to linearise your graphs. This means adjusting the variables of your graph on each axis so that the result is a straight line. By doing this, you will be able to determine values through the gradient, and get the maximum and minimum gradient lines — these will give you the uncertainty of your final result.

Plot a graph of your data, making sure you get a straight line, and use this graph to calculate the value for the acceleration. Include the minimum and maximum gradient lines on your graph.

If you need tips, you can check **Video 1** on how to find the minimum and maximum gradients for the graph.

Student
view

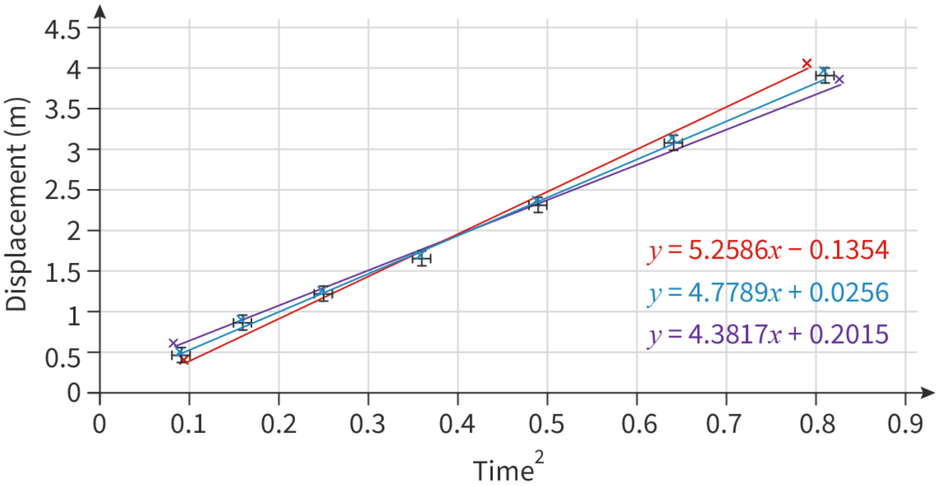
Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c



Video 1. Drawing min and max slope lines.

A sample graph has been completed for reference using the data above.

Your graph should look similar to the one shown below.



Graph of displacement vs time^2. The line of best fit is shown in blue, the minimum gradient is shown in purple and the maximum gradient is shown in red.

To determine the value for the acceleration:

The gradient is $\frac{1}{2}a$, so:

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

$$\frac{1}{2}a = 4.7789$$

$$a = 9.6 \text{ m s}^{-2}$$

This is the average value of the acceleration.

To get the uncertainty on this value, use the minimum and maximum gradient lines.

The minimum and maximum accelerations would be:

$$a_{\text{max}} = 2 \times 5.2586 = 10.5172 \text{ m s}^{-2}$$

$$a_{\text{min}} = 2 \times 4.3817 = 8.7634 \text{ m s}^{-2}$$

The formula for this uncertainty is:

$$\text{uncertainty} = \frac{(\text{maximum value} - \text{minimum value})}{2}$$

Substituting in the values gives:

$$\text{uncertainty} = \frac{(10.5172 - 8.7634)}{2}$$
$$= 0.8769$$

Therefore:

$$\text{acceleration} = 9.6 \pm 0.9 \text{ m s}^{-2}$$

with the uncertainty given to one significant figure, as is typical.

Whenever you calculate the value of a known constant, it is a good idea to compare it against what you would expect. In this case, the known value of the acceleration due to gravity is $9.8\,\text{m}\,\text{s}^{-2}$. This value is within the error bounds of the experiment, so we can be confident of our results.

Study skills

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Remember to always include the uncertainty in your final answer. Your uncertainty value should be given to one significant figure. You will be tested on laboratory skills, including the correct usage and interpretation of uncertainties, in your physics paper 1b.

It is likely that the result you get for the acceleration in your experiment is $9.81\,\text{m}\,\text{s}^{-2}$, the expected value of acceleration in free fall.

Think about some reasons why your value may deviate from the expected answer and check below to see if you have the same answer.

The deviation is not necessarily because of errors in your procedures or calculations. Rather, it highlights the limitations in the experiment. It might be that your object was not truly in free fall, but rather the air resistance had a greater impact than expected. Or that the method you used to measure the displacement was not ideal. These factors, among others, will cause your answer to deviate from the true value.

Study skills

Your reports should always end with a conclusion, in which you discuss your work. This includes analysing your results (for example, checking whether they match with the expected theoretical values) and indicating the main limitations in your work. You should explain all limitations (explain why they appear), judge their impact on your results, and suggest practical ways in which you could reduce their impact. Conclusion writing will be discussed in later experiments. For more information, check the Internal Assessment guide (/study/app/math-aa-hl/sid-423-cid-762593/book/introduction-id-46741/).

Internal assessment checklist

For your internal assessment work, remember the following that you have exercised in this practical:

Data analysis

- All qualitative and quantitative data is organised into tables for all variables, expressed with correct precision and includes units and uncertainties.
- Consideration of the uncertainties of each piece of apparatus used in your investigation (if applicable).

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

- Data processing relevant to research question is complete.
- Graphs (if applicable) showing the relationship between the dependent and independent variables are suitable and correctly labelled.

1. Essential skills and support guides / 1.4 Collected practicals

Investigating the relationship between velocity and the horizontal distance travelled by a projectile

? Guiding question(s)

- How can we predict exactly where a projectile will hit the ground?

Prior learning

Before attempting this practical, you should be familiar with the following concepts:

A.1 Kinematics

- The equations of motion for solving problems with uniformly accelerated motion (section A.1.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-equations-of-motion-id-44299/)).
- The behaviour of projectiles in the absence of fluid resistance (section A.1.4a (/study/app/math-aa-hl/sid-423-cid-762593/book/projectile-motion-id-44300/)).
- The application of the equations of motion resolved into vertical and horizontal components (section A.1.4a (/study/app/math-aa-hl/sid-423-cid-762593/book/projectile-motion-id-44300/)).

Understanding the factors that determine where a projectile will land is essential for various real-life applications, ranging from sports to engineering and even space exploration. In this practical, you will investigate projectile motion by rolling a ball down a ramp and assessing how its velocity on launch affects its landing point with the use of video analysis or photogates.

Student view

Imagine two tennis balls, one is rolled off the table and the other is simply dropped from the same height. Which ball will hit the ground first?

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

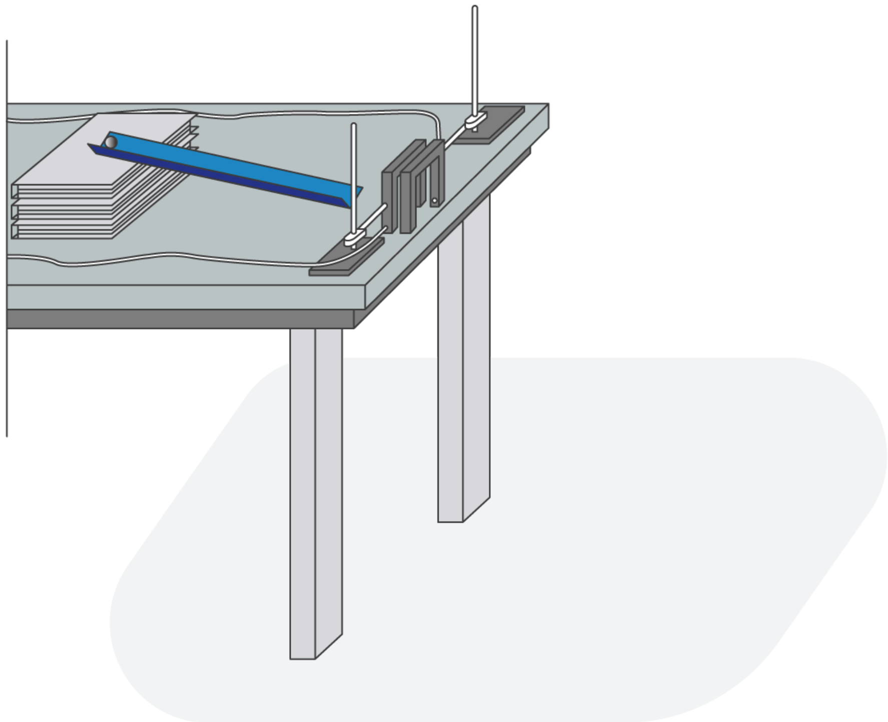


Figure 1. A possible experimental setup for measuring the distance a ball travels in projectile motion.

More information for figure 1

The image is a diagram depicting an experimental setup for measuring projectile motion. It shows a horizontal table surface with two vertical supports. A ramp is placed on the table, inclined downward, which is meant for rolling a ball off the edge. The setup is designed to study the motion of a ball in free fall after leaving the table, highlighting components like the ramp and the flat surface on which it rests. The purpose of the diagram is to visually describe how the ball will travel once it leaves the table edge, capturing the essence of projectile motion experiments.

[Generated by AI]

Practical skills

In this practical you will be using the following tools and skills:

Tool 1: Experimental techniques

- Understand how to accurately measure angles to an appropriate level of precision (see section 1.1.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-variables-with-analogue-equipment-id-48813/)).

Tool 2: Technology

- Use sensors (see section 1.2.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/sensors-id-48942/)).

Student
view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

- Carry out image analysis and video analysis of motion (see section 1.2.5 (/study/app/math-aa-hl/sid-423-cid-762593/book/image-analysis-id-48946/)).
- Represent data in a graphical form (see section 1.2.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/manipulating-and-representing-data-id-48945/)).

Tool 3: Mathematics

- Use basic arithmetic and algebraic calculations to solve problems (see section 1.3.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/mathematical-approaches-to-processing-scientific-data-id-48947/)).
- Select and manipulate equations (see section 1.3.6 (/study/app/math-aa-hl/sid-423-cid-762593/book/equations-id-48952/)).
- Derive relationships algebraically (see section 1.3.6 (/study/app/math-aa-hl/sid-423-cid-762593/book/equations-id-48952/)).
- Distinguish between continuous and discrete variables (see section 1.3.7 (/study/app/math-aa-hl/sid-423-cid-762593/book/continuous-and-discrete-variables-id-48954/)).
- Determine the effect of changes to variables on other variables in a relationship (see section 1.3.8 (/study/app/math-aa-hl/sid-423-cid-762593/book/proportionality-and-percentage-change-id-48955/)).
- Resolve vectors (limited to two perpendicular components) (see section 1.3.13 (/study/app/math-aa-hl/sid-423-cid-762593/book/scalars-and-vectors-id-48960/)).

Exploring and designing

Consider the following research question as you progress through this practical:

How does increasing the initial horizontal velocity affect the distance that a projectile travels when the mass of the ball is kept constant?

This research question is written in the style that is expected in your Internal Assessment. Note that it begins with 'How', identifies an independent variable, dependent variable and important control variable and ends with a question mark.

Study skills

For more guidance of the formulation of the research question, see the IA Guide (/study/app/math-aa-hl/sid-423-cid-762593/book/introduction-id-46741/).

Student view

Before you begin conducting the practical, think about the following:

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

1. What is the dependent variable?
2. What is the independent variable?
3. What variables should be controlled?
4. Describe what type of graph you will aim to get. Predict what your graph should look like.

1. The dependent variable is what we measure – in this experiment the dependent variable is the distance that the projectile travels from the edge of the table, Δx.
2. The independent variable is the variable that we change in the experiment. Here, the independent variable is the initial horizontal velocity of the projectile before it leaves the table, v. You should come up with a way of varying the velocity of the projectile.
3. The mass of the projectile should stay constant. You can achieve this by using the same ball throughout the experiment.
   The height the projectile is dropped from should stay constant. You can achieve this by using the same apparatus (table) throughout.
   The air resistance should also be kept controlled. This can be accomplished by turning off any fans, heaters or AC units that might blow directly onto the experiment.
   Note that the control variables above are factors that could influence the experimental results. It is best to avoid stating pieces of apparatus as control variables. It is best to say what variable would be changed if that piece of apparatus was to change. For example, when asked to suggest a control variable it would be poor practice to say 'the ramp'. It would be better to suggest the length of the ramp and the material that the ramp is made of.
4. In subtopic A.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43128/) you learned that the distance that the projectile travels depends on the horizontal velocity and the time that the ball travels for.
   The time that the ball travels for depends on how long the ball takes to hit the floor. Using the simplified equations of motion, the following equation can be derived:
   $$\Delta x = v_x\sqrt{\frac{2h}{g}}$$
   Where Δ_x is the distance that the projectile moves in the x-direction from the edge of the table, v_x is the speed in the x-direction, h is the height of the table and g is acceleration due to gravity.
   Rearranging this equation so that it in the form $y = mx + c$ (where y is the dependent variable, x is the independent variable, m is the gradient and c is the y-intercept), the equation becomes:
   $$\Delta x = \sqrt{\frac{2h}{g}}v_x$$
   From this equation it can be seen that as v_x increases, Δx also increases. There should

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

be a directly proportional relationship between the two variables and so we expect the graph of these results to be a straight-line graph through the origin.

Practical skills

Variables can be continuous or discrete (see section 1.3.7 (/study/app/math-aa-hl/sid-423-cid-762593/book/continuous-and-discrete-variables-id-48954/)).

Both of the variables identified above are examples of continuous variables.

Continuous variables are those that can take any value within a specific range or interval. They are typically measured on a scale and can have infinite possible values. These always have numerical values.

Examples of continuous variables include height, weight, temperature and time.

On the other hand, discrete variables can only take distinct, separate values. These values are often counted or categorised. Discrete variables do not have intermediate values and usually represent whole numbers or categories.

Examples of discrete variables include the number of students in a class, the number of cars in a parking lot, and the outcome of a coin toss (heads or tails).

Worked example 1

Can you derive the equation used in this practical,

$$s = u\sqrt{\frac{2h}{g}}$$

using the equations of motion?

Solution steps	Calculations
Step 1: Identify the required equation of motion	$s = ut + \frac{1}{2}at^2$

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Solution steps	Calculations
Step 2: Once the projectile roles off the table and moves forwards, it is also moving downwards, accelerated by gravity. (In this practical take the downwards direction as the positive *y*-direction). The ball drops from the height of the table, h, to the ground. The displacement in the *y*-direction is equal to h.	$s = h = ut + \frac{1}{2}at^2$
Step 3: As the initial velocity in the *y*-direction is zero, the equation can be simplified.	$h = 0t + \frac{1}{2}gt^2$ $h = \frac{1}{2}gt^2$
Step 4: Rearrange the equation to find t.	$t^2 = \frac{2h}{g}$ $t = \sqrt{\frac{2h}{g}}$
Step 5: Recall from section A.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43128/), in projectile motion there is no horizontal acceleration, so $s = ut + \frac{1}{2}at^2$ becomes $s = ut$	Thus, $s = u\sqrt{\frac{2h}{g}}$

Create a method that you can use to vary the velocity of a ball, car or other projectile and then measure the distance that it will travel.

You can change the velocity by rolling a ball down a small ramp with different angles.

Student view

The velocity of the ball can be measured by placing a phone camera perpendicular to the direction of travel. Place a ruler in the background, parallel to the direction of motion. Press record and roll the ball down the ramp. Using the distance marked on the ruler and

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

the time it took for the ball to roll this distance, you can calculate the average velocity of the ball.

Alternatively, if your school lab has the equipment, you can use two photogates. This will measure the time that it takes for the ball to travel between them. You then input the distance between the gates and the average velocity can easily be found.

For each ramp angle, you might want to take three readings of the time taken and calculate an average value of velocity.

If the two measurement points were very far apart, friction would have a large effect on the speed of the ball and it would affect the accuracy of your calculation of initial horizontal speed. If you measure a relatively short distance/put the photogates quite close together you can make the assumption that the frictional effect is negligible.

You can use a plumb line from the top of the table to mark the origin on the ground. The distance between the plumb line and the landing point is Δx.

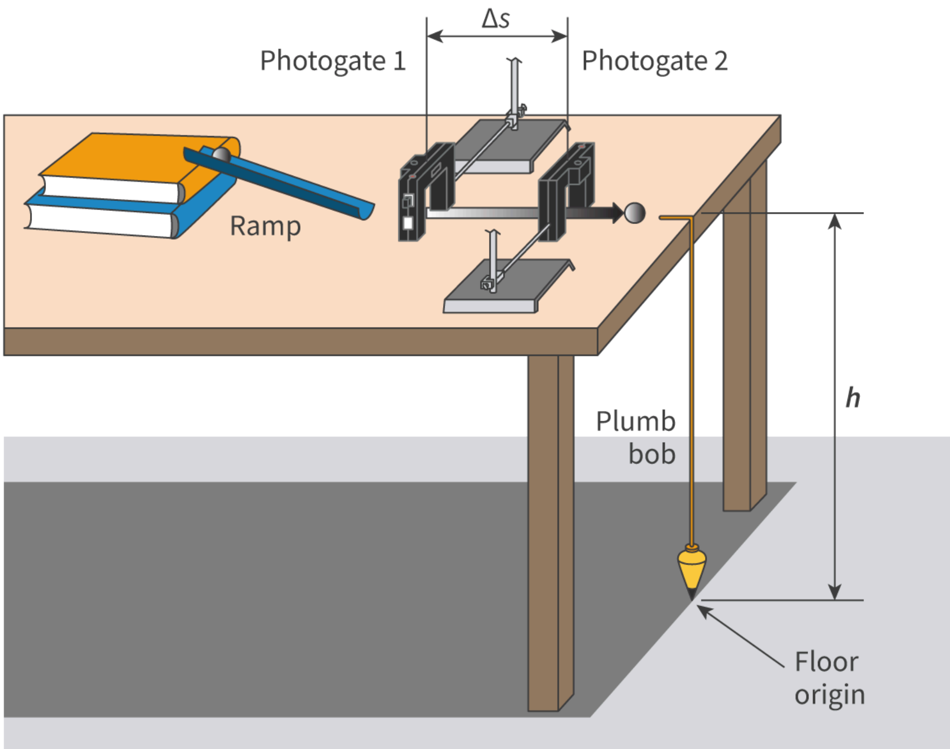


Figure 2. A diagram of a suggested method.

Student
view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Collecting and processing data

Your data might look something like the values below. The results of this experiment have been broken up into two tables. **Table 1** shows the calculation of the average velocity with each ramp angle.

Table 1. Calculating the average velocity of the ball from video analysis.

Angle (degrees)	Time (s)				Distance (m)	Average velocity (m s^{-1})
	Trial 1	Trial 2	Trial 3	Average		
10	0.40	0.42	0.44	0.42	0.05	0.12
20	0.22	0.23	0.24	0.23	0.05	0.22
30	0.12	0.11	0.14	0.12	0.05	0.42
40	0.07	0.08	0.08	0.08	0.05	0.63
50	0.06	0.04	0.08	0.06	0.05	0.83

Table 2 shows the distance travelled by the projectile with varying velocities.

If you can't collect data for the experiment yourself, you can use the data provided below.

Table 2. Horizontal distance travelled by the projectile with increasing velocity.

Velocity (m s^{-1})	Distance, Δx (m)			
	Trial 1	Trial 2	Trial 3	Average
0.12	0.11	0.12	0.13	0.12
0.22	0.20	0.21	0.22	0.21
0.42	0.41	0.41	0.44	0.43
0.63	0.62	0.62	0.64	0.63
0.83	0.81	0.81	0.82	0.82

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Graph your data and ensure that you include the line of best fit and error bars. Alternatively, you can use the data in the tables above.

Practical 1 (/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-the-acceleration-of-free-fall-id-43210/) has some helpful advice for graphing in the manner expected in your IA.

Internal assessment criteria

Conclusion

In this practical you will identify some questions that you should always ask when concluding on the results of your experiments, you will justify a conclusion that is relevant to the research question and fully consistent with the analysis presented.

Once you have collected and transformed your experimental data, you need to conclude your experiment by using your data and graph to answer your research question.

The question below will help you to create a sufficiently detailed concluding appraisal.

1. What graph was initially predicted from the research?
2. How would you describe the graph that you have obtained?
3. Does the data support the research question?

(You should ask yourself these three questions every time you conclude an investigation.)

1. The research discussed above suggested that the graph of velocity against horizontal distance would be a straight-line graph through the origin. This suggests a directly proportional relationship.
2. Graphing the sample data above, it can be seen that the graph is a straight-line graph that goes through the origin. This is the requirement to label a relationship as directly proportional. If the graph was a straight line that did not pass through the origin then it could be called a linear relationship. Alternatively, if it was not a straight line then it might be an inverse or exponential relationship and further processing would be required.
3. In this case the data provides a graph that agrees with the one that was theorised and so, the data supports what was predicted based on the research.

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

If the graph of your data does not match with the theory, this is not a problem. Simply report the data as you find it but consider what methodological issues could have led to errors in your data. Then suggest improvements that you could make to the experiment. We will discuss this in more detail in future practicals and in the IA Guide (/study/app/math-aa-hl/sid-423-cid-762593/book/introduction-id-46741/).

Once you have evaluated your research question and predictions, as above, you should justify your findings through comparison to the accepted scientific context. This means assessing whether your findings agree with what you have learned in class or in subtopic A.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43128/). You must cite these comparisons in your conclusion. Do some further reading online and see if other people have got data that agrees or disagrees with your data. In this section you should be sure to discuss the gradient of your line of best fit, the uncertainty in this value, the y-intercept and the uncertainty in the y-intercept.

Study skills

In your Internal Assessment you might do an experiment that can be used to find g. In this case, it is important that you compare your value of g with the accepted literature value, 9.8 m s^{-2}. If they are the same, then you can comment on the accuracy and reliability of your experiment. If there is a large deviation, then you should also discuss accuracy and reliability but in the context of methodological issues and ways of improving the practical. This goes for all experiments that relate to a literature value.

Extensions to the investigation

Interactive 1 can also be used to investigate projectile motion.

Identify new variables, pose a new research question and investigate the relationship using the skills that you have developed from these experiments. The application will also allow you to carry out the same investigation without omitting air resistance.

Student view

Interactive 1. Projectile motion experiments.

More information for interactive 1

The interactive titled, Projectile Motion Experiments, allows users to manipulate various parameters to explore their effects on a projectile's trajectory. The initial screen presents a selection menu with four modules: Intro, Vectors, Drag, and Lab, each represented by an icon, with Intro highlighted.

In Intro mode, users control a cannon launcher, adjusting the launch angle, initial speed, and projectile type (for example, pumpkin). Air resistance can be toggled, and velocity and acceleration vectors are available for analysis. The direction of velocity indicates a green arrow and the direction of the acceleration indicates a yellow arrow. The x and y components of velocity also can be seen by putting a tick on the components under velocity vectors. The net acceleration of the projectile is equal to the acceleration due to gravity on the surface of earth, so the yellow vector acts in the vertically downward direction. The dynamically updated trajectory illustrates basic projectile motion without external resistances. This mode helps learners understand the influence of launch parameters on range, height, and flight time while reinforcing the symmetrical nature of parabolic motion under gravity.

The Vectors mode introduces velocity, acceleration, and force vectors. The black arrow indicates the force vectors. A cannonball launched at 65 degrees with an initial speed of 18 meters per second experiences air resistance (drag coefficient 0.47). The trajectory visualization includes vector toggles, adjustable simulation speed, and customizable mass, size, and drag. Users observe how velocity splits into horizontal and vertical components, with the vertical component affected by gravity while the horizontal remains constant. The components of force vector and acceleration shown during the motion can also be studied. This mode highlights the importance of breaking motion into components.

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

In Drag mode, a projectile with a 0.8 meters diameter, 5 kilogram mass, and drag coefficient of 0.62 is launched at 18 meters per second. The trajectory accounts for air resistance, visualized with velocity and force vectors. Users can modify drag, altitude, mass, and diameter to see how real-world resistance affects motion. This mode demonstrates how drag reduces range and peak height while altering trajectory shape. By adjusting parameters, learners gain insights into how resistance depends on object properties and speed.

The Lab mode offers full experimental control. A cannonball of 17.6 kilograms, 0.18 meter diameter is launched at 18 meters per second, under standard gravity. It follows a smooth parabolic path with air resistance off. Users can explore various gravitational settings, enable or disable air resistance, and modify projectile characteristics. This mode promotes independent experimentation and deeper understanding of projectile motion dynamics.

Internal assessment checklist

For your internal assessment work, remember the following that you have exercised in this practical:

Conclusion

- The conclusion is fully supported by the processed data.
- The conclusion is compared to accepted scientific context.

1. Essential skills and support guides / 1.4 Collected practicals

Measuring the specific latent heat of vaporisation of water

? Guiding question(s)

- How can the specific latent heat of vaporisation of water be measured by the electrical method?

Prior learning

B.1 Thermal energy transfers

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

- Molecular theory in solids, liquids and gases (see section B.1.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/molecular-theory-in-solids-liquids-and-gases-id-44049/)).
- That the internal energy of a system is the total intermolecular potential energy arising from the forces between the molecules plus the total random kinetic energy of the molecules arising from their random motion (see section B.1.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/changing-temperature-and-changing-phase-id-44051/)).

A.3 Work, energy and power

- That power developed *P* is the rate of work done, or the rate of energy transfer as given by $P = \frac{\Delta W}{\Delta t} = Fv$ (see section A.3.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/power-and-efficiency-id-43086/)).

B.5 Current and circuits

- electrical power *P* dissipated by a resistor as given by $P = IV$ (see section B.5.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/circuits-and-power-id-44366/)).

Consider a kettle filled with water on a stove (**Figure 1**). What do you expect will happen to the contents of the kettle if we turn on the stove?

Figure 1. Kettle on a stove with the burner on.

Section Student... (0/0) Feedback Print (/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-the-acceleration-of-free-fall-id-43210/print/) Assign

Credit: Johnrob Getty Images

You probably already know that the water in the kettle will undergo two separate changes.

Firstly, its temperature will gradually rise: as the thermal energy from the burner is deposited into the water, the average kinetic energy of the water molecules increases. Secondly, if the water is heated to a temperature of 100 °C and we continue adding energy, the molecules will have enough energy to overcome the forces of attraction that keep them in liquid form. The water will boil and turn into vapour.

Student view

The simulation below can help you visualise this process, for a variety of substances.

1. Go into the simulation and select the ‘phase changes option’. You will be able to switch between different substances; try with ‘water’.
2. Modify the temperature using the dial below the container. What happens with the molecules as you increase their temperature?

Observe that the boiling and freezing points are affected by the pressure.

Interactive 1. States of matter simulation.

More information for interactive 1

The interface of “States of Matter: Basics”, presents two interactive options, States, and Phase Changes, with the States option highlighted.

The States screen displays a cylindrical container holding neon atoms at 28 Kelvin. By clicking on the “water” tab, the motion of the water (H_2O) molecules can be studied. The water molecules are closely packed and moving slowly at (-127°C), indicating a solid state. A thermometer is attached to the container, showing temperature adjustments, and a heater or cooler slider below allows users to modify thermal energy. On the right, a panel lists selectable substances (Neon, Argon, Oxygen, Water) and buttons to switch between solid, liquid, and gas states. The simulation visually represents molecular behavior at different states, helping users understand phase transitions and the effect of temperature

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

on particle motion. This screen helps learners understand the three fundamental states of matter, solid, liquid, and gas, by visualizing molecular arrangements and movements. It allows users to observe how molecules behave in different states and how temperature influences their motion.

The Phase Changes screen displays a container holding neon atoms at a temperature of 17 Kelvin, with the particles appearing closely packed in a solid state. A thermometer on the container measures temperature, and a pressure gauge above indicates 0.0 atmosphere. A hand is shown pressing down on the lid, simulating external pressure. A red pump on the left is connected to the container, allowing users to adjust pressure manually. The heater or cooler slider at the bottom helps modify thermal energy. The right panel offers options to select different substances, including neon, argon, oxygen, and water. A phase diagram button is also available for additional analysis. This screen enables learners to explore how substances transition between states due to changes in temperature and pressure. By selecting different substances and adjusting thermal energy, users can observe melting, freezing, boiling, and condensation processes. The simulation also demonstrates how pressure affects phase transition points, reinforcing the concept that boiling and freezing points vary under different conditions.

Practical skills

In this practical you will be exercising the following tools and skills:

Tool 1: Experimental techniques

- Recognise and address relevant safety, ethical or environmental issues in an investigation (see section 1.1.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/safety-of-self-others-and-the-environment-id-48941/)).
- Understand how to accurately measure time to an appropriate level of precision (see section 1.1.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-variables-with-digital-equipment-id-48814/)).
- Understand how to accurately measure volume and temperature to an appropriate level of precision (see section 1.1.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-variables-with-analogue-equipment-id-48813/)).

Tool 2: Technology

- Represent data in a graphical form (see section 1.2.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/manipulating-and-representing-data-id-48945/)).

Tool 3: Mathematics

- Select and manipulate equations (see section 1.3.6 (/study/app/math-aa-hl/sid-423-cid-762593/book/equations-id-48952/)).
- Determine the effect of changes to variables on other variables in a relationship (see section 1.3.8 (/study/app/math-aa-hl/sid-423-cid-762593/book/proportionality-and-percentage-change-id-48955/)).

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

- Draw lines of best fit (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).
- Determine the uncertainty in gradients (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).

Background research

Internal assessment criteria

Research design

In this practical you will need to describe a research question that investigates how a selected independent variable will influence a dependent variable and pose a scientific research question that can be answered through your experiment.

Before beginning the experiment you should do thorough background research to discover the scientific context surrounding the practical. The equation that you will use in this experiment is $Q = mL$. In your background research section you should discuss the scientific context of this equation, what each of the variables mean and what assumptions underpin the equation. You might like to include how the equation was derived.

Let us consider what happens when water starts to boil. You already know that changes of state happen due to a change in the object's internal energy (typically, by heat being transferred into or out of the object). As you studied in subtopic B.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43777/), the internal energy of the object is made up of its total molecular kinetic and potential energies, where the kinetic energy is related to an object's temperature.

A change of phase happens when the potential energy of the particles changes – but while this is going on, the kinetic energy will remain constant. This is true whether the change is between the gas and liquid states, or the liquid and solid states.

When we see ice melting, we tend to think of it as getting hotter. But what do we mean by 'hotter'? Have a look at the following video and pay attention to the thermometer inserted into the mixture. If we are only talking about the temperature, is the water really hotter than the ice?

Student view

Video 1. The temperature of ice as it melts.

But the ice is definitely receiving energy – this energy is going into overcoming intermolecular forces, and causing the change of phase. This always happens at a constant temperature.

In subtopic B.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43777/), you studied the formula for the energy, in this case heat, involved in a change of phase:

$$Q = mL$$

Where Q is the heat energy released or absorbed by a substance undergoing a change of phase, m is the mass of the substance, and L is called the specific latent heat of the substance.

The specific latent heat refers to the energy per unit mass that must be absorbed or released for a substance to change its phase. Depending on whether we talk about a change between solids and liquids, or liquids and gases, we refer either to the latent heat of fusion or latent heat of vaporisation. For example, the latent heat of fusion for ethanol is 108 kJ kg^{-1}. This means that, for every kilogram of ethanol, you would need to remove 108 kJ in order to freeze it, or add 108 kJ to frozen ethanol in order to melt it.

The latent heat of fusion: The amount of heat energy required to change a substance from its solid phase to its liquid phase, or vice versa.

The latent heat of vaporisation: The amount of heat energy required to change a substance from its liquid phase to its gaseous phase, or vice versa.

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Let us go back to the water in our kettle. How can we determine the water's specific latent heat of vaporisation?

The formula we have is relatively simple. If we can measure a substance's mass, and we know precisely how much heat went into changing its phase, we can solve for L:

$$L = \frac{Q}{m}$$

However, in real life, measuring heat Q is not so simple. For example, if you turn on an electric radiator, it is not easy to tell exactly how much heat is given out. However, we know its power, P, as the power output is usually given.

Study skills

In cases where the power of an electric device is not specified, look for its output voltage (V, measured in volts) and electrical current (I, measured in amperes or amps). As you will study in subtopic B.5 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-44361/), power can be obtained by multiplying these two values: ($P = V \times I$).

Now, before going further, try to arrange the latent heat equation in terms of the power, P, instead of Q.

Power can be generally defined as the rate at which energy is transferred.

$$\text{power} = \frac{\text{energy}}{\text{time}}$$

This is the general definition of power, which you will find in your DP physics data booklet.

In this practical, we are concerned with heat, so power becomes the rate at which heat is transferred:

$$P = \frac{Q}{\Delta t}$$

Student view

And so,

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

$$Q = mL$$

Becomes

$$P \times \Delta t = mL$$

If the power being supplied to a certain mass of substance is known, the time it takes for this mass to change phase can be measured. The specific latent heat of the substance can then be determined.

Making connections

You most likely first studied the concept of power back in subtopic A.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43083/), where you learned that power is related to work: $P = \frac{W}{t}$. Do not limit yourself to this definition for power. In general, power refers to the rate at which any type of energy is transferred — be it mechanical energy, electrical energy, or in this case, heat.

In this practical, the specific latent heat of vaporisation of water will be experimentally determined. You will then compare your results against the accepted theoretical value. You will do this by submerging an immersion heater in water, and measuring how much water boils over a certain amount of time.

Study skills

The research design section of your Internal Assessment will likely be structured as follows:

- Research question
- Background research
- Discussion of variables
- Materials
- Method
- Safety concerns

In this practical you will look at the discussion of variables and forming a scientific method that can be followed by others.

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

For specific guidance on each of these sections, see the IA Guide (/study/app/math-aa-hl/sid-423-cid-762593/book/introduction-id-46741/).

Materials

- Immersion heater (of known wattage or power), or water-heating rod (**Figure 2**)
- Tap water (or distilled water, if available)
- Insulated container (e.g. thermos flask)
- Thermometer
- Beaker
- Graduated cylinder
- Stirring rod
- Universal support (clamp stand) and clamps.

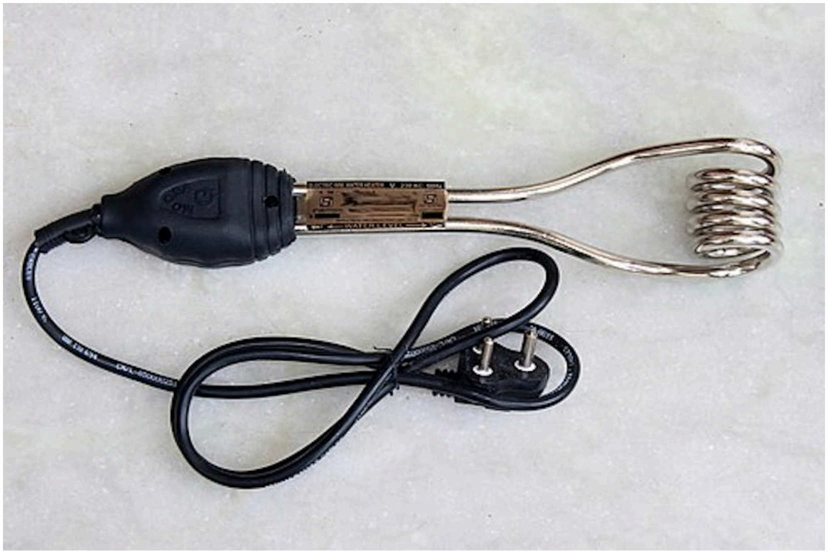


Figure 2. Immersion rod.

If you cannot get an immersion rod, or an equivalent device that can be directly inserted into the water, you can try using another source of heat, such as a hot plate, or even a stove. These will not always have the power output explicitly stated. How do you think you could first determine its power output, before carrying out your experiment? Whichever heating apparatus you use, complete this experiment in your school laboratory and ensure you complete a risk assessment beforehand (see Safety section below).

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

The power output of a heating apparatus can be estimated by measuring how much the temperature of a substance changes in a certain time. From subtopic B.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43777/), the formula for the heat associated with a change in temperature is:

$$Q = mc\ \Delta T$$

Replacing $Q = (P \times \Delta t)$:

$$(P \times \Delta t) = mc\ \Delta T$$

$$P = \frac{(mc\ \Delta T)}{\Delta t}$$

Study skills

In section 1.6.B (/study/app/math-aa-hl/sid-423-cid-762593/book/the-particulate-nature-of-matter-id-45161/) of the DP physics data booklet, you will only find the first version of the formula (the one referring to heat, Q), not the version expressed in terms of the power.

You should remember that this formula for power, $P = \frac{\Delta W}{\Delta t}$, works no matter what type of energy you are dealing with — it can be heat, electrical energy or other.

All you need is a substance for which you know the specific heat capacity (for example, water). Lists of the specific heat capacities of common substances are found in many databases online.

Measure how much the temperature of a given mass changes in a certain period of time, and insert your data into the equation above. You can even try it with a couple of different substances, to get a better estimate of the power output. Be aware that this method can lead to a less precise answer for the specific latent heat. This is because we do not have the exact value for the power!

Also, consider this as another experiment in itself – you could adjust this to determine the specific heat capacity of different samples or mixtures.

Safety

Observe all usual safety precautions when dealing with hot materials:

Student view

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

- Only use equipment designed to work in water.
- Ensure the equipment is well maintained and wires are fully insulated.
- Check the area is clean, dry and tidy.
- Be careful when handling hot containers, such as water near its boiling point, even if it is inside an insulating container. Wear insulating gloves.

While care has been taken to give relevant safety information above, a full risk assessment must be carried out before starting any practical activity. It is unsafe to carry out any practical work without first consulting the relevant guidelines for all included chemicals, equipment and quantities.

Procedure

Given that we know the power that the water receives, we can use the following formula:

$$P \times \Delta t = mL$$

Think of these questions when determining the variables:

1. State the independent and dependent variables.

Both P and L are constant values – the power is defined by the immersion heater, and the latent heat is a property of water. Thus, time, t, and mass, m are the only things that can be modified. Which one are you directly modifying?

The length of time the immersion heater is turned on can be varied – therefore, the independent variable is the time, t. The amount of water evaporated will be measured – this is the mass, m, the dependent variable.

1. Explain how your measured variables can be controlled.

Power, P – Using the same heater throughout will ensure that P the power being transferred will remain the same.

Latent heat, L, is a property of water and so, ensuring that the same substance is used throughout will ensure that L remains the same.

Student
view

Section Student... (0/0) Feedback Print (/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-the-relationship-between- Assign

Overview (/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-the-relationship-between...-id-46751/overview)

Additionally, precautions should be taken to control the heat lost to the environment by the containers. You must ensure that you insulate the container as much as possible to ensure that minimal heat is lost.

1. Explain why a stirring rod is needed.

When you are heating up a liquid, it is important to continuously stir the substance to make sure the heat is spread out evenly. Otherwise, you might record inaccurate data for the temperature.

1. Predict whether your experimental value for the specific latent heat of vaporisation is likely to be greater than or smaller than the actual value.

It is more likely that the measured experimental value is greater than the actual value of the latent heat. This is because of heat loss. Look back at the formula, solved for the latent heat,

$$L = \frac{(P \times \Delta t)}{m}$$

This assumes that all of the power is absorbed by the water. In reality, some of this energy will be lost to the environment, even if care is taken and an insulated container is used. Thus, the amount ‘$P \times \Delta t$’ will be overestimated, which will likely result in a larger value for the specific latent heat.

Study skills

In exam questions, you will often be asked to take into account the effects of heat loss on a given experiment or situation, even if you do not have to quantify these.

The experimental method is as follows:

1. Set up an insulated container, into which you measure out a specific mass of water, and record this mass. In your container, set a thermometer and a stirrer (**Figure 3**).

You can use a universal support to hold all instruments in their place.

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

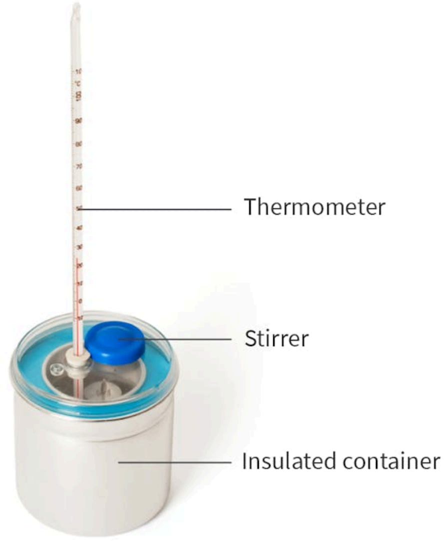


Figure 3. Insulated container with water and thermometer.

Credit: Arsty, Getty Images

More information for figure 3

The image shows an insulated container with a lid that has been labeled to indicate various components. There is a long thermometer protruding vertically from the container with a label pointing to it that reads "Thermometer." Adjacent to the thermometer, there is a label pointing to a circular component labeled "Stirrer." The main body of the container is labeled "Insulated container." The labels are written in black text and use lines to connect to the corresponding parts of the image. The thermometer is marked with temperature units, the stirrer appears to be blue in color, and the container is metallic.

[Generated by AI]

2. Place the immersion heater inside the water.

3. Heat up the water until it reaches its boiling point.

4. When the water starts boiling, start the timer.

5. After a defined amount of time – for example, 30 seconds – turn off the immersion heater, and measure the new mass of water in the container. Record your results.

6. Repeat steps 1–5, varying the time the immersion heater is on. Make sure to gradually increase the time by a fixed amount (for example: every minute, or every two minutes…). If you do not notice a significant or measurable change in the mass of water, you can try leaving the heater on for longer periods of time.

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Do this for at least seven different values of time, repeating each measurement three times.

Collecting and processing data

Once you have carried out the experiment, you will probably get data similar to the results shown in **Table 1**.

In all practicals, you should try to get five to seven increments of measurement of the independent variable, with three repetitions each. In the following sample, the average of the three repetitions has been calculated, and the uncertainty has been determined by finding half of the range (as discussed in practical 1 (/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-the-acceleration-of-free-fall-id-43210/)). Only three values of the independent variable are shown for simplicity, but in your own report or IA, you should include all measurements that you took.

$$\text{immersion heater power} = 300.0 \text{ W}$$

$$\text{initial water mass} = 100 \text{ g}$$

Table 1. Average evaporated mass of water, per time interval.

Heating time, Δt (s)	Time uncertainty (s)	Average evaporated mass, m (g)	Mass uncertainty (g)
30	1	3.1	0.1
60	1	7.3	0.1
90	1	10.2	0.1

You can now plot your measurements, and use the graph to get an estimated value for the latent heat. If you need guidance, check the solution below.

Student view

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

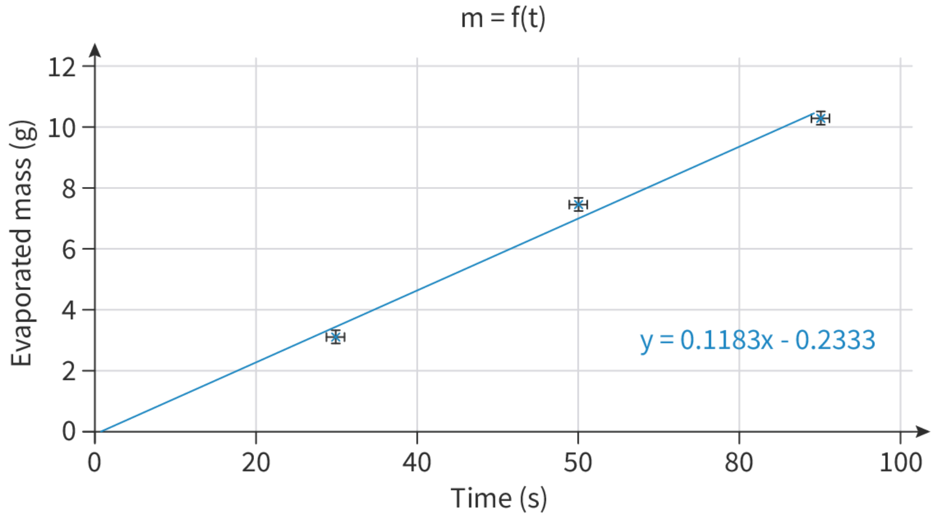


Figure 4. Graph of evaporated water mass vs elapsed time, extrapolated to the horizontal axis.

You should find that the graph is that of a straight line with a positive gradient (**Figure 4**). Going back to the original equation:

$$P \times \Delta t = mL$$

Solving for *m* (the dependent variable):

$$m = \frac{P}{L} \times \Delta t$$

Since Δt is the independent variable, $\frac{P}{L}$ is the gradient.

From the line of best fit, the gradient is 0.1183.

$$\frac{P}{L} = 0.1183$$

$$L = \frac{P}{0.1183} = \frac{300}{0.1183}$$

$$L = 2536 \text{ J g}^{-1}$$

According to the model,

Student
view

$$m = \frac{P}{L} \times \Delta t$$

the line of best fit should go through the origin, since there will be no evaporated mass $(m = 0)$ for a time period of $\Delta t = 0$. You can extrapolate the line of best fit, as shown in **Figure 4**, to see how close to the origin your line passes – in this case, the *x*-intercept is at the coordinate $(1.972, 0)$. The sample data does not show a line going through the origin, unlike what was expected – this is most likely indicative of error, such as systematic error, in the procedures carried out.

Study skills

When drawing a line of best fit your first priority is to draw a line that effectively represents your data.

The origin is often not one of your data points and so, trying to include it in your line of best fit is poor practice.

It is better to draw the line as it should be and then comment on why the line of best fit does not pass through the origin.

Once you have calculated the specific latent heat, you will need to work out the uncertainty on this measurement. This can be calculated by using the lines of minimum and maximum gradient. An example is given below.

Even though the error bars are too small to be clearly seen on the graph, it is important to include them and comment on the uncertainty of your measurements.

The lines with the minimum and maximum gradient (**Figure 5**) can be used to determine the uncertainty on our value for L (**Table 2**).

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

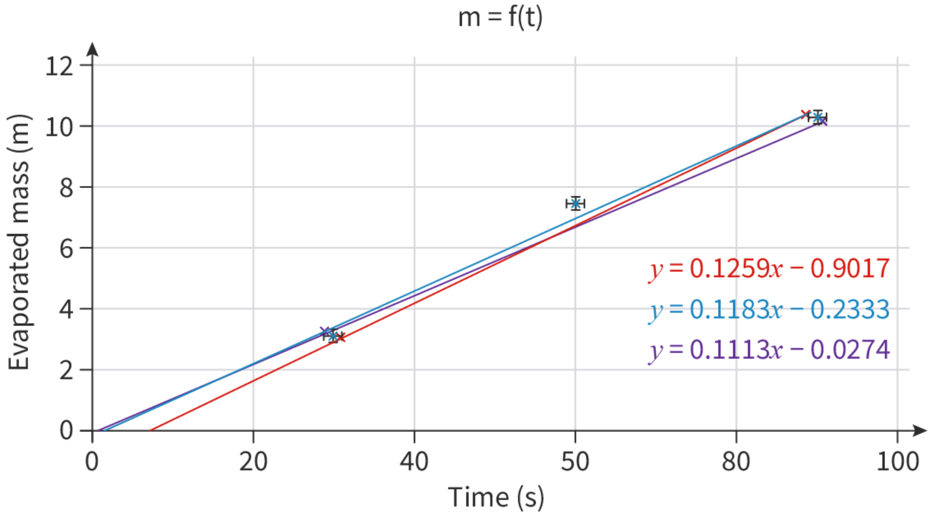


Figure 5. Graph showing line of best fit, and lines of minimum and maximum gradient.

Table 2. Minimum and maximum gradients, and corresponding latent heats of vaporisation.

Gradient	**Latent heat of vaporisation, *L* (J g^{-1})**
0.1259	2383
0.1113	2695

The uncertainty on the latent heat of vaporisation is:

$$\text{uncertainty} = \frac{(\max - \min)}{2}$$

$$\text{uncertainty} = \frac{(2695 - 2383)}{2}$$

$$\text{uncertainty} = 156 \text{ J g}^{-1}$$

And so our result for the latent heat of vaporisation of water is:

$$L = (2536 \pm 156) \text{ J g}^{-1}$$

$$L = (2.5 \times 10^3 \pm 6\%) \text{ J g}^{-1}$$

Student
view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

You can compare this result with the standard value for the latent heat of vaporisation of water, of $2.257 \times 10^3 \text{ J g}^{-1}$. This is an interesting result – the expected value actually falls outside of the error range of our gradient (which predicts values between 2380 J g^{-1} and 2692 J g^{-1}). In your conclusions, you should comment on this. You are expected to outline methodological errors which may have affected your results and explain how these can be improved.

Always remember to check your answers! Ask yourself: does the value make sense? In this practical, there is a simple way to check – the measured value should be relatively close to the expected value for the latent heat.

Study skills

Whenever your experiment does not match an expected or known theoretical result, make sure you address it in your conclusions — explain what factors could have led to the discrepancy, and how you could improve on these in the future.

Alternative method

An indirect method of measuring the specific latent heat of a substance involves using the idea of thermal equilibrium. For example, you could try measuring the specific latent heat of fusion of water, by mixing ice and water and looking at their final equilibrium temperature – with some algebra, you should be able to deduce the value for the latent heat of fusion!

Internal assessment checklist

For your internal assessment work, remember the following that you have exercised in this practical:

Research design

- Relevant background information that focuses on your methodology.
- A focused research question that includes both the independent and dependent variable.
- A detailed description of variables including the independent, dependent, control, and confounding variables.
- A detailed explanation of the decisions regarding scope and quantity of data collected.
- A methodology written with sufficient detail that another person could repeat the experiment.

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

1. Essential skills and support guides / 1.4 Collected practicals

Investigating an ideal gas law

Prior learning

Before attempting this practical, make sure that you understand the following concepts:

Kelvin and Celsius scales are used to express temperature (see section B.1.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/temperature-scales-id-44050/)).

The change in temperature of a system is the same when expressed with the kelvin or Celsius scales (see section B.1.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/temperature-scales-id-44050/)).

Kelvin temperature is a measure of the average kinetic energy of particles (see section B.1.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/temperature-scales-id-44050/)) as given by:

$$\bar{E}_{\mathrm{k}} = \frac{3}{2}k_{\mathrm{B}}T$$

Pressure as given by $P = \dfrac{F}{A}$ where F is the force exerted perpendicular to the surface of area A (see section B.3.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/what-are-ideal-gases-id-44290/)).

- Ideal gases are described in terms of the kinetic theory and constitute a modelled system used to approximate the behaviour of real gases (see section B.3.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/what-are-ideal-gases-id-44290/)).

? Guiding question(s)

- How can the gas constant be measured by investigating the relationships between the variables of the ideal gas law?

In subtopic B.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-44289/) you learned about the concept of an ideal gas (**Figure 1**). While an ideal gas is not an exact representation of a real gas, it is a very useful model that allows us to understand ideas such as what temperature represents at a molecular level. It is also a useful tool that lets us estimate what the behaviour of a real gas will be like under certain circumstances.

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

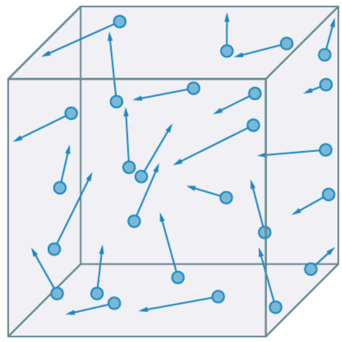


Figure 1. A small volume of an ideal gas.

More information for figure 1

The diagram shows a transparent cube where numerous small spheres represent gas molecules. Each sphere has an arrow indicating the direction and movement of the molecules, demonstrating the concept of an ideal gas. The arrows vary in length and direction, illustrating random movement, which is typical for gas particles in an ideal gas state. The cube is used to symbolically contain the gas, while the arrows showcase the kinetic activity of the molecules.

[Generated by AI]

Theory of Knowledge

To what extent do we trust the ideal gas model in explaining the behaviour of real gases? At what threshold of conditions and interactions does the model cease to accurately represent the complexities of real gases?

A series of experiments between the 17th and 19th centuries allowed scientists to establish the link between the pressure p, volume V and absolute temperature T of n moles of an ideal gas. This is commonly known as the ideal gas law, typically expressed as:

$$pV = nRT$$

Where R is the ideal gas constant (or universal gas constant). It has a value of $8.31\,\mathrm{J\,mol^{-1}\,K^{-1}}$.

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Study skills

In other resources such as online or alternative textbooks you might find different values of the gas constant in different units. Make sure that you always use SI units, $\text{J mol}^{-1}\text{K}^{-1}$.

The value of the gas constant is given to you in section 1.6.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/fundamental-constants-id-45155/)of the DP physics data booklet.

The ideal gas law is an equation of state – an equation that completely describes the state of the gas, since it gives information on all of its main characteristics (the pressure, the volume, etc.). It allows us to make predictions on the relationships that arise between the different variables. For example, what will happen to the pressure of an ideal gas if the volume of a sample increases? Or what would happen to the volume, if there is a decrease in the number of gas particles in a balloon?

Practical skills

Tool 1: Experimental techniques

- Understand how to accurately measure temperature to an appropriate level of precision (see section 1.1.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-variables-with-analogue-equipment-id-48813/)).

Tool 2: Technology

- Represent data in a graphical form (see section 1.2.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/manipulating-and-representing-data-id-48945/)).
- Generate data from models and simulations (see section 1.2.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/collecting-data-from-models-and-simulations-id-48944/)).

Tool 3: Mathematics

- Sketch graphs, with labelled but unscaled axes, to qualitatively describe trends (see section 1.3.10 (/study/app/math-aa-hl/sid-423-cid-762593/book/plotting-graphs-id-48957/)).
- Construct and interpret tables, charts and graphs for raw and processed data including bar charts, pie charts, histograms, scatter graphs and line and curve graphs (see section 1.3.10 (/study/app/math-aa-hl/sid-423-cid-762593/book/plotting-graphs-id-48957/)).
- Linearise graphs (only where appropriate) (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

- On a best-fit linear graph, construct lines of maximum and minimum gradients with relative accuracy (by eye) considering all uncertainty bars (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).
- Determining the uncertainty in gradients and intercepts (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).
- Interpret features of graphs including gradient, changes in gradient, intercepts, maxima and minima, and areas under the graph (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).

Simulation of an ideal gas

Real gases – such as air – can behave like an ideal gas under certain circumstances: specifically, at high temperatures and low pressures. These cases will not be explored here; rather, you will use a simulation to model an ideal gas.

In this practical, you will study one such relationship: how the pressure of a sample of an ideal gas changes as a function of its temperature. As you learned in section B.3.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/how-do-ideal-gases-behave-id-44292/) this relationship is commonly known as the Gay-Lussac law, after the scientist who first offered evidence of its existence.

Whilst considering the Gay-Lussac law, plan an investigation using the prompts below.

1. State your dependent variable.
2. State your independent variable.
3. Identify the control variables.
4. Create a research question that could be answered in this investigation.
5. Describe what type of graph you will plot and predict what the graph will look like.

Study skills

Do not confuse the variable n, the number of moles of a gas sample, with N, the number of particles in said sample! They are both related by the formula

$$n = \frac{N}{N_\mathrm{A}}$$

In which N_A is a constant, the Avogadro constant (see section 1.6.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/fundamental-constants-id-45155/) of the DP physics data booklet for its value). Make sure that you know

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

which letter stands for which value! As a quick check, the number of moles n will always be small, compared with the number of particles N.

1. In this scenario, your dependent variable is the Pressure, P.
2. From the ideal gas equation $PV = nRT$, you could choose one of three independent variables to modify: the volume of the gas sample, V; its temperature, T; or the number of moles n you have in your container. All three would have an effect on the pressure although, in a hands-on experiment in a laboratory, you might find it hard to modify the number of moles of gas you have, without also changing the volume.
   For the purposes of this practical, you will use the temperature T as the independent variable.
3. The volume and the number (and type) of particles should stay constant throughout the experiment. You can achieve this by using a sealed container, and making sure not to insert any more particles once you start taking measurements.
4. How does increasing the temperature of a gas affect the pressure in the container when the volume of the container and the amount of gas particles are kept constant?
5. Since you want to observe the relationship between pressure and temperature, you should plot a graph of the pressure on the vertical axis and temperature on the horizontal axis. According to the Gay-Lussac law, this relationship should be linear, which means you should get a straight line in your graph. This can be observed in the ideal gas law, if you rearrange the terms

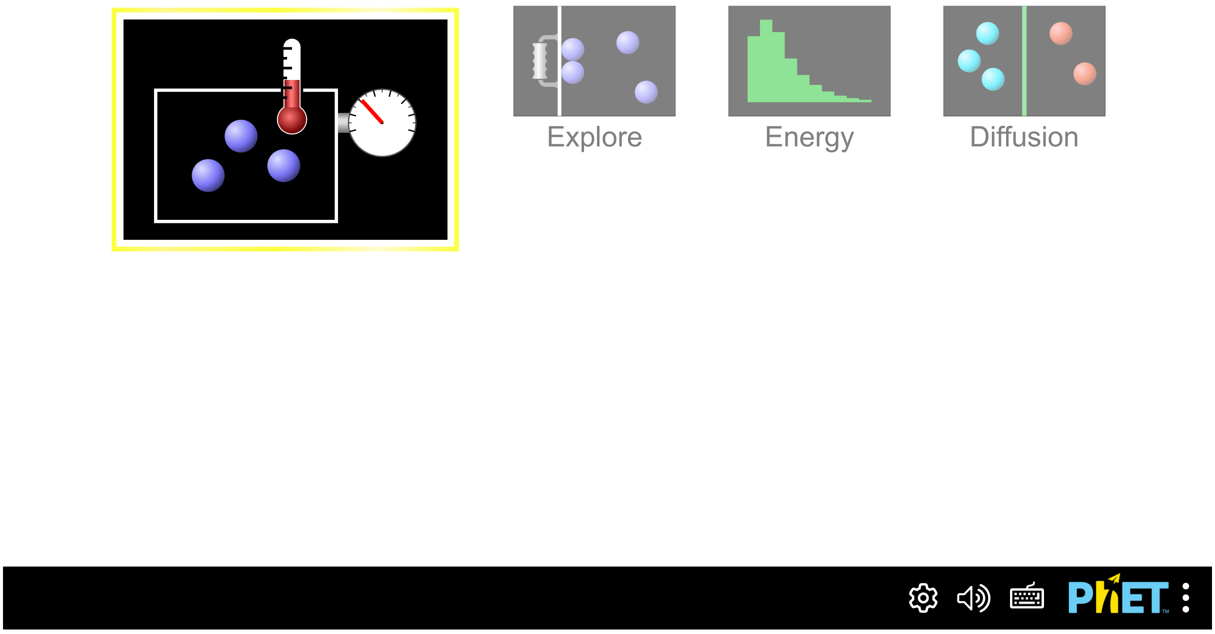
$$PV = nRT$$
$$P = \frac{nR}{V} \times T$$

   Where T is the absolute temperature, as stated above. Plotting pressure vs temperature should yield a straight line, with $\frac{nR}{V}$ as the slope. If you plot pressure vs absolute temperature, the line should go through the origin.

Using **Interactive 1** to conduct your practical on ideal gases.

Student view

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c



Interactive 1. Properties of an ideal gas.

More information for interactive 1

The Gas Properties interactive simulation explores the behavior of an ideal gas through four modules: Ideal, Explore, Energy, and Diffusion. The Ideal module focuses on investigating temperature, pressure, volume, and particle interactions in a gas system, helping users understand fundamental gas laws and kinetic molecular theory.

Users can manipulate variables such as temperature, pressure, volume, and particle number to observe real-time changes in gas behavior. The simulation features a gas container where particles move randomly after being introduced via a hand pump, along with a thermometer, pressure gauge, and heating/cooling unit for modifying thermal energy. By introducing light or heavy gas particles, users can explore how different conditions affect gas properties. The control panel allows users to hold certain variables constant, such as volume or pressure, enabling targeted investigations into gas laws like Boyle's and Charles' laws. Additional tools, including a stopwatch, collision counter, and width adjustment, enhance data collection and analysis.

Through this interactive simulation, users gain a deeper understanding of the statistical nature of gas behavior. They can observe how pressure fluctuates due to particle collisions with the container walls and how temperature changes influence particle motion and pressure. By conducting experiments, recording multiple temperature and pressure values, and

Student
view

calculating uncertainties, users develop experimental and data analysis skills. The simulation reinforces the direct relationship between temperature and pressure at constant volume, demonstrating the kinetic molecular theory in action and emphasizing the impact of temperature on molecular motion.

Instructions

1. Click on 'Ideal' to open the simulation.
2. Under 'Hold Constant', select 'Volume'. The grip on the left-hand side of the container should disappear.
3. Using the drop-down menu within 'Particles', insert an initial number of particles into your system. You can choose either heavy or light particles, and whatever number of particles you want to include (up to 1000). We recommend starting with 200 heavy particles.
4. Now you can begin to modify your variables and collect your measurement data.

To measure your variables

1. **Temperature** is measured by the thermometer on top, and can be displayed in either kelvin or degrees Celsius. Choose degrees Celsius (°C). Modify the temperature by moving the slider on the heating/cooling unit underneath the container. The temperature will be adjusted accordingly.
2. **Pressure** is measured by the manometer at the top right of the container. In this simulation, the pressure can be measured in either kilopascal (kPa) or atmospheres (atm). One atmosphere is equivalent to 101 325 Pa. The SI unit for pressure is the pascal, Pa (and this is the unit you will normally work with in the DP physics course). The linear relationship between pressure and temperature holds no matter what units you choose for pressure, so you can use either kPa or atm.
   When you start running the simulation, you will see that the pressure does not stay constant. Rather, it oscillates depending on how often the particles crash against the wall. Take at least three recordings of the pressure for each temperature, and then calculate the average pressure. Make sure to try to record both the highest and lowest pressure observed at each temperature.
3. Since this is a simulation, you can quickly get a lot of data. Aim to record data for at least ten different values of temperature.

Collecting and processing data

1. Arrange your data into a table, and work out the uncertainty for your variables. Your data should look something like the values in the sample data below.

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

$N = 200$ heavy particles

Table 1. Recorded values of pressure (atm) for temperatures going from 0 °C to 100 °C.

T (°C)	$p1$ (atm)	$p2$ (atm)	$p3$ (atm)
0	20.9	21.2	21.4
10	21.9	22.4	22.5
20	22.7	23.2	23.1
30	23.3	23.9	24.0
40	24.3	24.8	24.6
50	25.5	25.6	24.9
60	25.9	26.3	26.2
70	27.1	26.4	26.9
80	27.2	27.4	27.9
90	28.2	28.5	28.3
100	29.3	29.4	28.7

From the three readings, you can calculate an average value for the pressure.

The uncertainty in the temperature value is given by the smallest increment the simulation supports, which is 1 °C. The uncertainty in pressure is calculated by $\frac{\text{maximum trial value} - \text{minimum trial value}}{2}$ as discussed in Practical 1 (/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-the-acceleration-of-free-fall-id-43210/).

Table 2 shows the processed data.

Student view

Table 2. Average values of pressure (atm) for temperatures going from 0 °C to 100 °C.

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

T (°C)	Av. *p* (atm)	Uncertainty *p* (atm)
0	21.2	0.3
10	22.3	0.3
20	23.0	0.3
30	23.7	0.4
40	24.6	0.3
50	25.3	0.4
60	26.1	0.2
70	26.8	0.4
80	27.5	0.4
90	28.3	0.2
100	29.1	0.4

You can use the uncertainty above to define the error bars of each individual data point in your graph. In this example, the difference is too small to be observed. For this reason, you can take the uncertainty in the pressure to be of 0.4 atm for all measurements (the largest uncertainty value).

Plot a graph of your data to observe the relationship between the pressure and the temperature. Your graph should look something like **Figure 2** in the sample below.

Student
view

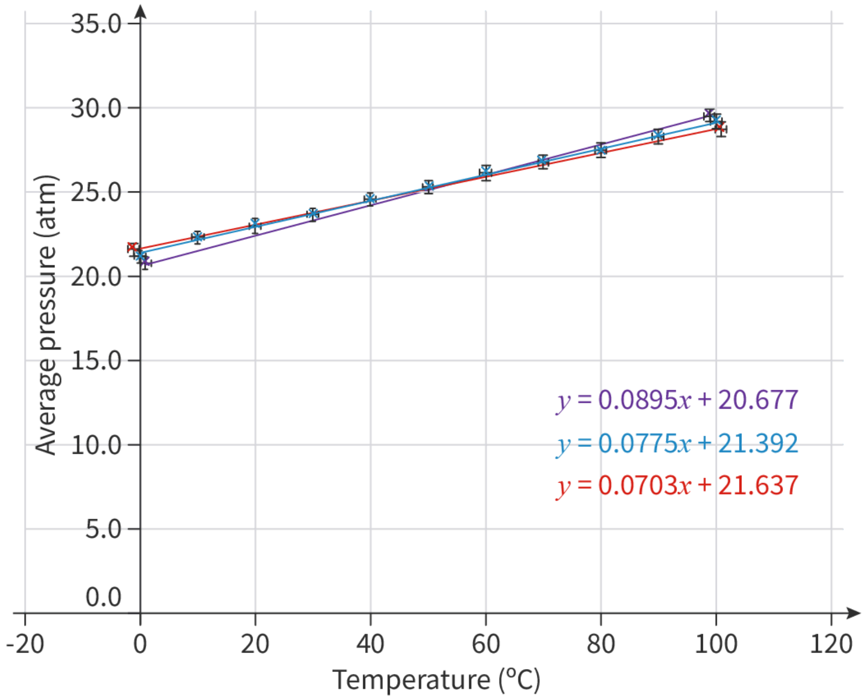
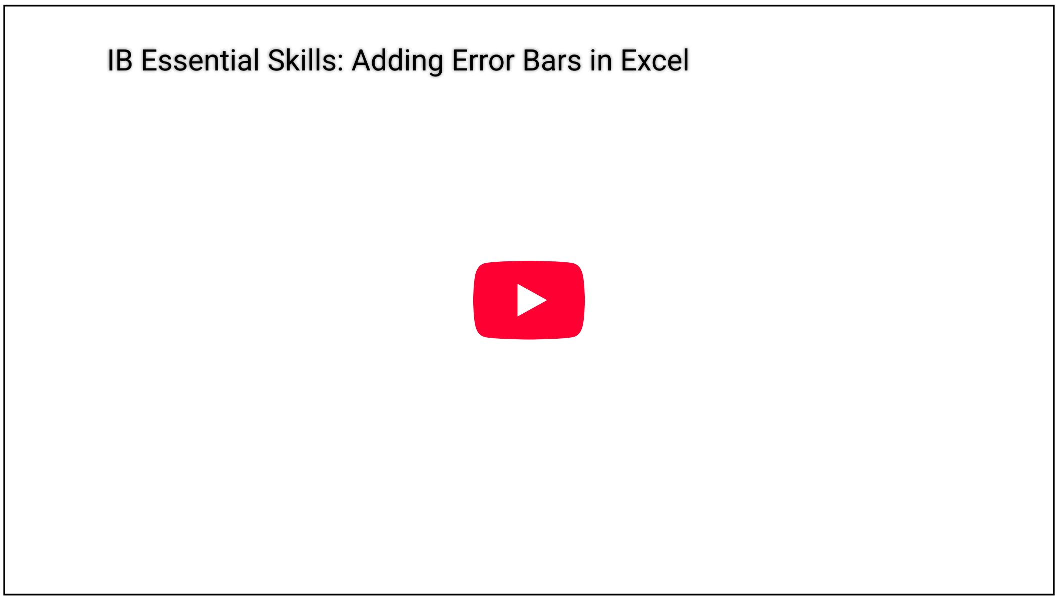


Figure 2. Graph of average pressure (atm) versus temperature (°C), including the line of best fit, and the minimum and maximum gradient lines.

The line of best fit in the plot of p vs T shows a very strong linear relationship.

Practise plotting error bars on a spreadsheet using **Video 1** for reference.



Video 1. Adding error bars in spreadsheets.

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Internal assessment criteria

Conclusion

In this practical we will create a justified conclusion that is relevant to the research question and fully consistent with the analysis presented. Our conclusion will be justified through relevant comparison to the accepted scientific context.

Concluding and evaluating

You now have an equation that models the relationship between the average pressure of an ideal gas and its temperature in degrees Celsius. How can you evaluate whether this is a reasonable equation? You could try looking at the characteristics of your equation.

1. Deduce what information the y-intercept of your equation gives you.
2. Deduce what information the x-intercept of your equation gives you.
3. Deduce what information the slope of your equation gives you.

1. The y-intercept represents the value of the pressure when the temperature is 0 °C. It is not a value of particular significance, but you can compare this with your measurements.
2. The x-intercept represents the value of the temperature for which the pressure is zero. This is a rather important value – it refers to the temperature at which, in theory, the particles would stop moving (no pressure means that there is no particle movement, to push on the walls). This temperature is known as the absolute zero, and should correspond to –273.15 °C. Does your model predict this value?
3. From the ideal gas equation,

$$\frac{PV}{nT} = \text{constant}$$

You should be able to tell that the slope represents a combination of the volume, the number of particles in your sample, and the ideal gas constant (in atmospheres). If you had the volume of the sample, you could use this slope to predict the universal gas constant.

Study skills

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Whenever you get an equation or model, you should aim to explain all of its characteristics or features. Evaluate whether the results of the model agree with what you would expect — for example, whether it can predict well-known results. This is particularly important in the context of your IA. More advice regarding how to evaluate your data is given in the IA guide (/study/app/math-aa-hl/sid-423-cid-762593/book/introduction-id-46741/).

Using the template below, write a conclusion to your investigation.

'The hypothesis suggested that the relationship between [independent variable, IV] and [dependent variable, DV] was [directly proportional / inversely proportional / other] . This predicted that the graphical representation of the results would be a [a straight line graph through the origin / negatively sloping curve / other]. The graph of the data collected suggests that the relationship between [IV] and [DV] is [directly proportional / inversely proportional / other] as the graph displays [a straight line graph through the origin / negatively sloping curve / other]. Thus, the data [supports / does not support] the hypothesis.'

Discuss the trend line from your graph in detail. Did you obtain a straight line through the origin? In this case the relationship is directly proportional. Maybe it was a straight line but it did not go through the origin? In this case, there is a positive or negative linear relationship.

Alternative method of conclusion

In this practical, we discussed a way in which you could study an ideal gas law, through the use of a simulation. There are experimental set-ups that would allow you to carry out a hands-on experiment in a laboratory. An example could be as follows:

Insert a container with a fixed volume of gas into a beaker filled with water (**Figure 3**). Heat the water in the container – this will cause both the temperature and the pressure of the fixed volume of gas to increase. Temperature can be measured with a thermometer, while the pressure is measured with a manometer (like the one shown in the simulation).

Student view

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

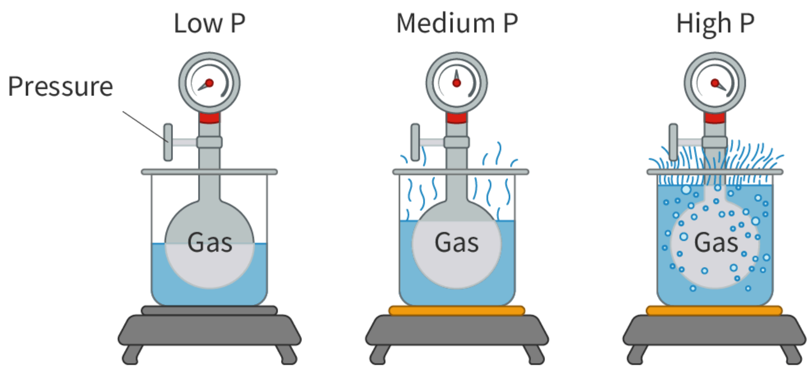


Figure 3. Experimental set-up to investigate the pressure-temperature relationship in a real gas.

More information for figure 3

The image shows three diagrams side by side, illustrating changes in pressure in a gas container placed in water. Each diagram depicts a different pressure level: Low P, Medium P, and High P.\n\n1. **Low P**: A glass container labeled 'Gas' is partially submerged in a beaker of water, with a gauge on top showing low pressure. There's minimal steam and no bubbles in the water.\n\n2. **Medium P**: The second diagram shows the same setup with more steam rising from the water, indicating increased heat. The gauge points to a medium pressure level.\n\n3. **High P**: The last diagram shows the container with increased bubbling in the water surrounding it, indicating high heat and pressure. The gauge points to a high pressure level.\n\nThese diagrams visually represent the relationship between temperature and pressure in a real gas, demonstrating how increased heat leads to increased pressure inside the gas container.

[Generated by AI]

Just like this, you can try coming up with other designs, that might allow you to investigate the relationship between pressure and volume, or between volume and temperature.

Internal assessment checklist

For your internal assessment work, remember the following that you have exercised in this practical:

The conclusion is fully supported by the processed data.

The conclusion is compared to accepted scientific context.

Student
view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Measuring the speed of sound

Prior learning

Before attempting this practical, make sure you understand the following concepts:

- Wavelength λ, frequency f, time period T, and wave speed v applied to wave motion as given by:
$$v = f\lambda = \frac{\lambda}{T}$$ (see section C.2.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/describing-waves-id-44906/)).
- The nature of sound waves (see section C.2.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/sound-waves-and-electromagnetic-waves-id-44907/)).
- Superposition of waves and wave pulses (see section C.3.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/superposition-of-waves-and-young's-double-slit-interference-id-46613/)).
- The nature and formation of standing waves in terms of superposition of two identical waves travelling in opposite directions (see section C.4.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/what-are-standing-waves-id-45181/)).
- Nodes and antinodes, relative amplitude and phase difference of points along a standing wave (see section C.4.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/what-are-standing-waves-id-45181/)).
- Standing waves patterns in strings and pipes (see section C.4.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/standing-waves-in-strings-and-pipes-id-45183/)).
- The nature of resonance including natural frequency and amplitude of oscillation based on driving frequency (see section C.4.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/resonance-and-damping-id-45186/)).

? Guiding question(s)

- How can the speed of sound be measured by using standing waves?

Sound is a longitudinal wave. As it propagates, it creates zones of high and low pressure, which causes molecules in air to undergo compression and rarefaction (**Figure 1**).

Student view

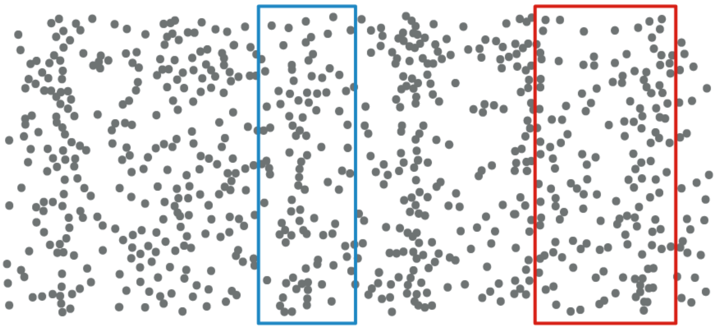


Figure 1. Compression and rarefaction in air molecules.

More information for figure 1

The image shows an illustration of air molecules to demonstrate the concepts of compression and rarefaction in a sound wave. On the left side, there's a section labeled 'Compression' in blue, where the molecules are densely packed, illustrating a high-pressure area. On the right side, there's a section labeled 'Rarefaction' in red, where the molecules are more spread out, illustrating a low-pressure area. This visualization aids in understanding how sound waves propagate through air by creating alternating zones of high and low pressure.

[Generated by AI]

Like all waves, sound is characterised by its wavelength and its frequency – you will typically recognise changes in frequency as a change in the pitch of a sound.

The speed of a wave is defined by its wavelength and frequency, such that

$$v = \lambda f$$

While you may have learned that the speed of sound is approximately 331 m s^{-1}, this is not a constant of nature (unlike the speed of light). Sound, as all mechanical waves, requires a medium to move through. The speed of sound will depend on the properties of the medium through which it travels. For example, in air, the speed of sound can be estimated as:

$$v_{\text{sound}} = 331 + (0.606 \times T_{\text{C}})\,\text{m s}^{-1}$$

Where T_{C} is the room temperature in degrees Celsius.

Student
view

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

Study skills

You are not required to learn this formula nor a value of the speed of sound. If you are asked to work out the speed of sound in an assessment, you should use the data provided and show a clear procedure to derive your results. It is not acceptable to simply memorise a value for the speed of sound and use that (though you should always check to see if your answers make sense!).

Different instruments create sound in different ways (**Figure 2**). Guitars strings are plucked, drums are banged and whistles are blown, what do all instruments have in common that allow them to make sounds?

Figure 2. Wind, percussion and string instruments.

Credit: Trodler, Getty Images

Practical skills

Tool 1: Experimental techniques

- Understand how to accurately measure length to an appropriate level of precision (see section 1.1.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-variables-with-analogue-equipment-id-48813/)).
- Understand how to accurately measure sound intensity to an appropriate level of precision (see section 1.1.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-the-specific-latent-heat-of-

Student view
Section Student... (0/0) Feedback Print (/study/app/math-aa-hl/sid-423-cid- Assign

762593/book/measuring-variables-with-digital-equipment-id-48814/)).

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Tool 3: Mathematics

- Use basic arithmetic and algebraic calculations to solve problems (see section 1.3.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/mathematical-approaches-to-processing-scientific-data-id-48947/)).
- Select and manipulate equations (see section 1.3.6 (/study/app/math-aa-hl/sid-423-cid-762593/book/equations-id-48952/)).
- Understand direct and inverse proportionality, as well as positive and negative relationships or correlations between variables (see section 1.3.8 (/study/app/math-aa-hl/sid-423-cid-762593/book/proportionality-and-percentage-change-id-48955/)).
- Determine the effect of changes to variables on other variables in a relationship (see section 1.3.8 (/study/app/math-aa-hl/sid-423-cid-762593/book/proportionality-and-percentage-change-id-48955/)).
- Understand the significance of uncertainties in raw and processed data (see section 1.3.9b (/study/app/math-aa-hl/sid-423-cid-762593/book/errors-and-uncertainties-id-49160/)).

Exploring and designing

In this practical, you will carry out an experiment to measure the speed of sound at room temperature. To do this, you will use the concept of a standing wave (**Figure 3**), which is a wave confined to a region of space (for more information, see subtopic C.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-43788/)).

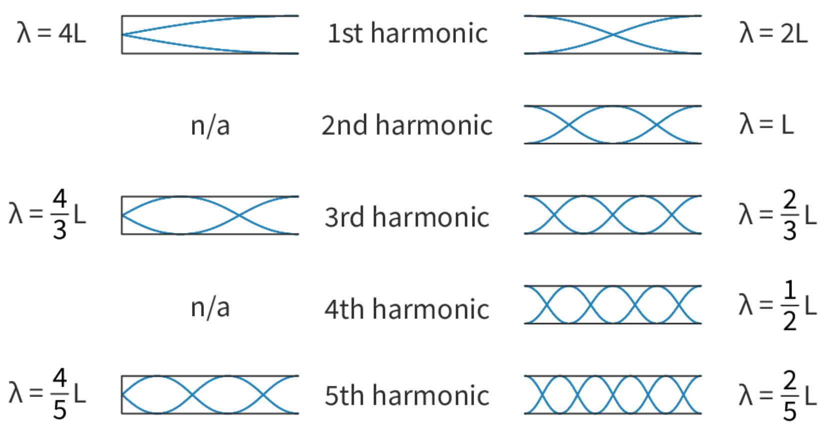


Figure 3. Standing waves inside pipes.

More information for figure 3

Student view

The image is a diagram illustrating standing waves inside pipes across different harmonics. It shows a series of images representing the 1st, 2nd, 3rd, 4th, and 5th harmonics both in closed and open pipes. The images display half-wavelengths, where 'n/a' appears for certain closed pipe harmonics indicating those harmonics do not exist for closed pipes. For each harmonic, the respective wavelength equations are given, such as λ = 4L for the 1st harmonic of a closed pipe and λ = 2L for an open pipe. The 3rd harmonic, for example, shows λ = 4/3L in closed pipes and λ = 2/3L in open pipes. This pattern corresponds to the visual doubling of the wave pattern as the harmonic number increases.

[Generated by AI]

Materials

- Measuring tape or metre rule.
- Tone generator or various tuning forks of known frequencies. (You can use an online tone generator on your phone or computer; make sure that the frequency of the tone is specified.)
- PVC pipes (**Figure 4**). Get at least 2 pipes of different diameters, such that one pipe fits inside the other, and can slide.
- Alternatively, if PVC pipes are not available, you can use large measuring cylinders and vary the length by filling the cylinders with differing amounts of water.

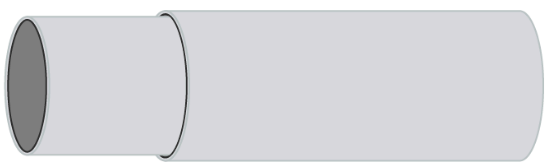


Figure 4. Nested PVC pipes. You should be able to easily slide the inner pipe, but make sure the diameter difference between the pipes is not too big.

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Consider ways of measuring the speed of sound using the equation and the equipment above. Before you go into the practical work, think about the following points.

1. Explain how you can use the concept of a standing wave to measure the speed of sound.
2. Describe how you will know whether a standing wave has formed inside a pipe.
3. Explain the purpose of having two pipes as shown in **Figure 4**.

1. To measure the speed of a wave, you need to find its wavelength and its frequency.
$$v = \lambda f$$
The frequency can be normally read from the tuning fork or tone generator that you are using, which leaves us with the problem of getting the wavelength.
Standing waves offer a solution to this problem. In section C.4.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/standing-waves-in-strings-and-pipes-id-45183/), you learned that there is a relationship between the length L of a medium, and the wavelength of the standing wave (the harmonic) that forms (check **Figure 3**). If you create a standing wave inside the tubes, you can measure their length L. From this, you can determine the wavelength, and use it to calculate the speed of sound.
2. When a standing wave is formed inside a resonance cavity, the sound will be loudest. By carefully modifying the total length of the tubes, you will find several such spots of maximum sound – these correspond to the harmonics. You will be measuring sound at the antinode at the open end of the pipe.
3. The purpose of having the two pipes as described in the image is so that you can modify the total length L of the tube. By modifying the length of the tube, you can find different harmonics, and thus measure the wavelength of the sound wave.

In this experiment, the length of the pipes will be modified, to find different harmonics for a given frequency. This will allow the wavelength of the sound wave to be measured. Given that the frequency of the sound from the tone generator is known, these two can be used to find the wave speed.

Your independent variable will be the frequency of the tone you use to create the wave. The dependent variable will be the length L of the pipes, at which the maximum sound intensity is heard (the harmonic is found). From this length, you can determine the wavelength λ, using the equations for the harmonics on an open tube. Your processed dependent variable is wavelength, λ.

Student view

One method to determine the wavelength from the length of the pipes is explained below.

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Procedure

1. Place the tone generator near one end of the PVC pipes (or measuring cylinders). Make sure the tone generator does not actually go inside, or touch the pipes. You can hold the tone generator in place with a universal stand, so you are free to manipulate the pipes.
2. Choose a frequency to produce a tone. Make sure that you can hear the sound being produced, but that the volume is low enough so that you can clearly tell when you find the standing wave. (You can use values between 100 and 2500 Hz as an approximate start point, but you should select values that work for your particular apparatus.)
3. Slowly slide the inner pipe, so that you increase the total length of your resonance cavity.
4. When you detect a sudden increase in sound, you have found a standing wave (make sure that this is the case by slightly increasing and decreasing the length of the pipes – the sound should decrease in both cases). Write down the length L at which a maximum was found.
5. For the same frequency, continue increasing the length of the pipes, until the next point of maximum sound is found. Record the length for this value.
6. Repeat steps 3–5 for a given frequency, finding as many standing waves as possible. Record their respective lengths.
7. The wavelength will be given by the difference in any two consecutive lengths you recorded, according to the following equation:
   $$L_{\mathrm{n+1}} - L_{\mathrm{n}} = \frac{1}{2}\lambda$$
   Where $L_{\mathrm{n+1}}$ and L_{n} refer to the lengths at which you find the 'n+1th' and the 'nth' harmonics.

For example, say that you produce a tone of a given frequency, and start modifying the lengths of the pipes. The first time when you hear a loud sound, you measure the total length of the pipes to be 0.50 m. As you continue stretching the pipes, you will notice the sound decreases, until suddenly it starts going up again. When it reaches the next loudest point, the total length of the pipes is of 0.80 m. In this case:

$$L_{\mathrm{n}} = 0.50\ \mathrm{m}$$

$$L_{\mathrm{n+1}} = 0.80\ \mathrm{m}$$

$$\frac{1}{2}\lambda = L_{\mathrm{n+1}} - L_{\mathrm{n}}$$

$$\frac{1}{2}\lambda = 0.30\,\mathrm{m}$$

$$\lambda = 0.60\,\mathrm{m}$$

Student view

In this example, the selected frequency caused a standing wave of wavelength $\lambda = 0.60\,\mathrm{m}$.

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

When carrying out the experiment, if you were able to find several harmonics for any one frequency, you should have several lengths recorded. This will let you make more measurements on the wavelength for that frequency, so you can get the average value and thus get more accurate results.

Confirming the information above, suggest why the equation $L_{\mathrm{n}+1} - L_{\mathrm{n}} = \frac{1}{2}\lambda$ must be true.

In this scenario, you have a medium with two free ends, which means that the standing wave will have antinodes at both its ends and nodes between them (check the right side of **Figure 3**).

The equation for the harmonics is the same as the equation in the case of two fixed ends presented in section C.4.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/standing-waves-in-strings-and-pipes-id-45183/),

$$L_{\mathrm{n}} = \left(\frac{\mathrm{n}}{2}\right) \times \lambda$$

Looking at the first three harmonics,

$$L_1 = \left(\frac{1}{2}\right) \times \lambda$$

$$L_2 = \left(\frac{3}{2}\right) \times \lambda$$

$$L_3 = \left(\frac{5}{2}\right) \times \lambda$$

This pattern repeats itself for all consecutive harmonics. From here, we can see that any two consecutive lengths at which harmonics appear will differ by $\frac{1}{2}\lambda$.

8. Once you have found and registered all possible standing waves for any given frequency, repeat steps 2–7 for other frequencies.

Collecting and processing data

Carry out your experiment and record your data.

Student view

Some sample data has been added into **Table 1** below for you to use as a reference.

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

Table 1. Sample experimental data.

f (Hz)	Length 1 (m)	Length 2 (m)	$L_2 - L_1$ (m)	λ (m)
600	0.530	0.810	0.280	0.56
700	0.615	0.860	0.245	0.49
800	0.590	0.830	0.240	0.48
1000	0.580	0.750	0.170	0.34
1100	0.550	0.705	0.155	0.31
1300	0.525	0.650	0.125	0.25
1400	0.545	0.660	0.115	0.23

As was explained previously, the wavelength was calculated as twice the difference between the two consecutive lengths:

$$\lambda = 2 \times (L_2 - L_1)$$

The uncertainty on the frequency will usually be outlined on your frequency generator or app. If not, it can be taken to be of 1 Hz, which amounts to a relative uncertainty of no more than 0.3%.

Each measurement of length has an uncertainty of about 1.5 cm, so the uncertainty on the wavelength can be taken to be of 0.03 m.

From the experimental data, you can plot a graph that will let you calculate the speed of sound. State which variable you should plot on each axis, so that you get the speed of sound as the gradient of the line of best fit.

You saw previously that the equation for the speed of a wave is:

$$v = \lambda f$$

Student
view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Rearrange this equation so that v is left as the gradient. You can do this by solving for either the wavelength or frequency. Frequency was previously identified as the independent variable, so you should solve for wavelength.

$$\lambda = v \times \frac{1}{f}$$

To get a straight-line graph, the wavelength λ should be plotted on the vertical axis, while the reciprocal of the frequency $\frac{1}{f}$ should be plotted on the horizontal axis. The speed of the wave will be given by the gradient.

Plot your data, including error bars, and make sure you get a straight line in your graph. From this graph you can get the speed of sound. Once you have your experimental result, compare it against the theoretical result for the speed of sound, which is given by the expression:

$$v_{\text{sound}} = 331 + (0.606 \times T_{\text{C}})\ \text{m s}^{-1}$$

Where T_{C} is the room temperature in degrees Celsius.

You can see an example of a graph (**Figure 5**) based on the sample data below (**Table 2**).

As mentioned previously, you need to get a graph of the wavelength, **λ**, versus the reciprocal of the frequency, $\frac{1}{f}$.

From the sample data shown in **Table 1**, the following values were calculated (**Table 2**).

Table 2. Values of wavelength and reciprocal frequency.

$f(\text{Hz})$	$\frac{1}{f}(s)$	$\lambda(\text{m})$
600	0.0017	0.56

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

$f(\mathrm{Hz})$	$\frac{1}{f}(s)$	$\lambda(\mathrm{m})$
700	0.0014	0.49
800	0.0013	0.48
1001	0.0010	0.34
1100	0.0009	0.31
1300	0.0008	0.25
1400	0.0007	0.23

As mentioned above, we can take the uncertainty of $\frac{1}{f}$ to be 0.3% (keeping the same percentage uncertainty as that for the frequency), and the uncertainty of the wavelength to be 0.03 m (for more on combining uncertainties, check section 1.2.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/data-analysis-id-46745/) of the IA guide**)**.

From this data, the graph in **Figure 5** can be plotted.

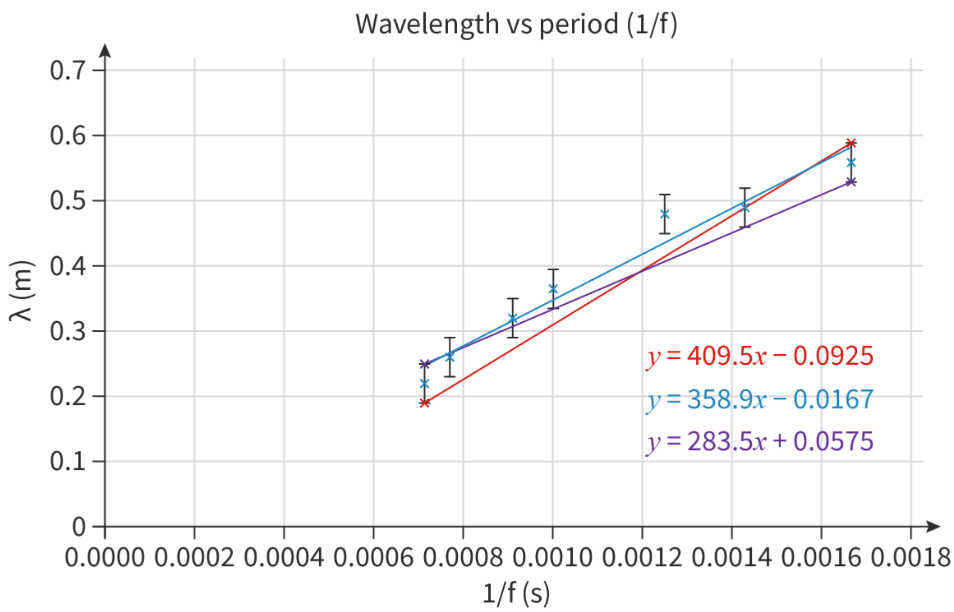


Figure 5. Graph of wavelength **λ** vs reciprocal of frequency (period) $\frac{1}{f}$. The minimum and maximum gradient lines are included.

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

The experiment for the sample data was conducted at a room temperature of 24.5 °C, so the expected value for the speed of sound is:

$$v_{\text{sound}} = 331 + (0.606 \times 24.5)\ \text{m s}^{-1} = 345.8\ \text{m s}^{-1}$$

Section Student... (0/0) Feedback Print (/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-an-ideal-gas-law-id-46508/print/) Assign

The gradient of the line of best fit gives a value of 359 m s^{-1} for the speed of sound, which is a difference of about 4%. Still if we look at the graph, we can see that there is a point which appears to be clearly different from the expected tendency. This value corresponds to the measurement at 800 Hz (on the horizontal axis, this corresponds to about $\frac{1}{f} = 0.0013\ \text{s}$). Because of this point, the minimum and maximum gradient lines are not going through all of the error bars, which should be the case.

If this measurement were to be disregarded, the tendency would look much more linear (**Figure 6**).

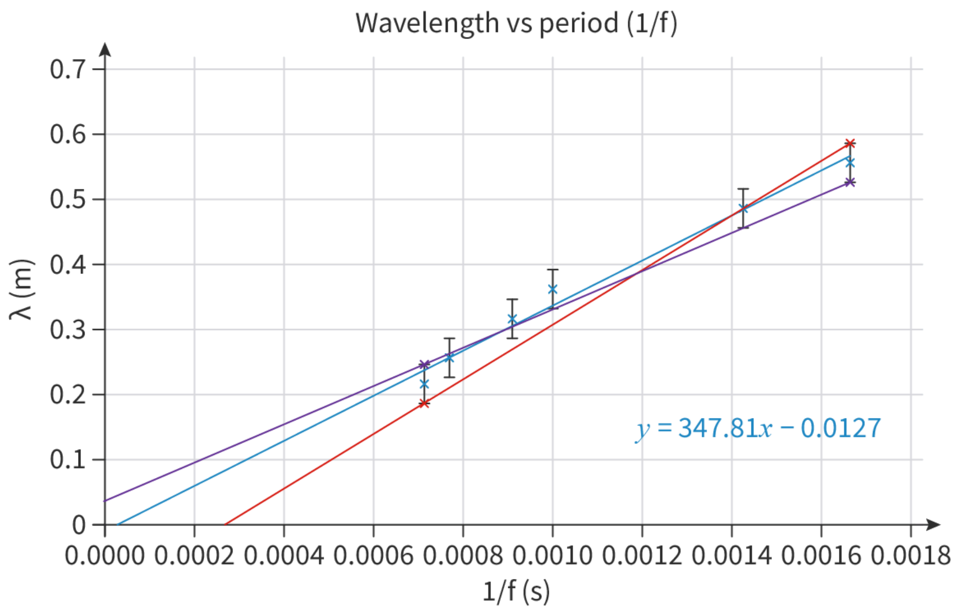


Figure 6. Adjusted graph of wavelength **λ** vs reciprocal of frequency (period) $\frac{1}{f}$.

In this new graph, the min and max gradient lines do go through all the error bars, as expected.

The new result for the speed of sound, from the adjusted graph, is of 348 m s^{-1}, which is a lot closer to the expected value, at a difference of about 1%.

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

In general, it is not good practice to simply eliminate data that does not fit with your expectations. This is particularly tempting when calculating a known value. Rather, you should look at the way this measurement was performed – it is likely that there was some mistake involved. Here, we could carry out more repetitions at that particular frequency, and with this get a better reading. Or eventually, if you find too many discrepancies, you might try another, more precise method – one such method is discussed further on in this practical.

You should always note any discrepancies you find in your results, and explain these in your conclusions.

Internal assessment criteria

In your IA, you will be graded on five different criteria, one of which is Evaluation (/study/app/math-aa-hl/sid-423-cid-762593/book/evaluation-id-46747/). This checks, among other things, that you are capable of discussing the 'strengths and weaknesses of your investigation', including limiting factors and sources of error. While you should always try to make precise and controlled measurements, it is important to recognise and discuss possible errors in your data, and the impact this has on your conclusions. You can read more and find other tips in the IA Guide (/study/app/math-aa-hl/sid-423-cid-762593/book/introduction-id-46741/).

In your IA, include a paragraph outlining the strengths of the experiment. Generally, it is good to discuss your range of data as you should have selected a large range of data from the outset. A large range gives more evidence for a proportional relationship. You should also discuss the large number of trials that you completed as this reduces experimental uncertainty. If your experimental value of the speed of sound was in close agreement with the theoretical value, this would be a strength and could be discussed here. (This goes for any experiment with a known value).

Limitations can be put in a table similar to the one below.

Table 3. Limitations in method.

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Limitation	How it affected the data	Improvements
Difficulty identifying the exact ‘loudest point’	It is difficult to establish the point at which the sound was the loudest and to measure this length exactly. This led to a large uncertainty in the length (and therefore the wavelength).	By using a probe/microphone and oscilloscope to detect the highest amplitude the error could be minimised.

Your limitations table should include at least three strong methodological limitations. Consider other limitations that could be added to the table above. You should discuss the limitations, how it affected the data and suggest possible ways of improving this.

Once you have the average value for the speed of sound, remember to get the uncertainties through the min and max gradient lines.

The average value for the speed of sound determined from the original set of data was of 359 m s^{-1}. The min and max gradients we calculated previously were 284 m s^{-1} and 410 m s^{-1}.

The formula for this uncertainty is:

$$\text{uncertainty} = \frac{\text{max} - \text{min}}{2}$$

Substituting in the values gives:

$$\begin{aligned}\text{uncertainty} &= \frac{410 - 284}{2}\\ &= 63\,\mathrm{m\,s^{-1}}\end{aligned}$$

The experimental value for the speed of sound would be:

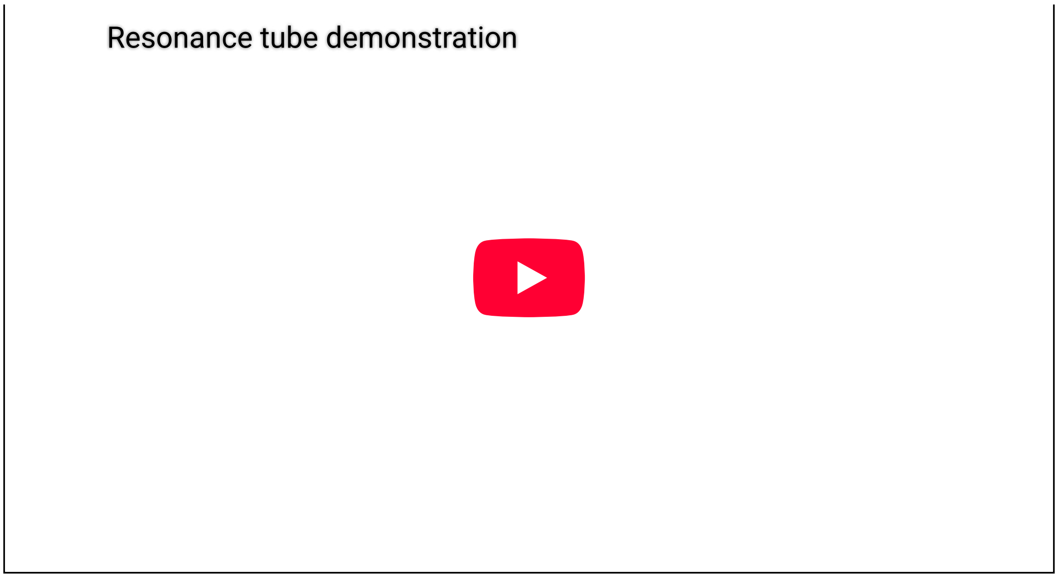
$$\text{speed of sound} = (359 \pm 63)\ \mathrm{m\ s^{-1}}$$

Alternative method

There are other methods to find the speed of sound. A more controlled version of this experiment involves the use of a resonance tube, as shown in **Video 1**.

Student view

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c



Video 1. Using a resonance tube.

Resonance tubes used for this purpose typically consist of a long cylinder (over one metre in length). The cylinder is held vertically, and filled with water nearly to the top. The top of the cylinder is kept open. Instead of modifying the length of the cylinder, you change the water level inside the cylinder. This will effectively change the length of the column of air, so you can find different harmonics. The rest of the experiment would proceed similarly to what you did above: you hold a tone generator (or tuning fork) on top of the cylinder with water and modify the water level until the standing wave is heard. By finding the lengths at which this happens, you can calculate the wavelength (through the same formula), and from that get the speed of sound.

The demonstrator in **Video 1** talks about the potential systematic error due to the thickness of the cylinder at its end. Why do you think this is not relevant for the main method described in this practical?

Internal assessment checklist

For your internal assessment work, remember the following that you have exercised in this practical:

Evaluation

- Suitable weaknesses and limitations in procedure identified and their impact on the data explained.
- Improvements to procedure suggested are realistic and relevant to the weaknesses and limitations identified.

Student
view

Determining refractive index

Prior learning

Before attempting this practical, make sure you understand the following concepts:

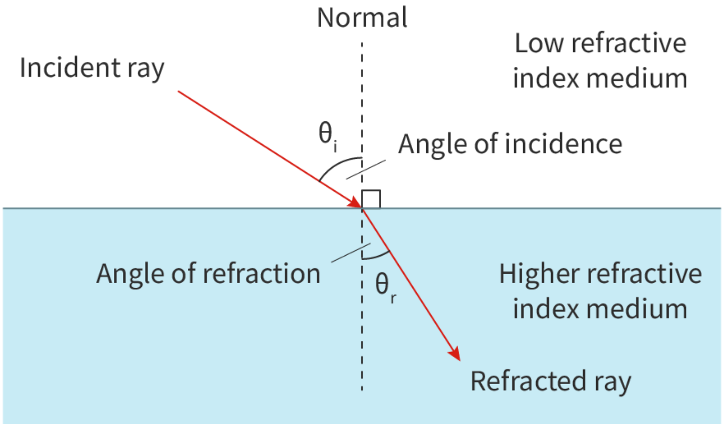
- Waves travelling in two and three dimensions can be described through the concepts of wavefronts and rays (see section C.3.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/reflection-refraction-and-diffraction-id-46611/)).
- Wave behaviour at boundaries in terms of reflection, refraction and transmission (see section C.3.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/reflection-refraction-and-diffraction-id-46611/)).

Guiding question(s)

How can the refractive index of a medium be found using Snell's law?

In section C.3.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/reflection-refraction-and-diffraction-id-46611/) you studied the concept of refraction: the fact that when a wave reaches the boundary between two mediums, it will change direction. This happens because the wavelength of the transmitted wave is modified, and so the velocity is adjusted.

We normally represent this process through the use of a ray diagram, such as the one shown in **Figure 1**.



Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Figure 1. Refraction of a ray at boundary of media having different optical densities.

More information for figure 1

The diagram depicts the refraction of a ray at the boundary between two media with different optical densities. An incident ray approaches the boundary, represented as a horizontal line separating two mediums: one labeled 'Low refractive index medium' at the top and 'Higher refractive index medium' at the bottom. The incident ray strikes the boundary at an angle defined as the 'Angle of incidence,' denoted by θi. A normal line, perpendicular to the boundary, is shown where the ray impacts.

The ray then bends as it enters the second medium, becoming the 'Refracted ray,' and continues downwards at an 'Angle of refraction,' denoted by θr. The refracted ray is shown inside the lower medium. The diagram labels the angles of incidence and refraction, emphasizing the change in direction as the ray transitions from the upper to the lower medium due to the difference in optical densities of the media.

[Generated by AI]

The relationship between the angle of incidence and the angle of refraction is given by Snell's law:

$$\frac{\sin\theta_{\mathrm{i}}}{v_{\mathrm{i}}} = \frac{\sin\theta_{\mathrm{r}}}{v_{\mathrm{r}}}$$

Where: θ_{i} is the angle of incidence, θ_{r} is the angle of refraction, v_{i} is the wave speed of the incident wave and v_{r} is the wave speed of the transmitted wave.

In the context of light waves, we define the concept of the refractive index n, which is the ratio of the speed of light in a vacuum to the speed of light in a specific medium. For light, Snell's law can be rewritten as:

$$n_{\mathrm{i}}\sin\theta_{\mathrm{i}} = n_{\mathrm{r}}\sin\theta_{\mathrm{r}}$$

Where n_{i} and n_{r} are the refractive indexes in the incidence medium and the transmittance medium, respectively.

In this practical, your objective is to measure the refractive index of a substance.

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Concept

All waves can be refracted upon crossing the boundary between mediums, but the concept of a refractive index applies solely to light waves. For other waves (such as sound), we use the first version of Snell's law, in terms of the wave speeds. In your data booklet, you will find both versions of Snell's law combined as one expression.

$$\frac{n_1}{n_2} = \frac{\sin\theta_2}{\sin\theta_1} = \frac{v_2}{v_1}$$

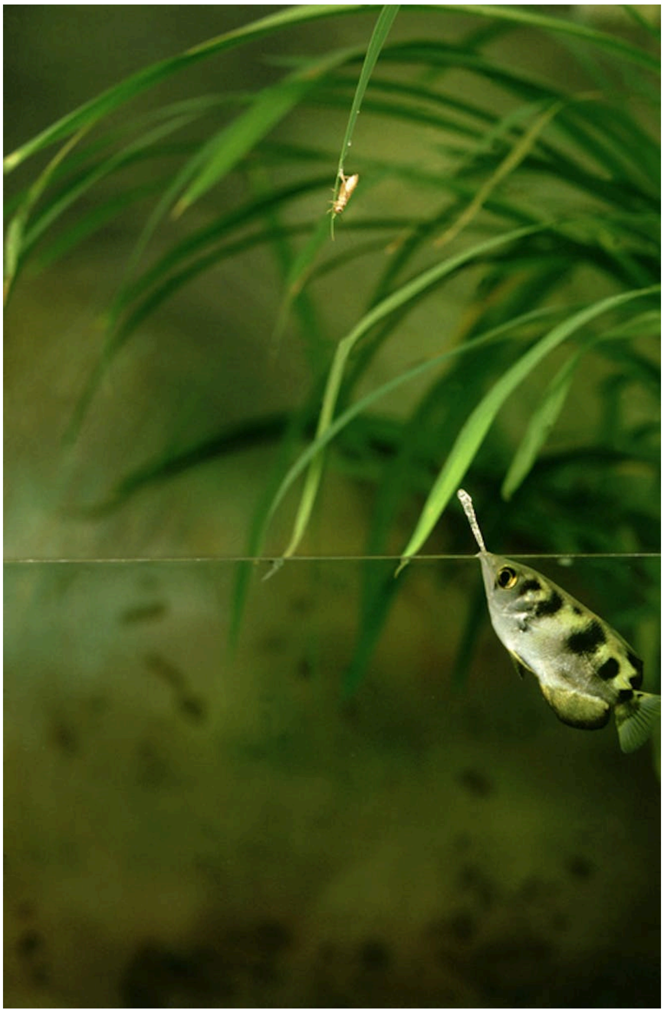


Figure 2. Archerfish use refraction to hunt prey.

Credit: Oxford Scientific, Getty Images

Animals like archerfish use refraction to detect and capture prey above the water's surface (**Figure 2**). Archerfish can accurately aim and shoot jets of water at insects on leaves or branches above the water. Why is refraction relevant to the hunting practices of the archerfish?

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Practical skills

Tool 1: Experimental techniques

- Understand how to accurately measure length to an appropriate level of precision (see section 1.1.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-variables-with-analogue-equipment-id-48813/)).

Tool 2: Technology

- Represent data in a graphical form (see section 1.2.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/manipulating-and-representing-data-id-48945/)).

Tool 3: Mathematics

- Carry out calculations involving decimals, fractions, percentages, ratios, reciprocals, exponents and trigonometric ratios (see section 1.3.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/mathematical-approaches-to-processing-scientific-data-id-48947/)).
- Calculate mean and range (see section 1.3.5 (/study/app/math-aa-hl/sid-423-cid-762593/book/measures-of-central-tendency-id-48951/)).
- Determine the effect of changes to variables on other variables in a relationship (see section 1.3.8 (/study/app/math-aa-hl/sid-423-cid-762593/book/proportionality-and-percentage-change-id-48955/)).
- Construct and interpret tables, charts and graphs for raw and processed data including bar charts, pie charts, histograms, scatter graphs and line and curve graphs (see section 1.3.10 (/study/app/math-aa-hl/sid-423-cid-762593/book/plotting-graphs-id-48957/)).
- Plot linear and non-linear graphs showing the relationship between two variables with appropriate scales and axes (see section 1.3.10 (/study/app/math-aa-hl/sid-423-cid-762593/book/plotting-graphs-id-48957/)).
- Draw lines or curves of best fit (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).
- Draw and interpret uncertainty bars (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).
- Extrapolate and interpolate graphs (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).
- Linearise graphs (only where appropriate) (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).

Designing the experiment

Student view

1. Outline an experiment that might allow you to determine the refractive index of a substance.

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

2. Describe the kind of materials will you need.

1. The refractive index is a measure of the bending of light when reaching the boundary between different media. To measure the refractive index, you need to see how much a ray of light bends (the angle at which it is transmitted). You could try pointing a laser pointer at a transparent substance, and measuring the angles of incidence and refraction. From Snell's law you can determine the refractive index for the substance.
2. First, you need a light source. A laser pointer would work best, since you will be able to more clearly follow the ray's path.

You will also need a substance to study. You will need to see the ray to measure its angles, so it should be something transparent. A crystal prism works well, and is easy to handle. Other options could be a clear container filled with water, or a solution which you can prepare – for example, distilled water, salt water, and a solution of sugar and water will all have different refractive indexes.

Materials

- Laser pointer (alternatively: a raybox with a single slit)
- Prism (alternatively: a piece of clear glass, a container with water, etc.)
- Ruler
- Protractor
- Millimetric paper (or graph paper).

Safety

Laser light can cause serious damage to the human eye and can even lead to blindness. You must take the following precautions when dealing with lasers:

- Ensure the beam is directed away from any person and there is no danger of someone accidentally moving into its path.
- Clamp the laser securely so there is no danger of it falling and pointing at people.
- Remove any reflective surfaces from near the path of the laser so it cannot reflect into anyone's eyes.
- Only turn on the laser once it is secured in position, and turn it off before unclamping it.
- If there are any other safety recommendations that come with the laser you are using, make sure you adhere to them.

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

- High-power lasers can also cause damage to the skin. Make sure you are familiar with the power of your laser and the manufacturer's safety recommendations.
- Only use the laser under supervision by a teacher or other qualified adult.

While care has been taken to give relevant safety information above, a full risk assessment must be carried out before starting any practical activity. It is unsafe to carry out any practical work without first consulting the relevant guidelines for all included chemicals, equipment and quantities.

Suggested method

You can use these instruments to calculate the refractive index of a substance.

1. Describe how you could set up your experiment.
2. State the independent and dependent variables.
3. Identify the type of graph you will aim to plot, to get the refractive index.
4. Predict the value you might expect for the *y*-intercept in your graph.
5. Describe which factors you should control.

1. Place the prism on top of the millimetric or graphing paper. By using the paper, you can trace the laser's path, so that measuring angles will be easier.

Place the protractor below the prism, on the page, so you can mark the incidence angle. Make sure to check the exact point at which the laser hits. Then, with a pen, mark the point at which the ray appears to exit the prism on the graphing paper (in case you cannot see the whole beam clearly). By lifting the prism, you can then measure the angle at which the refracted ray travelled.

You can check **Figure 3** to see what the setup should look like:

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

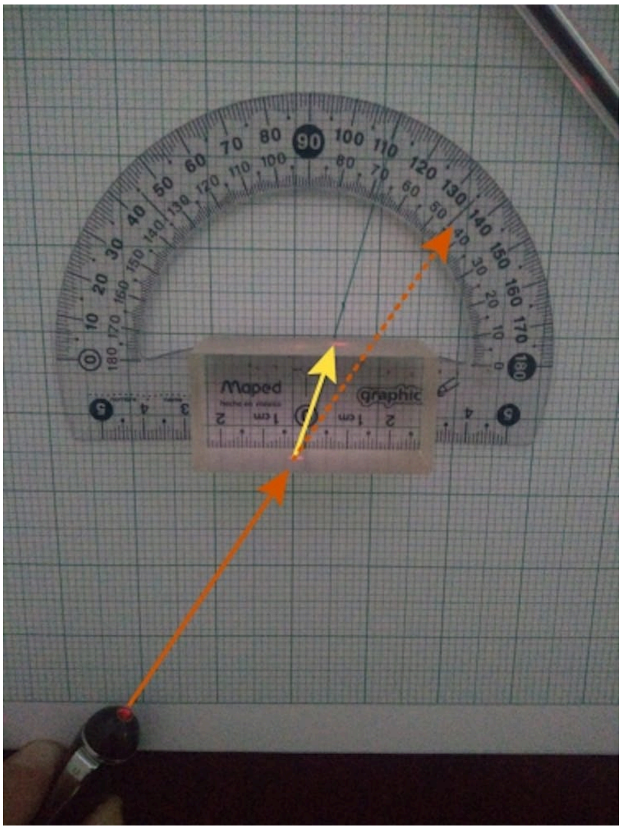


Figure 3. Experimental setup, including the laser pointer, prism and protractor over the graphing paper. The arrows represent: the longest, a solid orange — incident ray; the dotted orange — the path a ray would follow if there were no prism; and the shortest arrow, a solid yellow — refracted ray.

Credit: Eugenio Salazar

2. Given Snell's law, the best thing we can do is to modify the angles for the incident and refracted ray, and use these to calculate the index. The independent variable will be the incident angle, θ_{i} . You can modify this by moving the laser around. The dependent variable will be the angle at which the beam is refracted, θ_{r} .

3. The best way to measure a constant is to plot a straight-line graph of your experimental data, such that the constant is the gradient of the line of best fit. From Snell's law,

$$n_{\mathrm{i}} \sin \theta_{\mathrm{i}} = n_{\mathrm{r}} \sin \theta_{\mathrm{r}}$$

Given $n_{\mathrm{i}} = 1$ (the index for air), you will need to plot $\sin \theta_{\mathrm{r}}$ vs $\sin \theta_{\mathrm{i}}$. This should give a straight line with $\frac{1}{n_{\mathrm{r}}}$ as the gradient.

Student view

$$\sin \theta_{\mathrm{r}} = \frac{1}{n_{\mathrm{r}}} \sin \theta_{\mathrm{i}}$$

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

4. It is expected that the graph will go through the origin. If the incidence angle is 0°, then the angle of the refracted ray would be 0° as well – the ray would continue in a vertical path into the medium. When you plot your data and get the equation for the line of best fit, you should check that the y-intercept is zero, or very close to zero.

5. The most important thing to control is to make sure that the laser is steady at all times, since a very small difference could significantly affect your results. Use a stand to fix the laser and make sure it does not move while carrying out the experiment. Also, use the same laser pointer for the whole experiment.

Study skills

Remember that, when dealing with rays reaching a boundary, the angle of incidence and the angle of refraction are always measured from the normal to the plane (physicists often use the word 'normal' instead of perpendicular).

Carry out your experiment now and record your results. Small errors in measuring the angle can give a large divergence on the refractive index value, so be as accurate as possible. Doing repetitions for each measurement will ensure that you have accurate measurements.

Results

Your results might look something like the sample data in **Table 1**.

Table 1. Average angle of incidence and angle of refraction for the laser in the prism.

Angle of incidence, θ_i (°)	% uncertainty in angle of incidence	Average angle of refraction, θ_r (°)	% uncertainty in angle of refraction
20.0	0.5	13.0	3.3
25.0	0.4	16.3	2.2
30.0	0.3	20.0	2.6
35.0	0.3	22.4	1.7
40.0	0.3	25.6	1.5

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Angle of incidence, θ_i (°)	% uncertainty in angle of incidence	Average angle of refraction, θ_r (°)	% uncertainty in angle of refraction
45.0	0.2	28.2	1.2
50.0	0.2	31.0	1.0

Here we have directly reported the average values for the angle of refraction, and the uncertainty as a percentage uncertainty. The uncertainty for the angle of incidence is determined by the protractor (absolute uncertainty of 0.1°), while the uncertainty for the angle of refraction is given by the $\frac{(\text{max.value}-\text{min.value})}{2}$ as seen in previous practicals.

The following is relevant only if you need to process sin values in your Internal Assessment.

Processing uncertainties of sine functions is not directly on the DP physics course, however, it is a skill that you might need to use in your IA.

There are options, but the most appropriate way for your IA is as follows:

- Assume you take readings of an angle and the smallest value is 0.70 and the largest value is 1.10. The average of your reading was found to be 0.90.
- Sin (0.90) can easily be plotted on your graph but the error bars associated with this point will also need to be added. To do this, you can simply take the sine of the maximum value minus the sine of the minimum value and divide this by 2. This gives half the difference between the maximum and minimum and this can be used as your uncertainty.

Solution steps	Calculations
Step 1: Calculate sine for mean value.	**sin (0.9) = 0.78**
Step 2: Calculate sine values for minimum and maximum values.	sin (1.10) = 0.89 sin (0.70) = 0.64

Student view

Solution steps	Calculations
Step 1: Calculate sine for mean value.	**sin (0.9) = 0.78**
Step 3: Calculate uncertainty.	$\text{uncertainty} = \frac{\text{maximum} - \text{minimum}}{2} = \frac{(0.89 - 0.64)}{2} = 0.13$
Step 4: State the mean value and uncertainty.	0.78 ± 0.13 or 0.8 ± 0.1 (2 s.f.)

With these results, you should be able to plot a graph. As mentioned previously, you will need to calculate the refractive index of the medium from the gradient. Remember to correctly linearise your graph so that this is possible.

Your graph should look something like that shown in **Figure 4**.

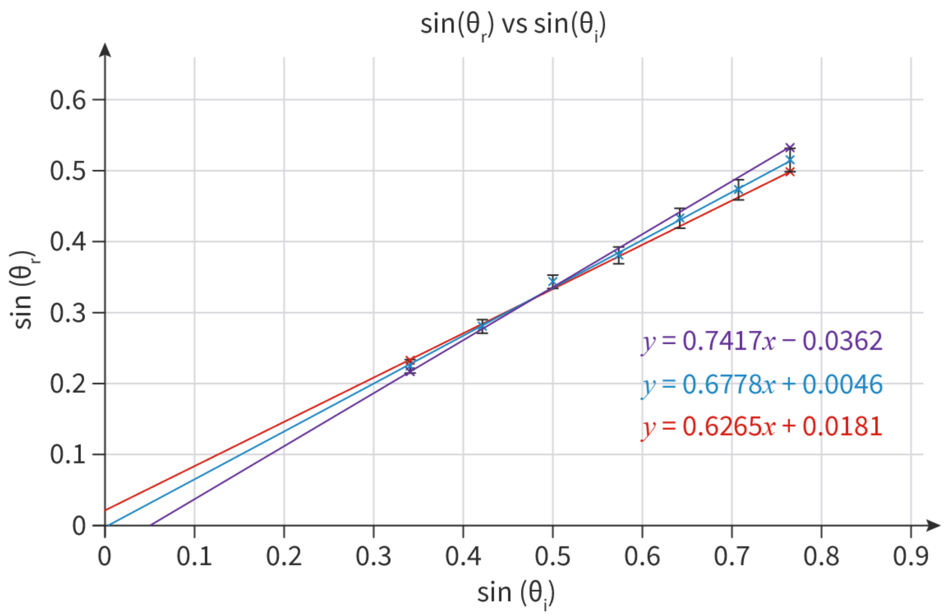


Figure 4. Graph of sin θ_r vs sin θ_i including the lines of best fit, the min gradient and the max gradient.

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

You can see that the y-intercept on the equation of the line of best fit is very small. This indicates that the measurements were carried out with a reasonable amount of precision.

Next, calculate the value for the refractive index. It was determined previously that the gradient would be $\frac{1}{n_{\text{r}}}$, so

$$\frac{1}{n_{\text{r}}} = 0.6778$$
$$n_{\text{r}} = 1.48$$

This would be the average value of the refractive index of the prism.

To get the uncertainty on this value, use the minimum and maximum gradient lines.

Using each gradient, the minimum and maximum values for the refractive index can be calculated:

$$n_{\text{min}} = \frac{1}{0.7417} = 1.35 n_{\text{max}} = \frac{1}{0.6265} = 1.60$$

The formula for the uncertainty is:

$$\text{uncertainty} = \frac{\text{max} - \text{min}}{2}$$
$$\text{uncertainty} = \frac{(1.60 - 1.35)}{2}$$
$$= 0.13$$

So we report our final answer as:

$$\text{refractive index, } n_{\text{r}} = 1.5 \pm 0.1$$

Remember, uncertainty is almost always quoted to 1 significant figure. You should then double check that the number of decimal places in your uncertainty match the number of decimal places in your value.

Study skills

Student view

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

Most spreadsheet software, such as Excel, have radians as the default unit for angles. If you try plotting a graph of sin θ and get nonsensical values, it might be because you have inserted the data for the angle in degrees — make sure to adjust your units.

As you complete any practical you should be aware of any factors or limitations that might affect the data that you are collecting.

While discussing control variables in the Research Design section of your report you will have identified variables that must remain the same throughout your practical and also, factors that you should try to control as the practical is carried out (room temperature for example). However, while carrying out the experiment it is common to see things that might affect your data which you have little control over. These limitations are referred to as methodological issues and should be discussed in the evaluation section of your report.

It is best to detail these limitations in a table like the **Table 2** as it shows that you understand the effect of the issue and that you can suggest a suitable improvement.

Table 2. Limitations in method.

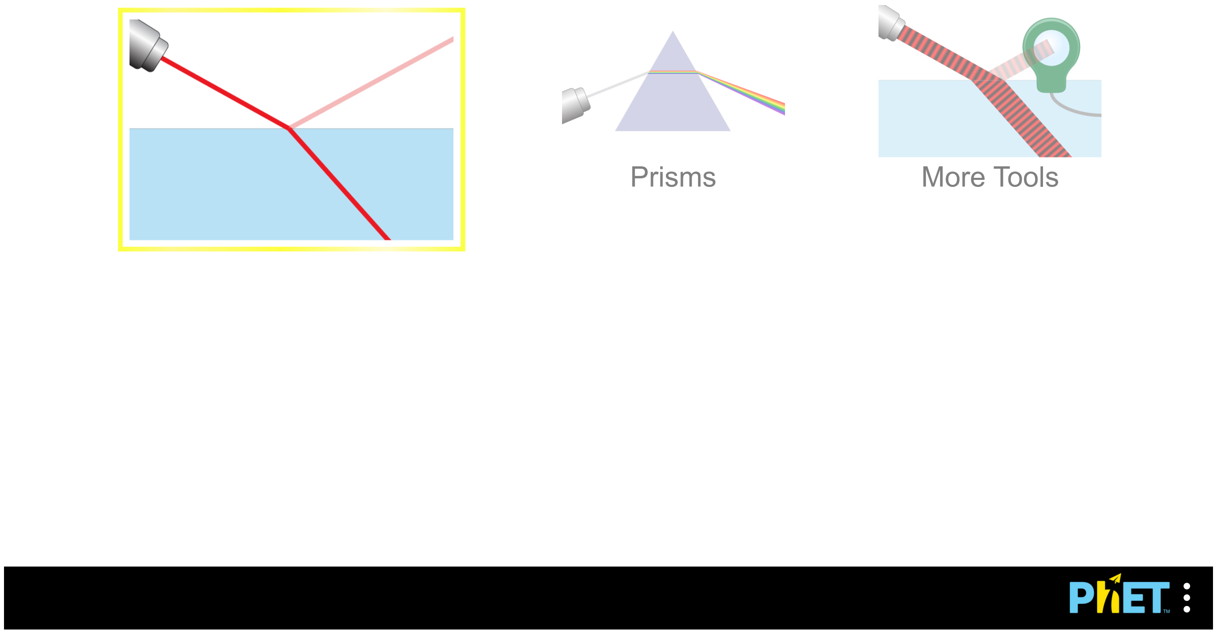
Limitation	How it affected the data	Improvements
Thickness of the lines drawn	A felt tip pen was used to draw the lines in this experiment. When the angle was measured using a protractor, it was difficult to tell exactly where the measurement should be taken from and so, uncertainty was added to the value.	By using a sharpened pencil to draw the lines on the paper, it would allow for a more accurate identification of where the measurement should be taken from.

Your limitations table should include at least three strong methodological limitations. Consider other limitations that could be added to the table above. You should discuss the limitations, how it affected the data and suggest possible ways of improving this.

Alternative method

If you are not able to access the materials needed to carry out this practical, or you want to get some more practise on calculating the refractive index, you can use the PhET simulator below:

Student
view



Interactive 1. Bending light simulation.

More information for interactive 1

The interactive simulation titled “Bending light simulation,” explores how light bends when transitioning between different materials with varying refractive indices. A laser emits a beam of light at an interface between two media, demonstrating refraction and reflection. Users can measure the angles of incidence and transmission with a simulated protractor or by enabling the “angle” option in the bottom left. The simulation allows adjustment of the material properties, including selecting a "mystery" medium, challenging users to determine its refractive index using Snell’s law. The speed of light in each medium can be observed, providing insights into how refraction relates to changes in wave velocity.

Users can also modify the wavelength of the incident light, exploring whether this affects refraction. The interface includes tools to measure intensity and speed, allowing a more quantitative approach to understanding light behavior. The first medium is typically air, while the second medium can be changed to water, glass, or a mystery substance. The refractive index of known materials is displayed, while the mystery medium requires calculation. Set the first medium as “air” and the second medium as “mystery A” by adjusting the slider in the “material” boxes.

Set the angle of incidence, $\theta_i = 60^{\circ}$. The angle of refraction as per the simulation will display, $\theta_r = 21^{\circ}$. According to Snell’s law, we have:

$$n_a \sin \theta_i = n \sin \theta_r$$

The value of n from the above equation is:

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

$$n = \frac{n_a \sin \theta_i}{\sin \theta_r}$$

Substitute the values in the above equation to determine the refractive index of the "mystery A" medium.

$$n = \frac{1 \times \sin 60^\circ}{\sin 21^\circ}$$

$$= 2.416$$

Thus, the refractive index of the "mystery A" medium is 2.416. In this way, the interactive helps to determine the refractive index of a medium.

Enabling the "wave" mode and adjusting the slider on the top right, users can experience the change in wavelength due to the change in speed of the wave. The increase in the index of refraction decreases the speed of light. Since the frequency of light is a constant, the wavelength should decrease.

The light beam can be switched between ray and wave representations, reinforcing the wave nature of light and how it interacts at boundaries. The near-perfect data accuracy contrasts with real experiments, where measuring instruments introduce variability. Despite this limitation, the simulation effectively visualizes refraction, total internal reflection, and the relationship between angle, speed, and refractive index. By adjusting different parameters and analyzing results, users develop a deeper understanding of light's interaction with materials.

Section Student... (0/0) Feedback Print (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-the-speed-of-sound-id-46509/print/) Assign

Go into the third option ('More Tools'). In this simulation you can measure the incidence and transmission angles (either through the simulated protractor, or checking the 'angles' box on the left), and the wave speed in each medium. On the right-hand side, change the second medium to one of the 'mystery' options, and by using Snell's law, determine what the value of the refractive index should be.

You might see that there are other things that you can modify here, such as the wavelength of light. What effect, if any, does this have on the refractive index?

Note that simulations provide near perfect results every time. The values attained are far more precise than any experiment that we would conduct in the lab. However, it is recommended to avoid using these for IAs as error analysis and evaluation of methodological issues is a large part of the IA marking scheme. It is quite hard to score high marks in these sections if a simulation is used.

Here is an example of a limitation that could be considered if this experiment was to be conducted in the lab.

Student view

Create a limitations table that would discuss the methodological limitations of this experiment.

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Table 3. Limitations in method.

Limitation	How this affected the data	Suitable improvement
Movement in the water	As the water was moving, the transmitted ray was difficult to measure. This meant that the point marked on the paper was not accurate and so, the angles that were quoted were inaccurate.	By allowing suitable time for the water to come to rest and not disturbing the container until the measurement is complete, more accurate readings for the transmission point can be recorded and so, the data would be more accurate.

Internal assessment checklist

For your internal assessment work, remember the following that you have exercised in this practical:

Evaluation

- Suitable weaknesses and limitations in procedure identified and their impact on the data explained.
- Improvements to procedure suggested are realistic and relevant to the weaknesses and limitations identified.

1. Essential skills and support guides / 1.4 Collected practicals

Investigating the resistivity of a conducting wire

Prior learning

Before attempting this practical, you should be familiar with the following concepts:

- Cells provide a source of emf (see section B.5.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/conductors-electric-potential-difference-and-id-44362/)).
- Circuit diagrams represent the arrangement of components in a circuit (see section B.5.3a (/study/app/math-aa-hl/sid-423-cid-762593/book/series-and-parallel-circuits-id-44364/)).
- The properties of electrical conductors and insulators in terms of mobility of charge carriers (see section B.5.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/conductors-electric-potential-difference-and-id-44362/)).

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

- Electric resistance and its origin (see section B.5.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/resistance-resistivity-and-ohms-law-id-44363/)).
- Electrical resistance R as given by $R = \frac{V}{I}$ (see section B.5.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/resistance-resistivity-and-ohms-law-id-44363/)).
- Resistivity as given by $\rho = \frac{RA}{L}$ (see section B.5.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/resistance-resistivity-and-ohms-law-id-44363/)).
- Ohm's law (see section B.5.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/resistance-resistivity-and-ohms-law-id-44363/)).

? Guiding question(s)

- How can the resistivity of a material be calculated by measuring the current and potential difference?

All metals are good conductors of electricity. So, does this mean that if we lined up an array of different metal wires, each equally thick and equally long, they would all allow current to flow through them equally?

Practical skills

In this practical you will be exercising the following tools and skills:

Tool 2: Technology

- Applying technology to collect data: use sensors (see section 1.2.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/sensors-id-48942/)).

Tool 3: Mathematics

- Calculating the mean and range (see section 1.3.5 (/study/app/math-aa-hl/sid-423-cid-762593/book/measures-of-central-tendency-id-48951/)).
- Select and manipulate equations (see section 1.3.6 (/study/app/math-aa-hl/sid-423-cid-762593/book/equations-id-48952/)).
- Calculate and interpret percentage uncertainty (see section 1.3.8 (/study/app/math-aa-hl/sid-423-cid-762593/book/proportionality-and-percentage-change-id-48955/)).
- Express quantities and uncertainties to an appropriate number of significant figures (see section 1.3.9a (/study/app/math-aa-hl/sid-423-cid-762593/book/recording-data-id-48956/)).

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Background

Resistance is one of the key characteristics of an electrical component. This is discussed in more depth in section B.5.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/resistance-resistivity-and-ohms-law-id-44363/). Resistivity is the resistance of a unit cross-sectional area of a material per unit length, or:

$$\rho = \frac{RA}{L}$$

Where ρ is resistivity of the material, L is the length of the wire and A is its cross-sectional area.

But what can affect the resistivity? The first thing to think about is the temperature of the component. The animation below shows the effect of increased temperature (and therefore the movement of the ions in the conductor) on the flow of electrons.

This Sketchfab 3D model has been disabled.

Interactive 1. The effect of increased temperature on the flow of electrons.

If the temperature is kept constant, then there are other factors that can vary the resistivity, in particular, the material through which the current flows.

In this practical you will investigate several different materials and calculate their resistivity at constant temperature.

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

What effect does changing the material have on the resistivity of a conductor?

Internal assessment criteria

Research design

In this practical you will identify some of the methodological considerations that you will need to look at when completing your IA such as the selection of variables, scope of measurements and discussion of safety issues.

Apparatus

- Power supply (battery or otherwise)
- Micrometer or vernier calipers
- Ruler
- Voltmeter
- Ammeter
- Wires
- Different materials for testing (e.g. a graphite pencil lead, constantan wire, copper wire, steel wire).

Safety

Observe all usual safety precautions when dealing with electricity:

- Ensure the equipment is well maintained and wires are fully insulated.
- Check the area is clean, dry and tidy.
- Do not touch live terminals or exposed wires.
- Take care when handling electrical conductors as they may become hot after use.

While care has been taken to give relevant safety information above, a full risk assessment must be carried out before starting any practical activity. It is unsafe to carry out any practical work without first consulting the relevant guidelines for all included chemicals, equipment and quantities.

Suggested method

Student view

Take a look at the equation at the start of this section. Your objective is to design an experiment which will allow you to calculate the resistivity of the materials you have chosen.

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Study skills

Remember, the best way to calculate the value of a constant is to rearrange the equation

$$\frac{RA}{L} = \rho$$

to the format

$$y = mx + c$$

make the required value (in this case the resistivity) the gradient, *m*, take multiple values and plot them on a graph.

First, rearrange the equation to make resistivity the gradient. State what you will plot on each axis of your graph. When you have done this, click 'Show' below to see the rearranged equation.

First, you need the equation for resistivity:

$$\frac{RA}{L} = \rho$$

Rearranging to the format $y = mx + c$ where m is the gradient, in this case ρ, gives:

$$R = \rho\frac{L}{A}$$

Therefore, R must be plotted on the *y*-axis and $\frac{L}{A}$ on the *x*-axis. The gradient of this graph will then be resistivity, ρ.

To make resistivity the gradient, the resistance needs to be measured for multiple values of $\frac{L}{A}$. There are several different ways in which you could do this. This practical will go into detail on one of them, but how many can you think of? Think about the following steps to help you construct your own experiment plans:

- State your independent variable and describe how you will change it.
- State your dependent variable and describe how you will measure it.
- Identify anything else you need to measure and how.
- Determine what kind of circuit you will need to construct. Draw the circuit diagram.

Student view

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

- Will increased current flowing through the circuit have an effect on the results? Explain why. Describe how you could minimise this.
- Predict the shape of your graph.
- Remember, we are ultimately trying to compare the resistivities of multiple different materials – could you carry out your experiment with multiple different materials? Explain how.

When you are ready, carry out your experiment and see if you were right about the shape of your graph.

If you need some guidance, one main method and some alternatives are given below.

Independent variable: Length of conductor

Dependent variable: Current, used to calculate resistance afterwards

Circuit diagram: See **Figure 1**.

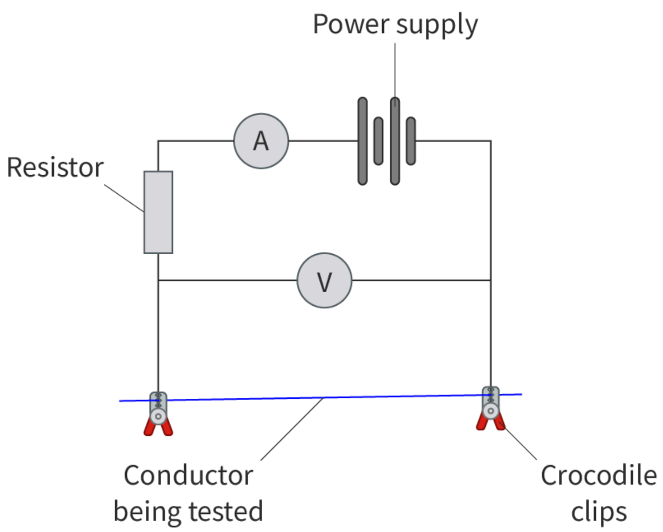


Figure 1. An example circuit diagram.

Suggested method

1. Take the conductor being tested and measure its diameter using vernier callipers or a micrometer in three different places. Calculate an average. Calculate the cross-

Student
view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

sectional area of the wire using $\mathrm{CSA} = \pi r^2$ or $\mathrm{CSA} = \pi\left(\frac{d}{2}\right)^2$, where r is the radius or d is the diameter.

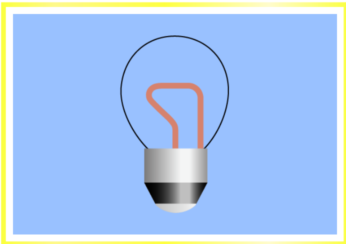
2. Set up the circuit and, if it is a variable power supply, set the voltage to 1 V. This will minimise the resistive heating of the conductor and help to keep temperature constant. (For the purpose of this practical we will assume internal resistance is negligible.)
3. Record the voltage, current and length of the wire between the crocodile clips. Repeat for seven different lengths, with three repeat readings for each length. Try to take your measurements quickly and do not allow current to flow for too long. This will heat up the wire and affect the resistivity.
4. Repeat this experiment with multiple different metals to measure the resistivity of each.

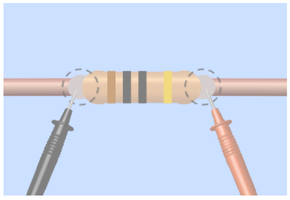
Alternative ideas for this practical

- Instead of varying the length, you could vary the cross-sectional area by using multiple thicknesses of conductor.
- You could measure the effect of temperature on the resistivity by using a similar method but wrapping the length of wire around the bulb of a thermometer and varying the emf to produce different levels of resistive heating of the wire.
- Similarly, you could measure the effect of temperature on resistivity using a filament bulb.

If you do not have access to any lab equipment, you could use the simulation below to investigate the resistivity of things like an eraser, a pencil, a hand, a coin or even a dog! (You may need to make some assumptions regarding their dimensions.)

Student view





Interactive 2. Circuit construction kit: DC.

More information for interactive 2

An interactive simulation titled, Circuit Construction Kit: DC, focuses on direct current circuit building. It presents two options, the first one is “Intro”, represented by a light bulb icon, and the second one is “Lab”, depicted with an image of a resistor connected to probes.

The Intro panel offers a simplified environment for constructing basic circuits using wires, batteries, bulbs, and other common components. Users can visually observe electron flow, and conventional current flow, and explore fundamental circuit concepts such as series and parallel connections. The interface includes draggable components from a sidebar and interactive measurement tools like voltmeters and ammeters. The resistance of the components (bulb, resistor, eraser, coin, pencil, paperclip, dollar bill) can be varied using a slider that appears on the bottom while clicking on the component.

The Lab panel provides a more advanced circuit-building experience, allowing users to test various materials' electrical properties, including unconventional conductors like a coin, a paperclip, or even a hand. The Lab panel also features an Advanced option for deeper exploration, including resistance, voltage, and current measurements.

Both panels share a current visualization feature, enabling users to switch between electron flow (negative charge movement) and conventional current (positive charge movement) representations. Users can experiment freely, connecting and disconnecting elements, measuring voltage and current, and even introducing resistors or fuses.

By engaging with this interactive, the users can understand how electrical circuits function, including how voltage, current, and resistance interact. By adding resistors and adjusting circuit components, users can explore Ohm's Law in action. The Lab panel allows users to test various objects' electrical conductivity, reinforcing the idea that different materials have unique resistivity. The use of voltmeters and ammeters introduces real-world circuit analysis techniques.

Results

By now, you should have a results table for each material that looks a little like the sample data given in **Table 1**.

Sample data:

$$\text{diameter of wire} = 0.560 \pm 0.005 \text{ mm}$$

Table 1. Sample data.

Length of wire (m)	Length absolute uncertainty (m)	Measured voltage (V)	Voltage absolute uncertainty (V)	Measured current (A)	Current absolute uncertainty (A)
0.100	0.005	1.0	0.01	4.91	0.01
0.200	0.005	1.0	0.01	1.63	0.01
0.300	0.005	1.0	0.01	1.22	0.01
0.400	0.005	1.0	0.01	0.97	0.01
0.500	0.005	1.0	0.01	0.97	0.01
0.600	0.005	1.0	0.01	0.82	0.01
0.700	0.005	1.0	0.01	0.70	0.01

Length was measured with a ruler and so, the smallest measurement on this analogue device is 1 mm. The uncertainty is half of 1 mm, thus, 0.005 m.

Voltage and current were measured on digital devices The small possible readings on these devices were 0.01, and so, this is the quoted uncertainty.

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Revisit the equation for the graph and produce a processed results table. Try to answer the following questions:

- Describe what needs to be done to the raw data before it can be plotted in the desired graph.
- Describe what needs to be done with the uncertainty.

When you have answered these questions, click below to see the processed data table.

The equation for the graph is $R = \rho\frac{L}{A}$. For the y-axis values you need to calculate R using $V = IR$. For the x-axis values you need to calculate $\frac{L}{A}$, so first calculate A using πr^2 and then divide the length values by this newly calculated area value.

The processed results table should look something like **Table 2**.

Table 2. Processed results table.

Resistance of wire = V/I (Ω)	Resistance uncertainty (Ω)	Cross-sectional area of wire (m^2)	$\frac{L}{A}$ (m^{-1})	Uncertainty in $\frac{L}{A}$ (m^{-1})
0.203	2.4×10^{-3}	2.46×10^{-7}	4.06×10^{5}	2.8×10^{4}
0.407	5.7×10^{-3}	2.46×10^{-7}	8.12×10^{5}	3.5×10^{4}
0.613	9.9×10^{-3}	2.46×10^{-7}	1.22×10^{6}	4.2×10^{4}
0.820	1.5×10^{-2}	2.46×10^{-7}	1.62×10^{6}	4.9×10^{4}
1.03	2.1×10^{-2}	2.46×10^{-7}	2.03×10^{6}	5.7×10^{4}
1.22	2.7×10^{-2}	2.46×10^{-7}	2.44×10^{6}	6.4×10^{4}
1.43	3.5×10^{-2}	2.46×10^{-7}	2.84×10^{6}	7.1×10^{4}

Sample calculations:

Resistance of wire:

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

$$R = \frac{V}{I}$$

$$R = \frac{1.0}{4.91} = 0.203\ \Omega$$

Resistance uncertainty:

From the data booklet, if the equation given is $y = \frac{ab}{c}$, then $\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$

In this case, $R = \frac{V}{I}$ so $\frac{\Delta R}{R} = \frac{\Delta V}{V} + \frac{\Delta I}{I}$

$$\frac{\Delta R}{R} = \frac{0.01}{1.00} + \frac{0.01}{4.91}$$
$$\frac{\Delta R}{R} = 0.01 + 0.002$$
$$\frac{\Delta R}{R} = 0.012$$

This is the fractional uncertainty of the measurement.

$$\Delta R = 0.012 \times 0.203$$
$$\Delta R = 2.4 \times 10^{-3}\ \Omega$$

Cross sectional area of wire:

$$\text{CSA} = \pi r^2 \text{ or } \text{CSA} = \pi\left(\frac{d}{2}\right)^2$$

Diameter of wire = 0.560 mm = 0.00056

$$\text{CSA} = \pi\left(\frac{0.00056}{2}\right)^2 \text{CSA} = 2.46 \times 10^{-7}\ \text{m}^2$$

Length/area:

Length of wire = 0.100 m (from **Table 1**)

Area = $2.46 \times 10^{-7}\ \text{m}^2$ (from **Table 1**)

$$\frac{L}{A} = \frac{0.100}{2.46 \times 10^{-7}} \frac{L}{A} = 4.06 \times 10^5$$

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

In your IA it is very important to include sample calculations. Note, you are not expected to show how you calculate an average but you are expected to show the calculation of uncertainties.

Practical skills

When propagating uncertainties (see section 1.3.9c (/study/app/math-aa-hl/sid-423-cid-762593/book/propagation-of-uncertainties-id-49161/)), be sure to do this on a carefully formatted excel spreadsheet. It might take you quite a while to set up your spreadsheet but it will save you a lot of time in the long run!

Now you can plot a graph of resistance (y-axis) against $\frac{L}{A}$ (x-axis) with error bars, and the gradient will be the resistivity.

Study skills

The error bars enable you to plot three gradients — the line of best fit, the max and the min. The max and min will give you the uncertainty for your line of best fit value.

$$\text{uncertainty of line of best fit} = \frac{\text{gradient of max uncertainty bar} - \text{gradient of min uncertainty bar}}{2}$$

Plot your graph, and then see how it compares with the sample data by clicking below (**Figure 2**).

Student view

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

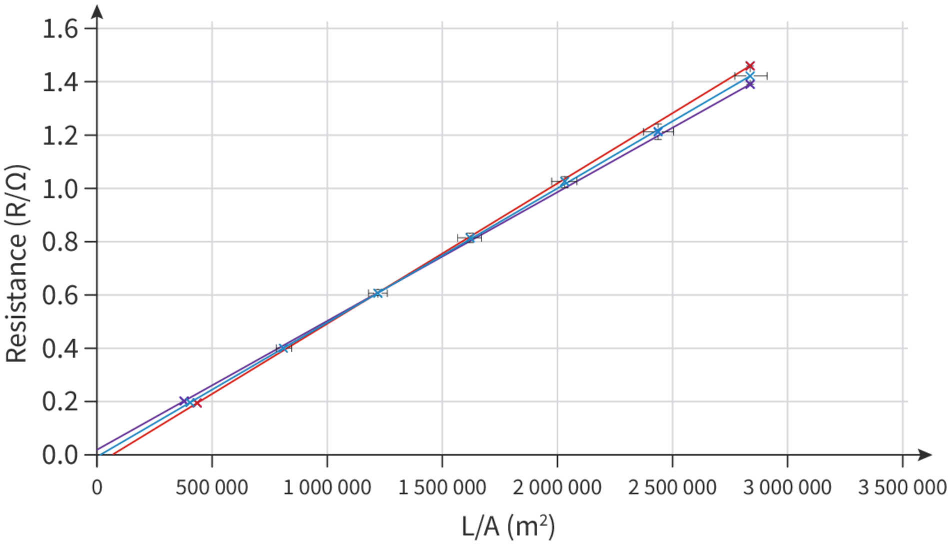


Figure 2. Graph of resistance against L/A showing the line of best fit and maximum and minimum gradients.

Gradients according to the graph (calculated from the processed data, using the limits of each error bar):

Line of best fit: $5.04 \times 10^{-7}\ \Omega\ (\mathrm{m}^2)$

Min gradient: $4.70 \times 10^{-7}\ \Omega\ (\mathrm{m}^2)$

Max gradient: $5.41 \times 10^{-7}\ \Omega\ (\mathrm{m}^2)$

Next, you need to calculate the final uncertainty of your line of best fit using the max–min gradients.

Calculating the uncertainty of the line of best fit gradient:

$$\text{uncertainty} = \frac{\max - \min}{2}$$

Giving:

$$\frac{5.41\times10^{-7} - 4.70\times10^{-7}}{2} = 3\times10^{-8}$$

Student
view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Which gives a final answer for the resistivity of constantan wire as:

$$5 \times 10^{-7} \pm 3 \times 10^{-8} \Omega m$$

Repeating this process for various different materials would allow you to investigate the variation of resistivity with different materials.

Internal assessment checklist

For your internal assessment work, remember the following that you have exercised in this practical:

Data analysis

- A detailed explanation of the decisions regarding scope and quantity of data collected.
- An explanation of the safety, ethical and environmental considerations of your investigation.

1. Essential skills and support guides / 1.4 Collected practicals

Measuring the internal resistance of a cell

Section Student... (0/0) Feedback Print (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-the-internal-resistance-of-a-cell-id-46512/print/) Assign

Guiding question(s)

- How can the internal resistance of a cell be found?

Prior learning

Before attempting this practical, you should be familiar with the following concepts:

- Cells provide a source of emf (see section B.5.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/conductors-electric-potential-difference-and-id-44362/)).
- Circuit diagrams represent the arrangement of components in a circuit (see section B.5.3a (/study/app/math-aa-hl/sid-423-cid-762593/book/series-and-parallel-circuits-id-44364/)).

Section Student... (0/0) Feedback Print (/study/app/math-aa-hl/sid-423-cid-762593/book/determining-refractive-index-id-46510/print/) Assign

- Electrical resistance R as given by $R = \frac{V}{I}$ (see section B.5.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/resistance-resistivity-and-ohms-law-id-44363/)).

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

- Electric cells are characterised by their emf ε and internal resistance r as given
- By $\varepsilon = I(R + r)$ (see section B.5.5a (/study/app/math-aa-hl/sid-423-cid-762593/book/cells-and-internal-resistance-id-44367/)).
- Resistors can have variable resistance. (see section B.5.5a (/study/app/math-aa-hl/sid-423-cid-762593/book/cells-and-internal-resistance-id-44367/)).

When you look at a circuit like the one in **Figure 1**, you probably already know that the bulb has a certain resistance.

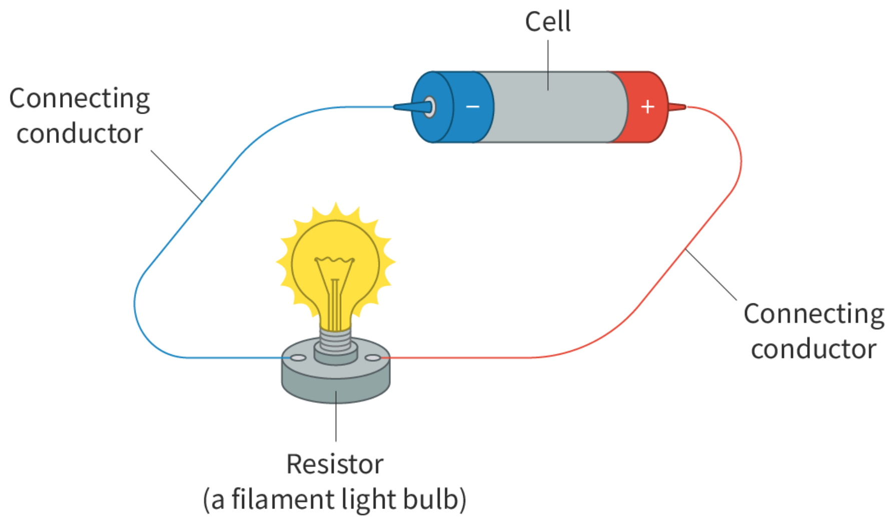


Figure 1. A simple circuit with a cell, connecting wires and a bulb.

More information for figure 1

The image shows a simple electrical circuit diagram. It includes a cell on the right with a positive and negative terminal, indicated by '+' and '-' signs. Two connecting conductors, represented by lines, run from the cell to a bulb labeled as 'Resistor (a filament light bulb).' The connecting conductors are marked as such, and the circuit loop connects the components in a circular manner. The diagram visually represents the flow of electricity through the circuit.

[Generated by AI]

You may also be aware that the wires have a small resistance too. But that is not all. The cell itself has a certain resistance, and this is what we call the **internal resistance of the cell.**

How does the internal resistance of a cell impact its performance and overall electrical circuit behaviour, and what factors contribute to variations in internal resistance among different types of cells?

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/o

Practical skills

In this practical you will be exercising the following tools and skills:

Tool 1: Experimental techniques

- Recognise and address relevant safety, ethical or environmental issues in an investigation (see section 1.1.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/safety-of-self-others-and-the-environment-id-48941/)).
- Understand how to accurately measure electric current and electric potential difference to an appropriate level of precision (see section 1.1.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-variables-with-analogue-equipment-id-48813/)).

Tool 2: Technology

- Represent data in a graphical form (see section 1.2.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/manipulating-and-representing-data-id-48945/)).

Tool 3: Mathematics

- Select and manipulate equations (see section 1.3.6 (/study/app/math-aa-hl/sid-423-cid-762593/book/equations-id-48952/)).
- Understand direct and inverse proportionality, as well as positive and negative relationships or correlations between variables (see section 1.3.8 (/study/app/math-aa-hl/sid-423-cid-762593/book/proportionality-and-percentage-change-id-48955/)).
- Determine the effect of changes to variables on other variables in a relationship (see section 1.3.8 (/study/app/math-aa-hl/sid-423-cid-762593/book/proportionality-and-percentage-change-id-48955/)).
- Understand the significance of uncertainties in raw and processed data (see section 1.3.9b (/study/app/math-aa-hl/sid-423-cid-762593/book/errors-and-uncertainties-id-49160/)).
- Record uncertainties in measurements as a range (±) to an appropriate precision (see section 1.3.9c (/study/app/math-aa-hl/sid-423-cid-762593/book/propagation-of-uncertainties-id-49161/)).
- Draw and interpret uncertainty bars (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).

Background

We saw in subtopic B.5 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-44361/) that internal resistance can be represented by adding a small resistor in series with the cell, as shown in **Interactive 1**.

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Section Student... (0/0) Feedback Print (/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-the-resistivity-of-a-conducting-wire-id-46511/print/) Assign

Interactive 1. The Internal Resistance of the Cell Is Represented by Resistor r.

More information for interactive 1

A video interactive showing a simple electrical circuit. The video aims to depict the calculation for electromotive force (emf) and internal resistance (r) of a cell. The play button at the bottom with a slider allows the users to play and pause the video as per convenience. The “Playback Rate” icon next to the slider has various options including 0.25, 0.5, 1, 1.25, 1.5, and 2 for the users to choose from. At the bottom right is the “Fullscreen” icon that enables the screen to view in full size.
The video opens with a dashed box at the center with emf and internal resistance depicted at its center. The emf and r are then connected to an external circuit with the resistor (R), which is connected to an external component connected to the battery. The R in the external circuit provides resistance. The resistor is then connected to an ammeter (A). The ammeter is responsible for measuring the current flowing through the entire circuit from left to right.
The external circuit is then connected to a terminal voltage (V) source parallel to R. This is responsible for measuring the terminal voltage across the external resistor (R).

In the same subtopic, we also derived the equation for calculating internal resistance:

$$\varepsilon = V + Ir$$

Where ε is the emf of the cell, V is the terminal voltage (the voltage across the two terminals of the battery, shown by the voltmeter in **Interactive 1**), I is the current and r is the internal resistance of the cell.

Student view

Overview (/study/ap aa- hl/sid- 423- cid- 762593/c

As with every practical, it is helpful to rearrange the equation to the form $y = mx + c$and to make the variable we are trying to calculate the gradient.

However, before doing this, take another look at the equation, and ask yourself:

- Which of these variables can I modify easily?
- Which of these variables will be affected by changes in the others?
- What effects could we measure easily?

Once you have answered these questions, you should have a more realistic idea about what your independent, dependent and control variables might be. While planning, keep in mind that we aim to find internal resistance, *r*, using the gradient of a graph.

Designing

Identify what can be ruled out as options for the independent and dependent variables. This equation from the data booklet might help:

$$\varepsilon = V + Ir$$

Once you have identified them, click 'Show answer' below.

Ignoring any temperature changes (which would be hard to control and would affect the resistance of other components too), the internal resistance is constant for any given cell, so should be ruled out as the independent or dependent variable.

We are trying to calculate the internal resistance of a particular cell, which will have a constant emf (ignoring the slight reduction over time as it discharges). This rules out emf as the independent or dependent variable.

So the independent and dependent variables should be either voltage, *V*, or current, *I*. Which one is which?

Final decision: Identify the independent variable. Explain your answer.

This is a practical consideration. Which one could be physically changed more easily?

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

As we are investigating a particular cell, it will have a constant emf, and hence modifying the voltage across the cell would be very difficult.

So, from a practical consideration, the current should be modified and the voltage measured.

Taking current as the independent variable and voltage as the dependent variable, explain how you will carry out the experiment, including how the current can be modified while keeping the same cell.

To modify the current, the resistance should be varied. Connecting a variable resistor to the circuit allows the resistance to change. This will in turn change the current and can be easily controlled while you carry out the experiment.

Alternatively, you could use a thermistor or LDR if you would like to make your experiment more creative.

To calculate the internal resistance, *r*, rearrange the equation to make this the gradient of a straight line graph.

$$\varepsilon = V + Ir$$

Rearranges to:

$$V = \varepsilon - Ir$$

Or:

$$V = -rI + \varepsilon$$

Plotting a graph of V (y-axis) against I (x-axis) should give a gradient of $-r$ and a y-intercept of ε.

In this practical you will vary the current I in a circuit and measure the voltage V. Plotting a graph of this will enable you to find both the emf ε of the cell and its internal resistance r. This means you are able to determine the internal resistance of a cell experimentally.

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Create a research question that you could answer in this investigation.

How does increasing the current in the circuit affect the voltage when the temperature and the EMF of the cell is kept constant?

More guidance on how to create a research question is found in the IA guide (/study/app/math-aa-hl/sid-423-cid-762593/book/research-design-id-46743/).

Materials

- Variable resistor/rheostat
- Ammeter
- Voltmeter
- Cell for testing (an AA cell is fine)
- Fixed resistor ≈ 10 ohms
- Connecting wires.

Safety

Observe all usual safety precautions when dealing with electricity:

- Ensure the equipment is well maintained and wires are fully insulated.
- Check the area is clean, dry and tidy.
- Do not touch live terminals or exposed wires.
- Take care when handling electrical conductors as they may become hot after use.

While care has been taken to give relevant safety information above, a full risk assessment must be carried out before starting any practical activity. It is unsafe to carry out any practical work without first consulting the relevant guidelines for all included chemicals, equipment and quantities.

Suggested method

Internal assessment criteria

Research design

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

In this practical you will choose between current and voltage as variables that will allow you to find internal resistance, r. You will describe a research question that will guide you to create a valid scientific method that will be used to find the internal resistance.

Take a look at the equation you just rearranged:

$$V = -rI + \varepsilon$$

You need to vary the current and measure the voltage across the terminals of the cell. Now, take a look at the apparatus. How will you use this equipment to achieve this? Think about the following questions to help you:

1. State your independent, dependent and control variables.
2. Describe how you will set up your circuit to make the correct measurements.
3. Suggest what the fixed resistor is for.
4. Sometimes, your teacher might advise you to only connect the circuit for a short amount of time while you take the readings and then disconnect it again. Explain why this is important.

If you need some guidance, click on the example answers below:

1. As stated above, we want to *vary* the current (so it is the independent variable) and *measure* the voltage (dependent variable). The main thing which could affect the results for current and voltage is the temperature of the circuit, so we want to keep this as constant as possible (control variable). Other control variables include the value of the fixed resistor and the resistance of the connecting wires (so using the same wires each time is sensible).

Additionally, the emf must remain constant. This can be done by using the circuit for as little time as possible. If, when you repeat your experiments, the output voltage is significantly different, you should replace the cell with an identical one.

2. Using the listed apparatus, the way to vary the current is to vary the resistance in the circuit using the variable resistor (**Figure 2**).

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

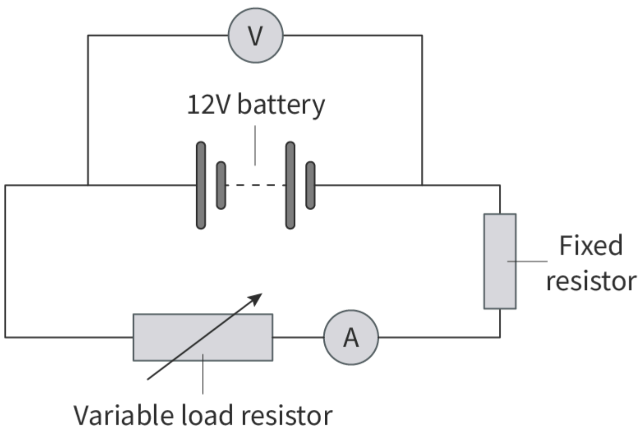


Figure 2. Investigating the internal resistance of the battery.

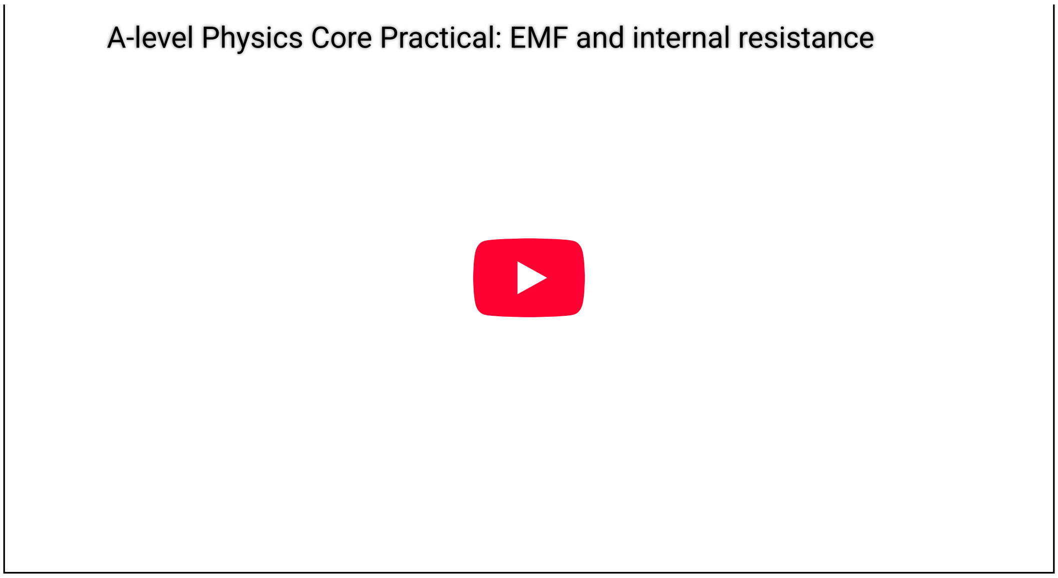
3. The resistance of the variable resistor can be adjusted so it is almost zero. If the resistance was almost zero then the current in the circuit would be very high, causing the cell to heat up. This would change the internal resistance of the cell significantly and would invalidate your results. The fixed resistor stops the current getting too high to minimise the cell heating.

4. Similar to the fixed resistor, the short connection time ensures that there is minimal heating of the circuit because it limits the amount of time that current is flowing for. Also, leaving the circuit connected for a long period of time will drain the cell, affecting the emf and therefore the results.

To be sure that you have set up your circuit correctly, you can check out **Video 1** below. It is designed for the A-level syllabus but the experiment is the same as the IB required practical.

Student view

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c



Video 1. EMF and internal resistance.

Alternative ideas for this practical

There are all kinds of ways you can make a cell, and therefore all kinds of different things you can measure the internal resistance of. Why not replace your cell with:

- a variety of different types of cell, e.g. button cell; AA cell; a removable mobile phone battery, etc.
- a lemon, orange or grapefruit
- variable power supply
- any electrolytic cell?

Watch **Video 2** to learn how to make a lemon battery.

Student
view

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

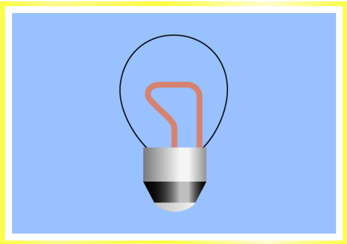
Video 2. How to make a lemon battery.

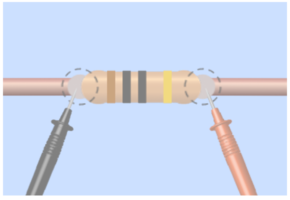
Results

If you have carried out this experiment, you should have a table of results with a record of at least five different readings, each repeated at least three times.

If you are unable to carry out the experiment yourself, or want to run it again on your own, you can use the simulation below.

- Select 'Lab' to begin.
- Pick up the components you wish to use from the list shown on the left. Don't forget to add a voltmeter and ammeter. Use the ammeter that has to be inserted into the circuit in series.
- Once you have built your circuit, you can vary the settings of any component by clicking on it. Use this to vary the value of the resistor.
- In the 'Advanced' drop down menu there is a slider to adjust the internal resistance of the cell.





Interactive 2. Circuit construction kit: DC.

More information for interactive 2

Student
view

An interactive simulation titled, Circuit Construction Kit: DC, focuses on direct current circuit building. It presents two options, the first one is “Intro”, represented by a light bulb icon, and the second one is “Lab”, depicted with an image of a resistor connected to probes.

The Intro panel offers a simplified environment for constructing basic circuits using wires, batteries, bulbs, and other common components. Users can visually observe electron flow, and conventional current flow, and explore fundamental circuit concepts such as series and parallel connections. The interface includes draggable components from a sidebar and interactive measurement tools like voltmeters and ammeters. The resistance of the components (bulb, resistor, eraser, coin, pencil, paperclip, dollar bill) can be varied using a slider that appears on the bottom while clicking on the component.

The Lab panel provides a more advanced circuit-building experience, allowing users to test various materials' electrical properties, including unconventional conductors like a coin, a paperclip, or even a hand. The Lab panel also features an Advanced option for deeper exploration, including resistance, voltage, and current measurements.

Both panels share a current visualization feature, enabling users to switch between electron flow (negative charge movement) and conventional current (positive charge movement) representations. Users can experiment freely, connecting and disconnecting elements, measuring voltage and current, and even introducing resistors or fuses.

By engaging with this interactive, the users can understand how electrical circuits function, including how voltage, current, and resistance interact. By adding resistors and adjusting circuit components, users can explore Ohm’s Law in action. The Lab panel allows users to test various objects' electrical conductivity, reinforcing the idea that different materials have unique resistivity. The use of voltmeters and ammeters introduces real-world circuit analysis techniques.

Your results might look a little like the sample data in **Table 1** below. Only the average values have been included here for clarity, but in your experiment you should record all the values.

The current uncertainty is 1 mA as this was the smallest reading on the digital ammeter. The uncertainty in voltage is 0.01 V as this was the smallest reading on the digital voltmeter. .

Table 1. Sample results.

Average current (mA)	Current uncertainty, Δ*I* (mA)	Average voltage (V)	Voltage uncertainty, Δ*V* (V)
41	1	1.45	0.01
121	1	1.40	0.01
175	1	1.36	0.01

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Average current (mA)	Current uncertainty, ΔI (mA)	Average voltage (V)	Voltage uncertainty, ΔV (V)
232	1	1.32	0.01
291	1	1.28	0.01
347	1	1.24	0.01
402	1	1.21	0.01

Next, plot the graph of current against voltage. Some things to think about:

1. Think about what you will do with the units.
2. Predict the shape of the graph.

Plot your graph and see how it compares with the graph from the sample data (**Figure 3**) by clicking below. Remember your error bars.

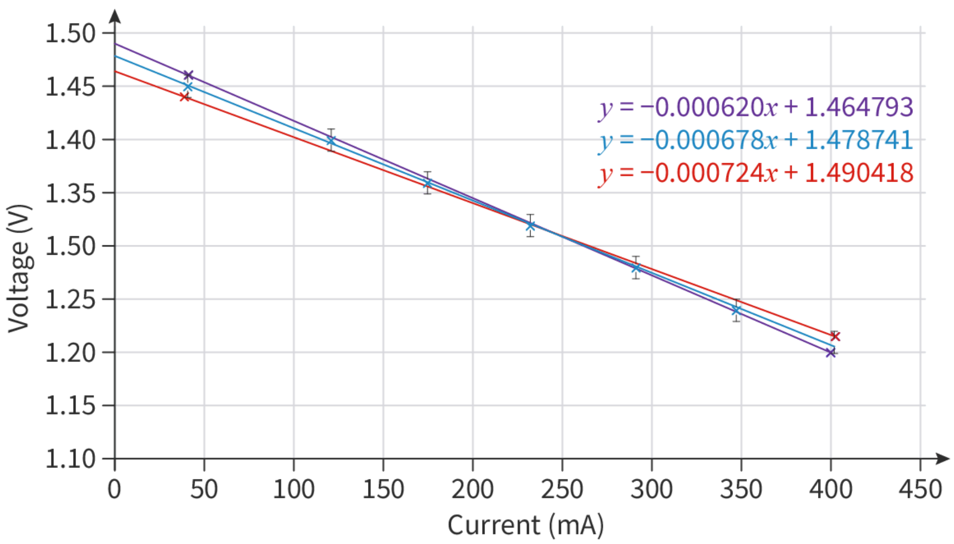


Figure 3. Graph of sample results: current (mA) plotted against voltage (V) with min and max gradients shown.

The graph is a straight line with a negative gradient. This is to be expected, given that the equation is in the form $y = mx + c$ (a straight line) and the gradient is $-r$:

$$V = -rI + \varepsilon$$

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Be careful with the units. The sample data has kept the current in mA, but you need it in amps to calculate the internal resistance in ohms. The gradients on the sample graph above should be multiplied by 1000 to give the answer in ohms.

Gradients from the graph:

Line of best fit:
-0.000678

Max gradient:
-0.000620

Min gradient:
-0.000724

Study skills

The error bars enable you to plot three gradients — the line of best fit, the maximum (max) and the minimum (min). These max and min will give you the uncertainty for your line of best fit value.

Next, you need to calculate the internal resistance using the gradients. You can do this with your data. The solution below shows the calculation based on the sample data.

First, the gradients need to be converted into ohms by multiplying them by 1000 (this step is unnecessary if you used amps on your graph instead of mA):

Line of best fit:
-0.678

Max gradient:
-0.620

Min gradient:
-0.724

Student view

Calculating the uncertainty of the line of best fit gradient:

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

$$\text{uncertainty} = \frac{\text{max} - \text{min}}{2}$$

Giving:

$$\text{uncertainty} = \frac{(-0.620) - (-0.724)}{2} = 0.052$$

The final answer for the internal resistance of the cell is given by the negative of the line of best fit gradient:

$$\text{internal resistance} = 0.68 \pm 0.05 \text{ ohms } (\Omega)$$

Notice the significant figures used here – the error falls on the second decimal, so there is no need to state the internal resistance value to three decimal places (even though our original data has three decimal places).

Likewise, there is no need to state the uncertainty to more decimal places than the internal resistance value, so one significant figure is fine here.

Remember to check your answer. You should always ask yourself the following questions once you have calculated your final answer to make sure you have not made any mistakes with the calculations:

1. Is it realistic? Is the answer the correct order of magnitude to what you were expecting or what your background research suggests? For example, an answer of 678 Ω for the internal resistance of a cell would be too high and the calculations should be reconsidered.
2. Is the uncertainty under control? If the percentage uncertainty of your answer is greater than 10%, you should figure out why and either change your method or at the very least address this in your conclusion and evaluation.
3. Were there any anomalies? How could you tell? What did you do about them? Anomalous results are points that do not fit the trend line. Ensure that you discuss all anomalous results in your IA conclusion.

Additionally, while discussing the scientific context of this experiment you can discuss the *y*-intercept as it should theoretically match the emf of your cell.

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

Study skills

You should never give uncertainty to more than two significant figures. As a convention, they are given to one significant figure.

Internal assessment checklist

For your internal assessment work, remember the following that you have exercised in this practical:

Research design

- A focused research question that includes both the independent and dependent variable.
- A detailed description of variables including the independent, dependent, control, and confounding variables.
- A detailed explanation of the decisions regarding scope and quantity of data collected.
- A methodology written with sufficient detail that another person could repeat the experiment.
- An explanation of the safety, ethical and environmental considerations of your investigation.

1. Essential skills and support guides / 1.4 Collected practicals

Determining the half-life of random processes as a simulation of radioactive decay

Section Student... (0/0) Feedback Print (/study/app/math-aa-hl/sid-423-cid-762593/book/determining-the-half-life-of-random-processes-id-46753/print/) Assign

Guiding question(s)

- How can radioactive decay of substances be modelled using everyday materials such as dice and foam?

Prior learning

Before attempting this practical, you should be familiar with the following concepts:

E.3 Radioactive decay

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

- The random and spontaneous nature of radioactive decay (see section E.3.3a (/study/app/math-aa-hl/sid-423-cid-762593/book/half-life-id-46544/)).
- The activity, count rate and half-life in radioactive decay (see section E.3.3a (/study/app/math-aa-hl/sid-423-cid-762593/book/half-life-id-46544/)).
- The changes in activity and count rate during radioactive decay using integral values of half-life (see section E.3.3a (/study/app/math-aa-hl/sid-423-cid-762593/book/half-life-id-46544/)).
- The decay constant λ and the radioactive decay law as given by $N = N_0 e^{-\lambda t}$ (see section E.3.6 (/study/app/math-aa-hl/sid-423-cid-762593/book/radioactive-decay-law-hl-id-46548/)).

Nuclear decay is a random process. It is impossible to predict when a nucleus will decay, but if you have a large enough number of nuclei, you can predict how long it will take for half of them to decay. This amount of time is known as the half-life of that isotope.

We saw in subtopic E.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-44319/) that the half-life for an isotope stays constant regardless of how many nuclei have already decayed, which leads to an exponential decay curve like the one shown in **Figure 1**.

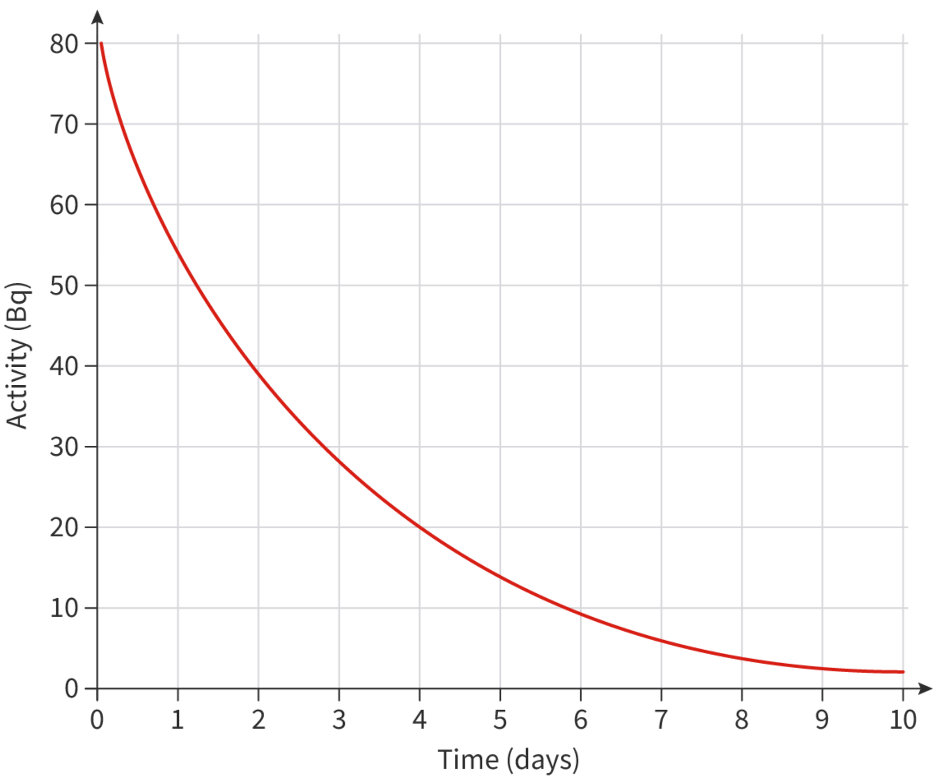


Figure 1. An exponential decay curve showing the activity of a radioactive sample over time.

More information for figure 1

The graph depicts an exponential decay curve that models the activity of a radioactive sample over time. The X-axis represents time in days, ranging from 0 to 10, marked in intervals of 1 day. The Y-axis indicates activity measured in Becquerels (Bq), ranging from 0 to 80 Bq with intervals of 10. Data points form a curve starting at 80 Bq on the Y-axis

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

when time is 0 days. As time progresses to 10 days, the curve declines exponentially, approaching but never quite reaching 0 Bq, demonstrating the characteristic exponential decay behavior of radioactive materials.

[Generated by AI]

Study skills

Remember, there are several different units you could use on the y-axis of these graphs to give a decay curve. Activity, number of undecayed nuclei or count rate could all be used, but would have slightly different units. Check your axes when drawing or reading these graphs.

It may seem simple to calculate the half-life from this graph, but this is an ideal graph with no uncertainty or error. This leads us to the key question for this practical. How can we accurately measure the half life of something which is decaying exponentially?

Practical skills

In this practical you will be exercising the following tools and skills:

Tool 2: Technology

- Identify and extract data from databases (see section 1.2.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/collecting-data-from-databases-id-48943/)).
- Generate data from models and simulations (see section 1.2.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/collecting-data-from-models-and-simulations-id-48944/)).
- Use spreadsheets to manipulate data (see section 1.2.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/manipulating-and-representing-data-id-48945/)).
- Represent data in a graphical form (see section 1.2.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/manipulating-and-representing-data-id-48945/)).
- Use computer modelling (see section 1.2.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/collecting-data-from-models-and-simulations-id-48944/)).

Tool 3: Mathematics

- Carry out calculations involving logarithmic and exponential functions (see section 1.3.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/mathematical-approaches-to-processing-scientific-data-id-48947/)).

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

- Construct and interpret tables, charts and graphs for raw and processed data including bar charts, pie charts, histograms, scatter graphs and line and curve graphs (see section 1.3.10 (/study/app/math-aa-hl/sid-423-cid-762593/book/plotting-graphs-id-48957/)).
- Construct and interpret graphs using logarithmic scales (see section 1.3.10 (/study/app/math-aa-hl/sid-423-cid-762593/book/plotting-graphs-id-48957/)).
- Plot linear and non-linear graphs showing the relationship between two variables with appropriate scales and axes (see section 1.3.10 (/study/app/math-aa-hl/sid-423-cid-762593/book/plotting-graphs-id-48957/)).
- Draw lines or curves of best fit (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).

Research design

Before we begin, we need something which decays exponentially. Of course, radioactive sources do, but the ones that you may have in your school lab have very long half-lives (otherwise they would be useless after a few days), so unless you have several years to carry out this experiment, an alternative is required.

(Any use of small source radioactive materials designed for schools should be done under ample supervision following all regulations set out by the responsible authority.)

Below are some different methods that you can use to simulate nuclear decay.

Materials

- At least 100 six-sided dice
  - If 100 dice are not available, you can get creative with your experiment. Try to come up with an alternative with what you have available, or else try to use technology as a replacement.
- A tub or similar to shake them in.

Internal assessment criteria

Data analysis

In this practical you will carry out complete data analysis using $N = N_0 e^{-\lambda t}$ to guide your processing and graph making. You will need to linearise data and represent it graphically.

Student view

Before you begin, think about the following questions.

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

1. Suggest why dice are good at simulating radioactive decay.
2. Suggest why you would need at least 100.

1. Dice are great at simulating radioactive decay because they are essentially completely random. There is no way of knowing for definite what value will be shown when dice are rolled.

The more dice the better. Random processes like dice rolling and radioactive decay only become predictable when there are large enough numbers of random events. Even then, we can never predict what an individual die will do, we can only predict the average number of outcomes across large numbers of events.

Procedure

The sample method for this simulation is straightforward:

Each dice represents a nucleus. Roll all the dice at the same time. Count how many show a six and record this number. The ones that showed a six have decayed. Remove the dice that showed a six and roll all the remaining dice again. Repeat until there are only a few dice left (or none at all). Repeat the whole process three more times and calculate an average.

There are many different ways in which this experiment can be conducted. Feel free to come up with your own or reimagine the one above and move forward with your new method. Consider any limitations of your method later in the practical.

Collecting and processing data

Try your method out and record your results. You may end up with a results table that looks something like the sample data below (**Table 1** and **Figure 2**).

After each roll the number of sixes was counted and recorded. This was completed three times.

The results below show the average of these three trials.

Table 1. Number of the roll and the average number of sixes from three repeats.

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Roll	Average number of sixes from three repeats
1	16
2	14.25
3	10
4	8.75
5	8.5
6	6.25
7	5.75
8	5
9	5
10	3.25

Assuming it took approximately 1 minute for each roll, we can then plot this familiar looking graph.

Plot a graph with your data putting time on the *x*-axis (1 roll = 1 minute).

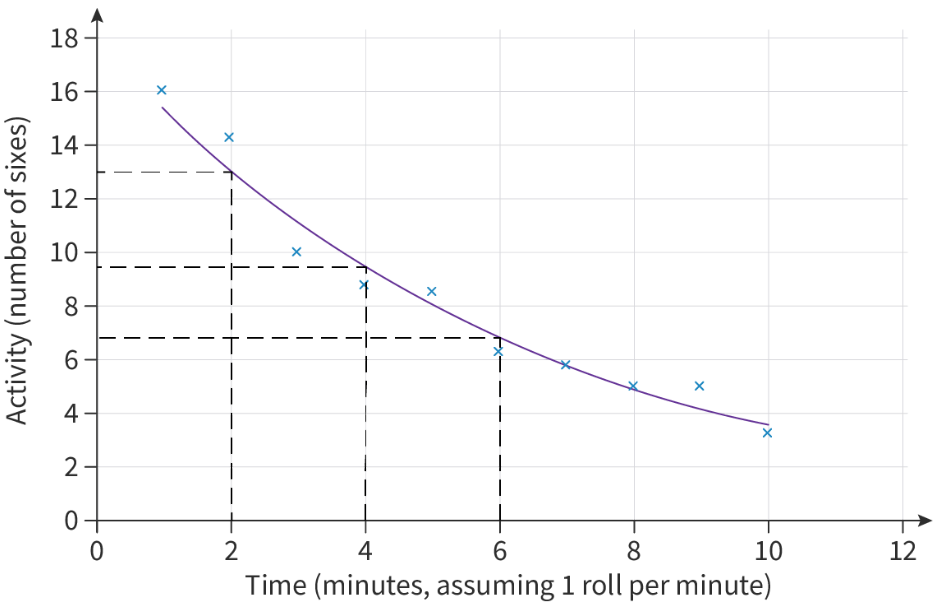


Figure 2. A graph of average number of sixes against time.

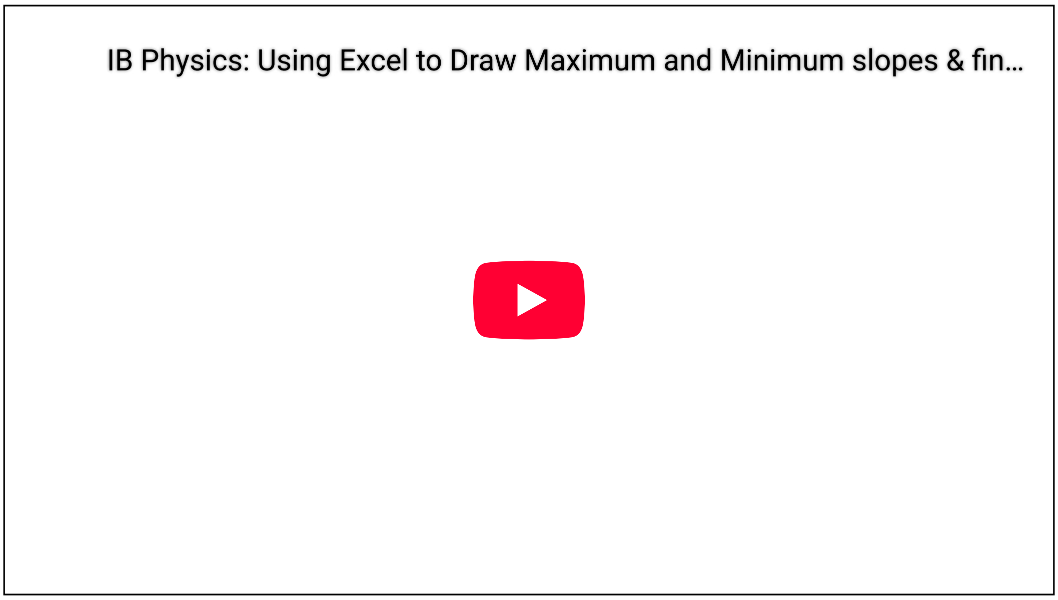
Student view

Judging from this curve, the half-life of this ‘sample’ is (roughly) 4 minutes, but there is a large uncertainty.

Study skills

When using MS Excel, Logger Pro, or any other graphing tool to plot your graph, remember the following rules:

1. Plot your points as X marks or + marks, not dots; they are more precise.
2. Add a line/curve of best fit.
3. Always include error bars. Use the (maximum value — the minimum value) /2 for each roll.
4. Make sure your best fit line passes through the error bars.
5. Plot your maximum and minimum gradients (see **Video 1** below for tips).
6. Where necessary, linearise your graph. Our half-life graph can be linearised to make it clearer. Below are some suggestions for how to do this.



Video 1. Using Excel to draw max and min lines.

You may notice that your points do not line up to make a perfect curve. This is because you are only rolling 100 dice. Random processes can only be predictable if there are huge numbers of potential events. Radioactive samples have billions of nuclei. Consider a sample of iodine-131, the decay curve for the sample is shown below in the graph of percentage of the sample remaining against time elapsed in days.

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

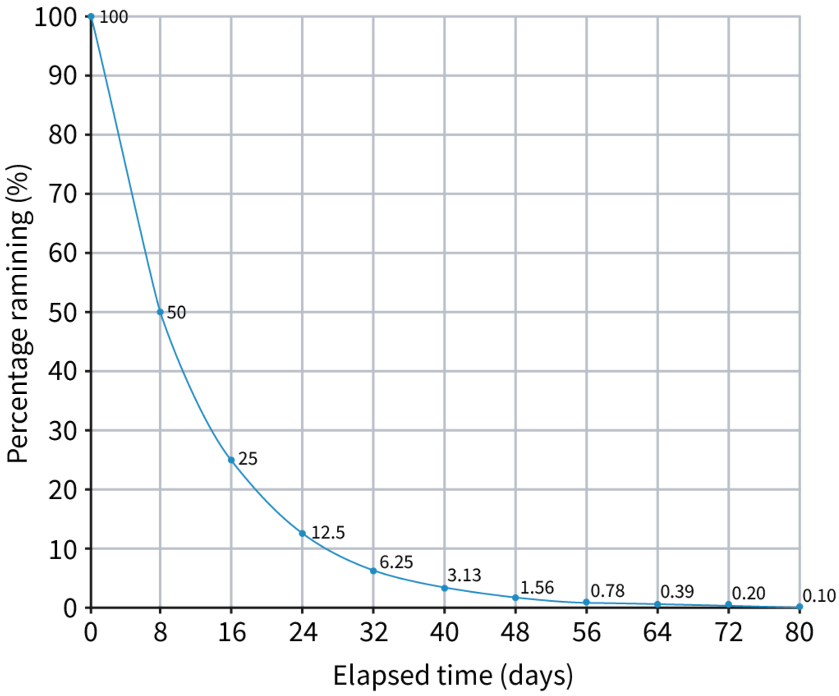


Figure 3. A graph of the decay of iodine-131.

More information for figure 3

The graph displays the decay of iodine-131 over a period of 80 days. The X-axis represents elapsed time in days, ranging from 0 to 80 in intervals of 8 days. The Y-axis shows the percentage of iodine-131 remaining, ranging from 0 to 100% in intervals of 10%. The graph depicts an exponential decay curve starting at 100% at day 0. Significant points on the curve include approximately 50% remaining by day 8, 25% by day 16, 12.5% by day 24, 6.25% by day 32, 3.13% by day 40, and further reducing to 0.10% by day 80. The trend shows a rapid decrease initially, slowing down as time progresses.

[Generated by AI]

If we had a billion dice and did the same experiment, the points would be closer to the curve.

So how can we be more accurate? You may remember from subtopic E.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-44319/) that the rate of decay of a radioactive substance $\left(\frac{\Delta N}{\Delta t}\right)$ is proportional to the number of undecayed nuclei, N, or:

$$\frac{\Delta N}{\Delta t} \alpha - N$$

In this equation, N is the number of undecayed nuclei and t is time.

Student
view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

In the original table the number of sixes was recorded which refers to the activity. The equation in the data booklet is in terms of *N*, the number of undecayed nuclei present, and so to calculate *N* from the data in the table we must subtract the amount of nuclei that have decayed (sixes in the table above) from the total number of nuclei, i.e.

$$N = 100 - \text{the number of sixes rolled}$$

Higher level (HL)

In section E.3.6 (/study/app/math-aa-hl/sid-423-cid-762593/book/radioactive-decay-law-hl-id-46548/) you learned the equation for the radioactive decay law is:

$$N = N_0 e^{\lambda t}$$

Where N is the number of undecayed nuclei at time t, N_0 is the original number of undecayed nuclei and λ is the decay constant, which equals $\frac{\ln 2}{\text{half-life}}$.

If we figure out the decay constant, λ, we can deduce the half-life.

Remember, the best way to view a relationship is with a straight-line graph where the desired result is the gradient.

1. Suggest how you can rearrange this equation to give a straight-line graph with λ as the gradient.
2. State what you need to plot on each axis.
3. Explain whether there will be an intercept.

Taking natural logs of everything in the equation gives us:

$$\ln N = \ln N_0 - \lambda t$$

Or, in the form

$$y = mx + c$$

$$\ln N = -\lambda t + \ln N_0$$

So a graph of $\ln N$ (*y*-axis) against t (*x*-axis) will give us a gradient of $-\lambda$ and a *y*-intercept of $\ln N_0$.

Using this equation, go back to your original results and calculate *N* for the beginning of each roll, giving a new results table.

Student view

It may look like the one in **Table 2** below (notice that ‘roll’ has been replaced with ‘time’ and now starts at zero):

Table 2. Adjusted results table.

Time (min)	Number of undecayed nuclei, *N*
0	100
1	84
2	69.75
3	59.75
4	51
5	42.5
6	36.25
7	30.5
8	25.5
9	20.5

Which gives a straight-line graph of (**Figure 4**):

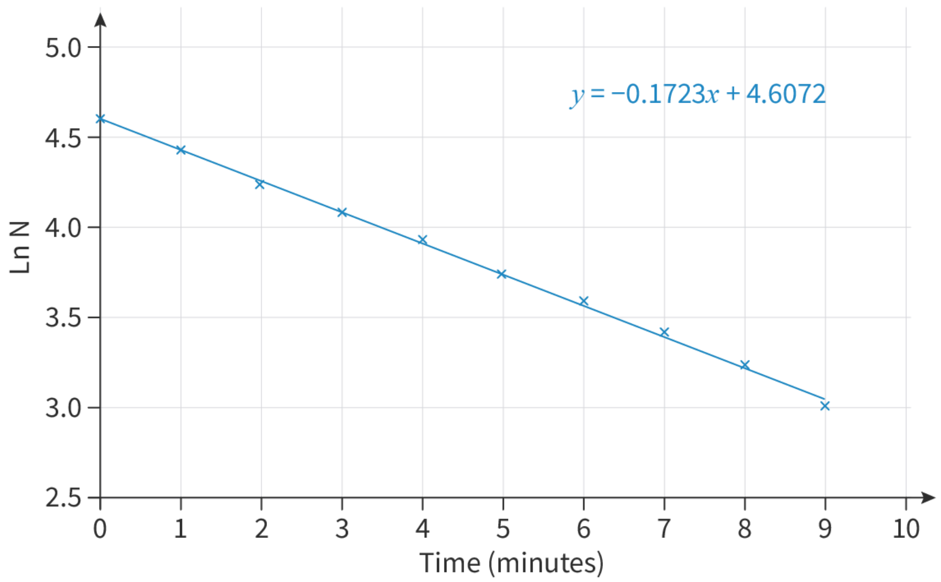


Figure 4. A linearised graph of the data above using natural logs.

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

The gradient of this graph is —0.1723, which gives a value for the decay constant, λ, of 0.1723.

$$\text{half-life} = \frac{\ln 2}{\lambda} = 4.023\ldots \approx 4.0\,\text{minutes}$$

This is what we estimated from the exponential curve, but the logarithm has removed the uncertainty from the points.

We can check the accuracy by looking at the y-intercept, 4.6072.

$$y\text{−intercept} = \ln\, N_0$$

So:

$$N_0 = e^{4.6072} = 100.2$$

We know we started with 100 dice, so this shows that the data is accurate.

Alternative method 1

An alternative method is summarised below, but your teacher may have other suggestions too – or perhaps you can come up with your own.

This method uses the decay of the foam on top of cola as a simulation of radioactive decay.

Materials

- Warm, unopened can of cola (or other carbonated beverage, the longer the foam stays on the drink, the better)
- Large glass measuring cylinder (at least 1000 cm^3)
- A video stopwatch (e.g. logger pro or iPhone slo-mo camera) – optional
- Stopwatch
- A glass marker pen for marking on the measuring cylinder.

Safety

A lab coat and eye protection must be worn at all times.

While care has been taken to give relevant safety information above, a full risk assessment must be carried out before starting any practical activity. It is unsafe to carry out any practical work without first consulting the relevant guidelines for all included chemicals, equipment and quantities.

Student view

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

Procedure

1. Set up the measuring cylinder so it is clearly visible by three people.
2. Shake the can of cola, open it and pour it quickly into the measuring cylinder.
3. As soon as you see liquid (not foam) at the bottom of the cylinder, start the stopwatch. At the same time, each person should mark the level of the liquid.
4. Every 3 seconds, mark the level of the liquid. Do this 10–15 times.
5. Wait until (nearly) all the bubbles have disappeared, and then mark the final level of the liquid (**Figure 5**).

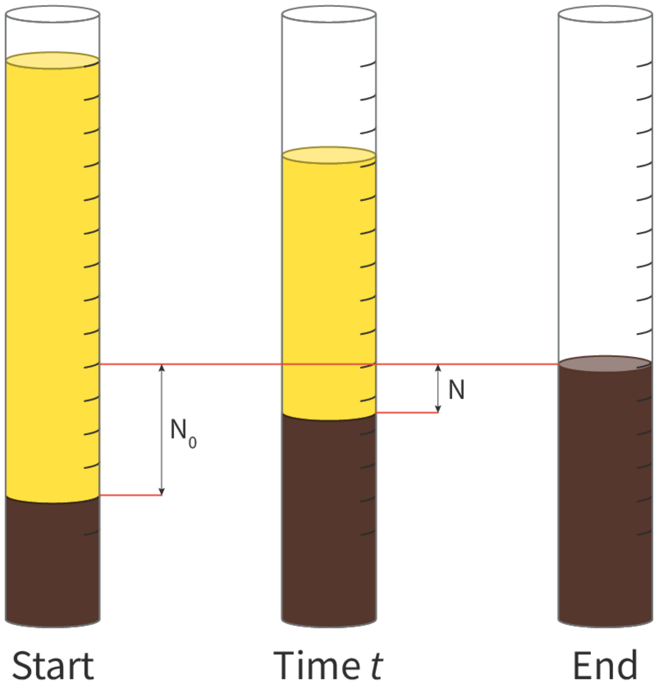


Figure 5. The measurements that should be taken during the cola experiment.

More information for figure 5

The image is a diagram depicting the cola experiment using three graduated cylinders. Each cylinder represents a different stage of the experiment, labeled "Start," "Time t," and "End."

1. **Start:** The first cylinder is filled with a yellow liquid above a brown liquid, indicating the initial measurement.
2. **Time t:** The second cylinder shows a decreased level of the yellow liquid and an increased level of the brown liquid compared to the first cylinder. An arrow labeled "N" shows the reduction in the yellow liquid, and the initial total column height is marked with a "N_0" arrow for reference.
3. **End:** The third cylinder contains only the brown liquid with no yellow liquid, indicating the final measurement.

Student
view

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

Graduated marks on each cylinder help illustrate the changes in liquid volumes over the course of the experiment.

[Generated by AI]

1. Calculate N (the 'number' of undecayed bubbles) by using the equation:
   $N = \text{Final level - liquid level at time } t$
2. Plot a graph of lnN against t and follow the same steps as the dice simulation above to find the half-life.

This experiment more closely mimics the radioactive nuclei than the dice throw as 1 cm of bubbles represents a vast amount of particles/bubbles. When discussing decay curves, they are only reliable when they are representative of a very large amount of particles.

Alternative method 2

There are many other different ways to simulate radioactive decay either through experiment or with simulations such as this one: Phet simulation of radioactive decay (https://phet.colorado.edu/sims/cheerpj/nuclear-physics/latest/nuclear-physics.html?simulation=alpha-decay).

Design a method that could be used to investigate half-live using this simulation. Use your method to carry out the experiment and try to identify the half-life.

Internal assessment checklist

For your internal assessment work, remember the following that you have exercised in this practical:

Data analysis

- All qualitative and quantitative data is organised into tables for all variables, expressed with correct precision and includes units and uncertainties.
- Consideration of the uncertainties of each piece of apparatus used in your investigation (if applicable).
- Data processing relevant to research question is complete.
- Graphs (if applicable) showing the relationship between the dependent and independent variables are suitable and correctly labelled.

Student
view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Investigating double-slit and double-source wave interference (HL)

Section Student... (0/0) Feedback Print (/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-double-slit-and-double-id-46754/print/) Assign

Higher level (HL)

Guiding question(s)

- How can the wavelength of light be found by analysing the results of the double-slit experiment?

Prior learning

Before attempting this practical, you should be familiar with the following concepts:

C.3 Wave phenomena

- Superposition of waves and wave pulses (see section C.3.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/superposition-of-waves-and-young's-double-slit-interference-id-46613/)).
- That double-source interference requires coherent sources (see section C.3.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/superposition-of-waves-and-young's-double-slit-interference-id-46613/)).
- The condition for constructive interference as given by path difference = $n\lambda$ (see section C.3.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/superposition-of-waves-and-young's-double-slit-interference-id-46613/)).
- The condition for destructive interference as given by path difference = $(n + 1/2)\lambda$ (see section C.3.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/superposition-of-waves-and-young's-double-slit-interference-id-46613/)).
- Young's double-slit interference as given by $s = \lambda D/d$ where s is the separation of fringes, d is the separation of the slits, and D is the distance from the slits to the screen (see section C.3.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/superposition-of-waves-and-young's-double-slit-interference-id-46613/)).

Young's double-slit experiment has been called one of the most important experiments in the history of physics. It proved that a beam of light produces an interference pattern when it passes through two adjacent slits, a phenomena which can only be explained

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

through the principle of superposition.

We saw in subtopic C.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-44900/) that Young's double-slit experiment creates a pattern of bright and dark fringes on a screen, as shown in **Figure 1**.

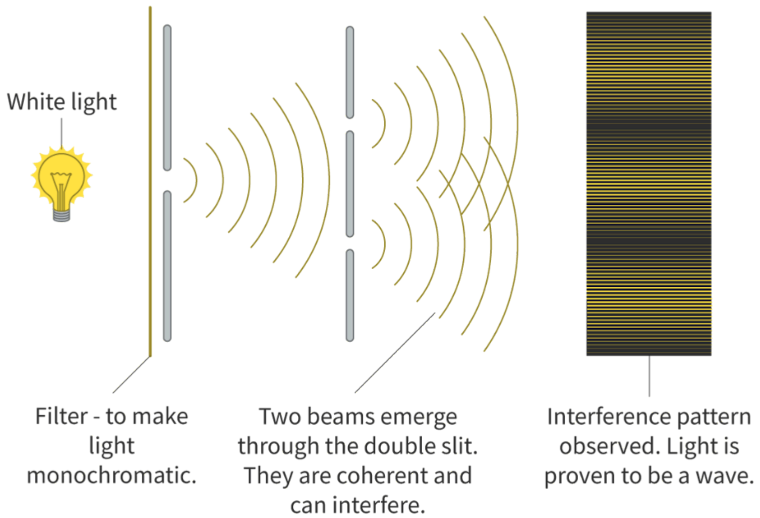


Figure 1. Young's set up for the double-slit experiment and the resulting interference pattern.

More information for figure 1

The diagram illustrates Young's double-slit experiment and its resulting interference pattern. On the left, there's a depiction of a light source labeled "White light" emitting waves. A vertical line labeled "Filter - to make light monochromatic" is placed in front of the light source.

In the center, there is a pair of vertical slits labeled "Two beams emerge through the double slit. They are coherent and can interfere." From these slits, wave patterns are shown spreading outward, indicating interference between the waves as they pass through both slits.

On the right, an interference pattern is displayed, consisting of alternating bright and dark stripes, labeled "Interference pattern observed. Light is proven to be a wave." This pattern reinforces the concept of wave interference resulting from the slits.

[Generated by AI]

Young did not have access to monochromatic lasers like we do today, so he used a filter to make the light monochromatic.

What would happen if white light was used without a filter?

Different wavelengths of light diffract by different amounts as they go through the slits, and so the distance between the fringes changes for each colour, creating a colourful spectrum on the screen. This would make it hard to distinguish between different wavelengths and therefore hard to take measurements.

Student view

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

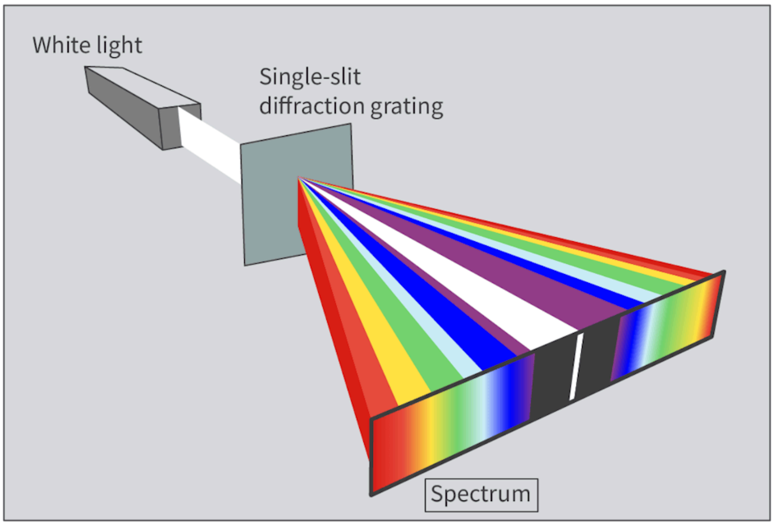


Figure 2. Diffraction of unfiltered light.

In addition, white light from a light bulb would not be coherent. Non-coherent light would create blurred peaks, making it difficult to reliably identify locations of maximum intensity.

In the modern Physics classroom however, we have access to lasers. Your school should have lasers with known wavelengths, but if not, you can use a regular laser pointer, or you can replicate Young's experiment and use a filter for white light.

You may remember from subtopic C.3 (/study/app/math-aa-hl/sid-423-cid-762593/book/the-big-picture-id-44900/) that the formula arising from the double slit experiment is:

$$s = \frac{\lambda D}{d}$$

Where s is the distance between fringes of constructive interference, λ is the wavelength of the light, D is the distance from the double slit to the screen and d is the separation of the slits.

Study skills

Struggling to remember which *D* is which? Try to remember that 'Big *D*' (the capital D) is the 'big distance', i.e. the distance that is much greater, the distance from the slits to the screen. 'Little *d*' (lowercase) is the smaller distance, the distance between the slits.

Student
view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

In this practical, we are going to calculate the wavelength of the light being used during the double-slit experiment.

It is possible to do this experiment both with light and sound. As Young's original experiment was with light, this section will go into more detail on the light experiment but also give you instructions for the sound experiment, which you can easily do at home.

Practical skills

In this practical you will be exercising the following tools and skills:

Tool 1: Experimental techniques

- Recognise and address relevant safety, ethical or environmental issues in an investigation (see section 1.1.1 (/study/app/math-aa-hl/sid-423-cid-762593/book/safety-of-self-others-and-the-environment-id-48941/)).

Tool 2: Technology

- Represent data in a graphical form (see section 1.2.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/manipulating-and-representing-data-id-48945/)).

Tool 3: Mathematics

- Determine rates of change (see section 1.3.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/rates-of-change-id-48950/)).
- Calculate mean and range (see section 1.3.5 (/study/app/math-aa-hl/sid-423-cid-762593/book/measures-of-central-tendency-id-48951/)).
- Use and interpret scientific notation (for example, 3.5×10^6) (see section 1.3.2 (/study/app/math-aa-hl/sid-423-cid-762593/book/scientific-notation-id-48948/)).
- Select and manipulate equations (see section 1.3.6 (/study/app/math-aa-hl/sid-423-cid-762593/book/equations-id-48952/)).
- Plot linear and non-linear graphs showing the relationship between two variables with appropriate scales and axes (see section 1.3.10 (/study/app/math-aa-hl/sid-423-cid-762593/book/plotting-graphs-id-48957/)).
- Draw lines or curves of best fit (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).
- Draw and interpret uncertainty bars (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).
- Linearise graphs (only where appropriate) (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

- On a best-fit linear graph, construct lines of maximum and minimum gradients with relative accuracy (by eye) considering all uncertainty bars (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).
- Determining the uncertainty in gradients and intercepts (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).

Internal assessment criteria

Data analysis

In this practical you will see how to record and process data and to calculate and show uncertainties in an IA. To achieve level 5—6 in your IA you must calculate uncertainties correctly and display them on your graph.

Method 1

Apparatus

- A single point light source with a known wavelength, such as a collimated discharge lamp (sodium, neon or hydrogen) or a low-powered laser (Class 1).
- A dark room at least 3 m across (preferably with a light-coloured wall)
- Measuring tape
- Double slit of known slit separation
- Ruler
- Stand and protractor for holding the laser and the slits.

Safety

Laser light can cause serious damage to the human eye, and can even lead to blindness. You must take the following precautions when dealing with lasers:

- Ensure the beam is directed away from any person and there is no danger of someone accidentally moving into its path.
- Clamp the laser securely so there is no danger of it falling and pointing at people.
- Remove any reflective surfaces from near the path of the laser so it cannot reflect into anyone's eyes.
- Only turn on the laser once it is secured in position, and turn it off before unclamping it.
- If there are any other safety recommendations which come with the laser you are using, make sure you adhere to them.

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

- High-power lasers can also cause damage to the skin. Make sure you are familiar with the power of your laser and the manufacturer's safety recommendations.
- Only use the laser provided and under supervision by a teacher or other qualified adult.

While care has been taken to give relevant safety information above, a full risk assessment must be carried out before starting any practical activity. It is unsafe to carry out any practical work without first consulting the relevant guidelines for all included chemicals, equipment and quantities.

Suggested method

We are trying to calculate the wavelength of the light being used. How would you carry out this experiment? Think about these questions:

1. State the independent variable, dependent variable and control variables.
2. Show how you will rearrange the equation above to make wavelength the gradient of a straight-line graph.
3. Describe what graph will you aim to plot, and what will it look like.
4. Explain how you will minimise random errors.
5. Explain how you will minimise your percentage error for your measurements.

Practical skills

Remember, the best way to calculate the value of a constant is to rearrange the equation to the format $y = mx + c$, make the required value the gradient, *m*, take multiple values and plot them on a graph (see section 1.3.11 (/study/app/math-aa-hl/sid-423-cid-762593/book/analysing-graphs-id-48958/)).

1. You are aiming to find out the wavelength. The slit separation cannot be varied, and the only other variable that can be varied is the distance from the slits to the screen, *D*. This will be the independent variable and the fringe separation, *s*, will be the dependent variable.

Control variables include: the separation of the slits, *d*; the angle between the beam and the screen (should be kept at 90° using the protractor); the position of the laser (clamp it in place); the wavelength of light (use the same laser each time); and the person measuring the fringe separation (the fringes will not be in one precise position so to minimise variability the same person should take every measurement).

2. The equation:

$$s = \frac{\lambda D}{d}$$

Rearranges to:

Student view

Overview
(/study/app/math-aa-hl/sid-423-cid-762593/c

$$s = \lambda\left(\frac{D}{d}\right)$$

Which is in the form $y = mx$, so we should plot s on the *y*-axis and $\frac{D}{d}$ on the *x*-axis, which should give us a gradient of λ.

3. You will be plotting *s* on the *y*-axis and $\frac{D}{d}$ on the *x*-axis, which is expected to be a straight-line graph through the origin, as there is no *y*-intercept.

4. The best way to minimise random errors is to take multiple readings and calculate an average.

5. To minimise the percentage error in the measurements, we want to make them as big as possible. We can do this easily by using large values of *D* (i.e. shine the laser from the other side of the room, not close to the screen. This will increase the size of both *D* and *s* and minimise the percentage error.

The step-by-step method will be:

1. Set up the laser and slits so they are pointing at 90° to a wall in a dark room.
2. Measure the distance from the slits to the screen, *D*, using the measuring tape.
3. Note down the slit separation (including uncertainty if possible).
4. Shine the laser at the opposite wall and measure the distance between at least three pairs of fringes being careful not to look in the direction of the laser.
5. Repeat for 5 different values of *D*.

Your experiment setup may look something like that shown in **Figure 3**.

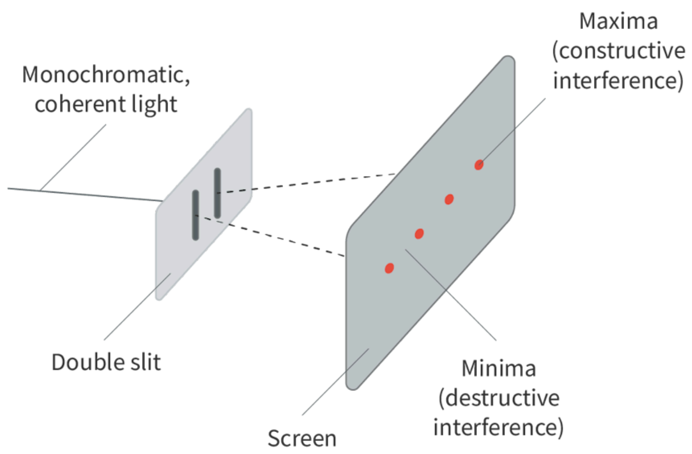


Figure 3. A possible experimental setup for measuring the wavelength of monochromatic light using Young's double slit.

More information for figure 3

Student view

The image depicts a setup for Young's double slit experiment to measure the wavelength of monochromatic light. It shows a source emitting monochromatic, coherent light that passes through a double slit, positioned between the light source and a screen. The diagram indicates the path of light leading from the slits to the screen, where maxima (constructive interference) and minima (destructive interference) are observed as red dots. Labels on the diagram identify these main components: "Monochromatic, coherent light," "Double slit," "Screen," "Maxima (constructive interference)," and "Minima (destructive interference)." The lines connecting the slits to the screen illustrate the concept of interference, resulting in a pattern of alternating bright and dark spots.

[Generated by AI]

Once you have carried out your experiment, you should have a set of results that may look something like the sample data below (**Table 1**).

$$\text{Slit separation (from manufacturer)} = 1 \times 10^{-5}\text{m} \pm 1\%$$

Table 1. Sample data.

Distance from slit to screen, *D* (m)	Fringe separation (m) (1)	Fringe separation (m) (2)	Fringe separation (m) (3)	Fringe separation, *s* (m) (average)
1.5	0.098	0.0955	0.098	0.097
2.0	0.131	0.127	0.131	0.130
2.5	0.163	0.159	0.163	0.162
3.0	0.195	0.191	0.196	0.194
3.5	0.227	0.222	0.228	0.226
4.0	0.258	0.258	0.261	0.259
4.5	0.292	0.284	0.294	0.290

Remember, error bars are extremely important because they enable you to calculate the uncertainty of the gradient, and therefore the uncertainty of the final answer for your wavelength. To add error bars, we need to calculate the uncertainty of our plotted values.

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

Calculate the uncertainty of all your plotted data values now. Bear the following guidelines in mind:

To find the uncertainty of an average value, find half of the range (as discussed in previous practicals). For example, take the fringe separation at $D = 4.5$ m from the sample data above.

Table 2. Calculating uncertainty — example.

Measurement	Value	Maximum or minimum values?	Uncertainty in the average = (maximum — minimum)/2
1	0.292		**Uncertainty in the average = (0.294 — 0.284)/2**
2	0.284	Min	
3	0.294	Max	Uncertainty in the average = 0.005

So, the mean fringe separation = $0.290 \pm 0.005\,\mathrm{m}$

Your final uncertainty data table may now look like the sample data below (**Table 3**).

Table 3. Uncertainty table .

Uncertainty in *s*, Δ*s* (m)	Uncertainty in *D*, Δ*D* (m)	% Uncertainty in *D*	% Uncertainty in *d*	% Uncertainty in *D*/*d*	u
0.001	0.0005	0.033	1	1.03	
0.002	0.0005	0.025	1	1.03	
0.002	0.0005	0.020	1	1.02	
0.003	0.0005	0.017	1	1.02	
0.003	0.0005	0.014	1	1.01	
0.002	0.0005	0.013	1	1.01	
0.005	0.0005	0.011	1	1.01	

Student view

Overview (/study/app/math-aa-hl/sid-423-cid-762593/c

The uncertainty in *D* comes from the measuring implement. In this case, a metre ruler with millimetre markings. On an analogue scale like this, the uncertainty is stated as half the smallest increment, so in this case that is 0.5 mm, or 0.0005 m.

Notice that the uncertainty in *D* is extremely small because of the large distances involved. This is what we were aiming for in the method section above.

Also remember that uncertainty should be quoted to one significant figure — it has been given to more than that here to make the calculations clearer.

Practical skills

You might be wondering how absolute uncertainty in $\frac{D}{d}$ was calculated (see section 1.3.8 (/study/app/math-aa-hl/sid-423-cid-762593/book/proportionality-and-percentage-change-id-48955/)).

Here is a quick refresher of the steps to take (row 1 used as an example):

- Identify the absolute uncertainty in *D* (this is the uncertainty in the measuring instrument as mentioned above) (0.0005)
- Turn this into percentage uncertainty by dividing the uncertainty by the value and multiplying by 100 (0.033%)
- Identify the percentage uncertainty in *d* (Slit separation (from manufacturer) = $1 \times 10^{-5}\ \mathrm{m} \pm 1\%$) (1%)
- Add the percentage uncertainties.

From your DP physics data booklet:

If: $y = \frac{ab}{c}$ then: $\frac{\Delta y}{y} = \frac{\Delta a}{a} + \frac{\Delta b}{b} + \frac{\Delta c}{c}$

i.e. the percentage uncertainty in $\frac{D}{d}$ is the sum of the percentage uncertainty of *D* plus the percentage uncertainty of *d*.

(1.03%)

- Then, turn the percentage uncertainty of *D*/*d* into the absolute uncertainty of *D*/*d* by multiplying the percentage uncertainty by the value (i.e. 1.03% × 150000 = 1545 ≈ 1550 (rounded))

You should now be able to plot a graph, using the absolute uncertainties for *s* and $\frac{D}{d}$ to form the error bars. Remember, the gradient should be the wavelength. To work out the uncertainty in this wavelength, we need to plot a maximum and a minimum gradient and use the formula:

Student view

$$\frac{\text{maximum gradient} - \text{minimum gradient}}{2} = \text{gradient uncertainty}$$

Your graph should look something like the sample below (**Figure 4**).

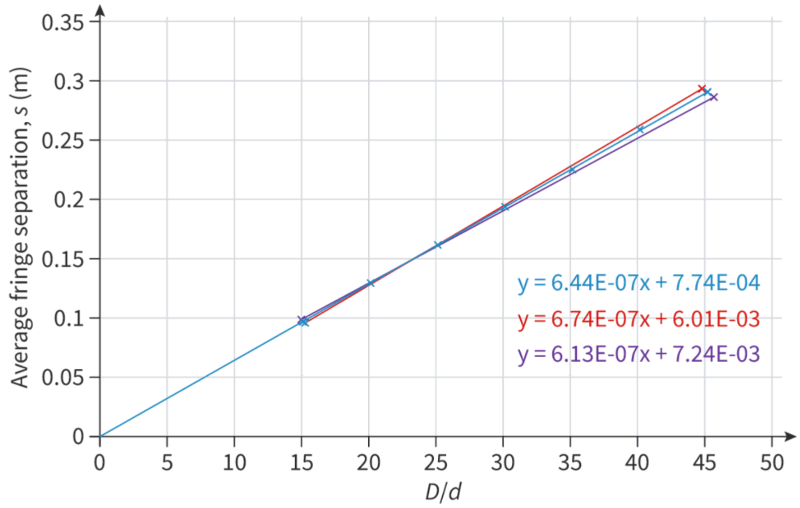


Figure 4. A graph of average fringe separation against D/d showing the line of best fit, max and min gradients.

The value of the gradient of the line of best fit should give the wavelength of the light, in this case it is 6.44 × 10^{-7}m which is in the red region of the EM spectrum.

To calculate the uncertainty:

$$\frac{\text{maximum gradient} - \text{minimum gradient}}{2} = \text{gradient uncertainty}$$

So:

$$\triangle\lambda = \frac{6.74 \times 10^{-7} - 6.13 \times 10^{-7}}{2} = 0.3 \times 10^{-7}$$

Giving a final answer for the wavelength of the laser light:

$$\lambda = 6.44 \times 10^{-7} \pm 0.3 \times 10^{-7}\ \text{m}$$

It is useful to note here that the *y*-intercept is very close to the origin, indicating that the data is quite accurate (our equation predicts a *y*-intercept of zero). A larger *y*-intercept but with small error bars would indicate some sort of unidentified systematic error, which you should comment on in your evaluation.

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

Method 2

Apparatus

- Two speakers
- Signal generator capable of frequencies greater than 2 kHz (using the sine wave setting)
- Measuring tape
- Microphone attached to an oscilloscope (or similar sensors).

Suggested method

1. Set up the equipment as shown in the diagram below (**Figure 5**), preferably outdoors or in a well insulated room (without many hard reflective surfaces). The distance between the loudspeakers, *d*, needs to be around 1 metre.

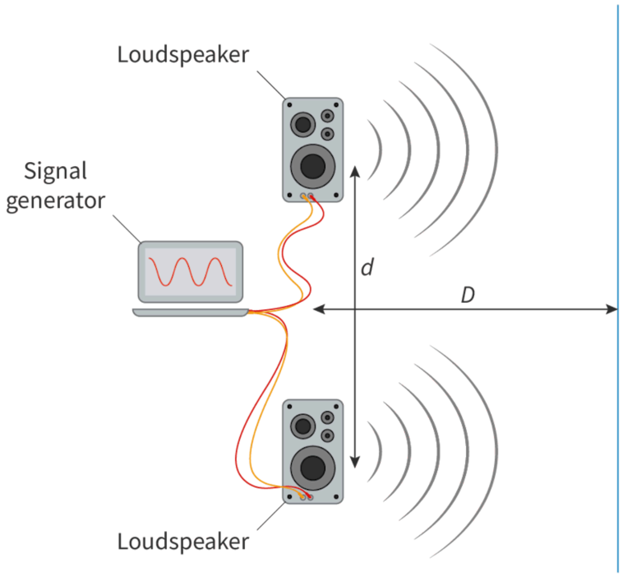


Figure 5. Set up your speakers in a line like this so they point out to the right and emit sound in the same direction as each other.

More information for figure 5

The diagram illustrates the setup of a pair of loudspeakers connected to a signal generator. Two loudspeakers are arranged vertically, one above the other, with sound waves emitting to the right. The signal generator connects to both speakers, depicted by lines showing the path of wiring. The distance between the speakers is labeled 'd' while the horizontal axis pointing outward is labeled 'D'. The diagram suggests alignment and spacing for optimal sound directionality.

[Generated by AI]

2. Measure a distance, *D*, and mark a line parallel to the line of the speakers. Make *D* at least 3 m. Walk along the line until you hear a maximum sound volume.
3. Walk further along the line until your sound reaches the loudest volume again. Measure and record the distance between the two points of maximum volume.
4. Repeat this three times and take an average.
5. Repeat the whole process again with 7 different values of *D*.

Student
view

Overview
(/study/ap
aa-
hl/sid-
423-
cid-
762593/c

6. Go through the same process as with light to calculate the wavelength of the sound. Check your answer against the frequency from the tone generator. The speed of sound in air, *v*, is approximately 340 m s^{-1}, and you can use $v = f\lambda$ to calculate frequency, *f*, from wavelength, λ.

If you have difficulty identifying changes in sound then you may need to use a sensor to take readings. You may have this equipment in the lab, or else, you may have the appropriate sensors on your smartphone (apps like PhysPhox are helpful).

Internal assessment checklist

Data analysis

- All qualitative and quantitative data is organised into tables for all variables, expressed with correct precision and includes units and uncertainties.
- Data processing relevant to research question is complete.
- Graphs (if applicable) showing the relationship between the dependent and independent variables are suitable and correctly labelled.

Student
view