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1. Essential skills and support guides / 1.1 Tool 1: Experimental techniques

Safety of self, others and the environment

Health and safety in the laboratory

Health and safety in the laboratory are two of the most important aspects to consider when carrying out practical work. In this section you will see why it is essential that you are able to work safely and confidently and how to minimise the risks and hazards to yourself, others and the environment.

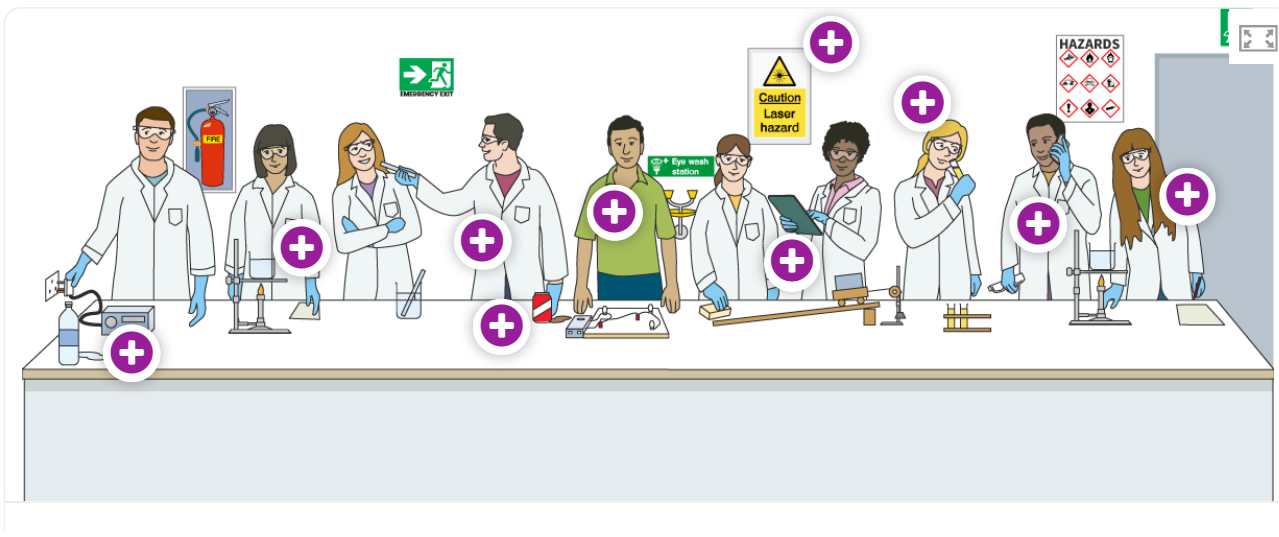
Throughout your IB studies, you will be required to undertake a number of practicals (see subtopic 1.4 (/study/app/math-aa-hl/sid-423-cid-762593/book/introduction-id-46750/)), as well as the internal assessment (see subtopic 1.5 (/study/app/math-aa-hl/sid-423-cid-762593/book/introduction-id-46741/)). During these activities, it is possible that you will come into contact with dangerous apparatus and harmful materials and/or chemicals.

Interactive 1 is an illustration of some practices and behaviour that are appropriate in the laboratory and some that are not. Look carefully and try to identify both the safe and the potentially dangerous practices presented. Discuss your findings with your group or class.



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Interactive 1. Identify the Good and Bad Practices.

More information for interactive 1

The interactive image depicts a laboratory scene with multiple people engaged in various activities. All of them except one are wearing white coats. The image emphasizes laboratory safety with visible signs, safety equipment, and protective gear. Several hotspot icons are present throughout the image, each providing additional information when interacted with.

Hotspot 1 appears on the yellow hazard sign on the wall that warns about laser hazards, which reads, This laboratory has the correct emergency equipment and hazard warning signs.

Hotspot 2 is above the woman who appears to smell from a test tube. which reads, Do not breathe in the emissions from experiments in case they are hazardous. Use a fume hood (fume cupboard) if toxic gases are likely to be produced.

Hotspot 3 is on the lab coat of the woman standing near the hazard sign on the right side of the image, which reads, This person should tie her hair back in the laboratory.

Hotspot 4 is positioned on the shirt of the man in a green polo, who is not wearing a lab coat, which reads, This person is not wearing a lab coat or safety goggles.

Hotspot 5 is on the coat of the man speaking on the phone, which reads, This person is being distracted by using a mobile phone and has removed his safety goggles.

Hotspot 6 is on the coat of the man holding a test tube close to the nose of another woman, which reads, This person is messing around and distracting their classmates.



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Hotspot 7 is located on the lab coat of the woman standing near the Bunsen burner, which reads, This person is working safely and appropriately.

Hotspot 8 is placed near the clipboard held by the woman in the middle-right section of the image, which reads, These two people are working safely and appropriately.

Hotspot 9 is placed on the table close to a beverage can, which reads, Do not bring food and drink into the laboratory.

Hotspot 10 is near the bottle placed on the left side of the image near a power socket, which reads, Do not plug in or switch on electrical equipment if water is nearby. Move the water and mop up any spills first.

The lab contains important safety elements such as an emergency exit sign, an eye wash station, and a fire extinguisher. Various scientific apparatus, including beakers, test tubes, and weighing scales, are placed on the lab benches.

The lists below include most of the important rules that should be followed when carrying out practical work. Be sure to follow these rules whenever undertaking any practical work in the laboratory (see [section 0.1.4 \(/study/app/math-aa-hl/sid-423-cid-762593/book/practical-activities-safety-id-43223/\)](/study/app/math-aa-hl/sid-423-cid-762593/book/practical-activities-safety-id-43223/))).

Preparing for work

- It is recommended that a full risk assessment is carried out before starting any practical activity (see later in this section).
- Make sure you are always being supervised by a teacher while in the laboratory.
- Read through the entire procedure before you begin. Ask a question if you are not sure of what to do.
- Tie back long hair and roll up long sleeves.

During the work

- Always wear proper safety attire, including safety glasses, aprons and gloves.
- Keep your workstation neat and clean.
- No eating or drinking while performing the activity.
- Do not leave any electrical apparatus or chemicals unattended.
- Do not leave an open flame unattended.



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- Follow all instructions for the handling of materials.
- Report any broken glass, spills or injury immediately.
- Watch out for mechanical moving parts that can cause injuries or entanglement.
- Be careful with surfaces or objects that might be hot, they can cause burns.
- Check electrical equipment for damaged wires or loose connections.
- Do not use electrical equipment near water/do not handle with wet hands.
- Do not overload power sockets.
- Keep an electrical device on only for the time period of your experiment measurements. Switch it off when not used.
- Use appropriate eye protection when working with lasers. Never point lasers at anyone, and avoid reflective surfaces that could scatter the beam.
- Be careful when using strong magnets, keep metal objects away.

After the work

- Leave your workstation clean after the activity.
- Properly dispose of waste materials.
- Wash hands thoroughly at the end of the activity.
- Make sure to always dispose of waste according to your local environmental guidelines.

Safety equipment

In this section, we will look at some common safety equipment found in most laboratories.

Firstly we have personal protective clothing such as goggles and a lab coat, which are used to protect your eyes and skin or clothing respectively. Gloves are also sometimes worn, depending on the apparatus being used. **Figure 1** shows the common personal protective equipment found in a school laboratory.

Try to locate this equipment in your school.



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Figure 1. Safety goggles, a lab coat and gloves — some basic but important personal protection equipment.

Credit: Eduard Lysenko, Getty Images

Credit: PhotoAlto/Frederic Cirou, Getty Images

Credit: onlyyouqj, Getty Images

There is emergency safety equipment that you can use if something goes wrong. This includes fire extinguishers, fire blankets, eye wash stations and safety showers. These are used in the event of a fire or if a person spills a hazardous material over their face or body. You should familiarise yourself with the location of this equipment in the event of an accident.

The fire extinguisher system might include a cylindrical vessel near or on a wall, or automatic water sprinklers (with or without smoke detectors) on the ceiling (see **Figure 2**). You should also locate the first aid kit near your laboratory in your school.



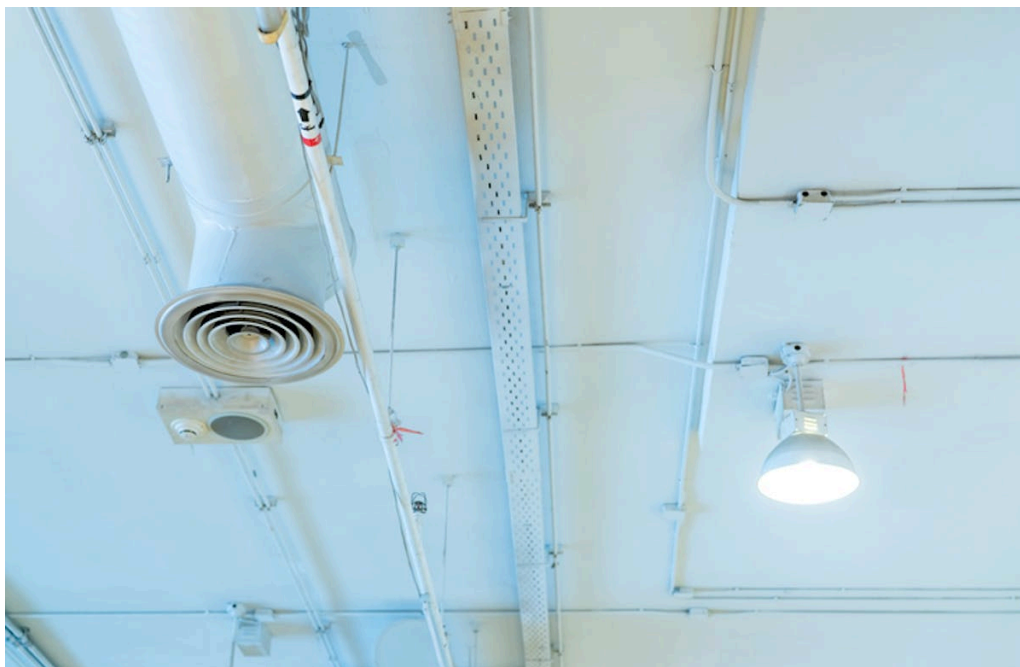
Credit: domonite, Getty Images



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Credit: Fahroni, Getty Images

Figure 2. Different systems for extinguishing a fire.

Know your hazards

As mentioned previously, it is likely that you will be using potentially dangerous equipment and materials. Using chemicals requires some special attention.

This is where the use of hazard pictograms is particularly important. A list of common pictograms (symbols) is shown in **Table 1**. Please note that this list is not exhaustive; if you come across an unfamiliar symbol in the laboratory, then always ask your teacher for guidance.

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.

Table 1. Hazard symbols meaning and precautions.



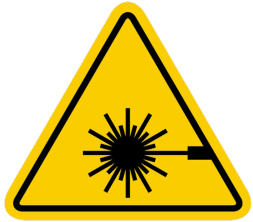

Credit: Aleksandr Potashev; Theerakit; Ondřej Pros; Migrenart, all Getty Images



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Symbol	Meaning	Precautions to be taken
	High voltage, danger of electrocution	Keep away or use electrically insulated gear
	This is used to indicate surfaces that are hot or may become hot	Check the object visually before you handle and always use thermally insulated gloves to handle
	This symbol is used to designate that laser radiation is being used	Use eye protection and do not look directly into the beam
	This symbol is used for flammable gases, solids or liquids	Avoid the use of open flames and keep away from possible ignition sources



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Symbol	Meaning	Precautions to be taken
<div></div> <div> More inform...</div> <div><p>The image is a hazard symbol with a red diamond border, indicating corrosive substances. Inside the diamond, there are two laboratory test tubes tilted downward. Drops from these test tubes are shown to corrode a surface below and a hand to the right, highlighting the hazard of coming into contact with corrosive materials. This symbol is typically used to warn about materials that can cause chemical burns or otherwise damage skin or surfaces.</p><p>[Generated by AI]</p></div>	<p>This symbol is used for substances that could cause eye or skin damage or cause corrosion of metals</p>	<p>Wear protective gloves, protective clothing and eye protection</p>
<div></div>	<p>This symbol is used for substances that could produce oxygen or contribute to the combustion of other substances</p>	<p>Avoid the use of open flames and keep away from possible ignition sources</p>



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Symbol	Meaning	Precautions to be taken
	This symbol is used for substances that have the possibility of exploding	Consult your teacher or lab technician for further guidance
	This symbol is used for gases under pressure such as an oxygen cylinder	Consult your teacher or lab technician for further guidance
	This symbol is used for substances that could irritate the skin or eyes	Wear protective gloves, protective clothing and eye protection
	This symbol is used for substances that could be harmful to aquatic organisms such as fish	Follow the local guidelines for the disposal of chemical waste



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Symbol	Meaning	Precautions to be taken
<div>  More inform...</div> <div><p>The image is a hazard pictogram depicting a black silhouette of a human figure. There is a white star-like pattern originating from the chest area, symbolizing internal health hazards or diseases spreading from the chest. The figure is enclosed within a red diamond-shaped border. This type of warning icon is often used to indicate health hazards in safety and compliance contexts.</p><p>[Generated by AI]</p></div>	<p>This symbol is used for substances that are <u>carcinogenic</u> or <u>mutagenic</u></p>	<p>Consult your teacher or lab technician for further guidance</p>
<div></div>	<p>This symbol is used for substances that are toxic if swallowed or pass through the skin</p>	<p>Wear protective gloves, protective clothing and eye protection</p>



Risk assessments

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In this final section, we will combine the safety elements discussed in this section and see how you can apply the ideas. To do so, we will look at the best practice to create a risk assessment.

Why is it important to conduct a risk assessment?

- Sometimes we underestimate the risks that we are putting ourselves into. Spending some time researching and thinking about what could go wrong can help us identify the main sources of risk and help realise the real level of danger.
- While working, our attention is focused on the task performed and the goal of the experiment. This can distract us from the danger that might exist. Having thought about this beforehand will make you more alert.
- A risk assessment report will prepare you for the event of an accident, with an appropriate procedure on how to act. This means that you will not need to think on the fly for what to do at that moment and for how to control the hazard.

The report is to be completed before you undertake any class practicals. Your teacher or a lab assistant will usually prepare this. However, you will also be responsible for writing your own risk assessment during your own practical work.

A typical risk assessment report includes:

- A brief description of the experiment.
- A detailed overview of the potential hazards.
- The level of risk associated with each potential hazard.
- The control measures taken.
- The emergency procedure in case of an accident.

Table 2 shows an example of a risk assessment for the use of a laser pointer of class 1 or 2 in an experiment.

Table 2. Example risk assessment for the use of a laser pointer (class 1 and 2).



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Brief description of the activity	Potential hazards	Level of risk	Control measures	Emergency procedures
A laser pointer of class 1 or 2 is clamped at an angle to provide a beam.	Damage to the eyes or skin.	<p>Medium risk if someone looks directly into the beam and/or if no eye protection is used.</p> <p>Medium risk if the beam is scattered on a reflective surface and directed to eyes.</p> <p>Very low risk of skin damage (class 1 and 2).</p>	<p>Wear protective glasses.</p> <p>Warn others that might be around when turning the laser pointer on.</p> <p>Turn on the laser only for the minimum time required and when it is secured. Then turn it off immediately.</p> <p>Do not direct the beam at someone or at a reflective surface.</p>	<p>Turn off the laser pointer immediately in case of an accident.</p> <p>If someone looks into the beam without eye protection, ask them to sit down and check with them for problems with their vision, pain in the eyes or generally in the head.</p> <p>Report to any teacher/lab assistant available.</p> <p>Seek medical attention. Go to the school doctor.</p>
	The laser pointer might fall off the clamp.	<p>Medium risk of the laser pointer to break.</p> <p>Low risk of injury.</p>	Secure the laser pointer in position.	Report any injuries or damages to the teacher/lab technician.

When it comes to using chemicals, you can find data for different chemicals online. You can search for material/chemical safety data sheets to find different databases. In this case, you will need to look at the packaging of the material you will use and find the product name, because most databases need it.

If you want to look up a substance without a product name you can use the database [Search for chemicals – ECHA \(europa.eu\)](https://echa.europa.eu/information-on-chemicals) [↗\(https://echa.europa.eu/information-on-chemicals\)](https://echa.europa.eu/information-on-chemicals).



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Exercise



Click a question to answer



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Tool in action

To read more about the skills in this section and see examples of them being used in physics, take a look at the following:

- [Section 0.1.4](/study/app/math-aa-hl/sid-423-cid-762593/book/practical-activities-safety-id-43223/) Practical activities: Safety.
- [Sections 1.4.3](/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-the-specific-latent-heat-of-vaporisation-of-water-id-46752/) , [1.4.6](/study/app/math-aa-hl/sid-423-cid-762593/book/determining-refractive-index-id-46510/) , [1.4.7](/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-the-resistivity-of-a-conducting-wire-id-46511/) , [1.4.8](/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-the-internal-resistance-of-a-cell-id-46512/) and [1.4.10](/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-double-slit-and-double-id-46754/) Collected practicals. Application of safety rules.
- [Section 1.5.2](/study/app/math-aa-hl/sid-423-cid-762593/book/research-design-id-46743/) Research design. How to incorporate the risk assessment report in your internal assessment.

1. Essential skills and support guides / 1.1 Tool 1: Experimental techniques

Measuring variables with analogue equipment

Recording measurements

Most equipment in physics can be divided into two categories – digital and analogue.

Digital equipment uses electronic sensors to take and display the measurement. Examples of digital equipment are an electronic mass balance or a stopwatch. Analogue equipment contains markings that require the user to determine the measurement. Examples of analogue equipment include rulers and graduated cylinders. The type of equipment will determine the way in which you take and record your measurements during experiments.



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This section will focus on analogue equipment while [section 1.1.3 \(/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-variables-with-digital-equipment-id-48814/\)](#) will look at digital equipment in more detail.

When taking measurements in physics, you want to ensure that your recorded values are reliable – ideally, any two students should record the same measurement. What must be done to be sure that your measurements are both accurate and precise?

Accuracy refers to the closeness of a measurement to its true value, while precision refers to the ability for the instrument to produce an identical result when measuring the same sample. Precision also refers to the ability to read a measurement to a greater number of significant figures. To ensure a measurement is accurate, it is important to use equipment that is made well and is in good working order. If you have any concerns about the accuracy of a measurement, you could measure the same object with more than one instrument and compare the measurements for consistency.

Consider the data in **Table 1**. Which thermometer does **not** appear to give an accurate reading?

Table 1. Checking for the accuracy of a thermometer involves comparing multiple instruments.

Thermometer	Temperature reading (°C)
1	22.8
2	22.8
3	25.6

Thermometers 1 and 2 give the same result, therefore you would conclude that these are accurate measurements. Since thermometer 3 has a very different result, you would conclude that this is an inaccurate result, likely due to a faulty thermometer.

To ensure precision for analogue equipment, you need to know how many significant figures are to be recorded. Using the markings on the instrument (sometimes called *hatch* or *tick marks*), you can determine the difference between certain and uncertain digits. Certain digits are those that are definitely known, while uncertain digits are those that you are not sure of. All measurements are typically recorded to **one uncertain digit** – this means



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making a careful approximation for the final digit in all measurements. You will make your best approximation for the final digit and if the measurement appears to be directly on the hatch mark, then your final digit will be 0.

Consider the rulers in **Figure 1**. One ruler has markings at each cm, while the other contains markings at each mm. The same object can be measured with both rulers with the same accuracy, but with different precision. When there are more hatch marks, the precision increases and so does the number of significant figures, which will then be helpful when performing calculations with measured values. Note, if the hatch marks are very close together, your final, uncertain digit will likely be a 0 (if the object appears to be on the hatch mark itself) or a 5 (if the object appears to be between two hatch marks).

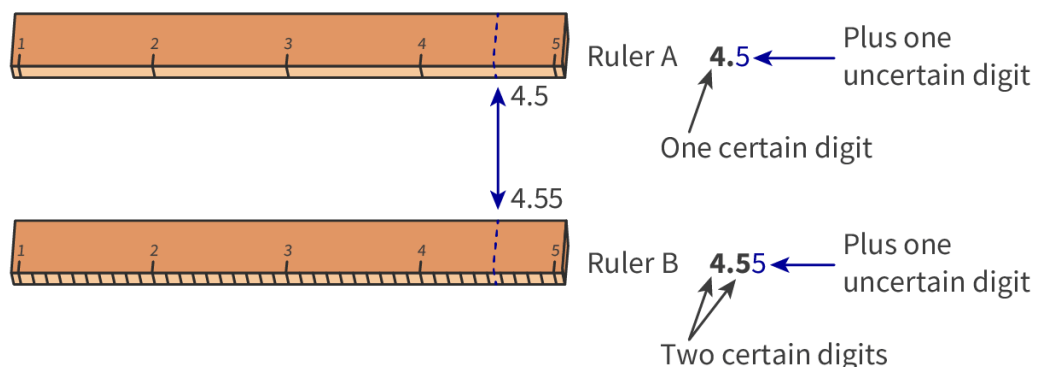


Figure 1. More hatch marks on an instrument allows for greater precision and more significant figures in the measurement.

 More information for figure 1

The image shows two rulers labeled as Ruler A and Ruler B, illustrating different levels of measurement precision. Ruler A, at the top, has marking increments for every centimeter, showing a measurement of 4.5 with an annotation indicating "Plus one uncertain digit, One certain digit." Ruler B, located below Ruler A, displays increments for every millimeter, with the measurement shown as 4.55 and annotated as "Plus one uncertain digit, Two certain digits." The illustration highlights how Ruler B allows for greater precision due to its finer hatch marks, resulting in more significant figures.

[Generated by AI]



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Recording uncertainties with analogue equipment

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In addition to the measurement, you must also record the uncertainty, which is then used to assign a quantity of error to your measurement. Uncertainty is an unavoidable error in the measurement that is due to your ability to correctly estimate the last digit in your measurement. In general, the uncertainty for analogue equipment is one-half of the value between hatch marks. In **Figure 1**, the uncertainty would be 0.5 cm for ruler A and 0.05 cm for ruler B.

For the first measurement, the final recorded length would be 4.5 ± 0.5 cm, indicating that the true value would be somewhere between 4.0 and 5.0 cm. For the second measurement, the final recorded length would be 4.55 ± 0.05 cm, indicating that the true value would be somewhere between 4.50 and 4.60 cm.

How would you record the temperature on the thermometer in **Figure 2**? Be sure to read to the correct number of decimal places and include the uncertainty.



Figure 2. Record the temperature reading and uncertainty.

This temperature would be recorded as 19.0 ± 0.5 °C. The 1 and 9 are certain digits and the 0 is an uncertain digit, as the measurement appears to be directly on the hatch mark itself. The uncertainty is one-half of the value between hatch marks. Since the hatch marks are at every 1 °C, the uncertainty is 0.5 °C.

Zero error

In **Figure 3**, a ruler is being used to measure the depth of water in a container. It looks like the depth of the water is 4.0 cm.



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Can you spot the mistake?

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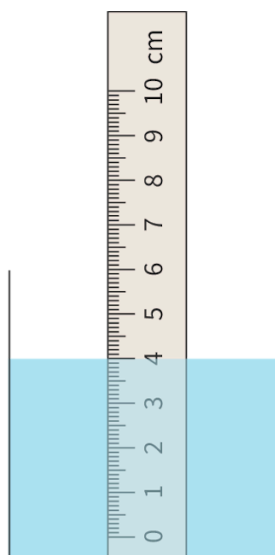


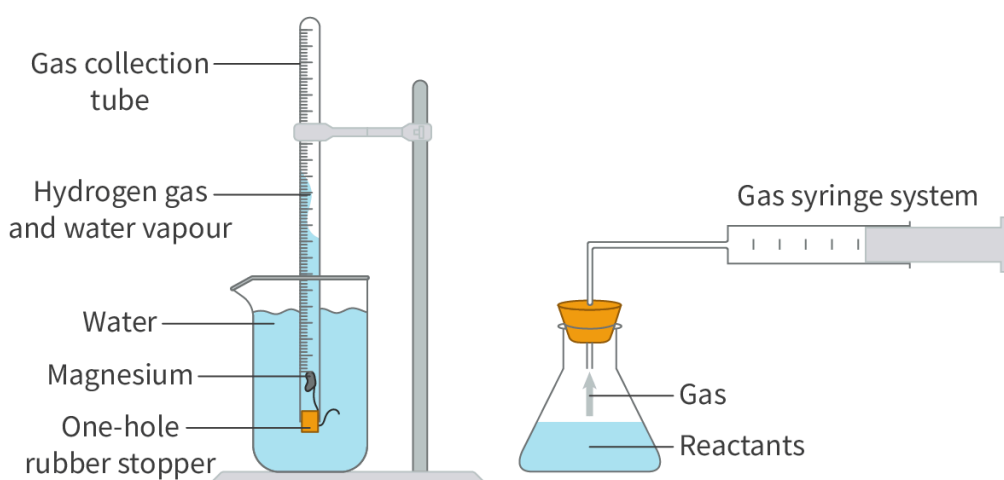
Figure 3. Measuring depth with a ruler.

Many rulers have a small extra piece of plastic or wood before the numbers start. You would need to measure this piece and add it to the depth reading. This is called a zero error. Any zero error reduces the accuracy of the measurement.

Different apparatus can have different versions of a zero error. For example, the needle on a dial might not start at exactly zero. Make sure to check all of your measuring equipment to see where the 'zero' mark is on the scale.

Measuring the volume of gases

The volume of a gas can be collected in a syringe, eudiometer or inverted graduated cylinder (**Figure 4**). You would measure these volumes similarly to how you would with a ruler: the final recorded digit would be uncertain with a careful approximation and an uncertainty of one-half of the value between hatch marks.

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Figure 4. Different methods to collect a sample of gas.

More information for figure 4

The illustration shows two experimental setups for collecting gas. On the left, a vertical gas collection tube is immersed in a beaker of water. The tube is labeled with several parts: the tube itself for collecting gas, sections indicating the presence of hydrogen gas and water vapor, the bulk of the beaker containing water, a suspended piece of magnesium, and a one-hole rubber stopper closing the bottom opening of the gas collection tube within the water. This setup aims to capture gas generated via a reaction inside the beaker.

On the right, there is a conical flask connected to a gas syringe system. This setup includes reactants at the bottom of the flask, producing gas that travels upward and gets collected in the syringe. The gas moving towards the syringe is highlighted by an arrow. The syringe allows for direct measurement of the volume of the gas produced by the reaction in the flask. Both setups are used to collect and measure gas volumes generated from chemical reactions, helping in calculations and experiments involving gaseous reactions.

[Generated by AI]

Measuring the volume of liquids

You will likely measure the volume of liquids in many experiments using a variety of glassware. Your choice of glassware will depend on the type of experiment and the quantity of liquid used. Look at the images of the different glassware in **Figure 5** and consider the following questions.

- Which item(s) seem to be more accurate for measuring the volume of liquids? What factors about the size or shape of the glassware influenced your choice(s)?
- Which item(s) would be suitable for measuring a smaller quantity of liquid? Which for a larger quantity?



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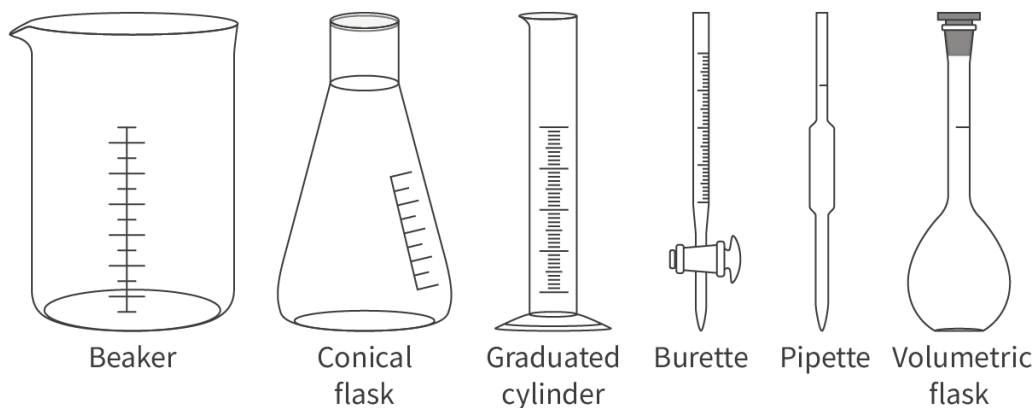


Figure 5. Different types of glassware for measuring the volume of a liquid.

More information for figure 5

The illustration depicts different types of glassware used for measuring liquid volumes, showing a side-by-side comparison of a beaker, conical flask, graduated cylinder, burette, pipette, and volumetric flask. Each piece of glassware is illustrated with measurement markings. The beaker is cylindrical and open-topped, the conical flask has a narrow neck and wide base, the graduated cylinder is tall and narrow, the burette features a stopcock for precise liquid dispensing, the pipette is thin and tubular, and the volumetric flask has a round body with a long neck. The eye level is indicated to illustrate the proper level to view the meniscus for accurate measurement.

[Generated by AI]

Liquids can accurately be measured in graduated cylinders, volumetric flasks, pipettes or burettes at room temperature. The volume of a liquid should never be measured in a beaker or conical flask, as these are neither accurate nor precise, even though these tools contain hatch marks. Beakers and conical flasks are used for mixing, heating or swirling liquids, but not for measuring. The hatch marks on beakers and conical flasks are simply included as a guideline to allow you to choose the correct size.

Burettes and pipettes are designed to measure small volumes of liquid, whereas graduated cylinders and volumetric flasks can measure larger volumes.

The volume of liquid should always be measured at room temperature, as hot or cold liquids can cause the glassware to expand or contract, which then affects the accuracy of the measurement. In addition, glassware made for measuring volumes – graduated cylinders,

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burettes, pipettes and volumetric flasks – should never be heated on a hotplate or with a Bunsen burner. They are not designed for heating and could shatter with temperature changes.

When liquids are in glass, you will notice that the liquid rises up the sides of the container, forming a curve known as a meniscus (**Figure 6**). This phenomenon is due to the attractive forces between the particles of the liquid themselves and the glass. Glassware is designed to allow for the measurement to be taken from the very bottom of the curve. In addition, your position relative to the liquid can change your perception of the volume, known as a parallax error. To ensure the most accurate reading, always read the bottom of the meniscus at eye level at room temperature.

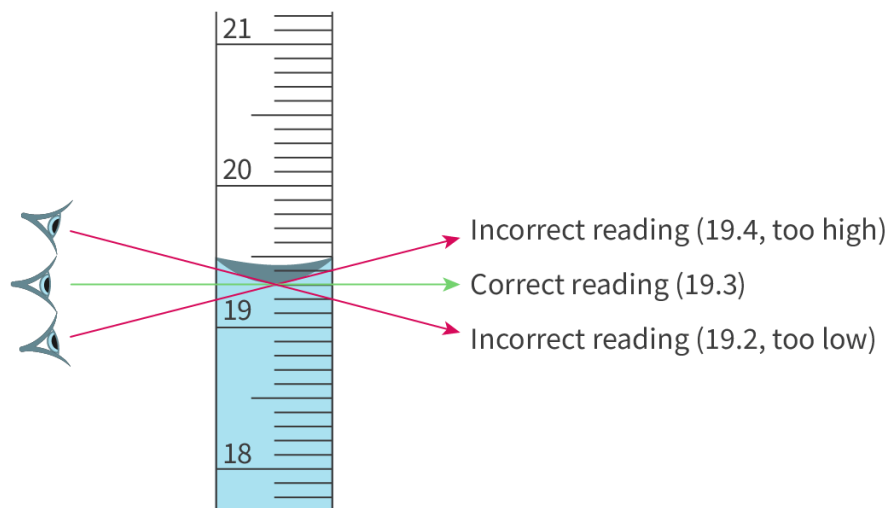


Figure 6. Always read the bottom of the meniscus at eye level when measuring the volume of a liquid.

 More information for figure 6

The illustration demonstrates how to accurately read a liquid measurement in a glass container by aligning the eye level with the bottom of the meniscus. On the right side, there is a scale marked from 18 to 21, resembling a graduated cylinder. The meniscus curves upwards against the glass. Three horizontal lines intersect with the meniscus at different points: the red lines show incorrect readings with the upper line at 19.4 (too high) and the lower line at 19.2 (too low). The central green line indicates the correct reading at 19.3. To the left, a side view shows how the meniscus should be viewed at eye level to avoid parallax error.

[Generated by AI]

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Glassware with hatch marks

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For graduated cylinders, burettes and many pipettes, use the hatch marks to read the bottom of the meniscus to one uncertain digit, just as you would measure with a ruler. The uncertainty is one-half of the value between hatch marks.

Consider the graduated cylinder in **Figure 7**. The hatch marks are at every 1 cm^3 , so the uncertainty is 0.5 cm^3 . This means that your measurement must read to the tenths place. Since the hatch marks are close together and the meniscus appears to be sitting directly on the line, you would take this measurement as $36.0 \pm 0.5\text{ cm}^3$.

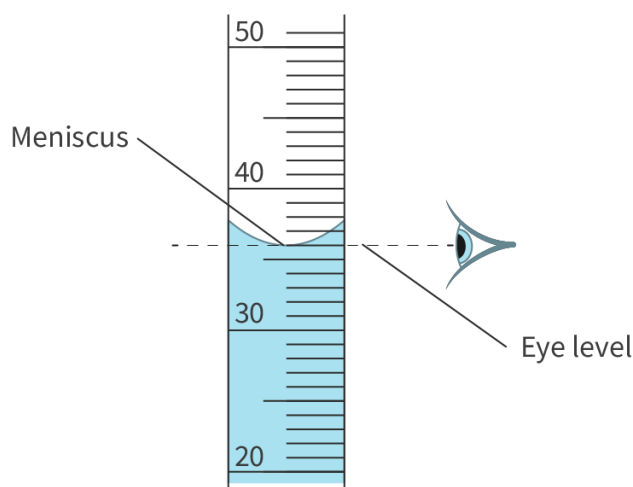


Figure 7. Use the hatch marks on a graduated cylinder to read the volume of a liquid to one uncertain digit.

More information for figure 7

The image is an illustration of a burette filled with liquid. The burette is marked with measurements ranging from 20 to 50, indicated by horizontal hatch marks. An eye icon is positioned to indicate the optimal angle for reading the liquid level at eye level. The liquid forms a concave meniscus, with a line drawn to show where the meniscus is read, which is between the 36 and 37 mark. The specific value is not labeled but can be inferred as approximately 36.0 cubic centimeters, considering the meniscus's position relative to the hatch marks. The illustration emphasizes the correct reading technique by aligning the meniscus with the eye level.

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When using a pipette or burette, the numbers are usually arranged with the largest number at the bottom and the zero at the top. Always check the orientation of the numbers to be sure you are reading the volume correctly.

Take a look at **Figure 8** and state the volume of solution in cm^3 to one uncertain digit, including uncertainty.

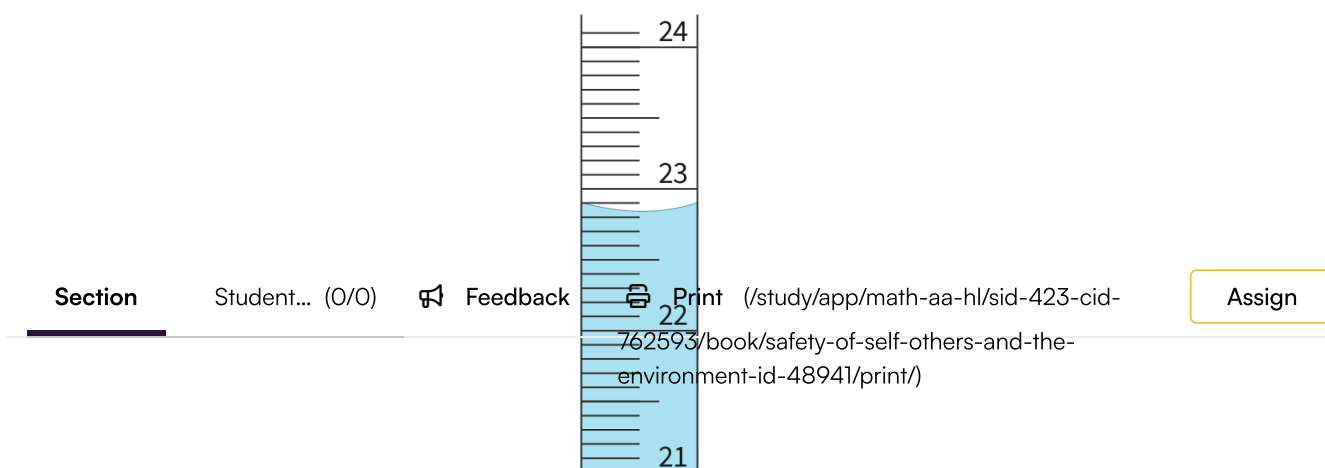


Figure 8. Read the volume of the liquid in the burette.

More information for figure 8

The image shows a vertical illustration of a burette filled with a liquid. The burette has measurement markings labeled in cubic centimeters (cm^3), with major markings at each full number and shorter lines at each tenth. The main markings visible are 21, 22, 23, and 24 cm^3 . The liquid inside forms a meniscus that appears to sit between the 22.8 and 22.9 cm^3 markings, indicating a measurement of approximately 22.85 cm^3 .

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This measurement of the volume should be recorded as $22.85 \pm 0.05 \text{ cm}^3$. Overall, you can see that the volume is between 22 and 23 cm^3 and more precisely between 22.8 and 22.9 cm^3 . The hatch marks are close together and the meniscus appears to be in between the hatch marks (rather than directly on a hatch mark or closer to one hatch mark than the other), therefore the uncertain digit is a 5, making the final measurement as 22.85 cm^3 . The hatch marks are at every 0.1 cm^3 , therefore the uncertainty is 0.05 cm^3 . Remember that the precision in the measurement and the uncertainty must match.



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Glassware without hatch marks

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You may have noticed that the images of the pipette and volumetric flask do not have any hatch marks at all. These are specialised pieces of equipment that can only measure one specific volume and are used in the preparation of standard solutions.

Volumetric flasks and pipettes come in different sizes and contain only one hatch mark where the meniscus must sit precisely. The uncertainty is often included on the glassware label and accounts for the thickness of the line to produce any variations in measurement.

Consider the example in **Figure 9**. The volumetric flask in the centre has a volume of 1000 mL ($1 \text{ mL} = 1 \text{ cm}^3$) and the displayed uncertainty indicates 0.16 mL at 20 °C. Therefore, you can infer that the volume is $1000.00 \text{ mL} \pm 0.16 \text{ mL}$ for the uncertainty to match the level of precision in the measured volume.

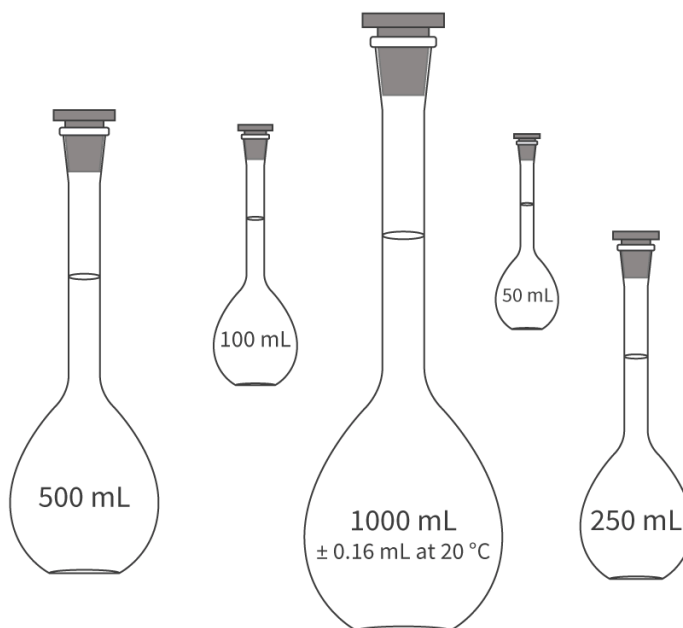


Figure 9. Volumetric flasks come in different sizes to precisely measure the volume of a solution.

Measuring electric current or potential difference

When building an electrochemical cell, you will likely measure variables such as the potential difference or current, using a voltmeter or ammeter respectively. Some voltmeters and ammeters are analogue and others are digital. Similar to a ruler, you would record your measurement to one uncertain digit with the uncertainty recorded as one-half the value between hatch marks.

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How would you record this measurement on the voltmeter in **Figure 10**?

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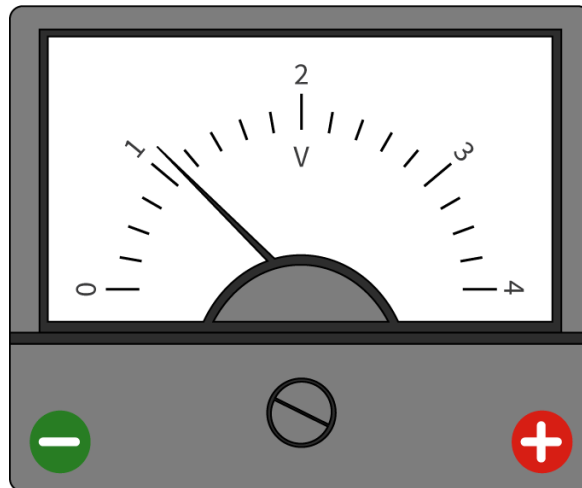


Figure 10. A measure of potential difference on an analogue voltmeter.

You would record this as $1.1 \text{ V} \pm 0.1 \text{ V}$. This is a hard example since the hatch marks are at every 0.2 V. The measurement is greater than 1.0 V, but less than 1.2 V and seems to be somewhere in the middle, but without any additional hatch marks to guide you, your estimated uncertain digit would have to be in the tenths place. The hatch marks at 0.2 V means that the uncertainty is 0.1 V. Remember that the precision in the measurement and the uncertainty must match.

The guidelines in this section can be applied to the measurement of any variable. In physics, angles and forces are typically measured using analogue equipment.

Tool in action

To read more about the skills in this section and see examples of them being used in physics, take a look at the following:

- [Section 1.4.1](#) (/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-the-acceleration-of-free-fall-id-43210/) Investigating the acceleration of free fall.
- [Section 1.4.3](#) (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-the-specific-latent-heat-of-vaporisation-of-water-id-46752/) Measuring the specific latent heat of vaporisation of water.



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1. Essential skills and support guides / 1.1 Tool 1: Experimental techniques



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Measuring variables with digital equipment

Recording measurements

Digital equipment uses electronic sensors to take and display the measurement, which allows for more efficient data collection than when using analogue equipment. However, it also requires the equipment to be correctly calibrated and to run on battery power or be connected to an electrical outlet, which might not always be convenient for the experiment. Digital equipment is frequently used to measure mass and can also be used to measure other variables such as time or temperature.

Since the equipment takes the measurement for you, you do not have to make a judgement for the uncertain digit as you do for analogue equipment. You simply record the value displayed on the machine. The uncertainty for digital equipment is different than for analogue equipment, however, as it is usually recorded as **one** unit of precision in the measurement. Always be sure to check the equipment instructions as the manufacturer sometimes includes uncertainty that differs from this general rule.

Use the display on the mass balance in **Figure 1** to measure the mass of the conical flask and contents.



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math-sl/
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762593/c**Figure 1. Measurement of mass on a digital mass balance.**

The mass would be recorded as 112.85 ± 0.01 g. The equipment displays the measurement for you, so you are only required to determine the uncertainty. Since the final displayed digit is in the hundredths place, the uncertainty is 0.01. Remember that the precision in the measurement and the uncertainty will match.

Practise your skills by completing the following exercises and recording the measurements, with their uncertainties, for each equipment.

**Exercises**

Measuring time

You might find yourself recording the length of time for a process in seconds, minutes or hours using a stopwatch or other digital timer. When recording time, you could follow the rule for uncertainty as one unit of precision from the measurement. However, there is an additional factor that comes with measuring time manually with a stopwatch. Can you think of what that might be?

The operator of the stopwatch will have an unavoidable reaction time that can influence their ability to start and stop the timer, affecting the accuracy of the measurement and increasing the uncertainty. Typical human reaction time is between 0.1–0.3 seconds, therefore the uncertainty should be changed to reflect this length of time. To maintain a consistent reaction time for different trials in an experiment, you should have the same person operate the stopwatch when possible and always pay close attention during the experiment.

Let's consider the stopwatch in **Figure 2**. How would you record this time measurement?

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Figure 2. Measuring time on a digital stopwatch introduces additional human reaction time.

Credit: t_kimura, Getty Images

The time measurement on the display reads as 43.48 s. Although the equipment displays the measurement for you, you must change the uncertainty to reflect human reaction time, which ranges from 0.1–0.3 seconds. Therefore, you should *adjust* the measurement so that the precision in the measurement matches the precision in the uncertainty.

Since the average reaction time contains a final digit in the tenths place, 43.48 will round to 43.5 seconds. Let's say that you consider yourself to have average reaction time, you then decide to use 0.2 seconds as your uncertainty. Therefore, your final measurement is 43.5 ± 0.2 seconds. Remember that the precision in the measurement and the uncertainty must match.

Other human factors can affect the measurement of time. For example, judging when to stop a timer can also lead to lower precision. Taking repeated measurements allows you to monitor how precise you are being.

The guidelines in this section can be applied to the measurement of any variable. In physics, sound and light intensity are typically measured using digital equipment.



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Tool in action

To read more about the skills in this section and see examples of them being used in physics, take a look at the following:

- [Section 1.4.1](/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-the-acceleration-of-free-fall-id-43210/) (/study/app/math-aa-hl/sid-423-cid-762593/book/investigating-the-acceleration-of-free-fall-id-43210/) Investigating the acceleration of free fall.
- [Section 1.4.8](/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-the-internal-resistance-of-a-cell-id-46512/) (/study/app/math-aa-hl/sid-423-cid-762593/book/measuring-the-internal-resistance-of-a-cell-id-46512/) Measuring the internal resistance of a cell.

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