Measurement and practical work

Unit 1

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One of the most important developments in the history of science was the scientific method, the procedure scientists use to acquire knowledge in any field of science.

Science is all about observing and experimenting. We need a framework to add relevance to observations and experiments.

Experiments may vary in size and expense, including using huge particle accelerators, making observations using space telescopes, testing simple circuits, or even just bouncing a ball! In order to be considered scientific, they must follow a key set of principles and be presented in a suitable manner. This section looks at how experiments should be represented and how the data should be analysed before drawing conclusions.

1.1 Science of measurement

By the end of this section you should be able to:

- Explain the importance of measurement.
- Identify and use appropriate units for data that will be collected.
- Describe what is meant by the term significant figures and how it is related to precision.
- Identify rules concerning the number of significant figures that a numeral has.
- Define the term scientific method.
- State the steps of scientific methods.
- State the uncertainty in a single measurement of a quantity.
- Identify the orders of magnitude that will be appropriate and the uncertainty that may be present in the measurement of data.


Figure 1.1 *The Hubble space telescope*

The scientific method

The scientific method is exceptionally important to the process of science. It ensures a rigorous, evidence-based structure where only ideas that have been carefully tested are accepted as scientific theory.

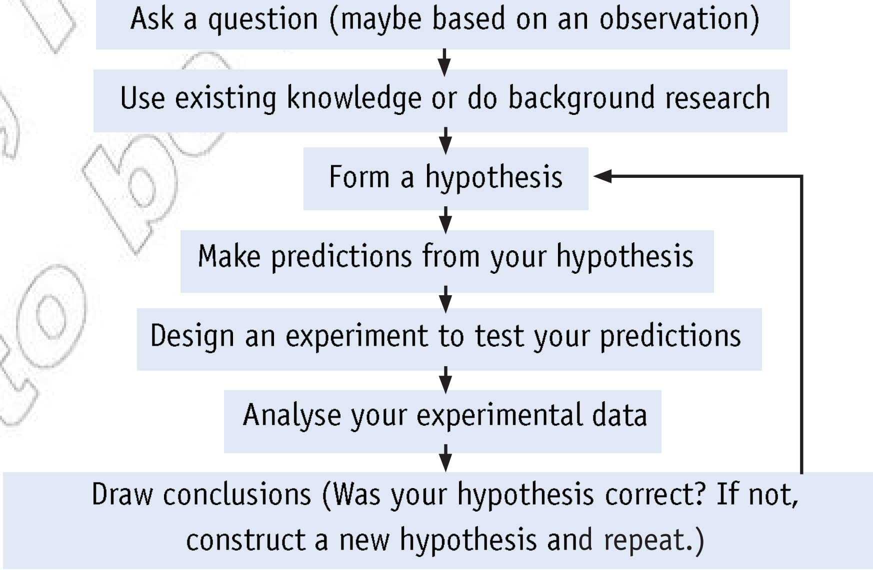


Figure 1.2 *The scientific method*

Your hypothesis will have to be tested by others before it becomes an accepted scientific theory. This process of peer review is very important and prevents scientists making up data.

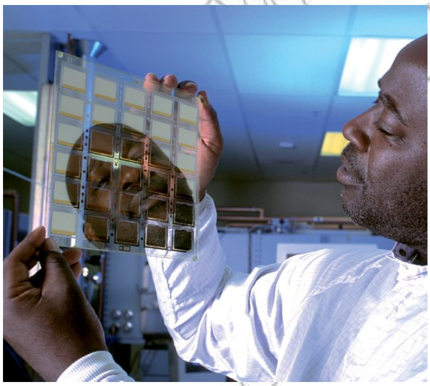


Figure 1.3 *This scientist is researching ways of making energy-efficient lighting.*

The process of science begins with a question. For example: Why is the sky blue? Why does the Sun shine? Scientists are curious about the world around them; it is this curiosity that is the spark of the process.

When you have a question, scientists may have already looked into it and devised an explanation. So the first step is to complete some preliminary research into the existing theories. These theories may provide answers to your question. It is quite probable most of the questions you encounter in your physics course already have answers. However, there are still some big unanswered questions in physics. They are waiting for someone like you to answer them! Are there any questions that science cannot answer?

Using your existing knowledge or information collected via research, the next step is to form a **hypothesis**.

A hypothesis is just an idea that might provide an answer to your question. A scientific hypothesis is based on scientific knowledge, not just made up!

For example: *Why does the Sun shine?*

You might form two hypotheses:

- Nuclear fusion reactions in the Sun release heat and light.
- There is a large lamp in the centre of the Sun powered by electricity.

The first is clearly a more scientific hypothesis using some thoroughly tested existing ideas. That is not to say you shouldn't be creative in making a hypothesis but you should include some scientific reasoning behind your ideas.

It is important to note your hypothesis might be incorrect, and this is what makes science special. An investigation must be carried out to test the ideas before you either rule out an idea or accept it.

Why does the Sun shine?

Once you have a hypothesis, you should use it to form a series of predictions that can be tested through **experiment**. These may range from 'easy to test' to 'hugely complex' predictions. You then design an experiment to test your predictions.

Discussion activity

Some simple questions lead to massively complex experiments costing billions of dollars. One of these is the ATLAS project in Switzerland. This costs billions of dollars; do you think it is right to spend such a large amount of money on scientific experiments?

Figure 1.4 *Scientists investigating renewable energy*

Activity 1.1: Using the scientific method

Look around your classroom or outside. Make three observations, and using your existing scientific knowledge, form a hypothesis for each of them. Discuss these with a partner.

Figure 1.5 *We all know that the Sun shines. But why?*

KEY WORDS

hypothesis *a proposed explanation for an observation*

experiment *a test under known conditions to investigate the truth of a hypothesis*

KEY WORDS

analyse *examine in detail to discover the meaning of a set of results*

conclusions *the overall result or outcome of an experiment. The hypothesis being tested may be supported by the results or may be proven incorrect*

significant figures *the number of digits used in a measurement, regardless of the location of the decimal point*

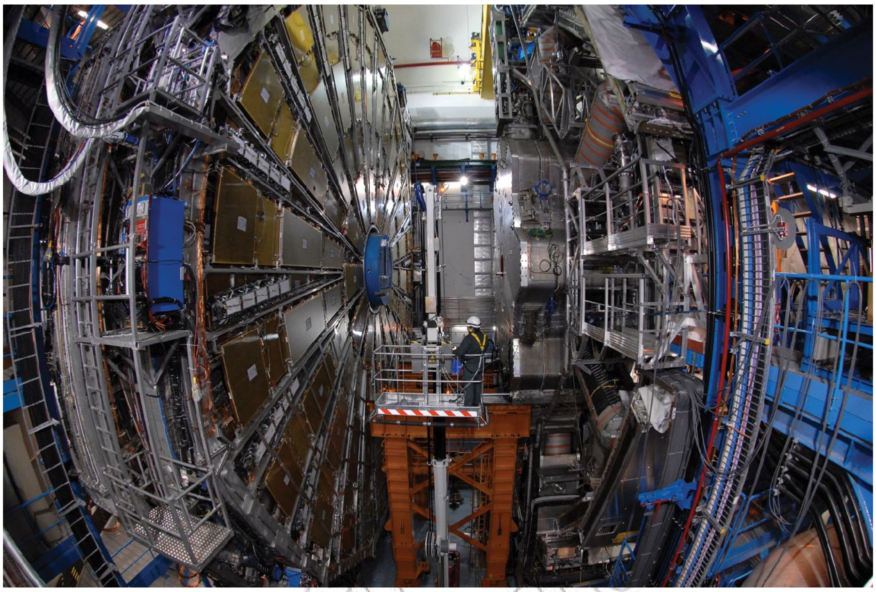


Figure 1.6 *The ATLAS detector in Switzerland*

It is important that your experiment is clearly planned. This will enable others to test your experiment and check your ideas (more detail on this can be found in Section 1.4).

Once you have carefully conducted your experiment, you will need to **analyse** your results and draw **conclusions**. At this stage you need to decide if your results support your prediction. If they do, then perhaps your hypothesis was correct. This will need to be confirmed by several other scientists before it becomes accepted as scientific fact.

If your results do not support your prediction, then perhaps your hypothesis was wrong. There is nothing wrong with that, you just go back and form a different hypothesis. This process continues and it may take years to come up with a correct hypothesis!

Activity 1.2: Choosing the right unit

In a group, discuss what units you would use when measuring each of the following:

- length of a football pitch, width of this book, diameter of a small seed, width of a finger nail.
- area of a page in this book, area of the floor in your classroom, area of a football pitch.
- volume of this book, volume of your classroom, volume of a bottle, volume of a soccer ball.

Making measurements

As part of your experiment you will have to make measurements and collect data. This process is very important and needs to be conducted carefully.

Choosing units

When you are planning your experiment, you need to choose units that are appropriate to the size of the quantity you are measuring. For example, you would measure the length of a finger in centimetres.

Explain why you have chosen the units.

Significant figures

All digits in a number that are not zero are called **significant figures**. For example, the number 523 has three significant figures and the number 0.008 has one significant figure. The zeroes in 0.008 are not significant figures but they are important as they tell you how big or small the number is.

When a number is given in standard form, the number of digits tells you how many significant figures there are. For example, 0.008 in standard form is 8×10^3 – it's now much more obvious that the number has one significant figure.

For any measurement you take, the number of significant figures (s.f.) must be consistent with the instrument precision. For example, if you are measuring length with a 1 m ruler that has mm on it, then all readings should be expressed to the nearest mm. For example:

0.6 m ✗

0.64 m ✗

0.643 m ✓

If your reading is exactly on an increment this still applies!

0.5 m ✗

0.50 m ✗

0.500 m ✓

You must be consistent with your use of significant figures in your results tables. If your data is to two significant figures, so should be your average. For example:

Reading one: 62 *Reading two: 61* *Average: ??*

The average here should be 62, not 61.5 as this is going from two to three significant figures.

If you then go on to calculate something using your data, you must express your answer to the lowest number of significant figures in your data. For example, if you are calculating average speed you might have the following:

$$\text{Average speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

Distance travelled = 4.345 m

Time taken = 1.2 s

The distance travelled is to four significant figures but the time taken is only to two. This means your answer should only be to two significant figures:

$$\text{Average speed} = \frac{\text{distance travelled}}{\text{time taken}}$$

$$\text{Average speed} = \frac{4.345\ \text{m}}{1.2\ \text{s}}$$

$$\text{Average speed} = 3.62083333\ldots$$

$$\text{Average speed} = 3.6\ \text{m/s (to 2 significant figures)}$$

Zeroes between the significant figures and the decimal point are also significant as well as demonstrating the magnitude of the quantity. 'Trailing zeroes' (e.g. the zeroes in 3.20000) are also considered significant.

***Table 1.1** Prefixes and their symbols*

Prefix	**Power of 10**	**Symbol**
giga-	10^9	G
mega-	10^6	M
kilo-	10^3	k
hecto-	10^2	h
deca-	10	da
deci-	10^{-1}	d
centi-	10^{-2}	c
milli-	10^{-3}	m
micro-	10^{-6}	µ
nano-	10^{-9}	n

Discussion activity

Is 100 V to one, two or three significant figures? The answer is it could be any of those! If your reading is to a whole number you may need to specify its number of significant figures.

KEY WORDS

uncertainty *the amount of doubt in a measurement*

Uncertainties

Every measurement you take will have an **uncertainty** associated with it. It does not mean it is wrong, it is just a measure of your confidence in your measurement. If you were measuring the height of a friend, you might write:

1.80 m

Does this mean exactly 1.8 m? Does it mean 1.80000000000000000000000000000 m? When you write 1.80 m you mean your friend's height is between 1.805 m and 1.795 m. You could write this as:

1.80 m ± 0.005 m

The 0.005 m is the uncertainty in your reading. You have measured the height to the nearest 5 mm. You should try to keep this uncertainty as small as possible (more on this in Section 1.3).

The uncertainty in every measurement will be related to the nature of the task and the precision of the instrument you are using.

For example, measuring the height of a ball bouncing is very difficult. You might measure the height using a ruler with mm on it as 16.0 cm, but what is the uncertainty?

16.0 cm ± 0.1 cm → Even though the ruler may measure to mm it is very hard to measure the height to the nearest mm as this is too small.

16.0 cm ± 0.5 cm → This is possible, if you ensure to measure the bounce height carefully; by getting down to eye level and doing a test drop it might be fair to say you can measure the height to the nearest ½ cm.

16.0 cm ± 1.0 cm → This is a realistic uncertainty for this experiment.

16.0 cm ± 2.0 cm → This might be a little unrealistic, but is also acceptable, since determining the bounce height by eye is quite difficult.

16.0 cm ± 5.0 cm → Hopefully you have designed the experiment to enable you to measure to more than the nearest 5 cm!

Which uncertainty you use is a judgement you will have to make depending on the results.

Activity 1.3: Measuring bounce height of a ball

Collect a ball and ruler. In small groups drop the ball from various heights (around ten different heights) and record how high it bounces. Notice how difficult it is to determine the bounce height to anything less than the nearest cm.

If you were using the same ruler to measure the width of a piece of paper, you might also get 16.0 cm; however, your uncertainty would be much less than 1.0 cm! This is because the piece of paper is not moving, so measuring is easier than with the bouncing ball. Perhaps you would write 16.0 cm ± 0.1 cm.

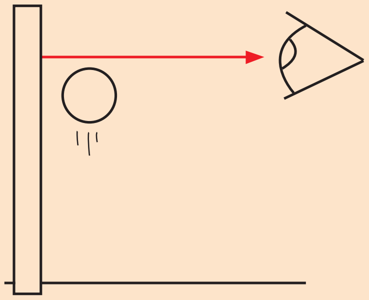


Figure 1.7 Measuring bounce height of a ball

Discussion activity

Can you think of some other examples of measurements you might take using a ruler and what the uncertainty might be in each case?

Percentage uncertainties

You may need to calculate the percentage uncertainty in one of your readings. This is just the uncertainty of the reading expressed as a percentage. If you measured the current through a bulb, you might express your measurement as:

$4.32\ A \pm 0.05\ A$

So the percentage uncertainty would be:

$$\frac{0.05}{4.32} \times 100 = 1.157407\ldots\%$$

So you would write 4.32 A ± 1.2%.

As a rule of thumb, percentage uncertainties should be to two significant figures.

You should always aim to keep your percentage error under 10%, although this may not always be possible.

Whenever possible you should measure **multiple values** instead of just one. For example, the time for 20 swings of a pendulum rather than just one, or several thicknesses of card rather than just one. This has the effect of reducing the percentage uncertainty as shown below:

One piece of card	Ten pieces of card
1.03 ± 0.05 mm ➞ 4.9%	10.41 ± 0.05 mm ➞ 0.48%

Notice the uncertainty is still the same but the percentages are very different.

Activity 1.4: Percentage uncertainty for the bouncing ball

Using the data collected on the bounce height of the ball, calculate the percentage uncertainty in each case. What do you notice about the smaller readings? The larger your reading, the smaller the percentage uncertainty. So small distances have a greater percentage uncertainty than large distances, if measured with the same instrument.

KEY WORDS

multiple values *several readings of the same measurement*

Calculations

You need to determine the uncertainty in a quantity you have calculated. For example, when calculating resistance from values of p.d. (potential difference) and current:

$\text{p.d.} = 4.32\ V \pm 1.157407\ldots\%$ $\quad$ $\text{Current} = 2.3\ A \pm 4.534641\ldots\%$

$$\text{Resistance} = \frac{\text{p.d.}}{\text{current}}$$

$$\text{Resistance} = \frac{4.32\ V}{2.3\ A}$$

Resistance = 1.9 Ω (2 s.f., as the value of the current is to 2 s.f.).

To find the percentage uncertainty in the resistance you just add the percentage uncertainties of the p.d. and current. This gives 5.692047…%, and so you would write: 1.9 Ω ± 5.7%. Do not round up until the end!

You could express the resistance (1.9 Ω ± 5.7%) as 1.9 ± 0.1 Ω. This is because 5.7% of 1.9 is 0.108...Ω and also as the resistance reading is to 1/10 of an ohm, you would write 0.1 Ω not 0.11 Ω.

This is same if you are multiplying quantities together. For example, calculating distance travelled using

distance travelled = average speed × time taken.

Activity 1.5: Uncertainty in the dimensions of a book

Using a ruler, measure the dimensions of a book in centimetres. Write down the dimensions, the uncertainty for each, and express this as a percentage.

Use your readings to calculate the volume of the book. Calculate the percentage uncertainty in the volume and express this in cm^3.

Average speed: ± 4.1….% *Time taken: ± 3.4…%*

Therefore: distance travelled: ± 7.5%

Be careful if there is a square in the equation. For example, area of a circle = πr^2. If r has a percentage uncertainty of 2.312…%, then the area will have a percentage uncertainty of 4.6% as the equation is effectively: area = $\pi \times r \times r$. So the error in r must be counted twice (2.312…% + 2.312…% = 4.624…% so 4.6% to 2 s.f.).

Summary

In this section you have learnt that:

- The scientific method includes: observing, researching, hypothesising, predicting, experimenting, analysing and concluding.
- Measurements must always be recorded to an appropriate number of significant figures (this depends on the equipment you are using).
- All measurements have an uncertainty associated with them. This is effectively a quantification of the amount of doubt in a measurement.
- To determine the uncertainty of a calculated value, you add the percentage uncertainties of the quantities used to perform the calculation.

Review questions

1. Describe each part of the scientific method. Explain why it is important to follow this structure when conducting a scientific investigation.
2. How many significant figures do the following numbers have:
   a) 258 b) 0.2 c) 12 000 d) 0.084
3. How can you reduce the percentage uncertainty in measurements that you make?
4. Nishan and Melesse have measured the voltage across a resistor to be 5.26 V and the current flowing through it to be 0.41 A. They work out the resistance.

   Nishan says that the resistance is 12.8 Ω. Melesse disagrees and says that the resistance is 13 Ω.
   Who is correct? Explain your answer.
5. A bulb is connected as part of a circuit. The following data is collected:

   Electric current: 3.2A ± 0.1 A
   Potential difference: 12.3 V ± 0.1 V

Use this data and the equation

$$\text{Resistance} = \frac{\text{potential difference}}{\text{electric current}}$$

to determine the resistance. Express the uncertainty in your answer.

1.2 Errors in measurement

By the end of this section you should be able to:

- Distinguish between random error and systematic error.
- Describe sources of errors.
- Identify types of errors.
- Distinguish between random uncertainties and systematic errors.

What are errors?

An experimental error (or just referred to as an error) is not the same as a mistake. An example of a mistake would be to measure the height of a desk when asked to measure the height of a chair. It is just plain wrong!

The measurements you take as part of your investigations will contain experimental errors, but hopefully no mistakes. Errors occur in every scientific investigation; they affect your measurements, making them different from the **accepted value** (sometimes called **true value**) of the item being measured. There are several different types of experimental error.

KEY WORD

accepted/true value *the actual value of the property being measured, made without any experimental errors*

random errors *unpredictable errors that have no pattern or bias and which may be above or below the true value*

Accepted or true value

This is the actual value of the physical property you are measuring. It is the value you would get if it were possible to make the measurement with no experimental errors.

Random error

Random errors are errors with no pattern or bias. They cause measurements to vary in an unpredictable manner. Importantly, they cause your measurements to be sometimes above the accepted value, sometimes below the accepted value.

For example, if you were measuring the acceleration due to gravity, random errors will cause your readings to vary both above and below the accepted value.

Accepted value for acceleration due to gravity = 9.80665 m/s² (to 6 s.f.)

Recorded values (m/s²)						
9.81	9.78	9.65	9.87	9.80	9.86	9.83

Activity 1.6: Testing random error with a ruler

Make yourself a ruler by cutting a strip of card 15.0 cm long. Use a ruler to carefully mark on the centimetre divisions.

Use your ruler to make several different length measurements of items in your classroom. You must resist the temptation to record your readings to the nearest mm. A suitable uncertainty will be to the nearest 0.5 cm.

Repeat the experiment using a real ruler. You will find about half of your readings were too high, the other half too low. This kind of random error happens with all measurements. Even those taken with the real ruler will either be 0.5 mm too high or 0.5 mm too low.

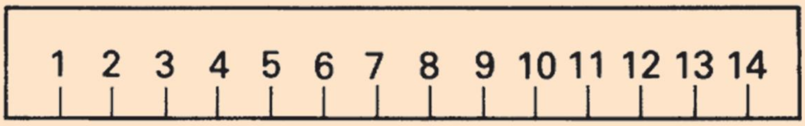


Figure 1.8 *Home-made ruler*

Another example of a random error could be encountered when completing investigations into heat. The surrounding temperature will vary depending on the time of day and general weather conditions. If you are conducting an experiment over a number of days, this will produce random errors in your measurements.

To reduce the effect of random errors, wherever possible you should take several reading and average them. The more repeats you take, the lower the impact of random errors.

Parallax errors with scales

The use of a ruler for length is not without its problems at times. If you wanted to measure the diameter of a table-tennis ball, how might you do it?

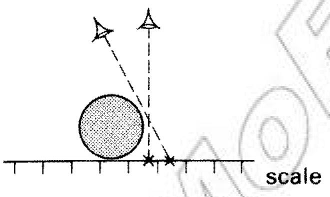


Figure 1.9 *Viewing from directly above avoids a parallax error.*

When the object and the scale lie at different distances from you, it is essential to view them from directly above if you are to avoid what we call parallax errors (Figure 1.9).

A clock in a public place has to be read from many different angles. A neat way of avoiding parallax errors in that case is shown in Figure 1.10.

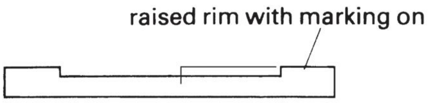


Figure 1.10 *How does this arrangement avoid parallax errors?*

With an instrument designed to be read by a single experimenter, you must take care to position your head correctly. Two ways of achieving the same thing with a current meter are shown in Figure 1.11.

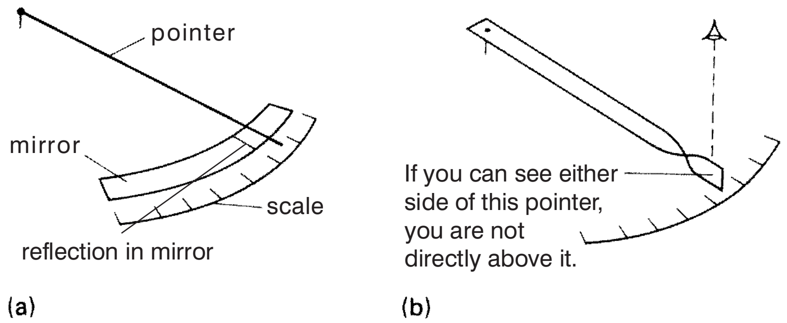


Figure 1.11 Two ways of preventing parallax errors. (a) You know you are looking straight down on the pointer when it is hiding its own reflection in the mirror. (b) A flat pointer is twisted so it is upright at the tip.

Returning to the question of the diameter of the table-tennis ball, two rectangular wooden blocks would help (Figure 1.12).

DID YOU KNOW?

Parallax is the name we give to an effect that you are familiar with in everyday life. As you travel along a road, objects in the distance seem to shift position relative to one another. Because of your movement, a distant house may disappear behind a nearer clump of trees, but as you travel further along it comes back into view the other side of them. That is parallax.

Discussion activity

A little thought is still needed for the best possible result. What if the blocks are not quite parallel? The doubt can be removed by measuring both ends of the gap as shown in the drawing; if the two lengths differ slightly, their average should be taken.

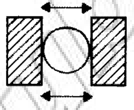


Figure 1.12 Measuring using wooden blocks

Figure 1.13 shows some calipers, which can do the same job as the ruler and the two blocks. They may be made of steel, and the part drawn shaded will slide along the main part. It must fit snugly, so that the shaded prong A is always at right angles to the arm B.

The arrow engraved on the sliding part indicates the diameter of the ball, on the millimetre scale. If the ball is removed and the jaws are closed, that arrow should then lie on the zero of the scale.

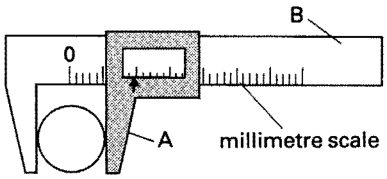


Figure 1.13 Measuring using the Vernier calipers

Systematic errors

A **systematic error** is a type of error that shows a bias or a trend. It makes your readings too high every time, or too low every time. Taking repeated readings will not help account for this type of error.

A simple example might be an ammeter that always reads 0.4 A too low. So if your reading was 6.8 A, the true value for the current would be 7.2 A. More complex examples include ignoring the effect of friction in Newton's second law experiments, or not measuring to the centre of mass of a simple pendulum.

The problem with systematic errors is that they can be quite hard to spot! When you have found the source you then either redesign the experiment or account for the error mathematically.

KEY WORD

systematic errors *errors caused by a bias in measurement and which show a bias or trend*

This is quite easy to do. Take for example a voltmeter where each reading is 0.2 V too large. To find the corrected value you need to subtract 0.2 V from each of your readings.

Recorded value (v)	Corrected value (v)
2.8	2.6
6.4	6.2
10.8	10.6
15.4	15.2
20.7	20.5

Zero errors

Zero errors are special examples of a systematic error. They are caused by an instrument giving a non-zero reading for a true zero value. For example, the ammeter mentioned above is a type of zero error. When the current is 0 A it would read –0.4 A.

KEY WORDS

zero errors *errors caused by equipment that has not been correctly zeroed*

Summary

In this section you have learnt that:

- Experimental errors cause readings to be different from their true value.
- Random errors cause readings to be above and below the true value.
- Systematic errors cause a bias in your readings (they are all either too high or too low).
- Parallax errors can cause your readings to be less accurate because of the position of your eye.
- A zero error is a type of systematic error caused by equipment not being zeroed properly.

Review questions

1. Explain the meaning of the term error.
2. Describe different types of errors, give examples, and explain how the effect of these errors might be reduced.

1.3 Precision, accuracy and significance

By the end of this section you should be able to:

- Distinguish between precision and accuracy.
- State what is meant by the degree of precision of a measuring instrument.
- Use scientific calculators efficiently.

What does 'accurate' mean?

KEY WORDS

accuracy *the closeness of a measurement to its true value*

precision *the quality of being exact and the degree to which repeated measurements under the same conditions give the same value*

significance *the number of significant figures used in a reading, which should be appropriate to the precision of the measuring instrument*

Accuracy means how close a reading is to the true value. The more accurate a reading, the closer it is to the true value.

Again using the acceleration due to gravity as an example:

Accepted value for acceleration due to gravity = 9.80665 m/s^2 (to 6 s.f.)

If you took three readings you might get:

9.76	9.87	9.82

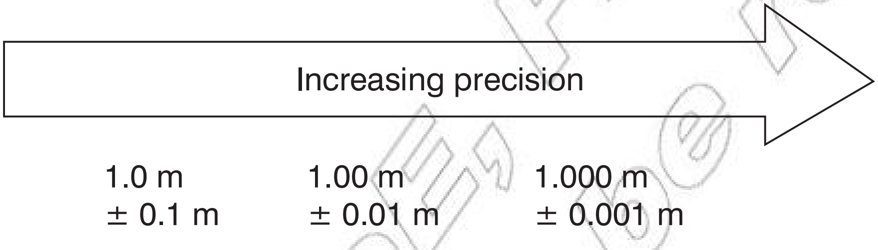
The most accurate reading is the third one; it is closest to the true value.

In order to obtain more accurate measurements you must ensure you have minimised random errors, taken into account systematic errors and conducted the experiment as carefully as you can.

Precision and significance

The **precision** of your reading is a measure of the degree of 'exactness' of your value; this is sometimes related to the number of significant figures in the reading. The more precise a reading is, the smaller the uncertainty. A series of precise measurements will have very little variation; they will all be very similar.

For example, dealing with lengths:



The **significance** of your reading is indicated by the number of significant figures you can express your data to. This was discussed in Section 1.1

It is very important not to overstate the significance of your readings. If your ruler measures to mm, then your readings should be to mm; it would not be right to give a length of 1.2756 m.

This is particularly true when calculating values. Take, for example, calculating the resistance of a light bulb:

$$\text{Resistance} = \frac{\text{potential difference}}{\text{electric current}}$$

Potential difference = 10.0 V ± 0.1 V (so a 1.0% uncertainty)

Current = 3.0 A ± 0.1 A (so a 3.3% uncertainty)

This shows a series of imprecise measurements, they are all quite spread out. In addition, the readings are inaccurate as they are not clustered around the true value. This is what you want to try to avoid!

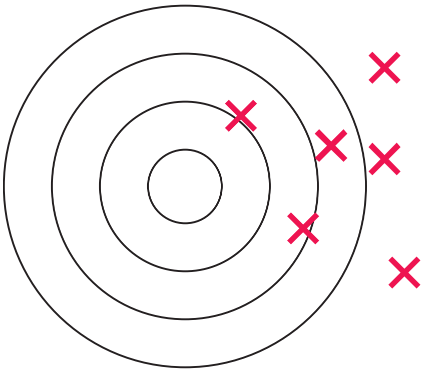


Figure 1.14 *Imprecise and inaccurate*

Put this into your calculator and you would get:

$$\text{Resistance} = \frac{\text{potential difference}}{\text{electric current}}$$

$$\text{Resistance} = \frac{10.0\ \text{V}}{3.0\ \text{A}}$$

$$\text{Resistance} = 3.333333333\ \Omega$$

As previously discussed you would answer 3.3 Ω to two significant figures, but why did the calculator give 3.3333333?

The answer is to do with how calculators treat values. When you enter 10.0 V, you mean 10.0 V ± 0.1 V but the calculator takes the value to be exactly 10. That is 10.0000000000000000…. The same sort of thing is true for your current reading.

To express the resistance as 3.333333333 Ω would be wrong. It implies the reading is more precise than it actually is.

Accurate and precise

Accuracy and precision are often confused. A common analogy to help overcome this involves using a target. The centre of the target represents the true value and each shot represents a measurement.

This shows a series of precise measurements; there is very little variation in the readings. However, they are also inaccurate as they are quite far from the true value (centre). A systematic error may give these kinds of results.

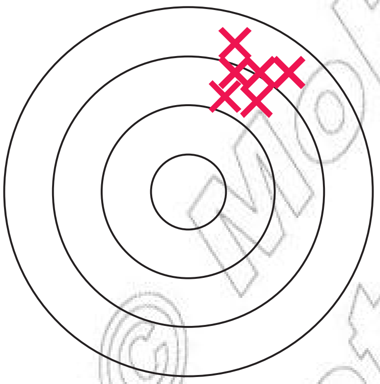


Figure 1.15 *Precise but inaccurate*

Here the measurements are imprecise as there is quite a large spread of readings, but at the same time they are accurate (they are all gathered around the true value). A large random error may cause this.

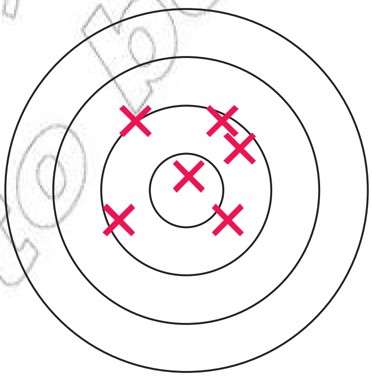


Figure 1.16 *Accurate but imprecise*

This is what we are aiming for! High precision, little spread from readings and all close to the true value.

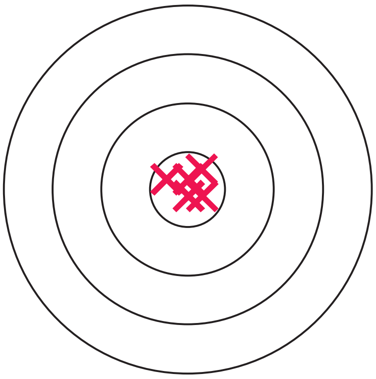


Figure 1.17 *Accurate and precise*

Instrument precision

The precision of an instrument is given by the smallest scale division on the instrument. A normal ruler may have a precision of 1 mm but a screw gauge micrometer has a precision of 0.01 mm.

When you are taking single readings, the precision of the piece of equipment you are using usually determines the uncertainty. For example, if you are using an ammeter with a precision of 0.01 A, then your readings might be:

$$0.32 \pm 0.01 \text{ A or } 2.61 \pm 0.01 \text{ A}$$

An exception to this rule would be if the nature of the task meant that there are other random errors that produce an uncertainty greater than the precision of the equipment.

For example, the bouncing ball experiment described earlier, or measuring the time of a pendulum swinging. A stopwatch may have a precision of ± 0.001 s but your reaction time is much greater. As a result it might be better to express the uncertainty as ± 0.1 s.

However, when you are taking multiple readings, for example recording p.d. with a voltmeter which has a precision of ± 0.01 V, you may obtain the following:

$$4.32 \text{ V} \qquad 4.36 \text{ V} \qquad 4.27 \text{ V}$$

The average would be 4.32 V (to 3 s.f., as the other readings). To express this average as 4.32 ± 0.01 V would not be right as you can tell by looking at your results the variation is more than ± 0.01 V.

In this case you would use half the range as your uncertainty. In the example above, the range from 4.27 V to 4.36 V is 0.09 V, so therefore half this range is 0.05 V. The average reading would be written as 4.32 ± 0.05 V. If you have no variation in your repeats, then you would use the precision of the instrument as the uncertainty.

Solving physics problems

When you are solving physics problems you need to make sure that you use the correct units. For example, one length may be given in feet and another in metres. You need to convert the length in feet to metres using a **conversion factor**. When you do the calculation, check that the units are correct using dimensional analysis.

If there are any intermediate stages in the calculation, keep all of the figures on your calculator screen for later stages in the calculation. You should only round your calculation to the appropriate number of significant figures at the end of the calculation.

Always check your calculations, because it is easy to make mistakes. Check that you are using the conversion factor correctly by making sure that when the units cancel, you are left with the units that you think you should have.

Activity 1.7: Determining instrument precision for different instruments

Look at a range of different pieces of measuring equipment. Determine the instrument precision in each case.

Activity 1.8: Uncertainty in the swing of a pendulum

Using a piece of string and some plasticine, make a simple pendulum. Working in pairs, time how long it takes to complete one swing for various different lengths. Repeat this three times for each length.

Calculate the average time of one swing for each length, and determine the uncertainty in this reading.

Discussion activity

How could you reduce the percentage error in the timing of the pendulum experiment?

KEY WORDS

conversion factor *a numerical factor used to multiply or divide a quantity when converting from one system of units to another*

Remember that when you are talking about an order of magnitude for an answer, this is much less precise than saying that it is approximately equal to something. For example, saying that N is ~ (is about) 10^{25} implies that N is in the range 10^{24} to 10^{26}, but saying that $N \approx 10^{25}$ implies that N is in the range, say 9×10^{24} to 1.1×10^{25}. The latter answer is much more precise.

Worked example 1.1

Berihun walks 3000 feet in 10 minutes. What speed is he walking at? Give your answer in metres per second.

First you need to convert the distance to metres and the time into seconds.

Conversion factor for feet to metres = 1 metre/3.28 feet

Distance = 3000 feet × 1 metre/3.28 feet

= 914.634 14 metres

Remember to keep all the digits from the conversion for the next stage in your calculation.

Time = 10 minutes = 10 × 60 seconds = 600 seconds

Speed = distance ÷ time

= 914.634 14 metres ÷ 600 seconds = 1.524 390 2 m/s

The greatest number of significant figures is three in the conversion factor, so your answer should be given to three significant figures.

Speed = 1.52 m/s

Summary

In this section you have learnt that:

- Accuracy is a measure of how close a measurement is to the true value of the quality being measured.
- Precision is a measure of the degree of 'exactness' of your value.
- A series of precise measurements will have very little variation.
- The significance of a measurement is indicated by the number of significant figures in your value.
- The precision of an instrument is usually given by the smallest scale division on the instrument. More precise instruments have smaller scale divisions.

Review questions

1. Explain the terms accuracy and precision. Describe how they differ using examples of experiments that you might conduct.
2. Research the precision of a range of instruments in your classroom.
3. Dahnay is 167 cm tall. Abeba is 66 inches tall. Who is taller and by how much.

   The conversion factor for inches to centimetres is 2.54 cm/1 inch.
4. a) What difference would it make to the answer in the worked example if you rounded the answer to the intermediate step to 3 significant figures?

   b) What effect do you think rounding the answer to each step might have in a calculation with several intermediate steps?

1.4 Report writing

By the end of this section you should be able to:

- Describe the procedures of report writing.
- Use terminology and reporting styles appropriately and successfully to communicate information and understanding.
- Present information in tabular, graphical, written and diagrammatic form.
- Report concisely on experimental procedures and results.

Presenting information

Science is a collaborative process. As discussed in the first section, all ideas must be independently tested and verified. It is therefore important to ensure that when you write up reports or write up experiments, you do so carefully.

Your results should be recorded in a clear and organised manner. This will usually be in a tabular format. Your tables should include all your raw data, including repeated readings and, where appropriate, columns for processed data (averages, calculations of resistance, etc). It is up to you if you wish to include clearly incorrect readings in your table, or simply repeat the reading.

Column headings must be labelled with a quantity and unit. You should use the standard convention for this: Quantity (unit). For example: Time (s) or Mass (kg).

A sample table can be seen below:

Length (m)	**Current (A)**			
	1st Set	2nd Set	3rd Set	Average

KEY WORDS

framework *an outline structure that can be used as the basis for a report*

A framework for writing up reports

There are lots of different ways to write up scientific investigations. Your teacher may have some suggestions.

A sample 10-point **framework** can be seen here. You might not always include every section for every experiment you write up, but instead just focus on three or four of the sections.

1 Title (and date)

2 Aim

- What theory are you going to test? Or what are you going to investigate, and why? Or what are you going to measure?

3 Theory

- Explain the theory behind your experiment, with all the equations set out and explained clearly.
- If you are going to plot a graph to find a quantity, explain how the graph will enable you to do this.
- You should then be able to refer back to/quote from this section in your method and in your analysis of results.

4 Diagram(s) of experimental arrangement(s)

- These should be BIG (don't be afraid to take up a full page), detailed and fully labelled, and showing how the experiment works.

5 Method

- Don't repeat information that is already in the diagram!
- Give a clear, detailed and step-by-step procedure (bullet-point list), including measurements to be taken, any repeats,

AND:

- Accuracy
- How did you ensure the accuracy of your measurements? (Any zero errors, was the experiment horizontal, etc.)
- How did you choose appropriate instruments to give readings to an appropriate precision? Mention the precision and range of key instruments used. For example, 1 m rule with a 1 mm scale, or a 0–10 A ammeter reading to 0.01 A.
- Did you do repeats? Were you looking from the correct angle when making measurements, etc?

6 Results

- Neatly set out ALL data/measurements recorded in a neat table, and averages (if applicable).
- Don't forget headings/explanations of each table, and don't forget the units either.

7 Analysis

- What does your data show?
- Draw large graphs (with suitable scales, so that points take up a least half of the paper) on graph paper, with titles, labelled axes (units), and best-fit (not necessarily straight) smooth lines drawn through the points.
- Describe what your graphs show.
- When you use information from your graph(s) explain what you are using – e.g. gradient, area, etc.

8 Error/uncertainty analysis

- Identify all possible sources of error in your measurements. Distinguish between random and systematic uncertainties.
- Quantify the uncertainty of these (e.g. using ½-range or instrument precision (see Section 1.3). Express the uncertainty as a percentage for important readings.
- Use these to estimate the uncertainty in your final results.

9 Conclusions

- This should refer back to the aim – i.e. can you answer the question implied by the aim?
- If measuring something, quote final value with experimental uncertainty. If there is an accepted value, comment on the difference between your value and the accepted value.
- Does your experimental data fit the theory within experimental uncertainty?

10 Evaluation

- How could you improve the experiment – how could you improve the reliability? Be specific and realistic – just saying 'be more careful' or 'use better equipment' is not enough.

Summary

In this section you have learnt that:

- Your experimental results should be recorded in a clear and organised manner.
- Experimental results are usually recorded in tabular form.
- You can use a 10-point framework to write up scientific investigations.

End of unit questions

1. Explain the importance of the scientific method.
2. Construct a glossary of all the key terms used in this unit.
3. Use the writing frame on pages 19–20 and complete all sections. Carry out a detailed investigation into one of the following:
   a) How the height a ball is dropped from affects the height it bounces up to.
   b) How the length of a piece of wire affects the electric current passing through it.
   c) How the angle of slope affects the time taken for a ball to roll down the slope.
4. For the two activities in question 3 that you did not carry out, identify:
   a) Possible sources of error.
   b) The sizes of the uncertainties in the measurements you would take.
5. Makeda says that you should write down all the numbers on the calculator display when recording the final result of a calculation. Is Makeda correct? Explain your answer.