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Working scientifically vocabulary booklet

Calibration

Calibration is the process of making sure the scale on the equipment is correct.

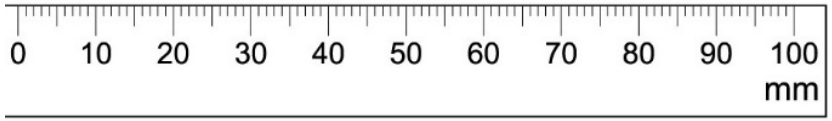
Normally manufacturers do this process for us and print the calibrated scale onto the equipment. They make sure the markings on the equipment exactly match the universally agreed standardised markings (the quantity values).

You can check whether equipment is calibrated correctly by applying universally agreed guidelines, for example by:

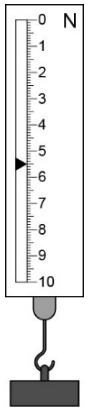
- placing a thermometer in melting ice to see whether it reads zero
- putting a pH probe into a solution with a known pH value to make sure the readings are the same.

Examples of equipment you could use in the lab

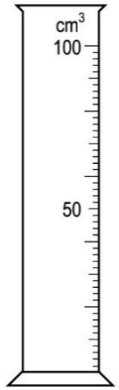
Ruler



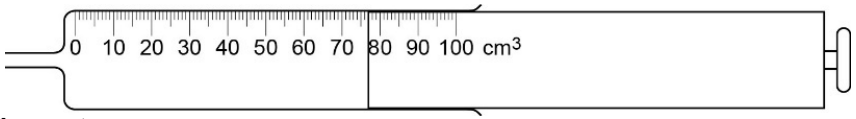
Newtonmeter



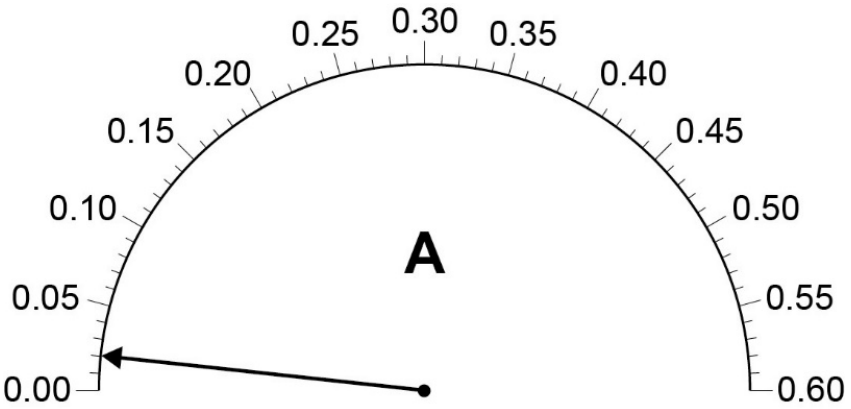
Measuring cylinder



Gas cylinder



Ammeter



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Resolution

Resolution is the smallest change a measuring instrument can detect.

When you're thinking about the resolution of a piece of equipment, it's important you're thinking about how **accurately** you can take the readings. So if the scale/intervals allows you to see very small changes then that's a good thing as it makes your readings more accurate.

Thermometers, like other measuring equipment, can have different resolutions. Here's an example of how to understand resolution in thermometers

(**Please note: we have included references to the original exam questions throughout this pack, but have adapted them slightly for the purpose of demonstration**).

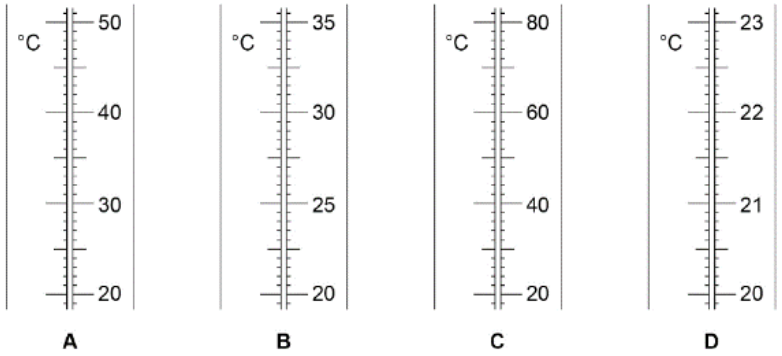
Please see next page for some example exam questions.

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Chemistry 1F, 2019, Q7.2
Look at the four thermometers below which all have a different resolution.

The student wanted to measure the temperature to a resolution of 0.1 °C

Which thermometer should the student use?



Answer and explanation (Chemistry 1F, 2019, Q7.2):
D

The thermometer you choose depends on how accurate you need to be in reading the temperature.

Thermometer D is the most accurate as you can see very small changes for each 1 °C, making the readings more accurate.

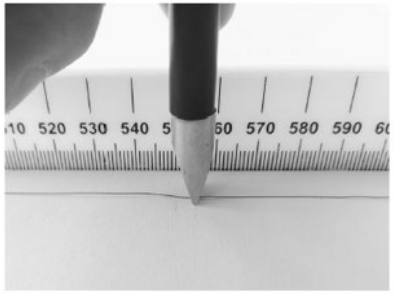
We say it has a high resolution.
Kitchen scales may have a resolution of 1 g but an electronic balance in the lab will have a resolution of 0.01 g. The electronic balance has a **higher** resolution.
Using equipment with a higher resolution will make your readings more accurate as they'll be closer to the true value.

Exam question (Picture from Physics 1F, 2018, Q12.4)

How would using the jockey have affected the accuracy and resolution of the student's results compared to using the crocodile clip?



Crocodile clip



Jockey

Answer
The accuracy of the student's results would be higher **because** the resolution of the length measurement would be higher (using the pointed shape of the jockey means you can read the length of wire to a millimetre rather than the wider crocodile clip).

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Range and interval In GCSE science, **the range** is the maximum and minimum values of variables you choose. It's important to choose the right range of values of variables, to make sure that you can see any pattern in the data you collect in your investigation. The **interval** is the quantity between each reading that you decide to take. In an investigation, the range and the interval are linked. **Don't mix up** the word interval with the markings on the piece of equipment you're using – these are the scale or graduations. **You decide** the interval that you're taking your reading at. **Don't forget** we often take a reading at the start of the experiment, eg at room temperature or at zero cm on a ruler. **Don't get mixed up** with the definition for range in GCSE Maths. In GCSE Maths statistics questions, when we ask about the range we're looking for the calculated value between the maximum and minimum value, ie the maximum minus the minimum value. In GCSE science, we're interested in the actual values themselves.	**Here's an example in science** If you were investigating the effect of temperature on enzyme activity, you'd use a range of readings between 20 °C and 60 °C as this covers the full range of temperatures where an enzyme starts to work and when it stops working and becomes denatured. You then need to choose enough readings within this range to see whether there is a pattern in the data. Usually, you space your intervals evenly across the range. In this example, a small interval of every 5 °C would be best to show the pattern. You could take 8 readings at 20, 25, 30, 35, 40, 45, 50, 55 and 60 °C. You probably wouldn't see the complete pattern if you chose intervals of 20 °C because the interval between readings is too large and you'd only have three readings at 20, 40 and 60 °C. If you have a set of temperatures, 20 °C, 27 °C, 32 °C, 41 °C, 53 °C, 66 °C: • In maths, you'd be asked to **calculate** the range giving an answer of 66–20 = 46 °C • In science, you could be asked to **state the range** of temperature readings. An answer of 66 °C to 20 °C would be correct.

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Sample
A sample is a subset of a population of data.

The term can also be applied to a sample of data obtained from an investigation into an event, for example:

- the volume of oxygen given off by a plant at different light intensities
- the distance different substances move in chromatography
- the amount of infrared radiation absorbed by different surfaces.

The more measured values there are in a sample, the more likely they are to be representative of the population or the event. This means you'll know more about the population from which you have taken the sample.

In exam questions, we won't be asking you to define a sample, but we could:

- ask you a practical question about the variables you would need to consider when selecting a sample
- give you a sample of data to answer questions on or analyse.

Exam question (Synergy 3H, 2018, Q7.3)
A teacher demonstrated the temperature change when hydrochloric acid is added to sodium hydroxide solution.

This is the method used:

1. Measure 25 cm^3 of sodium hydroxide solution, using a measuring cylinder.
2. Add the sodium hydroxide solution to a polystyrene cup.
3. Record the temperature of the sodium hydroxide solution.
4. Add 5 cm^3 of hydrochloric acid from a burette to the sodium hydroxide solution.
5. Stir the solution.
6. Record the temperature of the solution.
7. Repeat steps 4-6 until 50cm^3 of hydrochloric acid in total is added.

Table 1 shows some of the teacher's results.

Volume of hydrochloric acid added in cm^3	Temperature in °C
0	21.30
5	24.25
10	26.15
15	27.05
20	27.70

Suggest two ways of improving the accuracy of the results.
Answer
Any **two** from:

- repeat the experiment and calculate the mean
- use a lid
- insulate the polystyrene cup
- measure sodium hydroxide with a pipette/burette
- use smaller intervals for addition of the hydrochloric acid.

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True value
This is the value that would be obtained in an **ideal** measurement. In an ideal measurement, there would be no errors of any kind, and the value you obtain would be the true value.

When we take measurements, there'll always be errors, no matter how careful we are, so we can never know the true value for any measurement. All we can do is get as close to the true value as possible.

True value is used as a reference to judge how accurate the measurements we take are.

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Accuracy
A measurement is considered accurate if it's judged to be close to the **true value**.

You can't assign a number to accuracy; you just say if a measurement is more or less accurate.

To get more accurate measurements, you need to reduce **errors** and **uncertainties** as much as possible. For example, you could:

- use the same type of measuring equipment but one that has a higher resolution, eg to measure 8 cm^3 of water, use a 10 cm^3 measuring cylinder rather than a 100 cm^3 one
- take repeats and calculate a mean (this reduces random error, see later notes)
- make your observations something you can actually measure, like volume of gas, rather than counting number of bubbles or relying on subjective observations
- improve the steps in the method so chemicals are not 'lost' – if gas is escaping, put a lid on the container (see notes on validity)
- change the independent variable by finer amounts or have greater number of intervals. For example, add acid at 2 cm^3 intervals rather than 5 cm^3 intervals.

Don't confuse accuracy with precision.

Exam question (Physics 1H, 2018, Q7.1)

During an investigation, a student only recorded one set of results.

Give **two** reasons why taking repeat readings could provide more accurate data.

Answers
Any **two** from:
- to calculate a mean
- to reduce the effect of random error (human error not sufficient)
- to identify or remove anomalies.

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Uncertainty

This is the range within which you'd expect the true value to be.

Whenever a measurement is made, there'll always be some uncertainty or doubt about the result obtained because of errors.

Uncertainty can be expressed in terms of the spread of values obtained. For example, a length of 56 cm ± 2 cm would mean the true value could be anywhere between 54 cm and 58 cm.

There're two accepted ways of calculating uncertainty. They may give slightly different answers, but this is okay and **either approach** would score full marks if you use it correctly. You could:

either

- calculate the difference between the largest and smallest reading (the range), and divide it by two to give the uncertainty

or

- calculate the mean and then find the value that is furthest from the mean. The difference between the furthest value from the mean and the mean will give you the uncertainty.

Exam question (Physics 2H, 2018, Q5.3)

Table 2

	Angle of reflection			
Angle of incidence	**Test 1**	**Test 2**	**Test 3**	**Test 4**
20°	19°	22°	20°	19°
30°	31°	28°	32°	30°
40°	42°	40°	43°	41°
50°	56°	49°	53°	46°

Estimate the uncertainty in the angle of reflection when the angle of incidence is 50°.

Show how you determined your estimate.

Answer

Find range and divide by 2

$\frac{56° - 46°}{2}$ or $\frac{10}{2}$

Uncertainty = 5°

or

Calculated mean = 51°
Value furthest from the mean = 46°
Uncertainty = 51–46 = 5°

Precision

In science, precision refers to when you've taken repeat measurements and worked out the mean.

If the measurements are precise, they'll be very similar to the mean value you've calculated.

Scientists often use the phrase 'little spread about the mean value' when they feel that the results are close enough to the mean value to be an **acceptable** mean.

The spread in the readings taken is due to **random errors**.

The effect of random errors can be reduced by taking more measurements, disregarding any anomalous results and calculating a new mean.

Don't confuse precision and **accuracy**. Precision gives no indication of how close the readings are to the **true value** (ie how accurate they are).

Remember, precision refers to how close your readings are to the mean of your repeated readings.

Your readings could all be close to the mean value and so they would be precise, but these readings could all be very different from the true value due to some error you've made, so wouldn't be accurate.

If the error is a **systematic error**, your readings will probably be similar to each other.

Exam question (Physics 2H, 2019, Q7.5)

Table 2

Type of surface	Temperature in °C
Matt black	68.0
Matt white	65.5
Shiny black	66.3
Shiny silver	28.0

The four temperature values in **Table 2** cannot be used to show that the infrared detector gives precise readings.

Give the reason why.

Answer and explanation

The measurements for each surface have not been repeated. Repeats are needed to show that the readings are close or that they cluster.

A correct answer needs to say **why** the repeat is important when you want to make your readings precise.

Answers that said the repeats were for other reasons, such as to show accuracy or to get an average or to remove anomalies, were not acceptable.

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Types of errors

Different types of errors can happen during an investigation. Errors lead to measurements being different from the true value.

Measurement error

A measurement error is the difference between a measured value and the true value.

There're lots of things that can cause measurement errors. At GCSE, we group these causes into three types:

- random error
- systematic error
- zero error.

For example, a student measures the length of a spring as 15 cm, but its true value is 17 cm. This is a measurement error, but **the cause** of this error could be systematic or random, depending on whether the student is doing the wrong thing consistently (systematic) or only now and then (random).

It's important to read the exam question carefully and look at the context of the questions before deciding on what the type of error is and how to reduce or avoid it.

In an exam question, just putting '**human error**' is insufficient so you won't be given the mark

Exam question (Physics 1F, 2018, Q4.4 and 4.5)

A student wanted to determine the density of a small piece of rock.

To do this, they measured the volume of water the rock displaced when it was placed in water and then found its mass.

They then applied the formula:

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

a. Give **one** source of error that may have occurred when the student measured the volume of the rock.

b. How would the error you described affect the measured volume of the rock?

Answer

Source of error:

- eye position when reading the measuring cylinder
  or
- not all water displaced by the stone is collected

Effect of the error:

- the volume would be incorrect – higher or lower

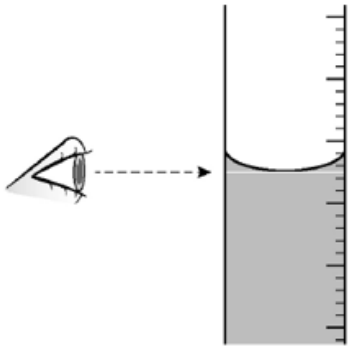
Random error Random errors cause readings to be spread about the **true value**, due to readings varying in an unpredictable way from one to the next. Random errors are present when any measurement is made, and can't be corrected. Random errors cause **uncertainty** in the results. Remember from earlier, you can reduce the effect of random errors by taking more measurements and calculating a new mean. By reducing random errors, you can make your results more accurate (closer to the true value).	**Exam question** (Physics 2F, 2018, Q11.2) The student measured the extension for five different forces rather than just measuring the extension of one force. Suggest why. **Answer** • to identify anomalous results or • to reduce the effect of random error **Please see next page for an extra exam question example.**

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Exam question (Physics 1H, 2018, Q7.2)

Figure 13 shows the position of the student's eye when taking volume measurements.

Figure 13



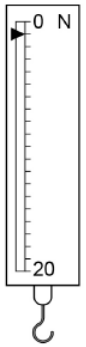
Explain what type of error would be caused if the student's eye was not in line with the level of the liquid in the measuring cylinder.

Answer

- Random error (parallax error would also be allowed).
- Because eye position would not be the same each time (relative to the liquid).

Note: If you could be certain that the student always viewed the liquid level from the same position above or below the meniscus then this might be classed as a systematic error.

Systematic error Systematic errors cause readings to differ from the **true value** by the same amount each time a measurement is made. Sources of systematic error can include: • the environment (where you are carrying out the experiment) • methods of observation • equipment used. You can't correct systematic errors simply by repeating the method. If you suspect a systematic error you should: • redo your data collection using a **different** technique or a **different** set of equipment • compare the two sets of results. If your second set of data is different from the first then there may have been a systematic error in your first method, which the second method has removed. To check, you should repeat the second method again to see if the results are similar. If they are, your data would be said to be **reproducible**.	**Exam question** (Chemistry 1F, 2019, Q7.3) A student investigated the temperature change in the reaction between dilute sulfuric acid and potassium hydroxide solution. This is the method used: 1. Measure 25 cm^3 of potassium hydroxide solution into a glass beaker. 2. Add 5 cm^3 of dilute sulfuric acid 3. Stir the solution 4. Measure the temperature of the solution 5. Repeat steps 2 to 4 until a total of 30 cm^3 of dilute sulfuric acid has been added. They repeated the experiment 3 times. The student did not put a lid on the beaker, so energy is transferred to the surroundings during the reaction. What type of error does this cause in the results? 1. Human error 2. Random error 3. Systematic error 4. Zero error **Answer** Systematic error

Zero error Zero errors occur when the measuring equipment is giving a reading, when it should be reading zero. An example would be an ammeter giving a reading even when there is no current flowing: it should read 0. Zero error will usually cause a consistent inaccuracy in the readings each time the equipment is used. You need to adjust for this inaccuracy.	**Exam question** (Combined Trilogy Physics 2H, 2018, Q4.2) The newtonmeter will give an error when used to make a measurement.  a. Name the type of error. b. Describe how this error can be corrected. **Answer** a. zero error b. record the value and subtract from readings taken or adjust the newtonmeter to zero

Anomalies

An anomalous result is a result that doesn't fit into the pattern of other results.

Anomalous results can usually be easily spotted.

You need to discard any anomalous results before calculating a mean. In some questions, we'll even tell you to ignore the anomalous result.

When you evaluate any data or information, you also need to look for possible anomalous results.

Some questions to ask yourself when evaluating would be:

- are there any anomalous results that can't be explained by experimental error?
- what could that show us?

Exam question (Chemistry 2F, 2018, Q7.3)

Time in seconds	Volume of gas collected in cm^3				
	Test 1	Test 2	Test 3	Test 4	Mean
0	0	0	0	0	0
40	46	30	47	49	**X**
80	78	83	83	82	82
120	98	94	96	95	96
160	100	100	100	100	100

Calculate mean value **X** in the table.

Do **not** include the anomalous result in your calculation.

Answer

$$\frac{46 + 47 + 49}{3} = 47.3$$

Repeats: Repeatability or Reproducibility Whether you use the term **repeatable** or **reproducible** about a measurement or investigation depends on who is doing the repeat. Repeatability is when the **original person** does the investigation again, using the same method and equipment, and obtains the same results. Reproducibility is when another person does the investigation, or the same person does it but uses **different equipment** or **techniques**, and gets the **same results**. Why scientists do repeats in the first place is to ensure the measurements they are taking are precise (readings are close to the mean) and accurate (close to true value).	**Exam question** (Combined Trilogy Physics 1F, 2019, Q1.4) A designer made some shoes that have lights in them. The designer tested how the number of cells affected the number of steps that could be taken before the lights stopped working. How could the designer test the repeatability of the test? Choose from the answers below: 1. Repeat the experiment with a different resistor 2. Repeat the experiment using exactly the same method 3. Repeat the experiment with different types of shoes **Answer** Repeat the experiment using exactly the same method.

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Valid: valid method or valid results/conclusions

Scientists want their investigations to be valid so the conclusion they're making will be accepted by the wider community of scientists. Scientists need to make sure that the design (the method) of an investigation is valid so the results and the conclusions made from the results are also valid.

When a method or procedure is **valid**, it means it's suitable to answer the question being asked.

For example, if you wanted to find out if the rate of a chemical reaction depends upon the concentration of one of the reactants, your method would **not be valid** if you don't control the temperature of the reactants because this is one of the control variables.

In exam questions you might be asked:

- to give a method that will give valid results
- to suggest changes to a method to make the results more valid
- to say why a conclusion is valid or not and explain why.

This means you need to bring together all you know about experimental procedures to see if the method is wrong or errors were made when taking the measurements.

Think about:

- choosing the correct sample
- setting up experimental controls
- the different types of variables
- the range and intervals of the variables
- any errors that may occur and how to correct them
- anomalous results and what could cause them.

In an investigation, a scientist may need to sample a population to collect data or views to back up a statement the scientist is making.

If you're trying to decide if the procedure or statement is valid, think about how the sample group has been chosen and the type of data collected.

In field work, it's often difficult to control all the variables and to make sure your sampling is representative of the area.

To make sampling more valid, more quadrats may be need to be sampled.

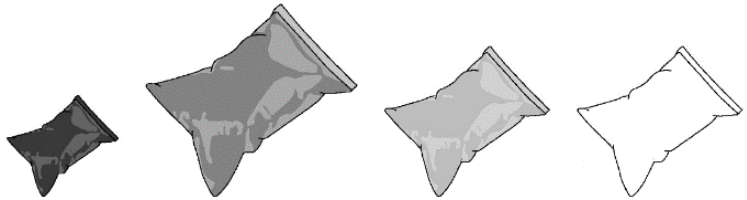
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Exam question (Synergy 2F, 2018, Q9.2)
A solar water bag can be used to heat water for an outdoor swimming pool.

A student wanted to find out if the colour of the solar water bag affects the temperature increase of the water inside the bag.

The figure shows some of the equipment used.



This is the method used:

1. Fill each bag with water.
2. Place the four bags on the ground outside.
3. After three hours, measure the temperature of the water inside each bag.
4. Repeat steps 1–3 on the next two days.

Suggest **three** changes the student should make to this method to get valid results.

Answer
Any **three** from:
- same surface area of bag (exposed to sun)
- same volume/mass of water
- use same starting temperature of water
- place all bags out at the same time
- place all bags out in same area/conditions
- same thickness of material/bag
- same type of material for each bag.

Exam question (Biology 2F, 2018, Q6.6)
Some students investigated the effect of a selective weed killer on the weeds growing in a lawn.

They sampled the area using quadrats, taking 5 samples of the treated area and 5 of an untreated area.

One student thought the results were **not valid**.

Suggest **one** improvement the student could have made to the method to make the results more valid.

Give a reason for your answer.

Answer
Improvement:
use more quadrats

Reason:
- original samples may not be representative of the whole area
  or
- the weeds may not have been unevenly distributed

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