

Practical skills

Revision notes • Planning, tables, graphs, biological drawings, magnification, evaluating experiments, errors and uncertainty, and indicators for Papers 5 and 6.

For Cambridge IGCSE Combined Science 0653. **Supplement** is Extended content, only examined on Papers 2 and 4.

Practical skills Spec S1, S2, S3, S4, S5, S6

Planning an investigation: variables, controls, range and repeats Spec S1

Paper 5 and Paper 6 often ask you to plan an investigation, sometimes one you have never done. A good plan says exactly what you change, what you measure, what you keep the same and how.

Independent variable	The variable that is changed in a scientific experiment by the scientist. Changing an independent variable may cause a change in the dependent variable.
Dependent variable	The variable that is observed or measured in a scientific experiment. It may change based on changes made to the independent variable.
Controlled (constant) variables	Other variables that could affect the dependent variable, so they are kept the same in every test.
Control experiment	A set-up that is identical except that the factor being tested is missing or inactive, for example boiled enzyme or no plant. It shows that any change is caused by the factor being tested.

What a full plan includes

- The **independent variable** and a suitable number and range of values: usually at least **five** values, evenly spaced, such as 20, 30, 40, 50 and 60 °C.
- The **dependent variable** and exactly how you measure it, with the apparatus: for example time with a stop-clock, volume with a measuring cylinder or syringe, mass with a balance.
- The variables you keep constant, **how** you keep each one constant and **why** it matters.
- A suitable control experiment.
- Repeats: do each test at least three times and calculate a mean.
- The risks and safety precautions.
- How you will record the results (a table) and process them (a mean, a rate, a graph) to reach a conclusion.

Example plan: the effect of temperature on the activity of amylase

Part of the plan	Example
Independent variable	temperature: 20, 30, 40, 50 and 60 °C, using water baths
Dependent variable	time taken for the starch to disappear, found by testing a drop of the mixture with iodine solution every 30 s until it stays orange-brown
Constant: volume and concentration of starch and amylase	measure each with a syringe or measuring cylinder, because more enzyme or substrate changes the rate
Constant: pH	add the same volume of a buffer solution, because pH also affects enzyme activity
Control	boiled (denatured) amylase with starch: the iodine stays blue-black
Repeats	three tests at each temperature, then a mean

Practical skill: Leave the enzyme and the substrate in separate tubes in the water bath for a few minutes before mixing, so both reach the test temperature.

Predictions and safety

A **reasoned prediction** gives the expected result and a reason, for example: 'the time will decrease from 20 °C to about 40 °C because the molecules have more kinetic energy and collide more often, then increase above 40 °C because the enzyme is denatured.'

- Wear eye protection when using chemicals, indicators or hot water.
- Take care with hot water baths and hot test-tubes: use a test-tube holder.
- Cut away from your body on a white tile when using a scalpel.
- Keep ethanol away from flames because it is flammable.
- Wash your hands after handling soil, plants or living organisms.

Exam tip: For a safety mark, link the precaution to the hazard, for example 'wear eye protection because iodine solution is an irritant'. 'Be careful' scores nothing.

Recording results: tables, units and the solidus Spec S2

Paper 6 often gives marks just for drawing a correct results table. Cambridge has strict rules for this, and the most important one is the **solidus**: the quantity and its unit are separated by a slash, as in **time / s**.

The rules for a results table

- Draw a ruled table with a border and lines between columns.
- Put the independent variable in the first column and the dependent variable (with any repeats and the mean) in the next columns.
- Head each column with the quantity and the unit, separated by a solidus: temperature / °C, time / s, mass / g, volume / cm³.
- Do not put units in the body of the table, only in the heading.
- Record data to reflect the **precision** of the measuring instrument, and give every value in a column to the same number of decimal places.
- For tests with no number, record the observation itself, for example 'blue-black' or 'stays orange-brown', not just 'positive'.

Badly drawn and well drawn table entries

Feature	Badly drawn	Well drawn
Column heading	Time (s) or Time or Seconds	time / s
Heading for a calculated value	Change	change in mass / g
Data in the body	45 s	45
Decimal places in one column	2.5, 2.48, 2.6	2.50, 2.48, 2.60
Qualitative result	positive	brick-red precipitate

A well drawn results table: the effect of sucrose concentration on the mass of potato pieces

concentration of sucrose / mol dm ⁻³	mass at start / g	mass at end / g	percentage change in mass / %
0.0	2.50	2.75	+10.0
0.2	2.48	2.60	+4.8
0.4	2.52	2.40	-4.8
0.6	2.50	2.30	-8.0

Precision follows the instrument. A stop-clock reading to 1 s gives whole seconds. A thermometer with 1 °C graduations gives readings to the nearest 1 °C. A ruler marked in mm gives lengths to the nearest mm. A balance reading to 0.01 g gives masses such as 2.50 g, so write the final zero.

Processing results

$$\text{percentage change} = (\text{final value} - \text{starting value}) \div \text{starting value} \times 100$$

Percentage change in mass

A potato piece has a mass of 2.50 g at the start. After 30 minutes in a sucrose solution its mass is 2.20 g. Calculate the percentage change in mass.

1. change in mass = $2.20 - 2.50 = -0.30$ g
2. divide by the starting mass: $-0.30 \div 2.50 = -0.12$
3. multiply by 100: $-0.12 \times 100 = -12$

Answer: -12 % (the minus sign shows the mass decreased)

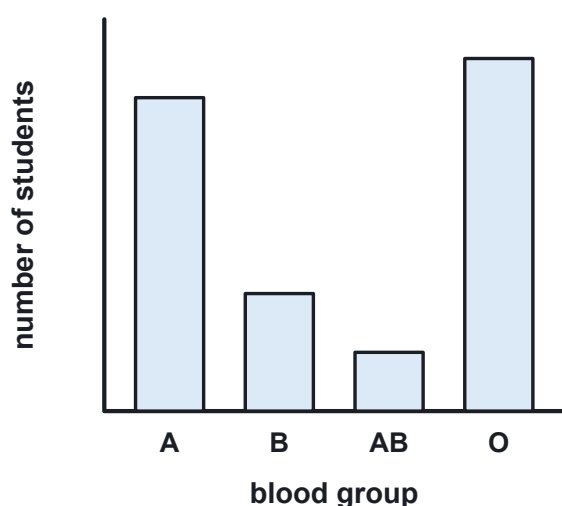
Maths skill: Always divide by the starting value, not the final value. Keep the + or - sign, because it shows whether the mass went up or down.

Drawing graphs and charts the Cambridge way Spec S3

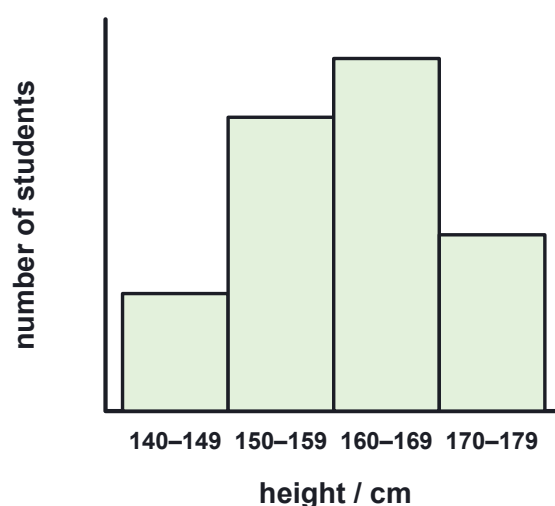
First choose the right kind of chart. The choice depends on whether the independent variable is continuous (any value on a scale) or categorical (separate groups).

Choosing a graph or chart

Type	Use it for	Rule
Line graph	a continuous independent variable, such as temperature or time	plot points, then a best-fit line or curve
Bar chart	categorical or discrete data, such as blood groups or species	bars of equal width that do not touch
Histogram	continuous data grouped into classes, such as height in 5 cm groups	bars that touch
Pie chart	percentages or proportions of a whole	sectors add up to 100 %



bars do not touch: categorical data



bars touch: continuous data

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A bar chart for **categorical data** has gaps between the bars; a histogram for **continuous data** has **bars that touch**.

Rules for a line graph

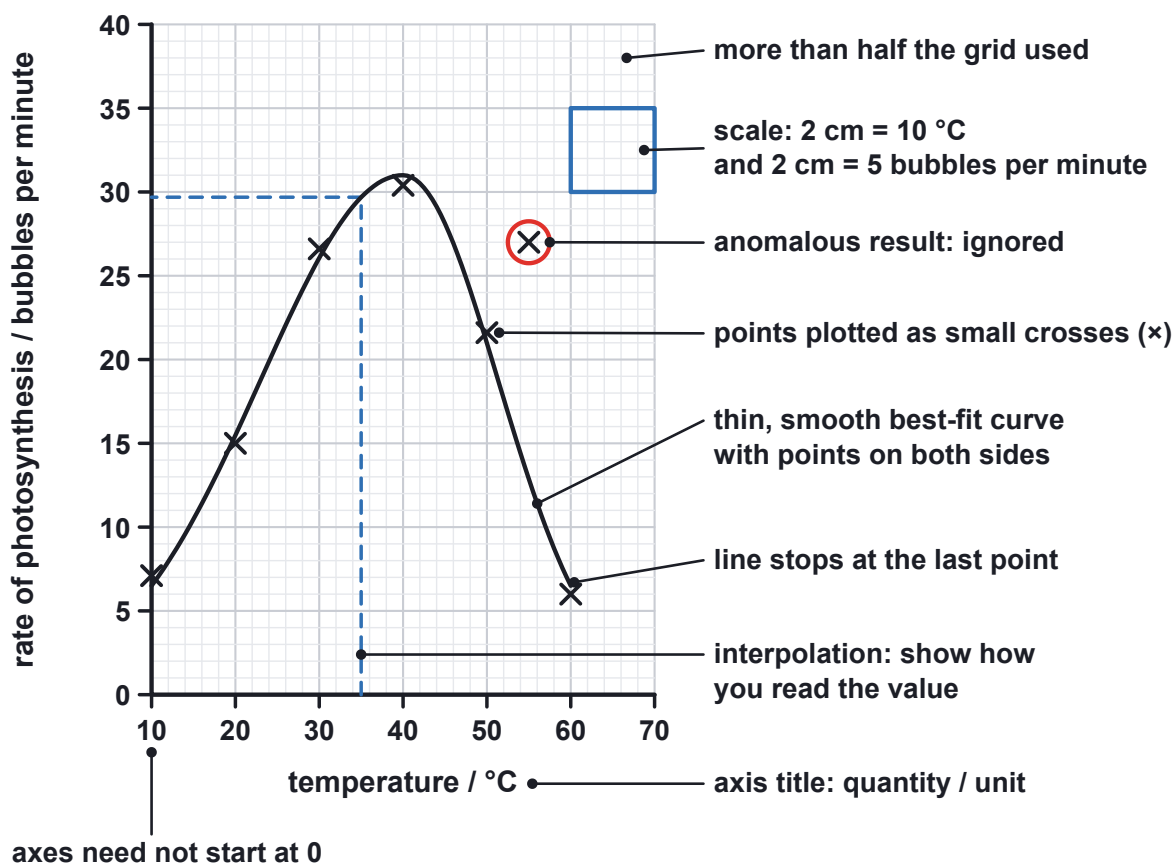
- Use a sharp pencil.
- Put the independent variable on the x-axis and the dependent variable on the y-axis, unless told otherwise.
- Label each axis with the quantity and unit, using the table headings: temperature / °C.
- Choose scales that use **more than half the grid** in both directions, with 2 cm representing 1, 2 or 5 units (or 10, 20, 50 ...). The axes do not have to start at (0, 0).
- Plot each point as a small cross (x) or an encircled dot (⊙), to within half of the smallest square.
- Draw a single, thin, smooth best-fit line or curve, with points spread evenly on either side. Ignore clearly anomalous points.
- Only draw a best-fit line if you can expect to predict values between the points. If asked to join the points instead, use ruled straight lines from point to point.
- Do not extend the line beyond the first and last points unless you are asked to extrapolate.

Choosing a graph scale

The temperature in an experiment ranges from 10 °C to 60 °C. The rate ranges from 4 to 46 bubbles per minute. The graph grid is 16 cm wide and 20 cm high, in 2 cm squares. Choose a scale for each axis.

1. x-axis (temperature): try 2 cm = 5 °C. From 10 to 60 °C is 50 °C, which needs 10 squares = 20 cm. That is too wide for a 16 cm grid.
2. Try 2 cm = 10 °C. From 0 to 60 °C needs 6 squares = 12 cm. This is more than half of 16 cm, so it is acceptable.
3. y-axis (rate): try 2 cm = 5 bubbles per minute. From 0 to 50 needs 10 squares = 20 cm. This fills the grid.
4. Reject 2 cm = 20 bubbles per minute: 0 to 60 uses only 6 cm, less than half the height. Reject 2 cm = 3: it is an awkward ratio that makes plotting and reading hard.

Answer: x-axis: 2 cm = 10 °C. y-axis: 2 cm = 5 bubbles per minute.



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A correctly drawn line graph: axis titles as **quantity / unit**, small crosses, a thin smooth **best-fit curve** and the anomalous result ignored.

Reading and describing a graph

Read values to within half of the smallest square, and draw lines on the graph to show how you read them. **Interpolation** means reading a value between plotted points. **Extrapolation** means extending the line beyond the plotted points to predict a value. For a straight line, the gradient = change in y ÷ change in x, which gives a rate.

Exam tip: To describe a graph, give the overall trend, any change in trend or peak, and quote data with units, for example 'the rate increases from 10 °C to a maximum of 31 bubbles per minute at 40 °C, then falls'.

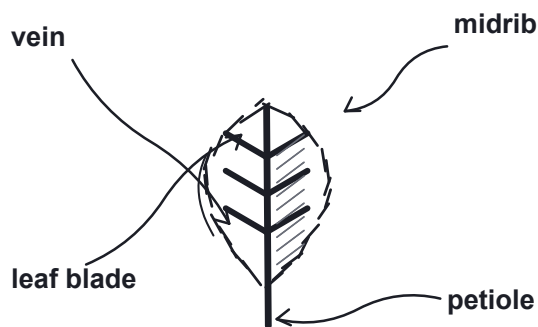
Biological drawings and measuring specimens Spec S4

You may be asked to draw a specimen in front of you (a flower, seed or leaf, often seen through a hand lens) or a photograph of one, then add labels and calculate the magnification or the actual size.

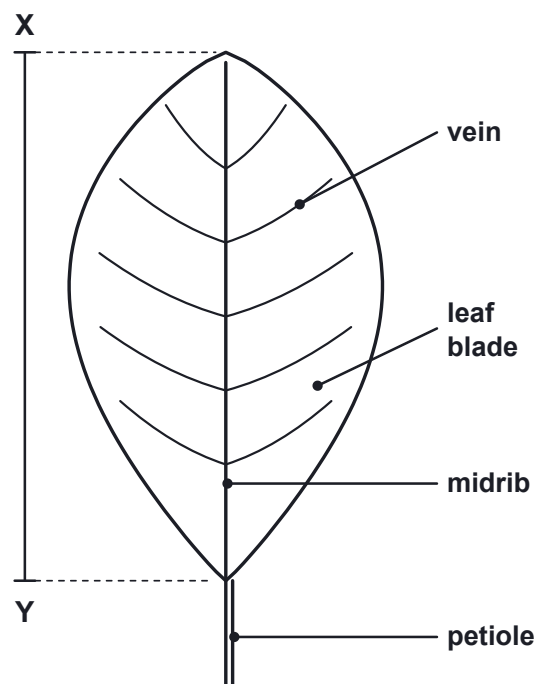
Drawing rules

- Use a sharp pencil to give fine lines that are **clear and unbroken**.
- Make the drawing large, using most of the space provided.
- Show all the features you can see in the specimen, in the correct proportions, and nothing you cannot see.
- Use **no shading** and no colour.
- Draw label lines with a ruler. Each line must touch the feature it labels. Do not use arrowheads, and do not let label lines cross.
- Write labels outside the drawing, and add a title.

Common faults in biological drawings		
Feature	Badly drawn	Well drawn
Outline	sketchy, broken or doubled lines	one clear, continuous line
Size	small, in a corner of the box	fills most of the space
Detail	shading, colour or features copied from a textbook	only the features seen, no shading
Labels	freehand lines with arrowheads that stop short	ruled lines that touch the feature



poor drawing



Drawing of a leaf

good drawing

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A good biological drawing is **large, clear and unshaded**, with ruled label lines that touch the features.

Measuring and magnification

Measure with a ruler in **millimetres**. To compare a drawing with a specimen or photograph, measure the same feature on both, for example the length along a line drawn between two marked points.

$$\text{magnification} = \text{image size} \div \text{actual size}$$

Here the image is your drawing or the photograph. Rearranged: $\text{actual size} = \text{image size} \div \text{magnification}$. Both sizes must be in the same unit. Magnification has no unit and is written with a $\times$ sign, for example $\times 3$.

Magnification of a drawing

The actual length of a leaf, measured with a ruler, is 45 mm. In a student's drawing the leaf is 135 mm long. Calculate the magnification of the drawing.

1. $\text{magnification} = \text{image size} \div \text{actual size}$
2. $= 135 \text{ mm} \div 45 \text{ mm}$
3. $= 3$

Answer: $\times 3$

Actual size from a photograph

A photograph of a seed has a magnification of $\times 4$. The seed is 52 mm long on the photograph. Calculate the actual length of the seed.

1. actual size = image size $\div$ magnification
2. = 52 mm $\div$ 4
3. = 13 mm

Answer: 13 mm

Supplement

To convert between millimetres and micrometres: 1 mm = 1000 μm . Multiply mm by 1000 to get μm , and divide μm by 1000 to get mm. For example, a cell that is 30 mm long in an image magnified $\times 600$ is $30 \div 600 = 0.05 \text{ mm} = 50 \mu\text{m}$ long.

Practical skill: Show your measurement, the formula and the working. If the answer has many decimal places, round it sensibly, for example $\times 2.5$ rather than $\times 2.4615$.

Evaluating experiments: errors, anomalies and improvements Spec S5

Evaluating means judging how good the method and the data are, then suggesting specific improvements. Paper 6 often describes an experiment with weaknesses for you to spot.

Anomalous result	A result that does not fit the pattern of the other results.
Repeats	Doing the same test again, so that anomalous results can be spotted and a mean calculated.
Replicates	Several identical set-ups tested at the same time, such as five seeds in each dish.
Source of error	Something in the method or apparatus that makes the measured values differ from the true values.

Dealing with anomalous results

- Identify the **anomalous result** by comparing it with the repeats and the trend.
- Repeat that test if you can.
- Leave it out when you calculate the mean.
- Ignore it when drawing a best-fit line.

Calculating a mean with an anomalous result

A student counts bubbles from pondweed in three trials: 21, 9 and 23 bubbles per minute. Calculate the mean.

1. 9 is much lower than 21 and 23, so it is anomalous and is left out.
2. Add the remaining values: $21 + 23 = 44$
3. Divide by the number of values used: $44 \div 2 = 22$

Answer: 22 bubbles per minute

Sources of error and improvements

Common sources of error and improvements	
Source of error	Improvement
Only one result for each value	repeat each test at least three times and calculate a mean
Temperature not controlled, or a lamp heats the water	use a thermostatically controlled water bath, or put a heat shield (a beaker of water) between the lamp and the plant
Colour end-point judged by eye	compare against a colour standard, or test more often (every 10 s instead of every 30 s)
Volumes measured with a beaker	use a syringe or measuring cylinder
Bubbles of different sizes counted	collect the gas in a gas syringe or measuring cylinder and measure its volume
Pieces of tissue different sizes	cut pieces of the same size with a scalpel and ruler, or measure their mass with a balance
Too few values or too wide a range	use at least five values, with smaller intervals near the peak

Also check the **control**. If there is no control, suggest one. A conclusion must be justified with data: state the pattern, quote values, and say whether the results support the prediction.

Common mistake: 'Human error' and 'be more accurate' score nothing. Name the exact problem and the exact fix, such as 'use a 10 cm³ syringe instead of a beaker'.

Errors, uncertainty and the language of measurement Spec S5

The Combined Science practical papers (Paper 5 and Paper 6) test some measurement skills that are shared with chemistry and physics. You need to read scales carefully, spot and correct errors, judge whether results agree, and use the words for measurement correctly.

Reading scales

- Take readings with the right **precision**. Where the marks on a scale are far apart, read to the nearest **half-scale division**. On a thermometer marked every 1 °C, a reading halfway between 24 °C and 25 °C is recorded as 24.5 °C.
- Correct for **zero errors**. A zero error is when an instrument does not read zero when it should, such as a balance that shows 0.2 g with nothing on it. Subtract the zero reading from every measurement: $5.6 \text{ g} - 0.2 \text{ g} = 5.4 \text{ g}$.
- If the end of a ruler is worn, measure from the 1.0 cm mark and subtract 1.0 cm from each reading.

Types of error

Three types of error		
Type of error	What it is	How to reduce it
Measurement error	The difference between a measured value and the true value. Every measurement has some.	Use an instrument with a finer scale, such as a syringe instead of a beaker
Random error	Readings vary unpredictably, some above and some below the true value, for example when judging a colour change or counting bubbles by eye	Repeat the readings and calculate a mean
Systematic error	Every reading is wrong by the same amount or in the same direction, for example because of a zero error or a thermometer that always reads 1 °C too high	Check and correct the instrument. Repeating the readings does not remove it

Uncertainty and the $\pm 10\%$ rule

Uncertainty means you cannot be sure that a value or a conclusion is correct. Causes include readings that are hard to judge (such as a colour end-point), variables that were not controlled, too few repeats, too small a range of values and anomalous results.

At this level, two results count as **equal within the limits of experimental accuracy** if they differ by no more than **10%**. Work out 10% of one value and check whether the other value is inside that range.

Are two results equal within $\pm 10\%$?

Two students time the same enzyme reaction. One records 50 s and the other records 54 s. Are the results equal within the limits of experimental accuracy?

1. 10% of 50 s = 5 s
2. The range allowed is 50 s $\pm$ 5 s, which is 45 s to 55 s.
3. 54 s is inside this range.

Answer: Yes, the results are equal within the limits of experimental accuracy ($\pm 10\%$).

The language of measurement

True value	The value that would be obtained in an ideal measurement.
Measurement error	The difference between a measured value and the true value of a quantity.
Accuracy	A measurement is accurate if it is close to the true value.
Precision	How close the measured values of a quantity are to each other.
Repeatability	A measurement is repeatable if the same or a similar result is obtained when it is repeated under the same conditions, by the same method, in the same experiment.
Reproducibility	A measurement is reproducible if the same or a similar result is obtained under different conditions, by a different method or in a different experiment.
Validity	An experiment is valid if it tests what it says it will test: a fair test in which only the independent and dependent variables change and the controlled variables are kept constant.
Range	The maximum and minimum values of the independent or dependent variable.
Anomaly	A value that is outside the general pattern of the results: very high or very low compared with the others.

Exam tip: You will not be asked to recall these definitions word for word, but you must use the words correctly. Precise means the repeats are close to each other. Accurate means close to the true value. Results can be precise but not accurate if there is a systematic error.

Indicators and tests: limewater, hydrogencarbonate, universal indicator and litmus

Spec S6

Indicators change colour to show a chemical change. You must know the colours for each one, and always give the colour **before and after**.

Indicators you need to know		
Indicator	What it shows	Colours
Limewater	carbon dioxide	colourless → milky (cloudy white) when carbon dioxide is bubbled through
Hydrogencarbonate indicator	carbon dioxide concentration	red at the level in air; yellow when carbon dioxide increases; purple when carbon dioxide decreases
Universal indicator	pH (a number)	red/orange in acid, green at pH 7 (neutral), blue/purple in alkali
Litmus	acid or alkali	turns red in acid, blue in alkali

Testing pH

1. Add a few drops of universal indicator solution to the sample, or dip universal indicator paper into it.
2. Compare the colour with the pH colour chart.

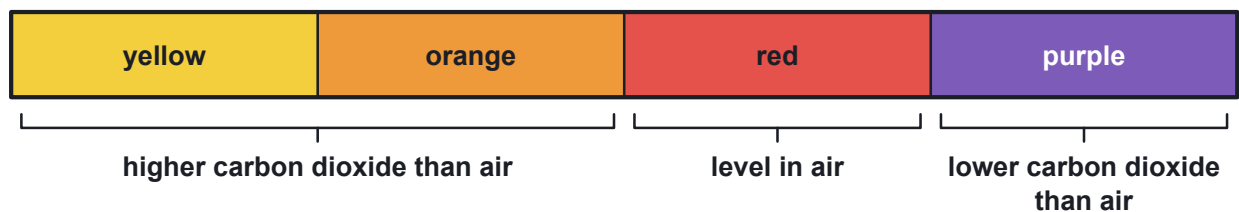
3 . Read off the pH number.

Litmus only tells you whether a solution is acidic or alkaline. Universal indicator gives the pH number, so it shows how strongly acidic or alkaline it is.

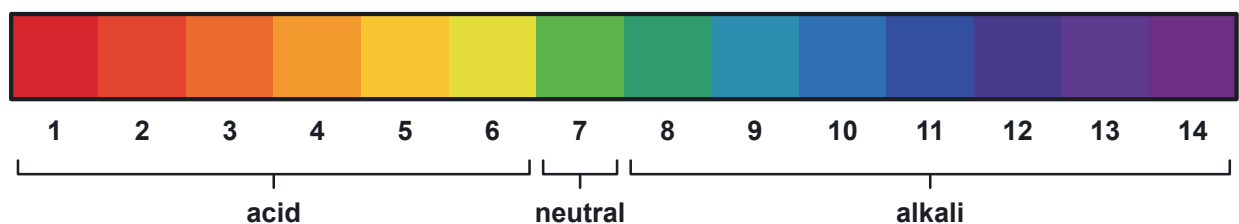
Where they are used

- Limewater: comparing inspired and expired air, and showing that yeast or germinating seeds respire.
- Hydrogencarbonate indicator: gas exchange in an aquatic plant in light and dark, or respiration of small organisms in a sealed tube.
- Universal indicator or litmus: the pH falling as lipase digests fat into fatty acids, or testing soil and water samples.

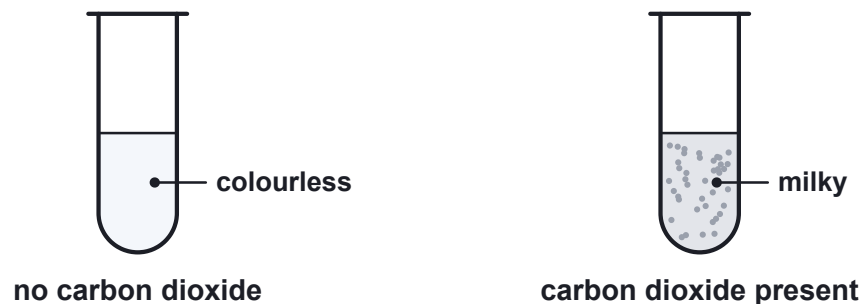
hydrogencarbonate indicator



universal indicator (pH scale)



limewater



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Indicator colours: always give the colour **before and after**. Limewater turns **milky** with carbon dioxide.

Food tests

Food tests (full details are in Biological molecules)		
Test	For	Positive result
Iodine solution	starch	orange-brown → blue-black
Benedict's solution, heated in a water bath	reducing sugars	blue → green, yellow, orange or brick-red
Biuret test	proteins	blue → purple
Ethanol emulsion test	fats and oils	cloudy white emulsion
DCPIP	vitamin C	blue → colourless

Practical skill: Wear eye protection for all these tests. Heat Benedict's in a water bath, not over a flame, and keep ethanol away from flames because it is flammable.

Quick check

1. How should a column heading for time in seconds be written?
2. Which variable goes on the x-axis?
3. State the formula for magnification.
4. What colour does hydrogencarbonate indicator turn when carbon dioxide increases?
5. A balance reads 0.3 g with nothing on it. What is this, and how do you correct for it?
6. Two results are 40 s and 43 s. Are they equal within the limits of experimental accuracy?

Quick check answers

Practical skills

1. time / s
2. The independent variable, unless told otherwise.
3. magnification = image size $\div$ actual size
4. Yellow (from red).
5. A zero error (a systematic error). Subtract 0.3 g from every reading.
3. Yes. 10% of 40 s is 4 s, so any result from 36 s to 44 s counts as equal.