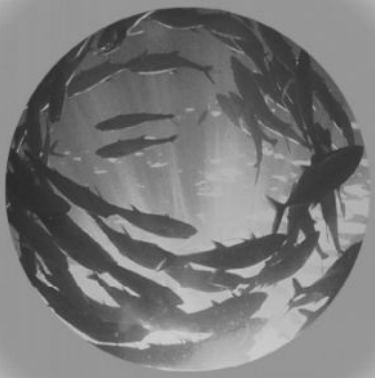


AS Experimental Skills & Investigations

AS Experimental skills and investigations

Almost one quarter of the total marks for your AS examination are for experimental skills and investigations. These are assessed on Paper 3, which is a practical examination.

There is a total of 40 marks available on this Paper. Although the questions are different on each Paper 3, the number of marks assigned to each skill is always the same. This is shown in the table below.

Skill	Total marks	Breakdown of marks	
Manipulation, measurement and observation, MMO	16	Successfully collecting data and observations	8 marks
		Making decisions about measurements or observations	8 marks
Presentation of data and observations, PDO	12	Recording data and observations	4 marks
		Displaying calculations and reasoning	2 marks
		Data layout	6 marks
Analysis, conclusions and evaluation, ACE	12	Interpreting data or observations and identifying sources of error	6 marks
		Drawing conclusions	3 marks
		Suggesting improvements	3 marks

The syllabus explains each of these skills in detail, and it is important that you read the appropriate pages in the syllabus so that you know what each skill is, and what you will be tested on.

The next few pages explain what you can do to make sure you get as many marks as possible for each of these skills. They give you guidance in how you can build up your skills as you do practical work during your course, and also how to do well in the examination itself. They are not arranged in the same order as in the syllabus, or in the table above. Instead, they have been arranged by the kind of task you will be asked to do, either in practical work during your biology course or in the examination.

There is a great deal of information for you to take in, and skills for you to develop. The only way to do this really successfully is to do lots of practical work, and gradually build up your skills bit by bit. Don't worry if you don't get everything right first time. Just take note of what you can do to improve next time — you will steadily get better and better.

The examination questions

There are usually two questions on Paper 3. The examiners will take care to set questions that are **not exactly the same** as any you have done before. It is possible that there could be three shorter questions instead of two longer ones, so do not be surprised if that happens.

It is very important that you do exactly what the question asks you to do. Candidates often lose marks by doing something they have already practised, rather than doing what the question actually requires.

Question 1

This is likely to be what is sometimes called a 'wet practical'. For example, it could be:

- an investigation into the activity of an enzyme
- an osmosis experiment
- tests for biological molecules

This question will often ask you to investigate the effect of one factor on another — for example, the effect of enzyme concentration on rate of reaction, or the effect of leaf area on the rate of transpiration.

Question 2

This question is likely to involve making drawings from a specimen. This could be a real specimen, or it could be a photograph. You may be asked to use a microscope, a stage micrometer and eyepiece graticule, or images of them, to work out the magnification or size of the specimen.

The two questions are designed to take up approximately equal amounts of your time. You should therefore aim to spend about 1 hour on each question.

Tips During your course:

- Every time you do a practical during your AS course, time yourself. Are you working quickly enough? You will probably find that you are very slow to begin with, but as the course progresses try to work a little faster as your confidence improves.

In the exam:

- Do exactly what the question asks you to do. This is unlikely to be exactly the same as anything you have done before.
- Leave yourself enough time to do each question, spending an appropriate number of minutes on each one.

How to get high marks in Paper 3

Variables

Many of the experiments that you will do during your AS course, and usually Question 1 in the examination paper, will investigate the effect of one factor on another. These factors are called **variables**.

Types of variables

The factor that you change or select is called the **independent variable**. The factor that is affected (and that you measure when you collect your results) is the **dependent variable**. The table shows some examples.

Some examples of investigations

Investigation		Independent variable	Dependent variable
1	Investigation into the effect of temperature on the rate of breakdown of hydrogen peroxide by catalase	temperature	volume of oxygen produced per minute
2	Investigating the effect of immersion in solutions of different sucrose concentration on the change in length of potato strips	sucrose concentration	change in length of potato strip
3	Testing the hypothesis: the density of stomata on the lower surface of a leaf is greater than the density on the upper surface	upper or lower surface of the leaf	number of stomata per cm^3
4	Investigation into the effect of leaf area on transpiration rate	total area of leaves	rate of movement of meniscus

We will keep referring back to these four examples in the next few pages, so you might like to put a marker on this page so you can easily flip back to look at the table as you read.

If you are investigating the effect of one variable on another, then you need to be sure that there are no other variables that might be affecting the results. It is important to identify these and — if possible — keep them constant. These are sometimes called **control variables**.

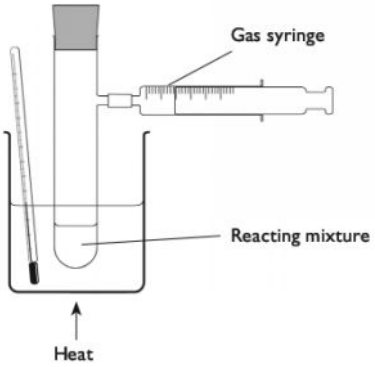
Making decisions about the independent variable

You may have to make your own decisions about the range and interval of the independent variable.

Let's think about **Investigation 1** in the table above — **investigating the effect of temperature on the rate of breakdown of hydrogen peroxide by catalase.**

The independent variable is the temperature. First, decide on the **range** of temperatures you will use. The range is the spread between the highest and lowest value. This will be affected by:

- the apparatus you have available to you, which will determine the possible range of temperatures you can produce. In this case, you will probably be using a water bath. If you are lucky, you may have a thermostatically controlled water bath, but in the exam you will probably have to use a beaker of water whose temperature you can control by adding ice or by heating it.



Changing the independent variable

- your knowledge about the range of temperature over which the rate of activity of the enzyme is likely to be affected. Even if you could manage it, there wouldn't be much point in trying temperatures as low as –50 °C or as high as 200 °C. However, you probably know that various enzymes can have optimum temperatures anywhere between 20 °C and 80 °C, so you should include these values in the range.

Next, decide on the **intervals** that you will use. The interval is the distance between the values that you choose. This will be affected by:

- the number of different values you can fit in within your chosen range, and how much time you have available to you. For example, you might ideally like to use intervals of 5 °C, so that you set up water baths at 0 °C, 5 °C and so on, all the way up to 80 °C. But obviously that would not be sensible if you only have five water baths, or if you only have 1 hour to do the experiment.
- the number of results you need to obtain. You are going to be looking for any pattern in the relationship between the independent variable (temperature) and the dependent variable (rate of reaction). You will need at least 5 readings to see any pattern. There is really no point trying to draw a graph if there will be fewer than 5 points on it. So, if your range of temperatures is 0 °C to 80 °C, you could use intervals of 20 °C. This would give you 5 readings — 0, 20, 40, 60 and 80 °C.

Producing different concentrations of a solution

In **Investigation 2, Investigating the effect of immersion in solutions of different sucrose concentration on the change in mass of potato strips**, the independent variable is the concentration of a solution. You may be given a sucrose

solution of a particular concentration, and then be asked to produce a suitable range of concentrations to carry out the experiment.

The *range* you should use will usually be from 0 (distilled water) up to the concentration of the solution you have been given (because obviously you can't easily make that into a more concentrated solution).

The *intervals* you use could be either:

- all the same distance apart, for example concentrations of 0.8, 0.6, 0.4 and 0.2 mol dm^{-3} (and, of course, 0.0 mol dm^{-3})
- produced by using serial dilutions to make concentrations of 0.1, 0.01 and 0.001 mol dm^{-3} (and, of course, 0.0 mol dm^{-3})

Producing a range of solutions of different concentrations from one given concentration

Let's say you need 10 cm^3 of sucrose solution of each concentration.

How to produce a range with equal intervals

Take a particular volume of your original solution and place it in a clean tube. Add distilled water to make it up to 10 cm^3.

Then do the same again, using a different volume of the original solution.

The table below gives some examples.

Producing a range of concentrations with equal intervals from a 1.0 mol dm^{-3} solution

Volume taken of original 1 mol dm^{-3} solution/cm^3	Volume of distilled water added/cm^3	Concentration of solution produced/ mol dm^{-3}
10	0	1.0
8	2	0.8
6	4	0.6
4	6	0.4
2	8	0.2
0	10	0.0

How to produce a range using serial dilutions

You could be asked to make up a series of solutions in which each one has a concentration that is one tenth of the previous one.

Take 1 cm^3 of your original solution and place it in a clean tube.

Add distilled water to make it up to 10 cm^3.

Now mix this new solution really well, and then take 1 cm^3 of it. Put this into a clean tube and make it up to 10 cm^3.

Keep doing this, each time taking 1 cm^3 from the new solution.

The table below summarises this.

Producing a range of concentrations using serial dilution of a 1.0 mol dm^{-3} solution

Solution used/ mol dm^{-3}	Volume taken of solution/cm^3	Volume of distilled water added/cm^3	Concentration of solution produced/ mol dm^{-3}
1.0	10	0	1.0
1.0	1	9	0.1
0.1	1	9	0.01
0.01	1	9	0.001
0.001	1	9	0.0001
0.0001	1	9	0.00001

You could also be asked to make up solutions where each is one half of the concentration of the previous solution.

Continuous and discontinuous variables

In Investigation 1, the independent variable (temperature) is **continuous**. This means that we can choose any value within the range we have decided to use. This is also true for Investigation 2, where we can choose any value of concentration within the range we have decided to use.

Sometimes, however, the independent variable is **discontinuous**. This means that there is only a limited number of possible values. For example, in **Investigation 3, Testing the hypothesis: the density of stomata on the lower surface of a leaf is greater than the density on the upper surface**, the independent variable has only two possible 'values' — either the upper surface of the leaf, or the lower surface of the leaf. So you don't have any choice about the range or intervals at all!

Tips During your course:

- Every time you do an experiment, identify and write down the independent variable and the dependent variable.
- Every time you do an experiment, think about the *range* and the *intervals* of the values you are using for the independent variable. For your own benefit, write down what the range is and what the intervals are, just to help you to think about them.
- Learn how to make up dilutions from a solution of a given concentration, and practise doing this until you feel really confident about it.

In the exam:

- Read the question carefully, then identify the independent variable and the dependent variable (even if the question does not ask you to do this).
- Next, decide if the independent variable is continuous or discontinuous (see above).
- If it is continuous, read the question carefully to see if you have been told the range and intervals to use, or if you are being asked to decide these for yourself.

Controlling the control variables

In your experiment, it is important to try to make sure that the only variable that could be affecting the dependent variable is the independent variable that you are investigating. If you think there are any other variables that might affect it, then you must try to keep these constant.

Look back at the Table on page 100.

In Investigation 1, the important control variables would be the concentration and volume of the enzyme solution and the concentration and volume of the hydrogen peroxide solution. Changes in any of these would have a direct effect on the rate of reaction.

In Investigation 2, the important control variables would be the dimensions of the potato strips and the potato tuber from which they came. You also need to think about time, but here the important thing is that the strips are left in the solution for long enough for equilibrium to be reached — after that, it doesn't really matter if one is left for slightly longer than another. You also need to be sure that all the strips are completely immersed in the solution, although the actual volume of the solution doesn't matter. Temperature, too, won't affect the final result, but it could affect the speed at which equilibrium is reached — if you leave the strips for long enough, then it does not really matter if the temperature varies.

In biology, we often want to do experiments where it is not possible to control all the variables. For example, we might want to investigate the effect of body mass index on heart rate when at rest. There are all sorts of other variables that might affect resting heart rate, such as gender, age, fitness, when a person last ate and so on. In this case, we just have to do the best we can, for example, by limiting our survey to males between the ages of 20 and 25. If we can collect results from a large *random* sample among this group of males, then we can hope that at least we will be able to see if there appears to be a relationship between our independent and dependent variables.

Tips During your course:

- Every time you do an experiment, think about which variables you have been told to control, or make your own decision about which ones are important to control. Get to know the standard ways of controlling variables such as temperature (use water baths), pH (use buffer solutions) and other variables.

In the exam:

- If you are not told what variables to control, then think about these carefully before deciding what you will control and how you will do it.

When to measure the dependent variable

In many experiments you will need to decide when, and how often, you should take a reading, observation or measurement of the dependent variable.

- With some investigations, you will need to leave things long enough for whatever is happening to finish happening. This would be important in Investigation 2, where you would need to leave the potato strips in the sucrose solutions for long enough for equilibrium to be reached.
- With some investigations, you may need to begin taking readings straight away. This would be important in Investigation 1, where you should begin measuring the volume of oxygen released each minute from time 0, which is the moment that the enzyme and its substrate are mixed.
- With some investigations, you may need to allow time for a process to settle down to a steady rate before you begin to take readings. This would be important in Investigation 4, where you would be measuring the rate of transpiration in a particular set of conditions.

Tips During your course:

- Every time you do an experiment where time is involved, think about why you should start timing from a particular moment, and when and why you should take readings.

In the exam:

- Think carefully about whether or not time is important. If you think it is, then decide when you will start taking readings, and how often you will take them. Remember that if you are going to use them to draw a graph, you will need at least 5 points to plot.

Taking measurements

You will often be asked to take measurements or readings. In biology, these are most likely to be length, mass, time, temperature or volume. You could be taking readings from a linear scale (for example, reading temperature on a thermometer, reading volume on a pipette, or reading length on a potometer tube). You could be reading values on a digital display, for example reading mass on a top pan balance or time on a digital timer.

There are some special terms that are used to describe measurements, and the amount of trust you can put into them. It's easiest if we think about them in terms of a particular experiment, so let's concentrate on Investigation 1. Look back at page 100 to remind yourself what is being measured.

Validity This is about whether what you are measuring is what you actually *intend* to measure. For example, in Investigation 1, does measuring the volume of oxygen in the gas syringe each minute really tell you about the rate of reaction? It is a valid method in this instance, because the volume of oxygen given off per unit time is directly related to the rate at which the reaction is taking place.

Reliability This is how well you can trust your measurements. Reliable results are ones that are repeatable. This could be affected by various factors, such as whether you are able to take a reading at the precise time you intended to.

Accuracy An accurate reading is a true reading. For your readings of volume to be accurate, then the gas syringe must have been calibrated correctly, so that when it says the volume of gas is 8.8 cm^3, then there really is exactly 8.8 cm^3 of gas in there.

Precision If you were able to put exactly 8.8 cm^3 of gas into your gas syringe, and it read 8.8 cm^3 every time, then your readings have a high degree of precision. If, however, the syringe didn't always read the same value (so there was variation in its readings, even though the actual volume of gas was exactly the same), then your measurements are less precise.

Resolution You probably already know this term, because we use it in microscopy to tell us the degree of detail that we can see. The smaller the detail, the higher the resolution. It means very much the same thing with a measuring instrument — the smaller the division on the scale of the measuring instrument, the higher its resolution. So, for example, a 10 cm^3 gas syringe marked off every 0.5 cm^3 has a higher resolution than a 20 cm^3 gas syringe marked off every 1 cm^3. If you get a choice, then go for the instrument with the highest resolution to make your measurements — so long as it can cover the range that you need.

Uncertainty in measurements— estimating errors

Whenever you take a reading or make a measurement, there will be some uncertainty that the value is absolutely correct. These uncertainties are **experimental errors**. Every experiment, no matter how well it has been designed, no matter how carefully it has been carried out and no matter how precise and accurate the measuring instruments, has this type of error.

You may be asked to estimate the size of the errors in your measurements. **This is nothing to do with how well you have made the measurements** — the examiners don't want to know about 'mistakes' that you might have made, such as misreading a scale or taking a reading at the wrong time. It is all about the inbuilt limitations in your measuring device and its scale.

- In general, **the size of the error is half the value of the smallest division on the scale**. For example, if you have a thermometer that is marked off in values of 1 °C, then every reading that you take could be out by 0.5 °C. You can show this by writing: 21.5 °C ± 0.5 °C.
- If your recorded result involves measuring *two* values — for example, if you have measured a starting temperature and then another temperature at the end, and have calculated the rise in temperature — then this error could have occurred for both readings. **The total error is therefore the sum of the errors for each reading**. Your final value for the change of temperature you have measured would then be written: 18.0 °C ± 1.0 °C.

Tip Every time you take a reading or make a measurement, get into the habit of working out and writing down the error (uncertainty) in each reading.

Recording measurements and other data

You will often need to construct a table in which to record your measurements, readings and other observations.

It is always best to design and construct your results table *before* you begin your experiment, so that you can write your readings directly into it as you take them.

Let's think about Investigation 2 again. You've made your decisions about the range and intervals of the independent variable (concentration of solution) — you've decided to use six concentrations ranging from $0.0\,mol\,dm^{-3}$ to $1.0\,mol\,dm^{-3}$. Your dependent variable is the change in length of the potato strips, and you are going to find this by measuring the initial length and final length of each strip.

These are the things you need to think about when designing your results table:

- The **independent variable** should be in the first column.
- The **readings** you take are in the next columns.
- Sometimes, these readings actually *are* your dependent variable. In this experiment, however, you are going to have to use these readings to *calculate* your dependent variable, which is the change in length of the strips. So you need to have another column for this. This comes at the end of the table. In fact, you really need to work out the *percentage* change in length of the strips, as this will allow for the inevitable variability in the initial lengths of the strips.

The table could look like this:

Results table for Investigation 2

Concentration of sucrose solution/ $mol\,dm^{-3}$	Initial length of potato strip/mm	Final length of potato strip/ mm	Change in length of potato strip/ mm	Percentage change in length of potato strip
0				
0.2				
0.4				
0.6				
0.8				
1.0				

Notice:

- The table has been clearly drawn, with lines separating all the different rows and columns. Always use a pencil and ruler to draw a results table.
- Each column is fully headed, including the unit in which that quantity is going to be measured. The unit is preceded by a slash /. You can use brackets instead — concentration of sucrose solution ($mol\,dm^{-3}$).
- The slash always means the same thing. It would be completely wrong to write: concentration of sucrose solution/mol/dm^3 as the heading of the first column. That would be really confusing. If you are not happy using negative indices like

dm^{-3}, you can always write 'per' instead. So it would be fine to write: concentration of sucrose solution/mol per dm^3.

- The columns are all in a sensible order. The first one is the independent variable, so you can write these values in straight away, as you have already decided what they will be. The next thing you will measure is the initial length of the strip, then the final length. Then you will calculate the change in length, and finally you will calculate the percentage change in length.

So now you are ready to do your experiment and collect your results. Here is what your table might look like.

Completed results table for Investigation 2

Concentration of sucrose solution/ mol dm^{-3}	Initial length of potato strip/mm	Final length of potato strip/ mm	Change in length of potato strip/ mm	Percentage change in length of potato strip
0	49.5	52.5	+3.0	+6.1
0.2	50.0	52.0	+2.0	+4.0
0.4	50.5	51.5	+1.0	+2.0
0.6	50.0	50.5	+0.5	+1.0
0.8	49.0	48.0	−1.0	−2.0
1.0	49.5	47.5	−2.0	−4.0

Notice:

- All the measurements in the second two columns were made to the nearest 0.5 mm. This is because the smallest graduation on the scale on the ruler was 1 mm. So it was possible to estimate the length to the nearest 0.5 mm. (Have a look at the scale on your ruler, and you will see that this is sensible.) Even if you decide that a length is exactly 50 mm, you must write in the next decimal place for consistency, so you would write 50.0.
- The values in the 'change in length' column each show whether they were an increase or a decrease.
- The percentage change in length is calculated like this:

$$\frac{\text{change in length}}{\text{initial length}} \times 100$$

(Do make sure you remember to take a calculator into the exam with you.)

- Each percentage change in length has been rounded up to one decimal place, for consistency with the change in length. For example, the calculation in the first row gives 6.0606, which you should round up to 6.1. The calculation in the sixth row gives 4.0404, which rounds up to 4.0.

Repeats

It is a good idea to do **repeats**. This means that, instead of getting just one reading for each value of your independent variable, you collect two or three. You can then calculate a **mean value**, which is more likely to be a 'true' value than any of the individual ones.

Let's say that you did this for the potato strip experiment. You could have used two potato strips for each sucrose concentration, then calculated the percentage change in length for each one, then finally calculated a mean percentage change.

This means adding some extra rows and an extra column to the results table, like this:

Completed results table (with repeats) for Investigation 2

Concentration of sucrose solution/ mol dm^{-3}	Initial length of potato strip/mm	Final length of potato strip/mm	Change in length of potato strip/mm	Percentage change in length of potato strip	Mean percentage change in length of potato strip
0	49.5	52.0	+2.5	+5.1	+4.6
	49.0	51.0	+2.0	+4.1	
0.2	50.0	52.0	+2.0	+4.0	+4.0
	50.5	52.5	+2.0	+4.0	
0.4	50.5	51.5	+1.0	+2.0	+2.5
	49.5	51.0	+1.5	+3.0	
0.6	50.0	50.5	+0.5	+1.0	+0.5
	51.0	51.0	0.0	0.0	
0.8	49.0	48.0	–1.0	–2.0	–2.0
	50.5	49.5	–1.0	–2.0	
1.0	49.5	48.0	–1.5	–3.0	–3.0
	50.5	49.0	–1.5	–3.0	

Notice:

- All of this information has been put in a single results table. This makes it much easier for someone to read and find all the information they need.
- The numbers in the final column have again been rounded up to one decimal place.

Qualitative observations

The results table for the potato strip experiment contains numerical values — they are **quantitative**. Sometimes, though, you may want to write descriptions in your results table, for example a colour that you observed. These are **qualitative** observations. If you are recording colours, write down the actual colour — do not just write 'no change'.

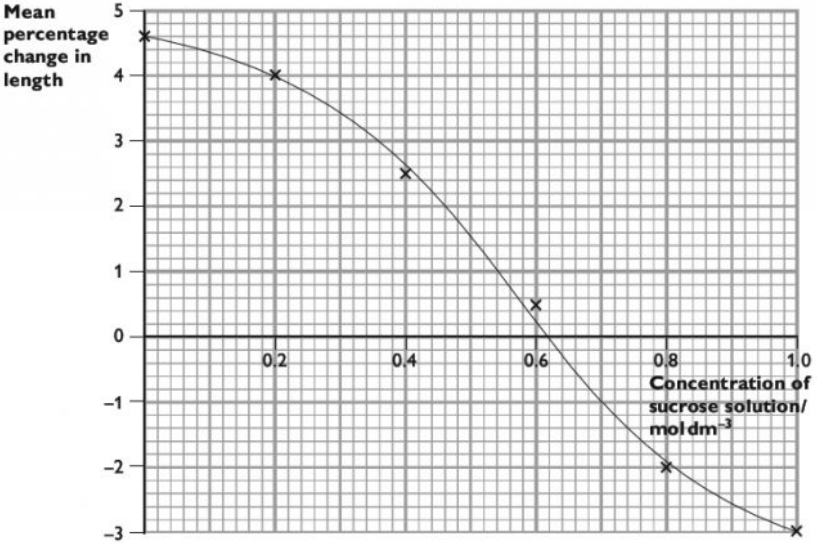
Use simple language that everyone can easily understand. Avoid using terms that are difficult for the examiner to interpret, such as 'yellowish-green'. Think about what is important — perhaps it is that *this* tube is a darker or lighter green than *that* tube. Using simple language such as 'dark green' or 'a lighter green than tube 1' is fine.

Graphs and other ways of displaying data

When you have collected your data and completed your results table, you will generally want to display the data so that anyone looking at them can see any patterns.

Line graphs

Line graphs are used when both the independent variable and the dependent variable are continuous (see page 103). This is the case for the potato strip data on page 109. The graph can help you to decide if there is a relationship between the independent variable and the dependent variable. This is what a line graph of these data might look like.



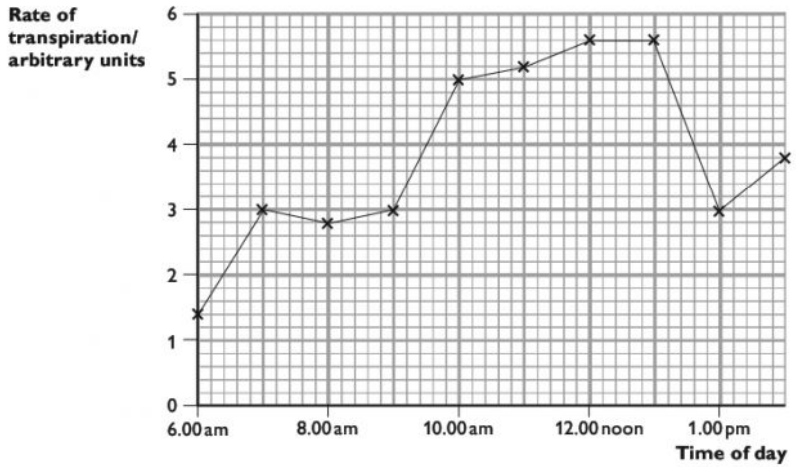
Graph of the results of Investigation 2

Notice:

- The independent variable goes on the *x*-axis, and the dependent variable goes on the *y*-axis.
- Each axis is fully labelled with units. You can just copy the headings from the appropriate columns of your results table.
- The scales on each axis should start at or just below your lowest reading, and go up to or just above your highest reading. Think carefully about whether you need to begin at 0 on either of the axes, or if there is no real reason to do this.
- The scales use as much of the width and height of the graph paper as possible. If you are given a graph grid on the exam paper, the examiners will have worked out a sensible size for it, so you should find your scales will fit comfortably. The greater the width and height you use, the easier it is to see any patterns in your data once you have plotted them.
- The scale on each axis goes up in regular steps. Choose something sensible, such as 1s, 2s, 5s or 10s. If you choose anything else, such as 3s, it is practically impossible to read off any intermediate values. Imagine trying to decide where 7.1 is on a scale going up in 3s...

- Each point is plotted very carefully with a neat cross. Don't use just a dot, as this may not be visible once you've drawn the line. You could, though, use a dot with a circle round it.
- A smooth best-fit line has been drawn. This is what biologists do when they have good reason to believe there is a smooth relationship between the independent and dependent variables. You know that your individual points may be a bit off this line (and the fact that the two repeats for each concentration were not always the same strongly supports this view), so you can actually have more faith in there being a smooth relationship than you do in your plots for each point.

Sometimes in biology (it doesn't often happen in physics or chemistry!) you might have more trust in your individual points than in any possible smooth relationship between them. If that is the case, then you do not draw a best-fit curve. Instead, join the points with a very carefully drawn straight line, like this:



Graph where we are not sure of the pattern in the relationship between the independent and dependent variables

Tips During your course:

- Get plenty of practice in drawing graphs, so that it becomes second nature always to choose the correct axes, to label them fully and to choose appropriate scales.

In the exam:

- Take time to draw your graph axes and scales — you may need to try out two or even three different scales before finding the best one.
- Take time to plot the points — and then go back and check them.
- Use a sharp HB pencil to draw the line, taking great care to touch the centre of each cross if you are joining points with straight lines. If you go wrong, rub the line out completely before starting again.
- If you need to draw two lines on your graph, make sure you label each one clearly.

You may be asked to read off an intermediate value from the graph you have drawn. It is always a good idea to use a ruler to do this — place it vertically to read a value on the *x*-axis, and horizontally to do the same on the *y*-axis. You can draw in faint vertical and horizontal pencil lines along the ruler. This will help you to read the value accurately.

You could also be asked to work out the gradient of a line on a graph. This is explained on page 40.

Tips During your course:

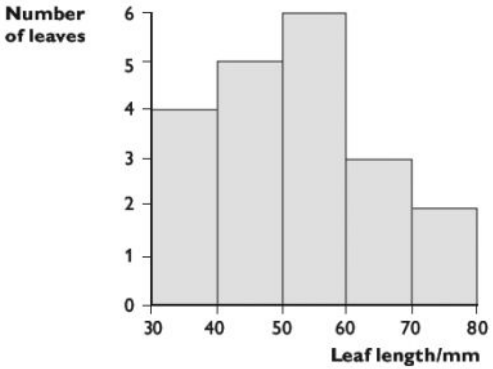
- Make sure you know how to read off an intermediate value from a graph accurately, and how to calculate a gradient.

In the exam:

- Take time over finding intermediate values on a graph — if you rush it is very easy to read off a value that is not quite correct.

Histograms

A histogram is a graph where there is a continuous variable on the *x*-axis, and a frequency on the *y*-axis. For example, you might have measured the length of 20 leaves taken from a tree. You could plot the data like this:



A frequency histogram

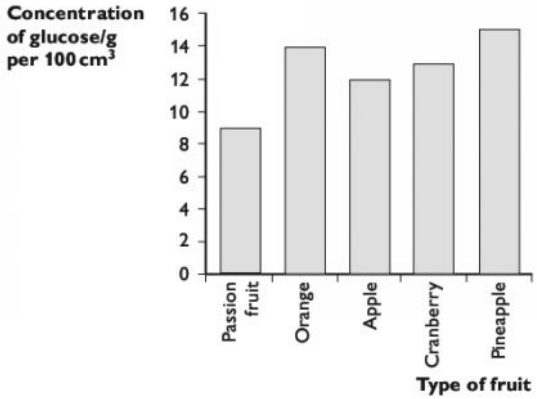
Notice:

- The numbers on the *x*-axis scale are written *on* the lines. The first bar therefore includes all the leaves with a length between 30 and 39 mm. The next bar includes all the leaves with a length between 40 and 49 mm, and so on.
- The bars are all the same width.
- The bars are all touching — this is important, because the *x*-axis scale is continuous, without any gaps in it.

Bar charts

A bar chart is a graph where the independent variable is made up of a number of different, discrete categories and the dependent variable is continuous. For example,

the independent variable could be type of fruit juice, and the dependent variable could be the concentration of glucose in the juice.



Bar chart showing concentration of glucose in different types of fruit juice

Notice:

- The *x*-axis has an overall heading (type of fruit), and then each bar also has its own heading (orange, apple and so on on).
- The *y*-axis has a normal scale just as you would use on a line graph.
- The bars are all the same width.
- The bars do not touch.

Drawing conclusions and interpreting your data

Once you have collected, tabulated and displayed your results, you can use them to draw a conclusion.

When you are thinking about a conclusion, look right back to the start of your experiment where you were told (or you decided) what you were to investigate. For example:

- in Investigation 1, Investigating the effect of temperature on the rate of breakdown of hydrogen peroxide by catalase, your conclusion should provide an answer to this question.
- in Investigation 2, Investigating the effect of immersion in solutions of different sucrose concentration on the change in length of potato strips, your conclusion should state the relationship between the concentration of sucrose solution and the change in length of the potato strips.
- in Investigation 4, Testing the hypothesis: the density of stomata on the lower surface of a leaf is greater than the density on the upper surface, your conclusion should say whether your results support or disprove this hypothesis.

Explaining your reasoning

There will often be marks for explaining how you have reached your conclusion. Your reasoning should refer clearly to your results. For example, your conclusion to Investigation 2 (whose results are shown in the table on page 109) might be:

> A sucrose solution with a concentration of 0.6 mol dm^{-3} and below caused an increase in length of the potato strips. A sucrose solution with a concentration of 0.8 mol dm^{-3} and above caused a decrease in length of the potato strips. From the graph, the solution that I would expect to cause no change in length of the strips would be 0.62 mol dm^{-3}.
>
> The strips gained in length because they took up water, which was because the water potential of the sucrose solution was greater than the water potential in the potato cells. This therefore means that the water potential inside the potato cells was the same as the water potential of a 0.62 mol dm^{-3} sucrose solution.

Showing your working, and significant figures

You may be asked to carry out a calculation and to show your working. There will be marks for doing this. If you do not show your working clearly, then you will not get full marks, even if your answer is absolutely correct.

For example, imagine you have measured four lengths as 46 mm, 53 mm, 52 mm and 48 mm. You are asked to calculate the mean and to show your working. You should write this down properly as:

$$\text{mean length} = \frac{46 + 53 + 52 + 48}{4} \text{ mm} = 50 \text{ mm}$$

You've already seen, on page 108, that the final answer to a calculation should have the same number of significant figures as the original numbers you were working from. If you do the calculation above, you'll find the answer you get is 49.75. But the original measurements were only to two significant figures (a whole number of mm) so that is how you should give the final answer to your calculation. You must round the answer up or down to give the same number of significant figures as the original values from which you are working.

There's another example of showing your working on page 119.

Tips During your course:

- Get into the habit of describing the main steps in your reasoning when drawing a conclusion, and using evidence from the results to support it.
- Get into the habit of taking time to set out all your calculations very clearly, showing each step in the process.
- Get into the habit of giving final numerical answers to calculations to the same number of significant figures as the readings you took, or the values you were given.

In the exam:

- Even if you feel rushed, take time to write down the steps in calculations and reasoning fully.

Identifying sources of error

It's worth repeating that it is very important to understand the difference between experimental errors and 'mistakes'. A mistake is something that you do incorrectly, such as misreading the scale on a thermometer, or taking a reading at the wrong time, or not emptying a graduated pipette fully. Do **not** refer to these types of mistake when you are asked to comment on experimental errors.

You've already seen, on page 106, that every measuring instrument has its own built-in degree of uncertainty in the values you read from it. You may remember that, in general, the size of the error is half the value of the smallest division on the scale.

Errors can also occur if there were uncontrolled variables affecting your results. For example, if you were doing an investigation into the effect of leaf area on the rate of transpiration, and the temperature in the laboratory increased while you were doing your experiment, then you can't be sure that all the differences in rate of transpiration were entirely due to differences in leaf area.

Systematic and random errors

Systematic errors are ones that are the same throughout your investigation, such as intrinsic errors in the measuring instruments you were using.

Random errors are ones that can differ throughout your investigation. For example, you might be doing an osmosis investigation using potato strips taken from different parts of a potato, where perhaps the cells in some parts had a higher water potential than in others. Or perhaps the temperature in the room was fluctuating up and down.

Spotting the important sources of error

You should be able to distinguish between significant errors and insignificant ones. For example, a change in room temperature could have a significant effect on the rate of transpiration (Investigation 4) but it would not have any effect at all on the number of stomata on the upper and lower surface of a leaf (Investigation 3).

Another thing to consider is how well a variable has been controlled. If you were doing an enzyme investigation using a water bath to control temperature, then you should try to be realistic in estimating how much the temperature might have varied by. If you were using a high-quality, electronically controlled water bath, then it probably did not vary much, but if you were using a beaker and Bunsen burner then it is likely that temperature variations could indeed be significant.

Tips During your course:

- Every time you do an investigation, work out and write down the uncertainty in all the types of measurement that you make.
- Every time you do an investigation, think carefully about any errors that may be due to lack of control of variables — which ones might genuinely be significant?

In the exam:

- If you are asked about an investigation that seems familiar, it is tempting just to try to recall what the main errors were in the investigation that you did before.

This is not a good idea, because the investigation in the exam may not be quite the same. Always think about the actual investigation in the examination question, and *think through* what the significant sources of error are.

Suggesting improvements

You may be asked to suggest how the investigation you have just done, or an investigation that has been described, could be improved. Your improvements should be aimed at getting more valid or reliable results to the question that the investigation was trying to answer — do not suggest improvements that would mean you would now be trying to answer a different question. For example, if you were doing an investigation to investigate the effect of *leaf area* on the rate of transpiration, don't suggest doing something to find out the effect of the *wind speed* on the rate of transpiration.

The improvements you suggest could include controlling certain variables that were not controlled, or controlling them more effectively. For example, you may suggest that the investigation could be improved by controlling temperature. To earn a mark, you must also say *how* you would control it, for example by placing sets of test-tubes in a thermostatically controlled water bath.

You could also suggest using better methods of measurement. For example, you might suggest using a colorimeter to measure depth of colour, rather than using your eyes and a colour scale.

It is almost always a good idea to do several repeats in your investigation and then calculate a mean of your results. For example, if you are measuring the effect of light intensity on the rate of transpiration, then you could take three sets of readings for the volume of water taken up by your leafy shoot in one minute at a particular light intensity. The mean of these results is more likely to give you the true value of the rate of transpiration than any one individual result.

Tips During your course:

- If time allows, try to do at least two (and possibly three) repeats when you do an investigation.
- As you do an investigation, be thinking all the time about how reliable or accurate your measurements and readings are. Think about what you would like to be able to do to improve their reliability or accuracy.

In the exam:

- Be very precise in suggesting how you could improve the investigation — for example, don't just say you would control a particular variable, but say *how* you would control it.

Drawings

One of the questions in the exam is likely to involve drawing a specimen on a slide, using a microscope, or drawing from a photomicrograph (a photograph taking through a microscope).

Making decisions about what to draw

You might have to decide which part of a micrograph to draw. For example, there might be a micrograph of a leaf epidermis, and you are asked to draw two guard cells and four epidermal cells. It is really important that you do exactly as you are asked and choose an appropriate part of the micrograph.

Producing a good drawing

It is very important that you draw what you can see, not what you think you ought to see. For example, during your AS course you may have drawn a TS of a stem where the vascular bundles were arranged in a particular way, or were a particular shape. In the exam, you could be asked to draw a completely different type of vascular bundle that you have never seen before. Look very carefully and draw what you can see.

Your drawing should:

- be large and drawn using a sharp pencil (preferably HB, which can be easily erased if necessary) with no shading, using single, clear lines;
- show the structure or structures in the correct proportions. The examiners will check that the overall shape and proportions of your drawing match those of the specimen. Don't worry — you don't need to be a wonderful artist — a simple, clear drawing is all that is required;
- show only the outlines of tissues if you are asked to draw a low power plan (LPP). A LPP should **not** show any individual cells. However, if you are using a microscope, you may need to go up to high power to check exactly where the edges of the tissues are.

You may be asked to label your drawing. In that case:

- use a pencil to draw label lines to the appropriate structure using a ruler, ensuring that the end of the label line actually touches the structure you are labelling;
- make sure that none of your label lines cross each other;
- write the actual labels horizontally;
- write the actual labels outside the drawing itself.

Tips During your course:

- Make sure you are familiar with the appearance of all of the structures listed in the syllabus that you could be asked about on the practical paper. You need to know the names and distribution of the tissues. Look in particular at the learning outcomes marked with [PA] at the beginning.
- Practise drawing specimens from micrographs, getting used to using your own eyes to see what is really there, rather than what you think ought to be there;
- Practise using an eyepiece graticule to help you work out the relative proportions of different parts that you are drawing.
- Take every opportunity to practise drawing specimens from micrographs or microscope slides, and either mark them yourself using a CIE-style mark scheme, or get your teacher to mark them for you. Find out what you need to do to improve, and keep working at it until you feel really confident.

In the exam:

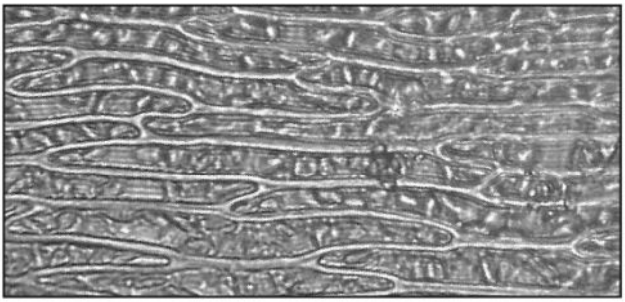
- Take one or two sharp HB pencils, a pencil sharpener, a clean ruler that measures in mm and a good eraser.
- Settle down and take time to get your drawing of the specimen right.
- Use your eyes first, then your memory.

Calculating magnification or size

The use of a stage micrometer and eyepiece graticule is described on pages 16–17. You might be asked to do this on Paper 3.

You could also be given the magnification of an image, and asked to calculate the real size of something in the image. Below is an example of the kind of thing you might be asked to do.

This micrograph shows some cells from a moss. Notice that the magnification is given.



Magnification ×300

Let us say you are asked to find the mean width of a cell from the tissue in the micrograph. There are several steps you need to work through here.

First, decide *how many* cells you are going to measure. It is generally sensible to measure a randomly selected sample of 5 to 10 cells.

Next, decide *which ones* you will measure. Choose cells where you can see the edges as clearly as possible, and where you can see the whole cell. If cells are evenly distributed, it is best to measure the total width of five cells in a row. That means you have to make fewer measurements, do fewer calculations and — better still — it reduces the size of the uncertainty in your measurements. However, if cells are irregularly shaped or distributed, you should measure each one individually.

Once you have decided which five cells to measure, mark this clearly on the micrograph. It doesn't matter exactly how you do this — perhaps you could carefully use a ruler to draw a line across the five cells, beginning and ending exactly at the first edge of the first cell, and the last edge of the fifth cell.

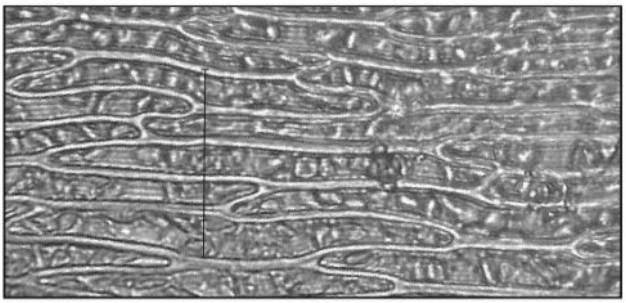
Now measure the length of the line in mm and write it down.

Next, calculate the mean length of one cell. Show clearly how you did this.

Next, convert this length in mm to a length in µm. (Alternatively, you could do this right at the end of the calculation.)

Next, use the magnification you have been given to convert this mean length of the image to a mean real length.

Here is what your answer might look like:



total width of 5 cells on micrograph = 29 mm

therefore mean width = $\frac{29}{5}$ mm = 6 mm

= 6 × 1000 = 6000 µm

magnification = ×300

therefore real mean width of a cell = $\frac{6000}{300}$ µm = 20 µm

Making comparisons

You may be asked to compare the appearance of two biological specimens or structures. You could be observing these using the naked eye or a lens, or using a microscope, or you could be looking at two micrographs.

The best way to set out a comparison is to use a table. It will generally have three columns, one for the feature to be compared, and then one for each of the specimens.

For example, you might be asked to observe two leaves and record the differences between them. Your table and the first three differences might look like this:

Feature	Leaf A	Leaf B
Leaf margin	Smooth	Toothed
Veins	Parallel to each other	A central vein with branches coming off it, forming a network
Shape	Length is more than twice the maximum width	Length is less than twice the maximum width

Notice:

- The table has been drawn with ruled lines separating the columns and rows.

- The descriptions of a particular feature for each specimen are opposite one another (that is, they are in the same row).
- Each description says something positive. For example, in the first row, it would not be good to write 'not toothed' for Leaf A, as that does not tell us anything positive about the leaf margin.

Note that the practical examination is likely to ask you to describe or compare observable features, **not** functions. Do not waste time describing functions when this is not asked for.