Physics Factsheet
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Writing Experimental Plans

There are two main types of experiment you will have to do in A-level Physics:
- Find a constant or verify a law.
- Investigate a relationship or demonstrate a principle.

Your experimental plan needs to provide all the instructions needed to do your experiment. You need to list the equipment, identify the main variables and how you will measure them and also identify the sources of error and explain how you plan to minimize them.

Given time, some preliminary tests will help in forming a plan. In practice however, you will probably write a rough plan that can be adapted when the experiment is done and the full method may be written up afterwards. In your exam, however, you may be asked to write parts of a method without the ability to try it out.

Preliminary Testing
What to look for?
- Have an idea of your basic method first.
- Get the equipment together and set it up.
- Make a note of all the equipment you need as you go; that way you won't forget the small things like crocodile clips.
- Try the experiment and take a reading.
- Now go to the extremes, your largest and smallest planned readings, and make sure your instruments are up to the job.
- Make a note if you need to use instruments with different scales, or maybe adjust the range of readings you plan to take.
- Pay attention to how you take your readings. You might automatically do things that reduce the errors, but would forget to mention in a method. Make a note of these things.
- Is there anything difficult about taking any of your readings, or setting up the experiment, that might impact on the results? Make a note of them and what you plan to do to reduce those problems.

Equipment
You may wish to write the equipment list after you have written the procedure:
- What instruments will measure the quantities you are comparing?
- If the quantities being compared are calculated, look at the equation to see what else needs to be measured and include the instruments for these.
- List all holders and containers for your equipment.
- Include anything involved in controlling other variables or reducing errors, for example a thermometer to monitor room temperature.
- Consider any safety equipment, like safety goggles.
- Include the intervals and scales of any equipment used (not usually necessary in an exam).

Example 1
For an experiment to investigate the relationship between the potential difference and resistance of a filament bulb, write an equipment list. Note that we will need to be able to measure the current as well as potential difference in order to calculate resistance.

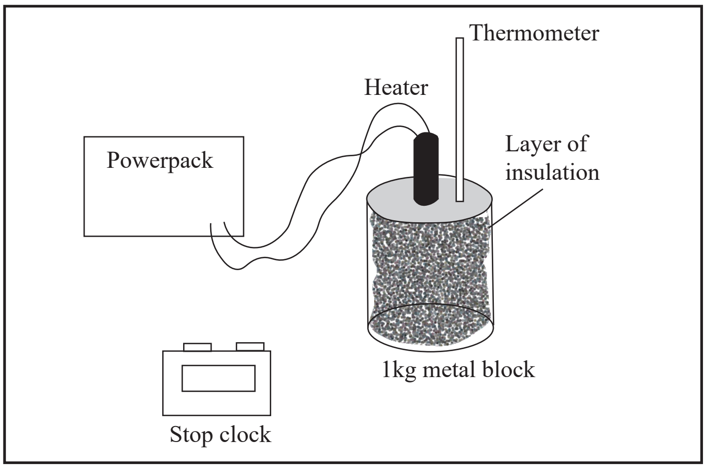
It is often preferred to use a number of cells (battery) and variable resistor to be able to change the potential difference across a component being investigated. In practice you may just use a power pack with a variable output.

Equipment List:
8 x 1.5V cells in holders
Variable resistor
Voltmeter 0-15V, 0.2V intervals
Ammeter 0-1A, 0.02A intervals
Filament bulb
Cables

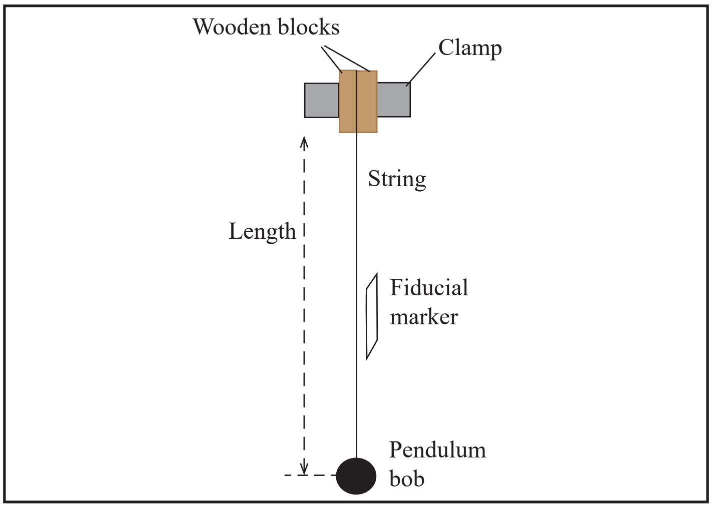
Always choose the smallest range analogue instrument as it will give you more precise intervals. In the example, if the current reached higher than 1A you can always make a change to the method. Alternatively, use a digital meter and give the number of decimal places it can be read to.

Diagram
- The diagram saves you having to explain how to set up the basic equipment.
- It should be as simple as possible, and show how the equipment is set up, using labels. If appropriate, everything in the equipment list should appear in the picture.
- If there are any quantities being measured it can be helpful to add these to the diagram rather than trying to explain it in the method.
- For electrical based experiments, proper circuit diagrams should be drawn.

Example 2
This example shows simplified squares labelled to represent certain pieces of equipment, like the powerpack. There is no need to show any detail on these parts. Showing the position of the heater and thermometer in the metal block might be useful when dealing with sources of error in the method and evaluation.



Example 3
On this simplified diagram of a pendulum, the length measurement is marked to clearly show that it is made from the base of the wooden blocks, to the centre of the pendulum bob. Showing measurements in this way can make writing the method a little more straightforward.



Basic Method

- Start by considering the variables you need to measure.
- Can you measure them directly (like distance, time, current), or do you need to calculate them by measuring other things (like speed, resistance, kinetic energy)? If so, then be clear about what you actually need to measure.
- If you need to calculate a variable, it is worth adding the equation you'll need at this stage.
- What range of readings will you do? The general rule for a graph is six points, which will give you a trend, even with an anomaly. Get the range to be as large as you can manage. This makes the results valid for a larger set of results. There are exceptions however, where using the full range of possible results is pointless, as they will be hugely inaccurate if too small or too large.
- How many readings and how many repeats?

If you can repeat any readings, then you should. Three sets of readings is the norm, but if the experiment is difficult to reset, two is acceptable. In some cases, for example producing a cooling curve, repeats are not really an option. You can repeat the whole experiment and see if the two results compare, but that isn't really the same thing. Just take a lot more readings at more regular intervals instead.

Repeat readings will reduce random error. Taking lots of readings will allow you to put a trend line on the graph which will have a similar effect.

Question 1
To find the resistivity of a wire, a 1.0m length of wire is connected to a 1.5V cell while the current and potential difference are measured. A crocodile clip is moved to vary the length of wire the current passes through.

Suggest, with reasons, what range of lengths should be used and in what intervals. [4 marks]

Answer
6 different lengths should be used. ✓
Short lengths of wire can create high currents that can cause heating effects in the wire that will affect the resistance and therefore the apparent resistivity. ✓ Choosing larger lengths of wire will ensure higher resistances and keep the current low, for instance from 0.5m to 1.0m ✓ in 0.1m intervals. ✓

Question 2
In order to produce a heating curve that studies the change of ice into steam, the temperature of the substance will be monitored. Rather than work on fixed time intervals, it is decided the time that the substance reaches certain temperatures will be recorded instead. Discuss the range and interval of temperatures that would be suitable and comment on whether repeat readings would be taken. [4 marks]

Answer
The lowest temperature depends on your freezer. About -15°C ✓ is probably the lowest you can go without specialist cooling equipment. As water boils at 100°C then the highest range should be above that ✓ (note that without a special pressure container, the highest you will reach with a thermometer and beaker will be 100°C). Initially, the temperature intervals should be 2-3° until the ice has melted. Then every 10° between 0°C and 100°C would be sufficient. ✓ Repeat readings would not be used, as there is no certainty that the substance would heat at the same point each time. Better to collect a lot of results to create the graph. ✓

Random errors

- *Some things might affect measurements in unpredictable ways. Sometimes they will cause a recorded value to be too large, other times it will be too small.*
- *These can be reduced by taking repeat readings.*
- *In graphs this causes scatter.*
- *Having more data points will allow accurate placement of the trend line despite the scatter.*

Systematic errors

- *These are things that always affect your measurements in the same way, or by the same amount.*
- *Most commonly they include parallax error (misreading the position of something due to position of the observer – including measurements of physical positions or lengths, or misreading the needle on an analogue meter.*
- *They can be corrected in the method, by ensuring consistent placement of the eye and taking steps to check for parallax error, and getting on a level with the object being viewed.*
- *Can also be caused by instruments that are not 'zeroed' or properly calibrated.*
- *Cause trend lines to shift, but do not affect gradients, so can sometimes be ignored or corrected.*

Identifying and planning for control variables and sources of error
For experiments where you take a range of readings, the whole idea is that you don't let anything change other than the variables you are studying.

What else might change and could it have an effect?

Question 3
Identify the sources of error in an experiment that uses masses hanging from a spring, and measures the spring's extension, in order to determine the spring constant from a graph of the results. Mention one source of random and one source of systematic error. [4 marks]

Answer
Random errors:
The mass of the hanging masses may not be equal. ✓This will affect the calculated value of the force or load. ✓
Systematic errors:
Parallax errors. The position of the bottom of the spring or mass will not be very close to the ruler and may be misread depending on position of the eye. ✓ This will cause variation in the value of the extension. ✓

Question 4
A trolley is rolled down a ramp to investigate how the gradient of the slope affects its average velocity. Only a metre rule and a stop clock are used to take measurements.
(a) State the variables involved and what measurements must be taken. [3 marks]
(b) Identify two sources of error and what affect they will have on the experiment. [4 marks]

Answer
(a) The two variables are average velocity ✓ and gradient. ✓ To get the velocity you must measure the displacement of the trolley down the ramp and the time it takes to reach the bottom. ✓ To get the gradient you can just measure the height, or you could also measure the length of the ramp in order to calculate the angle of the slope. ✓
(b) There are many possible sources of error. Here are a few and their effects:

Reaction time – judging when to hit the stop button on the stop clock (also depending on how it is released, as there can be an error in pressing the start button too). This will have a random effect on the time.

Parallax – judging when the trolley is at the bottom of the ramp to stop the timer. This will have a systematic effect on time (unless you keep moving, then it would be random). This is especially problematic in solo experiments where you must be at the top of the ramp to release it and may not have the best view of the bottom.

Variation in the line of travel of the trolley – if it takes a different path each time, the displacement will be randomly affected.

Forces on release – at the point of the release, small forces acting against the trolley by the hand releasing it, will affect the initial velocity and thus change the time and average velocity randomly.

Flexible ramp – if the ramp bows in the middle under its own weight, it may bow by different amounts as the gradient is changed affecting the time and average velocity.

There are others, but try not to go too obscure. Using a wooden ramp can throw up problems like varying surface friction, or imperfections on the ramps surface that may affect the trolley on some runs. Draughts from an open window, that vary changing the amount of air resistance will be negligible on a 1kg kinetic trolley. But if you were performing this with ping-pong balls then you might have a point.

Review your Background Physics
Understanding the physics behind your experiment will equip you to understand what problems you will face. For instance, if you didn't remember that temperature affects the resistance of a wire, then you wouldn't remember to take steps to stop the circuit from heating up. Unless you were unlucky enough to burn yourself carrying out the experiment, you would never realize it had been affected.

Planning to Reduce Sources of Error
Once you have identified the sources of error, say how you will *reduce* them. It is not necessary to eliminate them altogether – mostly that's never possible. No experiment will ever have no sources of error, it's just about keeping them insignificant enough that we can rely on your findings. You don't have to be clever or highly technical with the actions you take to reduce errors. It's fine if sometimes you simply plan to 'keep your head in the same place' when taking a reading.

Quite often you can reduce the significance of some errors by choosing larger values. This is true for things like reaction time and the ± error due to the scale on the meter itself. For example, measuring to the nearest mm means an error of ±0.5mm. If the length you are measuring is 5mm, then this is significant. If you are measuring 500mm then it is less significant. Just be aware of any other effects using larger measurements might have, for instance like the heating effect of large currents on wires.

Question 5
What can be done to reduce the errors you identified in question 3? [2]

Answer
Instead of relying on the masses to be consistent, use an electric balance to weigh each mass before it is added to the spring and record the cumulative mass. ✓

Attach a marker, such as a needle to the bottom of the spring that moves up, and down next to the ruler. You can also ensure you always read the position of the spring or mass by getting down to the same level as it. ✓

Question 6
What can be done to reduce the errors outlined in question 4 b) [6]

Answer
Reaction time – Take three repeat readings of time. ✓ There isn't really anything else you can do about this without using a different method of timing e.g. a light gate and datalogger. This would be fine, but the question restricted us to a metre rule and timer. You could mention the light gate in an evaluation, but the method must stick to the restrictions of the question.

Parallax – Using a second person to release the trolley, so the person with the timer can be level with the end of the ramp. Make sure that person stands in the same place each time. Alternatively, they could use a chock to hold the trolley in place, pulled away with a piece of string.

Variation in trolley path – use a ramp with tracks that keeps the trolley on the same line.

Flexible ramp – prop the trolley up in the middle to reduce the sagging, or use a stiffer material that does not sag.

Methods in exams
- *Keep them simple, don't include a full equipment list unless it asks.*
- *Mention the variables recorded and calculated.*
- *List the instruments used to make the measurements.*
- *Include at least one way to reduce errors as well as doing repeats if appropriate.*
- *If the question asks you to calculate a particular value, always choose a graphical method if possible and explain what to plot and how the gradient or y-intercept can be used to find what you need.*

Planning your results table
The biggest mistake students make is not to include enough headings in their table.

All the columns in your table must fit in the table. It is never acceptable to have to draw a second results table underneath because you didn't leave space.

Plan out what headings you will need in advance:
- All raw data being collected goes in the table.
- Remember to leave space for all the repeats.
- If you have repeated, you will need a mean column.
- Are any of your variables calculated? You will need to leave space for them and the variables you measured, to calculate.
- Plan ahead to your graph – what will you plot? If it is more than the variables you measured, you will need to leave a space for these to be calculated too.

Question 7
Plan a table for the experiment outlined in example 5.

Answer
We are investigating (and therefore plotting) speed against gradient, so we need the following headings:
- Speed
- Displacement down ramp
- Time down ramp (3 of these for each repeat)
- Mean time
- Height of ramp
- If not using height of ramp to represent gradient then we also need another column with the gradient as a ratio or angle.

Height /m	Time 1 /s	Time 2 /s	Time 3 /s	Mean Time /s	Average velocity / m/s	Displacement / m	Gradient /°

Arguably, if the displacement was the same each time, it does not need to appear in the table, but could be recorded underneath. Practically having it in the table will remind you to record it and might make following your results more straight forward.

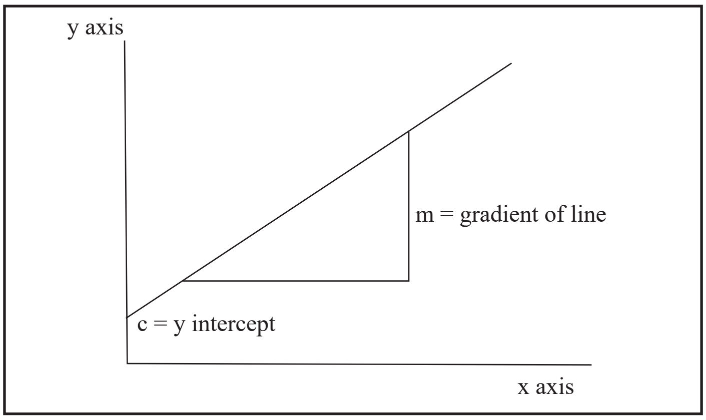
What sort of graph do I need?
In a method, you don't always have to explain what you will do with the graph, though if it is complicated it can be a good idea. In the exam, however, they may ask you to plan how you will collect the data and plot it in order to determine some constant or check a relationship.

- How does *this* affect *that?*

You just plot *this* and *that* on a graph, the independent variable – the thing you changed – on the *x* axis and the dependent variable – the thing you measured as a result – on the *y* axis. Then plot the points, and draw a trend line (line of best fit) or less commonly, for example, when dealing with discrete variables, a line graph (dot-to-dot).

- Find a constant / verify a relationship.

On paper, we are not expected to identify what sort of relationship a curve gives us (though you can be asked about things like half-lives and constant ratio properties). In these sorts of experiments, you need to plot whatever will give you a straight line. This can mean rearranging the equation you are using or verifying into the form of a straight line. **y=mx+c**



Ensure that the two things you plot are proportional to each other in order to get the straight line. If you are verifying a relationship, then you should get the straight line you were expecting, this means the relationship you plotted is correct. If you were trying to find a constant then you should be able to calculate this from either the gradient or the y intercept.

Question 8
The period of a pendulum,
T, depends on the length of pendulum,
l, by the relationship:

$$T = 2\pi\sqrt{\frac{l}{g}}$$

Where g is the gravitational field strength.

(a) In order to determine a value for g, explain what variables would be collected. Give the range of your independent variable with a reason. Explain how g would be determined from this graph. [4 marks]

(b) A student suggests taking a single value for period and measuring the length and finding g by substituting values into the equation. Explain why the graphical method is more accurate. [4 marks]

(c) Outline a method, including equipment needed, to collect the data necessary to graphically determine a value for g. Identify three sources of error with the experiment and suggest a procedure for reducing the effect of these errors. [6 marks]

Answers
(a) A range of lengths (independent variable) of pendulum would be used and the period of each would be collected. ✓ Use lengths from 0.500m to 1.000m in intervals of 0.100m. ✓ Using longer lengths increases the time of the period which makes the error from human reaction time less significant.

A graph of T against l would give a curve which is no good for calculating anything from.

By squaring both sides: $T^2 = 4\pi^2 \frac{l}{g}$

which means $T^2 \propto l$

If we plot T^2 on the y axis and l on the x axis, ✓

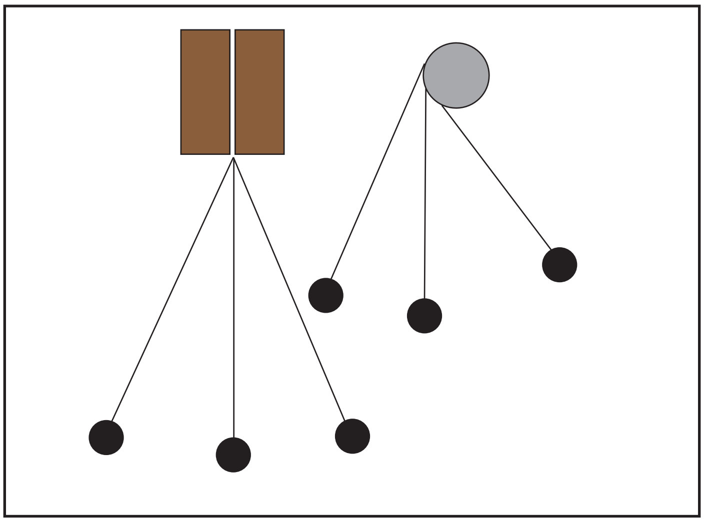
the gradient = $\frac{4\pi^2}{g}$

Therefore g = $\frac{4\pi^2}{\text{gradient}}$ ✓

(b) The graphical method will reduce random errors by using repeat readings and drawing a trend line through the centre of any scatter. ✓ The individual results may vary but on average the trend will be accurate. If we take only one result we have no idea what the level of inaccuracy of that measurement may be. ✓ On a graph we can ignore anomalies and they will not affect the calculation, but with a single measurement we have no way of knowing if that is an anomaly. ✓ Finally, the result from a single measurement is only valid for readings around that number. The pattern may change or reveal different results at other readings. With a graph, we would be able to see any larger scale pattern, or be more certain that any constant was valid over a range of values of the variables involved. ✓

(c) Equipment:
- Pendulum bob
- Light thin string or fishing line
- Clamp stand and clamp
- 2 small pieces of wood
- Stop clock
- Piece of card attached to clamp stand
- Metre ruler ✓✓

Method:



Time the period of oscillation for each length of oscillation.
If the string is wrapped around something, the length of the pendulum will vary as it oscillates. Trap the string between two blocks of wood to keep the pendulum length the same all through the swing. Human reaction time will be significant even using longer lengths. Measure 20 oscillations and divide by 20 to get T. Repeat this three times for each length.

It can be difficult to judge the exact position to start and stop timing. Use the card as a fiducial mark at the centre of oscillation (equilibrium point). This gives a definite point to start and stop the timer. It is also best at the centre, as the pendulum is moving fastest here and will be at the marker at a more definite point in time, than as maximum displacement (where it slows and stops for a moment).

Other important instructions to include in the method:
- Stand directly in front of the pendulum to avoid parallax error when judging the start and stop points.
- Measure the length of the pendulum to the centre of mass of the bob.
- Use small initial displacements. This will keep the velocity to a minimum which will make air resistance negligible.
- Keep the displacements about the same for each length so that the effect of drag is kept consistent between tests.
- Use a sufficiently heavy bob which will be least affected by the air resistance of the string.

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