6 · Practical Skills in Physics II

Pearson Edexcel · International A-Level · Physics

From a reading to a result

Two students measure the same damped pendulum. One records amplitudes; the other records amplitudes, processes them with logarithms, draws one straight line and reads off a decay constant and an initial amplitude. The second student has turned raw readings into a result. Unit 6 tests exactly that step.

WPH16 Practical Skills in Physics II is a written paper about the experiments you met while studying Units 4 and 5: gas laws, capacitors, damped oscillations, radioactive decay, light intensity. It lasts 80 minutes and has 50 marks. All questions are compulsory, and at least 20 marks use Level-2 mathematics. A written guide supports real laboratory work; it does not replace carrying out experiments yourself.

The four skill sheets follow the paper's own flow: plan the investigation, carry it out and judge the measurements, then process the data with uncertainties and graphs.

Planning an A2 investigation

A **valid measurement** still means measuring what you intend to measure. At A2 the plan has one extra demand: decide how the data will be processed **before** writing the method. The graph you intend to draw decides how many readings you need and where you take them.

■ Choose the graph before the method

Suppose you must test a predicted relationship. Work backwards:

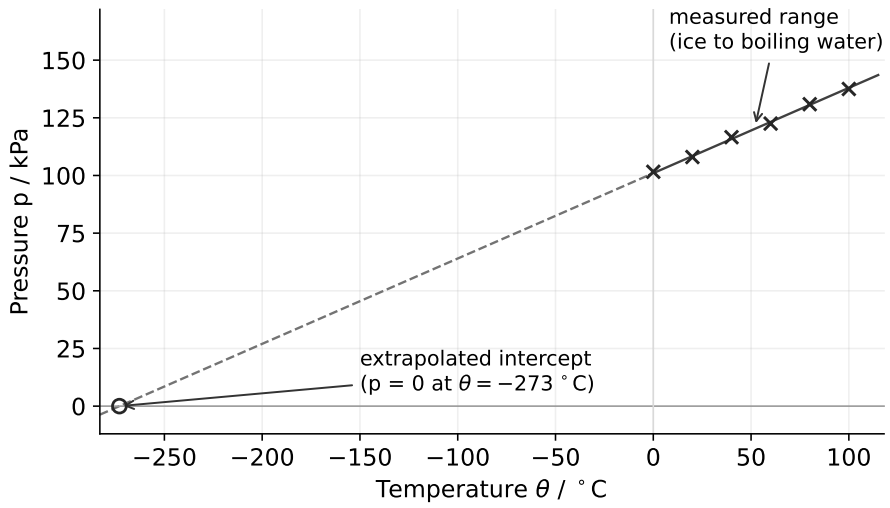
- Write the model, for example $P = kX^4$ or $A = A_0 e^{-\lambda n}$.
- Rearrange it into the straight-line form $y = mx + c$. This step is **linearisation** : choose a plot such as P against X^4, $\ln A$ against n, or $\lg P$ against $\lg X$.
- State what the graph proves: a straight line through the origin for P against X^4, or **gradient** 4 on the **log graph** of $\lg P$ against $\lg X$.
- Then choose the readings: at least five well-spread settings of the quantity you change.

A plan without its graph is an unfinished plan. The paper's six-mark "devise a method" questions expect the graph to appear in the answer.

■ Worked planning example: absolute zero from a gas flask

A flask of fixed air volume carries a pressure gauge and a thermometer. Predict how to estimate absolute zero.

- Known aim: the pressure of a fixed mass of gas falls linearly with temperature and reaches zero at absolute zero. Why this route: the zero-pressure point cannot be reached in water baths, but a straight line can be extended to it.
- Use a beaker of water with ice for 0 °C and a hot plate (or Bunsen burner) to raise the temperature to boiling. Stir so the water shares one temperature.
- Place the thermometer close to the flask, on the side away from the heater, and read the scale perpendicular to it.
- Record paired pressure and temperature readings at a minimum of five temperatures, spaced no more than about 20 °C apart. These are new settings, not repeats of one setting.
- Plot pressure against temperature in °C, draw the **best-fit line** and **extrapolate** it to $p = 0$. The **intercept** on the temperature axis estimates −273 °C.



Extrapolation extends a straight line beyond the measured range; the measured points themselves stay between ice and boiling water.

The extrapolated answer depends on the fitted line, so scatter matters more here than in a single reading. That is the price of a point you cannot measure directly.

■ Worked planning example: testing a power law

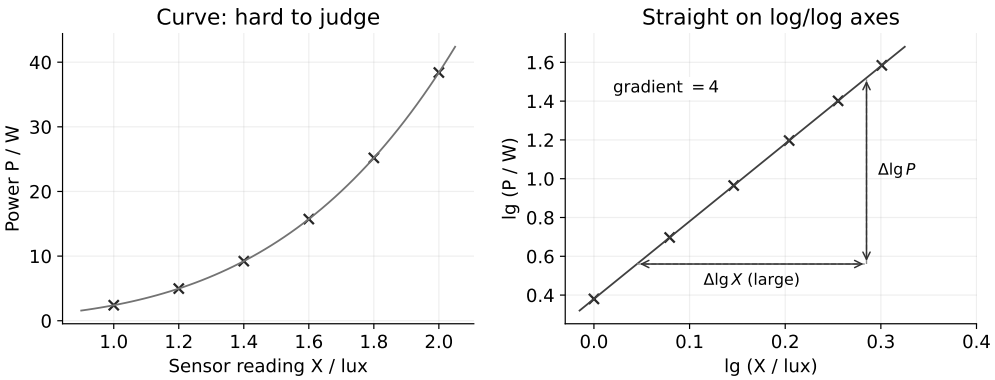
A light sensor a fixed distance from a filament bulb reads X; the electrical power is predicted to follow $P = kX^4$.

- Control what else changes X: keep the bulb-sensor distance and alignment fixed, and work in a darkened space so background light does not add to the reading.

- Measure the current I and potential difference V at each setting, and calculate $P = IV$.
- Take at least five settings by changing the current, then choose one of two graphs:

$$\lg P = \lg k + 4 \lg X \qquad \text{or} \qquad P = k\,(X^4)$$

- A graph of $\lg P$ against $\lg X$ should be straight with gradient 4. A graph of P against X^4 should be straight through the origin. Either answers the question; name the expected gradient or origin when you claim the test.



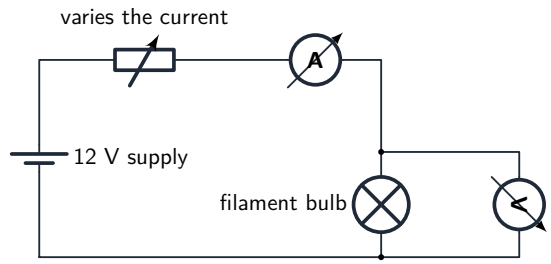
A power law becomes a straight line on log/log axes; the gradient is the power.

The specification's own example is a gas: plot an appropriate log/log graph of pressure against volume for a fixed mass at constant temperature. Log graphs are not only for exponential decay.

■ Circuits that measure what the investigation needs

An investigation of a component needs both meters in the right places:

- an **ammeter** in series with the component, so the same current flows through it;
- a **voltmeter** in parallel with the component under test **only**, so it reads that component's potential difference;
- a way of changing the current: a variable resistor or potentiometer, in series with a fixed supply.



The bulb investigation circuit: a variable resistor sets the current, the ammeter is in series and the voltmeter is in parallel with the bulb alone.

If the voltmeter straddles two components, the reading no longer belongs to the thing you are investigating. When a two-position switch moves a charged capacitor to a new circuit, draw the voltmeter across the one capacitor the question names, and connect the second capacitor in parallel with it.

Electrolytic capacitors add their own safety rules: connect with the correct polarity, keep the supply below the working voltage, and discharge the capacitor before handling it.

■ Data loggers and safety, with reasons

A **data logger** with probes records pairs of readings at the same moment, removes **parallax** from scale reading, and its probes usually have a better **resolution** than a liquid-in-glass thermometer. Say which of these changes improves the measurement; "more accurate" alone names no mechanism.

Safety answers follow the same rule: name the hazard and the action. Hot water and immersion heaters burn – move glass with tongs or heat-proof gloves, and clamp the heater so its leads cannot topple the beaker. Switch off before removing anything electrical.

Judging the measurements

■ Record what you can actually judge

A damped pendulum swings past a rule, and its turning points move quickly. Judging the amplitude to the nearest 1 mm claims a precision the eye cannot deliver, especially viewing the scale at an angle or with the bob far from the rule. Recording to the nearest 5 mm matches the recording to what can honestly be judged.

This is a two-way skill: criticise a recording resolution that is too fine, and justify a coarse one with the reason it is appropriate.

Timing oscillations

Measure the time for many oscillations, then divide. The reaction-time uncertainty is nearly the same whether you time one swing or ten, so a larger measured time gives a smaller percentage uncertainty in the period.

Two techniques earn marks on their own:

- put a **timing marker** at the centre of the oscillation and time passes through it, because the mass moves fastest there and the moment of passing is clearest;
- start the timer only after several oscillations, when the motion has settled, and use a small initial displacement.

For the period itself, record repeats of the *total* time, take the mean, and only then divide by the number of swings.

Length instruments at A2

The Unit 3 techniques still earn the marks, now with reasons attached:

- measure a spring or cylinder diameter with calipers at several **orientations** around the coil or cross-section and average, because a real object is not perfectly round (this attacks **random variation**);
- check the zero reading with the jaws closed and subtract a zero error, because it shifts every reading the same way (this attacks a **systematic error**);
- use the micrometer ratchet so the jaws tighten the same amount each time.

Justifying an instrument is quantitative: a micrometer resolves 0.01 mm, so a single 1.21 mm slide has an uncertainty of 0.005 mm. Its **percentage uncertainty** is:

$$\text{percentage uncertainty} = \frac{0.005\ \text{mm}}{1.21\ \text{mm}} \times 100\% = 0.4\%$$

A small percentage uncertainty is the justification; "it is accurate" is not.

Criticising tables and graphs

For a table of results, check:

- **significant figures**: raw readings use the same decimal places as the instrument's resolution; processed values for plotting are commonly 3 significant figures. A column mixing 5.1 with 5.143 has a fault to name.
- **units**: every column heading carries its unit, once, in the heading.
- values that stand outside the pattern of the others, judged against the graph as well as the table.

For a plotted graph, the examiner's checklist is short:

- enough data points, spread over more than half of each axis, on scales that are not awkward (multiples of 3 or 7 are hard to read);
- points plotted to within 1 mm (half a small square);
- a thin, continuous best-fit line that balances the scatter;
- whether the points actually support a straight line at all.

Criticising a graph is not listing everything you know. Point at the actual defect: five points crowded into a quarter of the grid, or a gentle curve drawn as a line.

Compounding uncertainties

Unit 6 expects **compounded uncertainties**, which Unit 3 did not. The rules come from the specification's Appendix 10.

The building blocks

A single reading has an uncertainty of half the instrument's resolution. Repeated readings have an uncertainty of half the range (the reading furthest from the mean is an accepted alternative). A percentage uncertainty is:

$$\text{percentage uncertainty} = \frac{\text{uncertainty}}{\text{value}} \times 100\%$$

Quote percentage uncertainties to one or two significant figures. Halving or doubling a measured quantity leaves its percentage uncertainty unchanged, which is why percentages, not absolute values, are the working currency.

The three compounding rules

1. **A power multiplies the percentage uncertainty.** If $A = \pi r^2$ and r has 0.6% uncertainty, then A has $2 \times 0.6\% = 1.2\%$. A diameter and its radius share the same percentage uncertainty.
2. **Products and quotients add percentage uncertainties.** Density $\rho = m/l^3$ from m with 0.1% and l with 2.1% gives $3 \times 2.1\% + 0.1\% = 6.4\%$.
3. **Sums and differences add absolute uncertainties.** Subtracting two heights measured to ± 0.5 mm each gives $\Delta h = \pm 1$ mm, even though the heights themselves are several hundred millimetres.

The third rule is why differences of similar measurements carry large percentage uncertainties, and it combines with the first two: the percentage uncertainty of $D^2/(2d^2)$ is $2 \times \%U(D) + 2 \times \%U(d)$.

Worked example: the ramp measurement of g

A sphere rolls a distance s down a ramp of height difference Δh in time t, where:

$$t^2 = \frac{14s^2}{5g\,\Delta h} \qquad \Rightarrow \qquad g = \frac{14s^2}{5t^2\Delta h}$$

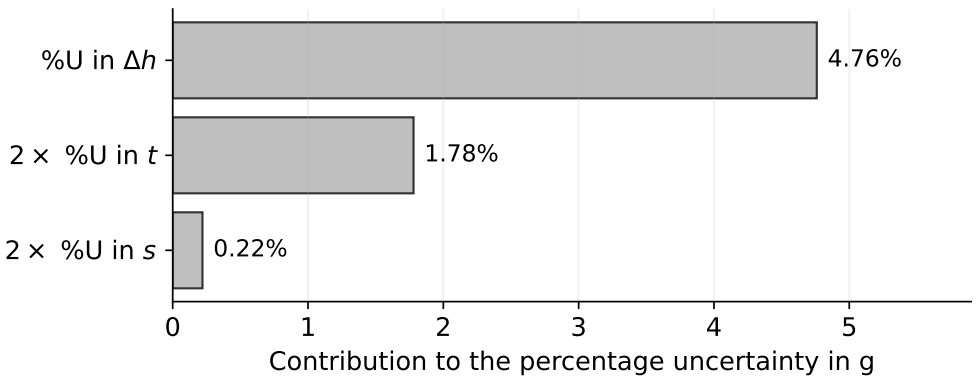
- Known: $s = 90.0$ cm $\pm$ 0.1 cm, $\Delta h = 21$ mm $\pm$ 1 mm, $t = 3.36$ s $\pm$ 0.03 s. Why these rules: s and t are squared (powers), and the quantities are multiplied and divided.

$$g = \frac{14 \times (0.900\ \text{m})^2}{5 \times (3.36\ \text{s})^2 \times 21 \times 10^{-3}\ \text{m}} = 9.6\ \text{m s}^{-2}$$

Each percentage contribution:

$$\%U(s) = \frac{0.1}{90.0} \times 100\% = 0.11\% \qquad \%U(t) = \frac{0.03}{3.36} \times 100\% = 0.89\% \qquad \%U(\Delta h) = \frac{1}{21} \times 100\% = 4.8\%$$

$$\%U(g) = 2(0.11\%) + 2(0.89\%) + 4.8\% = 6.8\%$$



The height difference dominates. Improving the timing would barely change the result; improving Δh would.

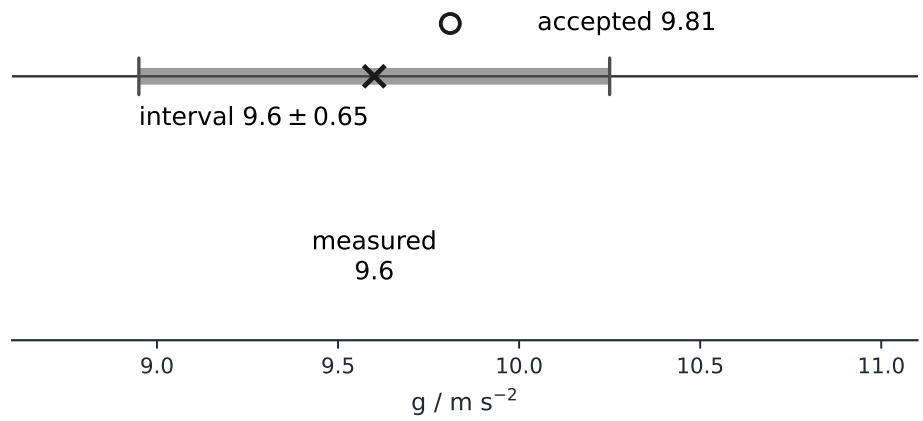
Compounding is also an improvement finder: the largest term names the measurement to fix first.

■ Using the uncertainty in a conclusion

With a percentage uncertainty, turn the result into an interval and compare:

$$g = 9.6\ \text{m s}^{-2} \times (1 \pm 0.068) \qquad \Rightarrow \qquad 8.9 \text{ to } 10.3\ \text{m s}^{-2}$$

The accepted 9.81 m s^{-2} lies inside the interval, so the measurement is accurate to the precision claimed.



A number line showing the interval 8.95 to 10.25 metres per second squared around the measured 9.6, with the accepted 9.81 marked inside it.

Without an uncertainty for the measured value, compare percentages instead: a percentage difference below 5% suggests an accurate result:

$$\%\ \text{difference} = \frac{9.81 - 9.6}{9.81} \times 100\% = 2.1\% < 6.8\%$$

Both routes end in a sentence that states what the evidence supports. A value of $\nu = 0.276 \pm 6\%$ spans 0.259 to 0.293; a data-book 0.265 for steel falls inside, so the spring **could** be steel. That is the honest strength of the claim – the interval does not prove it is steel, only that steel is not excluded.

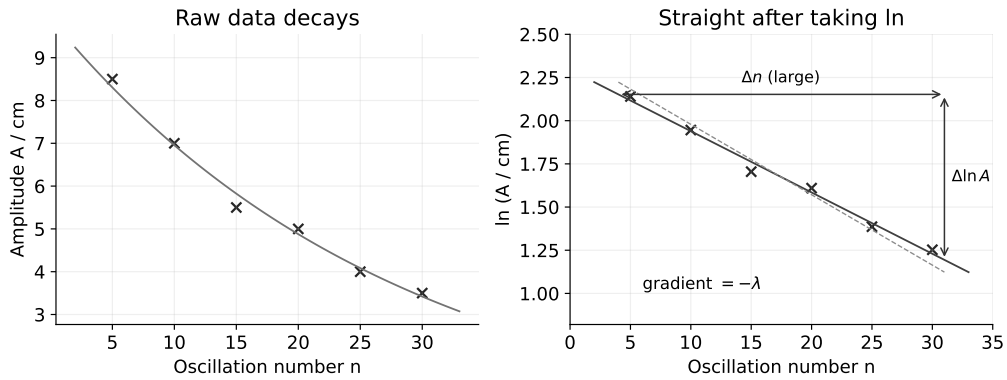
Log graphs and linearisation

■ Straighten an exponential with ln

A damped pendulum's amplitude follows $A = A_0 e^{-\lambda n}$, where n counts oscillations. Take the natural logarithm of both sides:

$$\ln A = \ln A_0 - \lambda n$$

Compare this with $y = c + mx$: a graph of $\ln A$ against n is straight, with gradient $-\lambda$ and intercept $\ln A_0$. The minus sign is part of the physics – amplitude decays, so the line slopes down.



Left: amplitude against oscillation number decays as a curve. Right: the natural log of amplitude against oscillation number lies on a straight line; a large triangle gives the gradient.

Worked example. The line's intercept is 2.295 and its gradient is −0.0355.

- Known: intercept $= \ln A_0$, gradient $= -\lambda$. Why: A was measured in centimetres, so $\ln(A/\text{cm})$ was plotted.

$$\lambda = 0.0355 \qquad A_0 = \mathrm{e}^{2.295} = 9.9 \text{ cm}$$

λ has no unit because n is a count. Had n been time in seconds, λ would carry s^{-1}.

Processing discipline: compute ln of every value to a consistent 3 decimal places, label the axis with the exact quantity logged – $\ln(A/\text{cm})$, not "$\ln A$" with a unit bolted on – and take the gradient from a **large triangle** covering more than half the drawn line, using points on the line rather than data points off it.

■ When the intercept is an extrapolation

A_0 sits at $n = 0$, where there is no data if the first reading was taken at $n = 5$. The intercept is then only as good as the fitted line:

- large scatter leaves the best-fit line uncertain, moving the intercept;
- a systematic error in amplitude shifts the whole line;
- the pendulum's first swings may not follow the model (a large starting angle stretches the period and distorts early amplitudes).

"Extrapolating beyond the data assumes the model still holds" is the sentence that earns the mark. Say which of these applies to the experiment in front of you.

■ Use the fitted line to predict

A fitted relation answers questions the raw table cannot. If $\ln V = \ln A - Bw$ for light passing through glass, and the line gives $B = 0.0104 \text{ mm}^{-1}$, the thickness w needed to dim a reading to 75% follows without touching the apparatus again:

$$\ln\left(\frac{V}{A}\right) = -Bw \qquad \Rightarrow \qquad \ln 0.75 = -(0.0104 \text{ mm}^{-1})\, w \qquad \Rightarrow \qquad w = 27.7 \text{ mm}$$

With slides of 1.22 mm each, that is $27.7/1.22 = 22.7$, so 23 slides – round **up**, because 22 slides would not reach the required dimming. Prediction questions test the direction of the final rounding as much as the algebra.

■ Straighten a power law with lg

For $y = kx^n$, taking base-10 logarithms gives:

$$\lg y = \lg k + n \lg x$$

A graph of $\lg y$ against $\lg x$ is straight with gradient n and intercept $\lg k$. Use it when no power of x makes a convenient linear axis, and keep the base consistent: lg for the power-law plot, ln for the exponential one. Both operate on the number after the unit is divided out, so the axis label is $\lg(P/\text{W})$, never $\lg P$ with watts attached.

Check yourself

Before attempting a Unit 6 question, check that you can:

- choose the processing graph first and write a method that feeds it;
- plan an extrapolation with its control variables, safety and reading plan;
- place both meters correctly and vary the current in a component investigation;
- justify an instrument or recording resolution with a percentage uncertainty;
- time oscillations and criticise tables and graphs against the examiner's checklist;
- compound uncertainties for powers, products and differences, and name the dominant term;
- turn a result into an interval and state honestly what it supports;
- linearise an exponential with ln and a power law with lg, and convert gradient and intercept back into physical quantities;
- round a prediction the right way and say when an extrapolation is trustworthy.