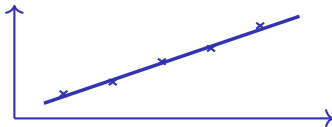


Paper 3: Practical Physics

AS Physics ■ Measurement, analysis and evaluation

A-Level Physics



Practical skills and worked examples

This deck follows all 20 handbook pages in order. The subsection heading identifies the matching page.

- 1 Measurement and apparatus: handbook pages 1–5.
- 2 Data, uncertainty and graphs: pages 6–9.
- 3 Conclusions and evaluation: pages 10–12.
- 4 Complete worked practicals: pages 13–16.
- 5 Practice with answers: page 17.
- 6 Final checks: page 18; decisions and practical checkpoints: pages 19–20.

Use these skills with real laboratory practice. The deck applies measurement and data analysis; it does not repeat mechanics, waves or electricity theory.

1

Measurement and apparatus

What Paper 3 asks you to do

Two questions

Two hours; 40 marks in total. Each question carries 20 marks.

Usually no more than one hour with each question's apparatus.

Follow the actual paper: the number of readings, permitted methods and comparison allowance can change.

Question 1

Usually a range of measurements, a graph and constants from its line.

Question 2

Usually measurements, uncertainty, a relationship test and evaluation; it can also contain a graph.

A workable hour with each apparatus

Time / min	Task
5	Read, identify quantities and check the setup.
25	Take and record all required readings.
25	Process, graph, calculate and evaluate.
5	Check units, missing entries and conclusions.

This is a planning guide. Start processing while the apparatus is still available so you can check a doubtful reading.

Read the instructions before touching the setup

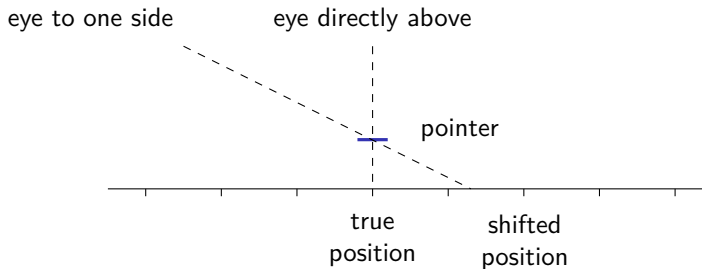
- The **independent variable** is what you change; the dependent variable is what you measure.
- Control variables must stay fixed. Copy each symbol and its reference points from the diagram.
- Find the starting conditions, initial answer spaces, required settings and supplied model.
- Take a trial reading to check the usable range and whether the motion is clear.

A height is not a track length; a diameter is not a radius; total mass includes the hanger when specified.

Record evidence in the answer spaces

- Write observations immediately in the question paper, using dark blue or black pen.
- Use a sharp HB pencil for graphs and diagrams. Preserve original readings and show calculations with units.
- Follow the centre's apparatus changeover instructions.
- If apparatus fails, tell the supervisor promptly. Help is recorded and may affect collection marks; you can still complete analysis and evaluation.

Parallax: place the eye in front of the mark



Keep the ruler parallel to the measured distance and close to the pointer. Read along a line perpendicular to the scale.

Measure between the defined endpoints

Length from two readings

$$l = r_2 - r_1 = 13.7 - 1.0 = 12.7 \text{ cm}$$

The physical end of a ruler may not be its zero mark. Keep both readings.

Length is not always extension

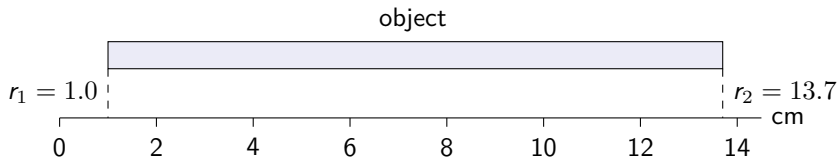
$$x = L - L_0$$

Measure the requested spring endpoints. A coil length, total spring length and extension are different quantities.

For a vertical height, use a vertical ruler and a set square. A sloping path is longer than its vertical height.

Two scale readings define the measured length

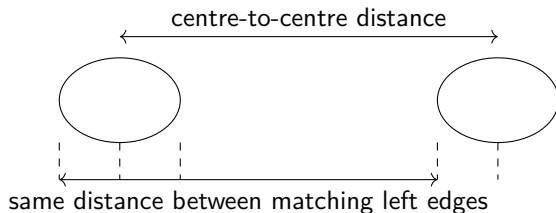
The ruler's physical end is not necessarily its zero mark.



$$l = r_2 - r_1 = (13.7 - 1.0) \text{ cm} = 12.7 \text{ cm}$$

Keep both endpoint readings. An unclear endpoint can contribute more uncertainty than the ruler's resolution.

Hidden centres and matching edges



$$c = \frac{r_{\text{left}} + r_{\text{right}}}{2}$$

Average both edges to locate a hidden centre. Matching-edge separation equals centre separation only for equal-size objects.

Diameters and spring endpoints

Sphere diameter

Use calipers across the widest part. With a ruler, use two flat blocks against opposite sides.

Turn the sphere and repeat to assess shape variation.

Spring length or extension

Check whether hooks are included. Use exactly the endpoints shown.

$$e = L - L_0$$

For extension, use the same reference for loaded and unloaded lengths.

Keep a vertical height vertical and a horizontal distance horizontal. A set square helps transfer a level to the ruler.

A repeat must test the measurement method

Genuine repeat	What it tests
Reposition the ruler or calipers.	Endpoint choice and alignment.
Measure along a wire or sheet.	Variation between positions.
Turn an object and measure again.	Variation in diameter with orientation.
Reset and repeat a release.	Variation in release and timing.

Keep the required controls unchanged. Re-reading an unchanged display does not test positioning; an oval paper cylinder needs a shape remedy.

Resolution and the correct caliper contact

Resolution is the smallest change the instrument can show.

Required measurement	Correct part of the calipers
Outside diameter or thickness	Outside jaws
Inside width	Inside jaws
Depth	Depth rod

Keep the instrument square to the surface and close gently. Contact force can compress soft materials, changing the measurement itself.

Vernier resolution comes from its scale

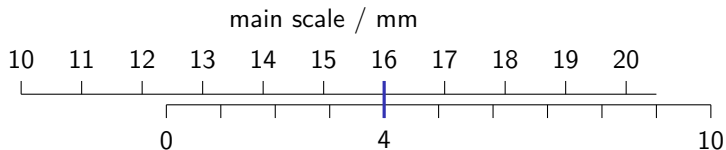
In the handbook example, ten vernier intervals equal nine main-scale intervals of 1 mm. Write s_{main} and s_{vernier} for their interval sizes.

$$s = s_{\text{main}} - s_{\text{vernier}} = 1 \text{ mm} - \frac{9 \text{ mm}}{10} = 0.1 \text{ mm}$$

- 1 Read the main scale immediately before the vernier zero.
- 2 Find the vernier division aligned with a main-scale division.
- 3 Add its division number multiplied by the actual resolution.

A different instrument can have a different resolution. For a micrometer, use the sleeve, any visible half-millimetre, and the thimble resolution.

Read the vernier, then add the two parts

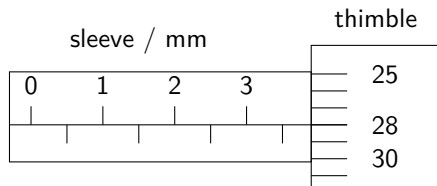


Ten vernier intervals equal nine 1 mm main-scale intervals: resolution $s = 0.1$ mm.

$$d = M + ns = 12 + 4(0.1) = 12.4 \text{ mm}$$

Read the main scale just before the vernier zero. Use the resolution of the actual instrument.

Include the micrometer half-millimetre mark



$$d = S + ns = 3.5 + 28(0.01) = 3.78 \text{ mm}$$

Use the ratchet for gentle, repeatable contact. Digital calipers: check zero, select the unit and record all displayed places.

Zero error has a sign

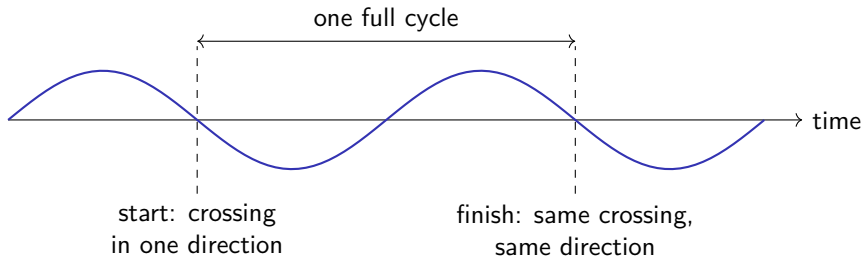
Check clean, closed jaws before measuring.

$$d_{\text{corrected}} = d_{\text{observed}} - e$$

Observed	Zero error e	Corrected
3.78 mm	+0.03 mm	3.75 mm
3.78 mm	-0.02 mm	3.80 mm

Subtract a positive zero error; subtracting a negative error increases the corrected reading.

One oscillation returns in the same direction



Use a fixed marker near equilibrium. Start at count 0, then count complete cycles. Release without a push and keep the intended mode and amplitude.

Time several cycles to reduce percentage uncertainty

At the same setting, take two independent timings of N cycles, then find the period. Investigate a large disagreement with another timing.

$$\bar{t} = \frac{t_1 + t_2}{2} = \frac{24.36 + 24.52}{2} = 24.44 \text{ s}$$

$$T = \frac{\bar{t}}{N} = \frac{24.44}{20} = 1.222 \text{ s}$$

Use 10 or 20 cycles when motion stays clear and the instructions allow it. If repeats use different N , calculate each period before averaging.

Repeat periods when cycle counts differ

If motion dies away, use fewer clear cycles when permitted. Record the total interval *and* the count for every trial.

$$T_1 = \frac{t_1}{N_1}, \quad T_2 = \frac{t_2}{N_2}$$

$$\bar{T} = \frac{T_1 + T_2}{2} = \frac{1}{2} \left(\frac{t_1}{N_1} + \frac{t_2}{N_2} \right)$$

Average the periods when counts differ, not the totals as if they covered the same interval. A correctly counted N is exact and does not limit significant figures.

Release, motion and rolling events

- Release without pushing; use the same starting position and release method.
- Use the specified vertical, sideways or twisting motion. Let unrelated motion settle.
- For an ordinary pendulum, keep amplitude small unless instructed otherwise; keep it consistent.
- Keep the stand stable and clamps secure. For a rolling object, define start and stop events, reset to the same mark, keep the required slope and supports fixed, and catch it safely.

Timing uncertainty belongs to the total interval

Suppose $t = 24.44 \text{ s}$ for $N = 20$ cycles and the estimated total timing uncertainty is $\Delta t = 0.20 \text{ s}$.

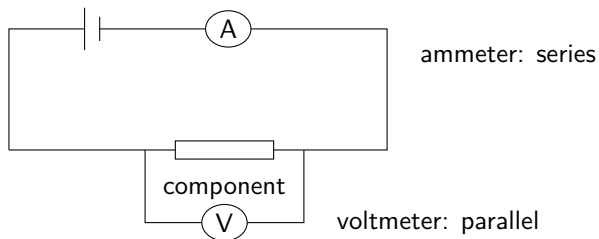
$$T = \frac{t}{N} = \frac{24.44}{20} = 1.222 \text{ s}$$

$$\Delta T = \frac{\Delta t}{N} = \frac{0.20}{20} = 0.010 \text{ s}$$

$$u_T = \frac{\Delta T}{T} \times 100\% = \frac{0.010}{1.222} \times 100\% \approx 0.82\%$$

The example assumes an uncertainty for the whole start-to-stop interval. If you estimate start and stop separately, combine them first.

Connect meters to measure the intended quantities

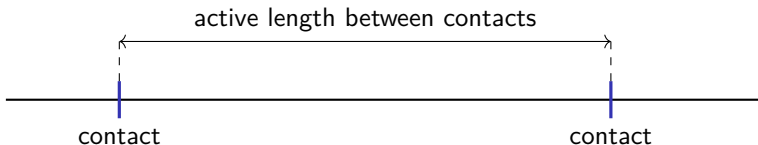


Select d.c., the correct sockets and a safe high range. Switch off before rewiring. Never connect an ammeter directly across a cell.

Keep circuit readings comparable

- Zero reading? Check switch, supply, socket, range and connections in order.
- A negative reading may mean reversed leads; do not change the circuit to manufacture an expected value.
- For resistance, keep heating small: use low current and switch off between readings when allowed.
- Wire length is between electrical contacts; measure diameter at several positions, excluding insulation.
- A rheostat uses a slider and an end terminal. For an LDR, keep ambient light, direction and shading fixed.

A wire measurement follows its electrical contacts



Measure diameter at several positions and orientations, excluding insulation.
Heating changes resistance: use low current and switch off between readings when allowed.

Rheostat terminals and light-sensor controls

Variable resistance

A rheostat uses the slider and an end terminal. Two end terminals alone do not change the resistance as the slider moves.

Trace the supplied circuit and check the terminal positions.

LDR experiment

Keep room lighting, sensor direction and the required source geometry fixed.

Avoid shading with your hands or body.
Measure source distance from the reference stated in the question.

Other instruments: use the correct reference

Instrument	What to check
Balance	Tare; include hanger, attachments and adhesive if they are part of the moving mass.
Newton meter	Zero in the working orientation; force is in newtons.
Protractor	Correct centre, baseline and choice of scale.
Thermometer	Immerse the bulb; wait for a steady reading; stir if allowed; avoid the vessel wall.
Measuring cylinder	Place level; check the scale interval and volume unit; read at eye level at the bottom of a water meniscus.

An analogue reading depends on the selected range

An instrument has a 0–10 scale and is set to a 0.50 A range. The pointer reads 6.

$$I = \frac{s}{s_{\max}} I_{\text{range}} = \frac{6}{10}(0.50) = 0.30 \text{ A}$$

Record the selected range. On a mirrored scale, align the pointer with its reflection to reduce parallax.

Safety during the practical

- Use low-voltage supplies as directed; keep water away from electrical equipment.
- Support masses over the bench, where a falling mass can be contained.
- Handle hot water carefully and keep the apparatus stable.
- Keep clear of stretched wires and moving objects.

Follow the paper's safety instructions and ask the supervisor if the apparatus is unsafe or faulty.

2

Data and graphs

Plan a table before taking readings

- One set contains all required readings at one setting, usually one row. Use the requested number of different settings.
- Spread readings across the usable range; do not cluster them.
- Include raw readings, repeats, means and calculated quantities.
- Put the symbol and unit in every heading; keep units out of the data cells.
- If a sample changes during the experiment, use fresh comparable samples when needed.

Read the symbols before averaging

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At each mass, determine both T_1 and T_2 : periods for two different arrangements. Repeat this for five different masses.

- Keep T_1 and T_2 separate. They are not repeated estimates of one period.
- Repeat timing within each arrangement to estimate its period.
- Five masses give five sets, each containing both periods.

Subscripts alone do not tell you whether readings are repeats. Read what each symbol means in this question.

Keep the symbols printed on the paper

- Use one table for the whole data set, including initial readings when instructed.
- Keep the given symbols: do not change a travel time t to period T without explanation.
- Include the required number of different settings. Repeat trials at one setting are not additional settings.
- Test allowed low and high settings; spread the others across the range and reset controls after adjustments.

The handbook timing table has three illustrative rows; it does not replace the full number requested by the paper.

Units belong to the quantity in the heading

Quantity	Suitable heading	Meaning
Length	l/cm	Values expressed in centimetres
Squared length	l^2/cm^2	Values expressed in square centimetres
Current	I/mA	Values expressed in milliamperes
Period ratio	T/T_0	Dimensionless: no unit

Use units in headings, not repeated in each table cell. Powers apply to the unit as well as to the numerical measurement.

A table that preserves the original readings

All timings below are for 20 cycles.

l/cm	t_1/s	t_2/s	$\bar{t}/\text{s}$	T/s	T^2/s^2
30.0	21.92	22.04	21.98	1.099	1.208
40.0	25.34	25.42	25.38	1.269	1.610
50.0	28.36	28.44	28.40	1.420	2.016

$$T = \frac{t_1 + t_2}{2N} = \frac{21.92 + 22.04}{2(20)} = 1.099 \text{ s}$$

Trailing zeros matter: 30.0 cm and 28.40 s record the precision of the original reading.

Raw precision and calculated precision

Readings

Use consistent decimal places appropriate to the instrument: e.g. all ruler readings to 0.1 cm.

A sum or difference follows the decimal-place precision of its inputs.

Calculated quantities

Usually use the same significant figures as the least precise input used, or one more.

Keep extra digits in the calculator until the final answer.

For $R = V/I$, a 3 s.f. voltage and 2 s.f. current normally justify 2 or 3 s.f. in R .
Follow any explicit paper instruction.

Which input actually limits significant figures?

For the first timing row: $l = 30.0 \text{ cm}$, $t_1 = 21.92 \text{ s}$ and $t_2 = 22.04 \text{ s}$, with $N = 20$ cycles.

$$T = \frac{t_1 + t_2}{2N} = \frac{(21.92 + 22.04) \text{ s}}{2(20)} = 1.099 \text{ s}$$

$$T^2 = \left(\frac{t_1 + t_2}{2N} \right)^2 = (1.099 \text{ s})^2 \approx 1.208 \text{ s}^2$$

The two times each have 4 s.f.; l is not an input and N is exact. Four s.f. are appropriate here. Calculated columns need not have matching decimal places.

Explain rounding with the measurements used

A justification that identifies the inputs

“My voltage has 3 significant figures and my current has 2. I give $R = V/I$ to 3 significant figures, one more than the least precise input.”

For subtraction, use the input decimal places. A difference such as $24.6 - 22.3 = 2.3 \text{ cm}$ has only 2 s.f.; its precision matters in later calculations.

Keep trailing zeros that record precision. “My calculator gives this” is not a justification, and squaring does not create more measured information.

Absolute and percentage uncertainty

Absolute uncertainty has the same unit as the reading.

Percentage uncertainty compares it with the size of that reading.

$$u_x = \frac{\Delta x}{|x|} \times 100\%$$

For $h = 3.2 \text{ cm}$ and $\Delta h = 2 \text{ mm} = 0.2 \text{ cm}$:

$$u_h = \frac{\Delta h}{|h|} \times 100\% = \frac{0.2}{3.2} \times 100\% = 6.25\% \approx 6.3\%$$

Convert the uncertainty and the reading to the same unit before dividing.

One clear scale reading: what does half a division mean?

A ruler has marks 1 mm apart. Suppose you can locate a point clearly and round its position to the nearest mark.

- Halfway between adjacent marks is 0.5 mm from either mark.
- A simple allowance for this one read-off is therefore ± 0.5 mm.
- This accounts for rounding a clear position, not every source of uncertainty.

If the endpoint moves, is blurred or is hard to align, estimate a larger uncertainty and explain why. Follow any supplied uncertainty.

Subtract readings; add their uncertainty amounts

A length is found from two scale readings, each uncertain by 0.5 mm:

$$l = r_2 - r_1 = 137 \text{ mm} - 10 \text{ mm} = 127 \text{ mm}.$$

For the largest possible uncertainty, the endpoint errors can act in opposite directions, increasing the error in the difference:

$$\Delta l = \Delta r_2 + \Delta r_1 = 0.5 \text{ mm} + 0.5 \text{ mm} = 1.0 \text{ mm}.$$

The 1.0 mm applies to this length from two read-offs. It is not an extra allowance to add again to an uncertainty already estimated for the whole length.

Digital resolution and practical uncertainty

What does one unit of the last digit mean?

A balance displays 25.4 g and changes in steps of 0.1 g. One unit of its last displayed digit is 0.1 g, not 1 g.

- If no accuracy is stated, ± 0.1 g is a simple display-step allowance.
- Use the stated instrument accuracy when provided. A 0.1 g display step does not guarantee accuracy to 0.1 g.
- Fluctuating readings or the measurement method can require more.

A stopwatch displays 0.01 s, but manual starting and stopping usually introduces a much larger uncertainty. Identical repeats do not imply zero uncertainty.

Choose an uncertainty for this apparatus

Why the handbook uses 2 mm for a height

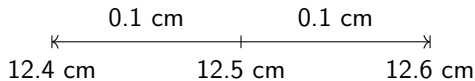
The ruler has 1 mm divisions. In this illustrative setup, movement and alignment make the whole height reproducible only within about ± 2 mm. Use $\Delta h = 2$ mm, based on that observation, not merely on the ruler divisions.

Explain the endpoint, alignment, movement or repeat-reading evidence behind your chosen Δh .

This is not a rule that every ruler reading has a 2 mm uncertainty. A stable digital display also does not prove correct calibration.

Repeated readings: full range and the amount after $\pm$

Readings: 12.4, 12.6, 12.5 cm. Mean: 12.5 cm.



$$\Delta l = \frac{l_{\max} - l_{\min}}{2} = \frac{12.6 \text{ cm} - 12.4 \text{ cm}}{2} = 0.1 \text{ cm}.$$

Thus $l = (12.5 \pm 0.1) \text{ cm}$ describes an interval of total width 0.2 cm.

Divide by two to turn the full width into an amount on either side. This is not division by the number of readings.

When is half-range a suitable estimate?

Cambridge's syllabus accepts half the range of repeated readings where appropriate.

- Show the repeat readings and half-range calculation.
- Retain a realistic uncertainty if all repeats are identical.
- Consider larger known instrument or method uncertainties too.
- For uneven scatter, the mean need not be the midpoint of the extremes.

Half-range is a simple practical estimate of scatter, not an exact statistical uncertainty or a guarantee that future readings lie inside the interval.

Propagate uncertainty through the calculation

Calculation	Rule	Example form
Sum or difference	Add absolute uncertainties	$\Delta(a - b) = \Delta a + \Delta b$
Product or quotient	Add percentage uncertainties	$u_{ab} = u_a + u_b$
Power	Multiply percentage by $ n $	$u_{x^n} = n u_x$

Exact counts and exact constants add no uncertainty. For $T = t/N$ with an exact cycle count, $\Delta T = \Delta t/N$.

A small extension can have a large uncertainty

Two ruler readings each have uncertainty 0.1 cm.

$$x = L - L_0 = 24.6 - 22.3 = 2.3 \text{ cm}$$

$$\Delta x = \Delta L + \Delta L_0 = 0.1 + 0.1 = 0.2 \text{ cm}$$

$$u_x = \frac{\Delta x}{|x|} \times 100\% = \frac{0.2}{2.3} \times 100\% = 8.7\%$$

The uncertainty is attached to both endpoint readings, even though the extension is their difference.

Products and powers: apply the uncertainty rule

For T^2 , double the period's percentage uncertainty. Using $T = 1.222 \text{ s}$ and $\Delta T = 0.010 \text{ s}$:

$$u_T = \frac{\Delta T}{T} \times 100\% = \frac{0.010 \text{ s}}{1.222 \text{ s}} \times 100\% \approx 0.82\%$$

$$u_{T^2} = 2u_T = 2(0.82\%) \approx 1.6\%$$

For the model $k = t^2/x$, the same rules give $u_k = 2u_t + u_x$.

For $T = t/N$, $u_T = u_t$ when N is exact. Dividing by N reduces absolute uncertainty in T , not its percentage relative to the total t .

Repeats reduce random scatter, not a fixed bias

Random effects

Reaction-time variation; a pointer read slightly differently each time.

Repeat and average to reduce their effect.

Systematic effects

An uncorrected zero error; a ruler consistently tilted away from vertical.

Correct the method or instrument.
Repeating the same biased method preserves the bias.

Choose the axes and scale before plotting

- For “y against x”, put y vertically and x horizontally.
- Use the requested transformed quantity: T^2 , $1/x$, $\sqrt{T}$ or a ratio.
- Label symbols and units. For $\sqrt{T}$, the unit is $\text{s}^{1/2}$.
- Choose simple scales based on 1, 2 or 5 times powers of ten; mark labels at intervals no larger than 2 cm.
- Make the points cover at least half the grid in both directions. A clearly labelled false origin can help.

A graph scale must stay uniform

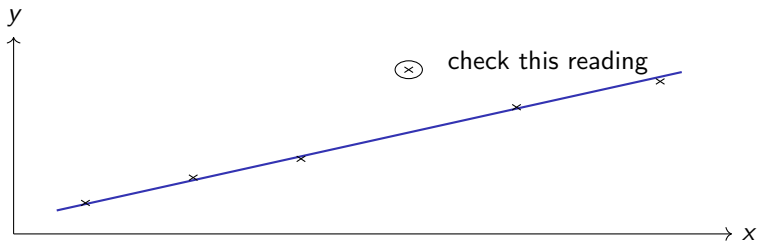
Axis labels	Interval	Decision
0, 2, 4, 6, 8	2 per large square	Simple and uniform
30, 40, 50, 60	10 per large square	Valid false origin
0, 1, 2, 5, 10	Changing interval	Invalid on equal squares

Choose 1, 2 or 5 times a power of ten per large square. Label regularly at least every 2 cm; check that the data fill half the grid in both directions.

Draw a line supported by the observations

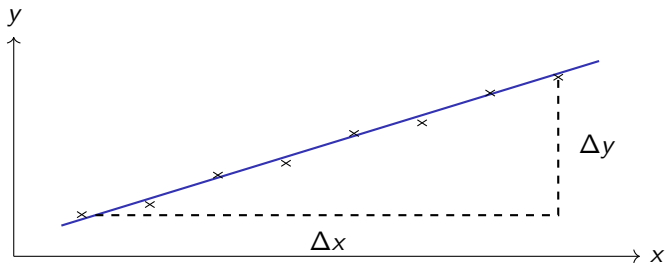
- Use fine crosses or dots smaller than about 1 mm. Plot to better than 1 mm.
- Plot every observation; draw one thin, balanced best-fit line.
- Do not join points, fit just the first and last observations, or force the line through zero.
- Investigate an anomalous point while apparatus is available; preserve the original reading and clearly identify any exclusion.
- If excluding one of six points, retain at least five. Follow the question if it asks for a curve or tangent.

An anomaly needs a measurement check



Check the observation while apparatus is available. If exclusion is justified, circle and label it, retain its value, and fit at least five of six points. Never remove data merely to force agreement.

A gradient belongs to the fitted line



$G = \Delta y / \Delta x$. Use two widely separated points on the fitted line and a triangle spanning more than half its length; they need not be measured points.

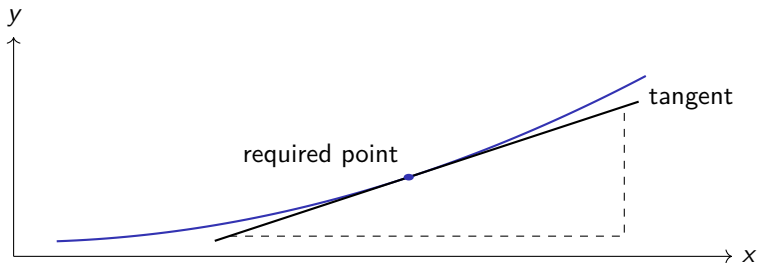
Gradient read-offs, sign and units

Read from	Use in the gradient	Avoid
Horizontal axis	$x_2 - x_1$ in its unit	Ruler cm on the paper
Vertical axis	$y_2 - y_1$ in its unit	Counting squares without scale
Fitted line or tangent	Widely separated coordinates	Two arbitrary raw points

$$G = \frac{y_2 - y_1}{x_2 - x_1}, \quad [G] = \frac{[y]}{[x]}$$

Retain a negative sign for a falling line. Draw the triangle and record both actual coordinate pairs.

A curve needs a tangent for a local gradient



Draw the requested smooth curve. At the required point, draw a tangent and use two distant points on that tangent for $G = \Delta y / \Delta x$.

Match the supplied model to the line equation

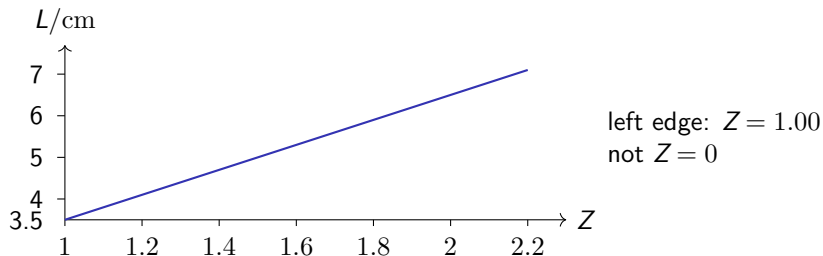
$$y = Gx + C$$

Past-paper model and axes	Gradient	Intercept
$L = aZ + b$: L against Z	a	b
$T/T_0 = Ph + Q$: T/T_0 against h	P	Q

Sources: November 2025 Paper 34 Q1; June 2025 Paper 35 Q1. Match the supplied equation to the line; these are not models to memorise.

A false origin does not redefine the intercept

For $L = aZ + b$, the fitted line is $L = (3.00 \text{ cm})Z + 0.50 \text{ cm}$.



The line at the left edge has $L = 3.50 \text{ cm}$. The intercept is at $Z = 0$, outside this grid: calculate $b = L - aZ = 0.50 \text{ cm}$.

Use a line point to calculate the intercept

For $L = aZ + b$, fitted-line points are (1.20, 4.10 cm) and (2.00, 6.50 cm); Z is dimensionless.

$$a = \frac{L_2 - L_1}{Z_2 - Z_1} = \frac{6.50 - 4.10}{2.00 - 1.20} = 3.00 \text{ cm}$$

$$b = L - aZ = 4.10 - 3.00(1.20) = 0.50 \text{ cm}$$

The intercept means the value at the true $x = 0$. The left edge of a graph with a false horizontal origin is not automatically the intercept.

Transform the data and the units together

Requested quantity	Calculation	Unit if T is in s and l in cm
Squared period	T^2	s^2
Reciprocal length	$1/l$	cm^{-1}
Square root of period	$\sqrt{T}$	$\text{s}^{1/2}$
Period ratio	T/T_0	No unit

Use exactly the graph requested, even if another is more familiar. Carry the transformed unit through table headings, axes, gradients and constants.

Convert a gradient using its axis units

For the past-paper model $T/T_0 = Ph + Q$, suppose a graph against h/cm gives $P = 0.0400/\text{cm}$.

$$P_{\text{SI}} = P \times 100 \frac{\text{cm}}{\text{m}} = (0.0400/\text{cm}) \times 100 \frac{\text{cm}}{\text{m}} = 4.00/\text{m}.$$

The same gradient is 0.0400 per centimetre or 4.00 per metre. Match the height unit when using the equation.

3

Conclusions and evaluation

Calculate a constant separately from each trial

Test the model $t^2 = kx$: if it holds, k should be constant.

Trial	x/m	t/s
1	0.200	0.640
2	0.400	0.890

$$k_1 = \frac{t_1^2}{x_1} = \frac{(0.640 \text{ s})^2}{0.200 \text{ m}} = 2.048 \text{ s}^2/\text{m}$$

$$k_2 = \frac{t_2^2}{x_2} = \frac{(0.890 \text{ s})^2}{0.400 \text{ m}} \approx 1.980 \text{ s}^2/\text{m}$$

The inputs have 3 s.f.; report k to 3 or 4 s.f. Compare using unrounded working values, including $k_2 = 1.98025 \text{ s}^2/\text{m}$.

State how you calculate percentage difference

A symmetric convention uses the mean magnitude as the reference:

$$D = \frac{|k_1 - k_2|}{(|k_1| + |k_2|)/2} \times 100\%$$

$$k_{\text{ref}} = \frac{|k_1| + |k_2|}{2} = \frac{2.048 + 1.98025}{2} = 2.014125$$

$$D = \frac{|k_1 - k_2|}{k_{\text{ref}}} \times 100\% = \frac{|2.048 - 1.98025|}{2.014125} \times 100\% = 3.36\%$$

If the question gives a denominator, use it. Otherwise state your convention and apply it consistently.

Compare with the allowance the paper gives

A conclusion using evidence

The constants differ by 3.36%, which is below the stated 10% allowance. The results therefore support the relationship within this allowance.

Some papers specify 10%, 20% or 30%; there is no universal tolerance.

Do not claim the model is proved. Do not double a stated allowance or replace it with an unrelated uncertainty calculated earlier.

Two data sets must stay separate

For each object or setting	What to do
A changing dimension or time	Re-measure and use that trial's value.
A required fixed control	Retain its stated value and check it remains fixed.
A model with a sum in a denominator	Keep the complete sum inside brackets.
A relationship test	Compare the calculated constants, not unequal raw readings.

The percentage difference compares two measurements, not a measurement with a known true value. Do not change observations to make the model agree.

A useful limitation names the affected measurement

Quantity + cause + consequence

Replace “parallax error” with an explanation

The spring end is separated from the ruler, so its apparent position changes with eye position and the length reading is uncertain.

“Human error”, “inaccurate apparatus” and “repeat more” do not identify a specific problem and remedy.

Find independent limitations in the actual setup

Look at	Ask
Reading	Is the endpoint hidden, blurred or far from the scale?
Motion	Does the pointer move, the motion decay or the path wander?
Apparatus	Does the track bend, the pivot stick or the sample deform?
Model or evidence	Is a control drifting, or are there too few different settings to test the model?

Give the number of distinct limitations and improvements requested. Four pairs are common, but the actual question controls the answer.

Replace vague evaluation with a cause and effect

Weak wording	What the explanation needs
“Human error”	The ball reaches the box quickly, making the stop event difficult to judge.
“Not enough readings”	Only two diameters were tested, giving weak evidence for a general relationship.
“Inaccurate equipment”	Caliper jaws compress the rubber; measured diameter depends on contact force.

Name the quantity, specific cause and consequence. Choose independent problems; four versions of one ruler difficulty are not four limitations. Do not claim a problem you did not have or that the method prevents.

Correct technique and method improvements

Usually do during collection	A specific change to a weak method
Read at eye level.	Add a pointer and clamp the ruler beside a moving endpoint.
Repeat the timing.	Put light gates at defined start and end positions.
Tighten the clamp.	Add supports to a track that bends under the ball.

Basic correct technique may already be required or possible with the apparatus. Name new equipment, its position, what it measures and how it helps; keep the same investigation.

Match a remedy to the reading problem

Specific limitation	Matching improvement
A small height is hard to read with a ruler.	Use suitable depth calipers.
The spring end moves beside a distant scale.	Add a pointer and clamp the ruler close to it.
The object's centre is hidden.	Measure both edges and calculate the centre.
A paper cylinder becomes oval.	Form it on a circular template; secure the seam consistently; remove the template before testing deformation.

Match a remedy to motion and construction

Specific limitation	Matching improvement
A ball's travel time is short and hand timing varies.	Use light gates or video with a known frame rate or visible timer.
Oscillations decay before counting is clear.	Use video to track cycles; avoid increasing amplitude beyond the model's conditions.
A track bends under the ball.	Use a rigid track with support along its length.
A card catches on its pivot.	Use a thinner pin and a smooth, clear hole.

Describe where the improved apparatus goes

Short rolling time

Put light gates connected to a timer at the defined start and end positions. Align their beams with the ball's path. Alternatively, use video with a visible timer or known frame rate.

Small height above the bench

Use a suitable depth gauge or calipers between the bench reference and the required surface. Name both contact points.

Number matching limitation and improvement pairs alike. These are examples to adapt to real problems, not a list to copy into every experiment.

Changed samples, attachment mass and friction

Problem	Specific procedure change
Wet paper changes shape between trials.	Fresh identical samples; keep dimensions and orientation fixed; repeat placement and timing.
Adhesive adds mass omitted by the model.	Weigh adhesive with attached masses and use the total, or a specified lighter attachment.
A card sticks on a thick nail.	A thinner smooth pin with a suitable smooth hole, allowing free motion.

Control the sample and improve the evidence

- If adhesive adds moving mass, include it in the measured total.
- If wet paper changes during the experiment, use fresh identical samples.
- More repeats at one setting assess scatter. More different settings test whether the proposed relationship holds over a range.
- Use additional settings to compare several constants or produce a suitable graph.
- An improvement should be realistic, preserve the investigation and go beyond instructions already carried out.

4

Worked practicals

Magnet practical: use a verified exam model

9702/35 May/June 2025, Q1: oscillations of a magnet.

$$\frac{T}{T_0} = Ph + Q$$

- h : height from the small magnet's bottom to the paper.
- T_0 : reference period at $h = 3.0$ cm before adding the bar magnet.
- T : period with the bar magnet fixed in the specified position.

The setup and model are from the exam. The readings and fitted line in this example are illustrative teaching data.

Magnet practical: the collection plan

- 1 Determine T_0 without the bar magnet. Keep this reference value.
- 2 Position the bar magnet as directed and mark its position.
- 3 Take six settings in $3.0 \leq h/\text{cm} \leq 9.0$, including the first.
- 4 Restore alignment over the marked point after changing height.
- 5 Release gently along the marked direction; time repeated sets of complete cycles where motion remains clear.

Do not average T_0 with T : they describe different conditions. t_1 and t_2 below are repeat total times at one setting.

Magnet data: six heights and repeat timings

Reference: $T_0 = 1.200$ s. Each timing below is for 20 cycles.

h/cm	t_1/s	t_2/s	T/s	T/T_0
3.0	14.80	14.88	0.7420	0.6183
4.0	15.84	15.92	0.7940	0.6617
5.0	16.72	16.80	0.8380	0.6983
6.0	17.76	17.84	0.8900	0.7417
7.5	19.12	19.20	0.9580	0.7983
9.0	20.64	20.72	1.034	0.8617

All heights satisfy the paper's limits. T increases with h and remains below T_0 , consistent with the mark scheme's expected trend.

Process the reference and one magnet row

Without the bar magnet, two 20-cycle totals are 23.96 s and 24.04 s:

$$T_0 = \frac{t_{01} + t_{02}}{2N} = \frac{23.96 \text{ s} + 24.04 \text{ s}}{2(20)} = 1.200 \text{ s}.$$

At $h = 3.0 \text{ cm}$ with the bar magnet:

$$T = \frac{t_1 + t_2}{2N} = \frac{14.80 \text{ s} + 14.88 \text{ s}}{2(20)} = 0.7420 \text{ s}.$$

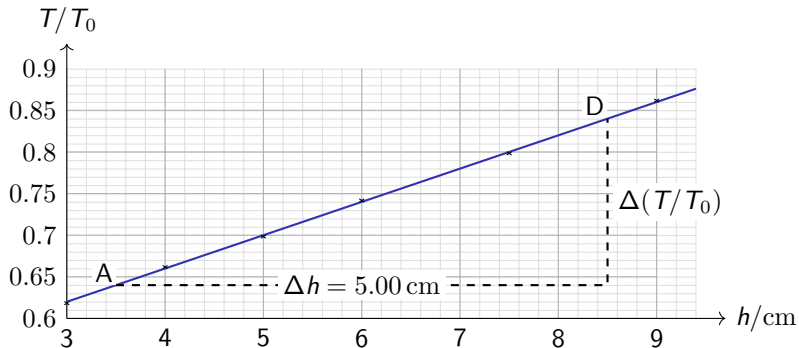
$$\frac{T}{T_0} = \frac{0.7420 \text{ s}}{1.200 \text{ s}} = 0.6183.$$

Magnet table: precision follows the timing inputs

- Record h to the nearest millimetre: 3.0 cm, 4.0 cm, and so on.
- Record raw stopwatch readings to its 0.01 s display step.
- Use 4 significant figures for the calculated period and ratio here, matching the least number in the timing inputs.
- $N = 20$ is an exact count. Height is not an input to T or T/T_0 .

Seconds cancel in T/T_0 . Keep extra calculator digits for later working; the ratio has no unit.

Magnet graph: a fitted line and a large triangle



Both axes have false origins. The triangle corners are fitted-line points, not a selected pair of raw readings.

Magnet graph: check the use of the grid

Direction	Data span	Available span
Height	$9.0 - 3.0 = 6.0 \text{ cm}$	6.4 cm
Period ratio	About 0.24	0.30

Both spans exceed half the grid. All six rows are plotted, with balanced scatter.

The lower-left corner is (3.0, 0.60). The line's y-intercept is its value at $h = 0$, outside this grid.

Magnet gradient: use changes in the plotted quantities

Fitted-line points: A (3.50 cm, 0.640); D (8.50 cm, 0.840).

$$G = \frac{(T/T_0)_D - (T/T_0)_A}{h_D - h_A} = \frac{0.840 - 0.640}{8.50 \text{ cm} - 3.50 \text{ cm}} = 0.0400/\text{cm}.$$

The numerator has no unit; the denominator is a length. Thus the gradient has inverse-length units.

Triangle base: 5.00 cm of height change. This is the difference in axis values, not a distance measured with a ruler on the graph.

Recover the magnet model constants and units

Compare $T/T_0 = Ph + Q$ with $y = Gx + C$: $P = G$ and $Q = C$.

$$Q = \left(\frac{T}{T_0} \right)_A - Ph_A = 0.640 - (0.0400/\text{cm})(3.50 \text{ cm}) = 0.500.$$

$$P_{\text{SI}} = P \times 100 \frac{\text{cm}}{\text{m}} = (0.0400/\text{cm}) \times 100 \frac{\text{cm}}{\text{m}} = 4.00/\text{m}.$$

Q has no unit. Use centimetres with $P = 0.0400/\text{cm}$, or metres with $P = 4.00/\text{m}$.

Further practice: predict a new magnet period

The exam asks for P and Q . This additional teaching task uses the fitted model to predict T at $h = 6.50$ cm, inside the measured range.

$$T = T_0(Ph + Q) = (1.200 \text{ s})[(0.0400/\text{cm})(6.50 \text{ cm}) + 0.500] = 0.912 \text{ s}.$$

$$t = NT = 20(0.912 \text{ s}) = 18.24 \text{ s} \approx 18.2 \text{ s}.$$

A prediction at 12 cm would extrapolate beyond the 3.0–9.0 cm range. The nonzero intercept means T/T_0 is not directly proportional to h .

Magnet result: final statement and checks

A complete final statement

“My fitted line gives $P = 0.0400/\text{cm}$ and $Q = 0.500$.”

Support this with triangle read-offs, gradient working, the model comparison and the intercept calculation.

- Q is not the bottom axis label, 0.60, or the left-edge line value, 0.620.
- The plotted ratio has no unit. Its gradient does have a unit.
- Use your own fitted line and readings in the exam.

Rolling spheres: define every symbol before calculating

Symbol	Meaning	What happens between trials
t	Travel time	Measure for each sphere
h	Track height	Keep fixed
x	Rail spacing	Keep fixed
d	Sphere diameter	Changes with the sphere

The November 2025 Paper 34 model concerns rolling spheres. Work from the supplied track diagram and definitions; do not derive a different model.

Unfamiliar model: protect the brackets

9702/34, November 2025: supplied rolling model

$$t^2 h = k \left(5 + \frac{2}{1 - (x/d)^2} \right)$$

Break the calculation into intermediate quantities:

$$q = 1 - (x/d)^2, \quad F = 5 + \frac{2}{q}, \quad k = \frac{t^2 h}{F}.$$

The ratio x/d requires the same unit for both lengths. Use the question's definitions; keep h in metres when reporting k in m s^2 .

Rolling model: rearrange the entire bracket

The original relation is $t^2 h = kF$, where the bracket factor is dimensionless:

$$F = 5 + \frac{2}{1 - (x/d)^2}$$

$$k = \frac{t^2 h}{F} = \frac{t^2 h}{5 + \frac{2}{1 - (x/d)^2}}$$

The 5 is added after the division by $q = 1 - (x/d)^2$. It is not inside q , and the whole factor F divides $t^2 h$.

Rolling model: first trial

Illustrative measurements: $x = 1.60$ cm, $d = 2.00$ cm, $h = 0.032$ m and $t = 5.20$ s:

$$q_1 = 1 - (x/d_1)^2 = 1 - (1.60/2.00)^2 = 0.360$$

$$F_1 = 5 + \frac{2}{q_1} = 5 + \frac{2}{0.360} = 10.5556$$

$$k_1 = \frac{t_1^2 h}{F_1} = \frac{5.20^2 (0.032)}{10.5556} = 0.0819739 \text{ m s}^2 \approx 0.0820 \text{ m s}^2$$

Rolling model: units and significant figures

The ratio x/d and the factor F are dimensionless. With t in seconds and h in metres:

$$[k] = \frac{[t]^2[h]}{[F]} = \text{s}^2 \text{ m}$$

For $h = 3.2 \text{ cm} = 0.032 \text{ m}$, h has 2 s.f. Reporting $k_1 = 0.0820 \text{ m s}^2$ to 3 s.f. is appropriate.

Justify rounding using t, h, x, d , not the exact constants 5 and 2. Keep guard digits in q, F, k until the final result and percentage comparison.

Rolling model: change the trial, recalculate the factor

For the second sphere, $d_2 = 2.50$ cm and $t_2 = 4.80$ s. The same x and h apply.

$$F_2 = 5 + \frac{2}{1 - (x/d_2)^2} = 5 + \frac{2}{1 - (1.60/2.50)^2} = 8.38753$$

$$k_2 = \frac{t_2^2 h}{F_2} = \frac{4.80^2 (0.032)}{8.38753} = 0.0879019 \text{ m s}^2 \approx 0.0879 \text{ m s}^2$$

A changed diameter changes the bracket factor. Do not reuse F_1 for the second sphere.

Rolling model: test and diagnose the result

$$k_{\text{ref}} = \frac{|k_1| + |k_2|}{2} = \frac{0.0819739 + 0.0879019}{2} = 0.0849379 \text{ m s}^2$$

$$D = \frac{|k_1 - k_2|}{k_{\text{ref}}} \times 100\% = \frac{|0.0819739 - 0.0879019|}{0.0849379} \times 100\% = 6.98\%$$

For these illustrative measurements, this is below the stated 30% allowance: the data support the relationship within that allowance.

When d is close to x , the small denominator is sensitive to diameter errors. If it is zero or negative, recheck readings and definitions; do not insert an absolute value.

5

Practice

Try it: correct the thickness

A micrometer reading

Observed thickness: 2.46 mm.

Zero error: -0.02 mm.

Find the corrected thickness. Write the signed correction before substituting.

Thickness: the signed correction

$$d_{\text{corrected}} = d_{\text{observed}} - e$$

$$d_{\text{corrected}} = d_{\text{observed}} - e = 2.46 - (-0.02) = 2.48 \text{ mm}$$

The closed instrument reads below zero, so the observed reading underestimates the thickness.

Try it: difference and repeated timing

- 1 A length is found from $18.4 - 16.7$ cm. Each endpoint has uncertainty 0.1 cm. Find the length and its percentage uncertainty.
- 2 Two timings of 15 cycles are 18.30 s and 18.42 s. Find the mean period.

Answers: preserve the measured precision

Endpoint difference

$$l = r_2 - r_1 = 18.4 - 16.7 = 1.7 \text{ cm}$$

$$\Delta l = \Delta r_1 + \Delta r_2 = 0.2 \text{ cm}$$

$$u_l = \frac{\Delta l}{l} \times 100\% = \frac{0.2}{1.7} \times 100\% \approx 12\%$$

Mean period

$$T = \frac{t_1 + t_2}{2N}$$

$$T = \frac{t_1 + t_2}{2N} = \frac{18.30 + 18.42}{2(15)} = 1.224 \text{ s}$$

The count is 15 full cycles, not 15 half-cycles.

Try it: a dimensionless vertical axis

The model is

$$\frac{T}{T_0} = Ph + Q.$$

Two points on the fitted line are (2.00 cm, 1.120) and (8.00 cm, 1.480).

- 1 Find P , including its unit.
- 2 Calculate Q .

Ratio graph: gradient and intercept

Let $y = T/T_0$, the dimensionless vertical-axis quantity.

$$P = \frac{y_2 - y_1}{h_2 - h_1} = \frac{1.480 - 1.120}{8.00 - 2.00} = 0.0600 \text{ cm}^{-1}$$

$$Q = \frac{T}{T_0} - Ph = 1.120 - 0.0600(2.00) = 1.000$$

T/T_0 and Q have no unit. The gradient has reciprocal-length units because the horizontal axis is a length.

Try it: how strong is the agreement?

Two constants, in the same unit, are 0.420 and 0.455.

- 1 Find the percentage difference using the mean as reference.
- 2 Do the results support the model within a 10% allowance?
- 3 Would the conclusion change for a 5% allowance?

Agreement depends on the stated tolerance

$$D = \frac{|k_1 - k_2|}{(|k_1| + |k_2|)/2} \times 100\% = \frac{|0.420 - 0.455|}{(0.420 + 0.455)/2} \times 100\% = 8.0\%$$

Allowance	Conclusion
10%	Supports the model within this allowance.
5%	Does not support the model within this allowance.

Try it: explain why a rigid track helps

A ball rolls down a flexible track. The track bends differently as the ball moves.

- 1 State one specific limitation and its effect on the experiment.
- 2 Suggest an improvement that directly addresses it.

Avoid the phrases “human error” and “use better equipment”.

Evaluation answer: cause and remedy are linked

Limitation

The track bends under the moving ball, changing the local slope and making the travel time depend on a changing path.

Improvement

Use a rigid track supported along its length so that the path and slope stay fixed during each run.

A computer or a finer stopwatch display would not fix a changing track geometry.

6

Final checks

Measurement checklist

- Identify every endpoint and reference surface.
- Check zero, range, units, alignment and the required setup.
- Record initial readings in their own answer spaces.
- Complete the required different settings over a useful allowed range.
- Keep controls fixed and record genuine repeats.
- Record observations immediately, with appropriate precision and units.

Graph checklist

- Use requested quantities and units, including powers and ratios.
- Fill at least half the grid in both directions; choose uniform, easy scales and regular labels.
- Plot every observation accurately with a small mark.
- Balance the fit and identify any excluded anomaly.
- Use distant fitted-line points, coordinate read-offs and a large triangle.
- Find the intercept at true $x = 0$ or calculate it; match the model and give constants with units.

Question 2 checklist

- Explain the measurement problem behind the uncertainty and use consistent units.
- Justify significant figures using the actual calculation inputs.
- Calculate each constant from its own data set.
- Show percentage difference and use the allowance printed on the paper.
- Let the numbers determine the conclusion; two settings do not prove a model.
- Give the requested distinct limitations and matched, workable improvements; check every answer space.

Companion handbook and exam scope

AS Physics Paper 3 practical handbook

The 20-page handout and this deck cover the measurement guidance, uncertainty rules, graph methods and worked examples. Use the matching handbook page shown in each subsection.

Scope: Cambridge International AS & A Level Physics 9702, 2025–2027 syllabus, practical assessment guidance (pp. 42–48).

Handbook review: November 2025 papers 31, 34 and 35; June 2025 papers 31, 32, 34 and 35.

The magnet setup/model are from June 2025 Paper 35 Q1; the rolling model is from November 2025 Paper 34. Numerical readings, fitted lines, predictions and diagrams here are illustrative teaching examples. Check the correct syllabus if using this material after 2027.

7

Decisions and practical checkpoints

Choose: do these students have six settings?

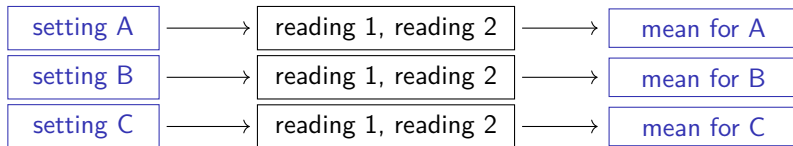
Discuss before revealing the answer

Student A times one length six times. Student B uses six different lengths and times each once. Both record six times.

- 1 Who has six settings for a graph?
- 2 Who has evidence of scatter at one setting?
- 3 What useful measurements should each student take next?

Settings give a range; repeats assess scatter

Student A has one setting and evidence of scatter. Student B has six settings and evidence of a trend. Combine a range with useful repeats:



Keep every mean within its own setting. Repeated manual timings and a range of settings serve different purposes.

Try it: decide which readings belong together

- 1 Six settings are required, including the first. You have three settings timed twice. How many settings remain?
- 2 At one setting, 20 cycles take 24.36 s and 24.52 s. Calculate the period.
- 3 Can you average this period with the period at another setting?
- 4 Does averaging loaded and unloaded lengths give an extension?

Explain the meaning of each value before choosing a calculation.

Answers: average only the same quantity

Three settings remain. Six timing readings are not six different settings.

$$T = \frac{t_1 + t_2}{2N} = \frac{24.36 \text{ s} + 24.52 \text{ s}}{2 \times 20} = 1.222 \text{ s}.$$

Keep results from different settings separate.

$$e = L - L_0 = 24.6 \text{ cm} - 22.3 \text{ cm} = 2.3 \text{ cm}.$$

Extension is the difference between two conditions.

Try it: two timings disagree

Same setting; nominally 10 cycles each

The recorded totals are 12.20 s and 18.30 s.

Choose and justify a next action:

- 1 Immediately use the mean.
- 2 Delete the larger value.
- 3 Check the count and release, reset, and time again.

What evidence would make you question one of the original readings?

A mean cannot repair an unexplained mistake

Choose action 3: investigate the large disagreement.

- Check full-cycle counting and the start/stop reference.
- Check that the setting and release conditions stayed the same.
- Take another independent timing; preserve original readings.

Two repeats are a starting point, not a universal rule. Copying a stable display twice adds no evidence; repeating cannot remove a zero error.

Translate the instruction into an action

Instruction	Action
Plot y against x	y vertically; x horizontally.
Keep h constant	Check and restore h after adjustments.
Including your first reading	Count the first complete set in the total.
Total suspended mass	Include the hanger as defined.
Hence determine	Use the preceding result.
Within the stated allowance	Compare your percentage difference with it.

Try it: replace a vague evaluation

A ball passes two marked positions quickly. You manually start and stop a stopwatch.

Improve this answer

“Human error. Use a computer.”

- What event is difficult to judge? Which measurement is affected?
- What equipment would you use, and where would it go?
- How would it measure the interval the question defines?

An evaluation pair explains cause and remedy

Limitation: judging the ball's crossing of each mark adds reaction uncertainty to the travel time.

Improvement: place a light gate at each marked position. Align the beams with the path and connect the gates to an electronic timer.

Why it helps: the timer measures the interval between crossings without manual start and stop reactions.

Check that the new method measures the same defined interval. Adapt this answer to the actual apparatus.

Show the practical skill yourself

Swap apparatus roles; each student keeps their own data and reasoning.

- 1 Measure: locate endpoints and justify an uncertainty.
- 2 Time: show one cycle, choose a count, repeat and calculate.
- 3 Record: identify settings and repeats in your own table.
- 4 Analyse: draw a graph and recover a model constant.
- 5 Evaluate: explain one observed problem and a matching change.

A correct calculation is one part of the skill. Demonstrate the measurement as well.

Transfer: what changes with a twisting oscillator?

You have practised timing a vertical spring. Now a suspended object twists back and forth.

- 1 Demonstrate one complete cycle and choose a visible reference.
- 2 Explain when to start and stop, including direction of motion.
- 3 Choose a cycle count that stays visible and repeat the timing.
- 4 Use the supplied model to decide what to calculate or plot.

The timing principle transfers. Re-identify the motion, symbols and controls for this apparatus.

Check yourself

- 1 A stopwatch shows 0.01 s. Why can hand timing still have a much larger uncertainty, and how does timing more cycles help?
- 2 A graph of T/T_0 against h/cm has gradient 0.0400/cm. Give it per metre and state the unit of its intercept.
- 3 Two constants differ by 8%, with a stated 10% allowance. Give a justified conclusion, then distinguish an extra repeat from an extra setting.