# AS Physics Practical Handbook

A-Level Physics

## 1 How to use this guide

**Cambridge International AS Physics 9702: Paper 3, Advanced Practical Skills.** Based on the 2025-2027 syllabus. This guide teaches the practical habits you need across different experiments. Use it with real laboratory practice.

You do not need to recognise the experiment in advance. Read the supplied model and follow the diagrams. A question may use unfamiliar physics; the extra information needed is supplied.

### What the paper asks you to do

- **Two questions, two hours, 40 marks.** Each question has 20 marks and up to one hour with its apparatus. Follow your centre's changeover instructions.
- Question 1: set up apparatus, collect a range of data, draw a graph, and find constants.
- Question 2: collect data, estimate uncertainty, test a suggested relationship, and evaluate the method. A graph is possible here too.
- **Evaluation** means explaining what limits the method and how to improve it. In the papers reviewed, four limitations and four improvements were requested. Read the number on your paper.

### A useful routine for each hour

1. Spend about 5 minutes reading and setting up. Find every distance, starting condition, and instruction to keep something fixed.
2. Use about 25 minutes for measurements. Record the first readings, then complete the requested data sets and repeats.
3. Use about 25 minutes for calculations, graph work, conclusions, and evaluation.
4. Leave about 5 minutes to check units, empty answer spaces, and your working. These times are a guide; adapt to the apparatus.

### Read actively before you touch the apparatus

Identify the **independent variable** : what you change. Identify the **dependent variable** : what you measure. Mark the **control variables** : what must stay the same.

Copy the meaning of each symbol from the diagram. A spring's coiled length is not its extension. A height above the bench is not a track length. A diameter is not a radius. Include a mass hanger when the question asks for total hanging mass.

Write observations immediately in the question paper, using dark blue or black pen. Use a sharp HB pencil for graphs and diagrams. Show calculations and units. If apparatus fails, tell the supervisor promptly. Help is recorded, and may affect collection marks, but you can still complete analysis and evaluation.

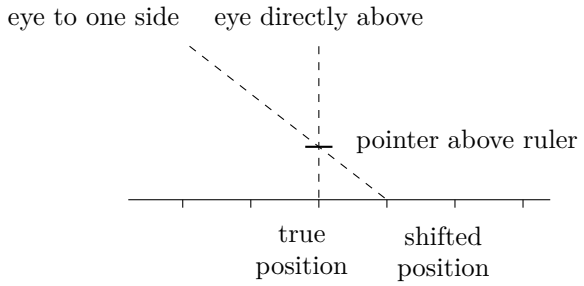
### Where to find each skill

Pages 2-5: measurement and apparatus. Pages 6-8: tables, repeats, precision, and uncertainty. Pages 9-11: graphs, constants, and conclusions. Pages 12-13: evaluation. Pages 14-16: a complete worked Question 1 (magnet oscillations). Pages 17-18: a complete worked Question 2 (a sphere on a track), including four limitations and four improvements. Page 19: practice with answers. Page 20: exam English and practical checkpoints. Page 21: final checklist and sources.

## 2 Measure the distance the diagram defines

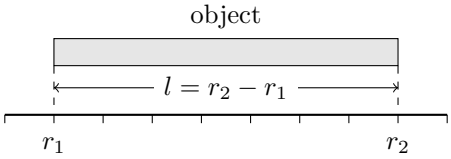
### Align the ruler and the object

Keep the ruler parallel to the distance being measured and close to it. Read with your eye directly in front of the mark. **Parallax** is an apparent change in position when your eye moves sideways.




For a vertical height, keep the ruler **vertical** with a set square. For a horizontal distance, keep it **horizontal**. Do not measure a sloping path when a vertical height is required.

The physical end of a ruler may not be its zero mark. Put one end at a clear scale mark, then subtract the two readings.




### Worked example: a ruler with an unused end

The left end is at 1.0 cm. The right end is at 13.7 cm. Length is the difference between scale readings:

$$l = r_2 - r_1$$

$$l = 13.7 - 1.0 = 12.7\,\text{cm}.$$

Keep both original readings when a difference matters. If the endpoint is unclear, its uncertainty can exceed the ruler's smallest division.

### Centres, curved edges, and spring ends

- For a sphere, use calipers across its widest part. With a ruler, place two flat blocks against opposite sides.
- For two equal objects, the gap between their matching left edges equals their centre-to-centre distance.
- To locate a hidden centre, measure both edges and use their mean. Do not guess where the centre is.
- For a spring, check whether the question includes hooks. Measure the exact endpoints shown.
- For **extension**, measure loaded and unloaded lengths from the same reference: $e = L - L_0$.

### Repeat the measurement properly

For a repeat, reposition the instrument or repeat the release. Keep the required fixed setup unchanged. For a wire or sheet, measure at several positions. For a diameter, also turn the object. Record the readings and take their mean when they estimate the same quantity. Do not average different settings, loaded and unloaded lengths, or two different quantities. Re-reading an unchanged display does not test positioning.

Distinguish shape changes from reading uncertainty. A paper cylinder that becomes oval has a changing diameter; a finer ruler alone cannot fix its shape.

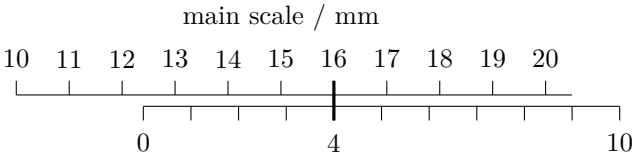
# 3 Calipers, micrometers, and scale readings

**Resolution** is the smallest change the instrument can show. Check your instrument's actual resolution.

## Vernier calipers

**Vernier calipers** can measure an outside diameter, an inside width, or a depth with different parts. Choose the correct jaws or depth rod. Keep the instrument square to the object and close gently.

1. Read the main scale just before the vernier zero.
2. Find the vernier line that matches a main-scale line.
3. Add its line number times the vernier resolution. Determine the resolution from the instrument, not from memory.



line 4 matches; vernier zero is after 12 mm

In this example, ten vernier intervals equal nine 1 mm main-scale intervals. Resolution is 0.1 mm. The main-scale reading is 12 mm; line 4 matches:

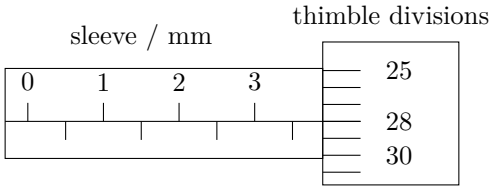
$$d = 12 + 4(0.1) = 12.4\,\text{mm}.$$

Digital calipers: check zero, select the unit, and read all displayed places.

## Micrometer screw gauge

A **micrometer screw gauge** measures a small thickness or diameter. Read the sleeve scale, including a visible half-millimetre mark. Add the thimble reading times its resolution. Use the **ratchet** to apply a light, repeatable force; do not tighten the thimble hard.

Example for a 0.01 mm micrometer: sleeve 3.5 mm, thimble division 28:



3.5 mm visible on sleeve; division 28 meets reference line

$$d = 3.5 + 28(0.01) = 3.78\,\text{mm}.$$

## Zero correction

**Zero error** is the reading when the true measurement is zero. Check clean, closed jaws before measuring. Use its signed value:

$$\text{corrected reading} = \text{observed reading} - \text{zero error}.$$

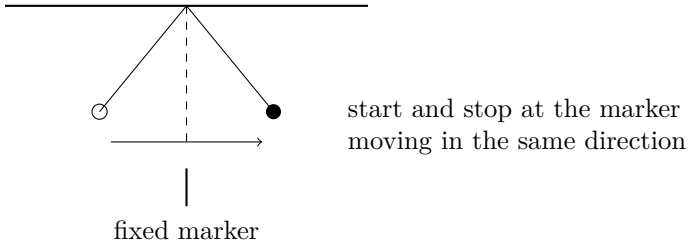
From a 3.78 mm reading: zero error +0.03 mm gives 3.75 mm; zero error −0.02 mm gives 3.80 mm.

# 4 Timing, oscillations, and moving objects

An **oscillation** is one complete cycle: back to the same position, moving in the same direction.
**Period** is the time for one cycle. A half-cycle is not a period.

### Time several cycles when possible

Use a fixed marker near the equilibrium position. Start as the object passes the marker in a chosen direction. Count that crossing as zero. Stop after $N$ complete cycles, at the same position and direction.




Take two timings at the same setting. Time 10 or 20 cycles if motion stays clear; use fewer if it dies away. Follow the paper's instructions. Record totals and $N$. For different counts, calculate each period before averaging. Investigate large disagreements (page 7).

### Worked example: finding a period

Two timings for 20 cycles are 24.36 s and 24.52 s. A longer timed interval reduces the percentage effect of start and stop reaction:

$$\bar{t} = \frac{t_1 + t_2}{2}$$

$$\bar{t} = \frac{24.36 + 24.52}{2} = 24.44\,\text{s}.$$

$$T = \frac{\bar{t}}{N}$$

$$T = \frac{24.44}{20} = 1.222\,\text{s}.$$

The counted number $N$ is exact if counted correctly. It does not limit significant figures.

### Release and motion

- Release without pushing. Keep the starting position and the release method the same.
- Use the motion shown: vertical, sideways, or twisting. Avoid an extra mode of motion.
- Keep amplitude small for an ordinary pendulum unless instructed otherwise. Keep amplitude consistent between trials.
- Let unrelated motion settle. Keep a stand stable and clamps tight without damaging the apparatus.
- For a rolling object, define the start and end events. Reset it to the same mark each time.
- Keep the track slope and supports fixed when the paper says so. Catch the object safely at the end.

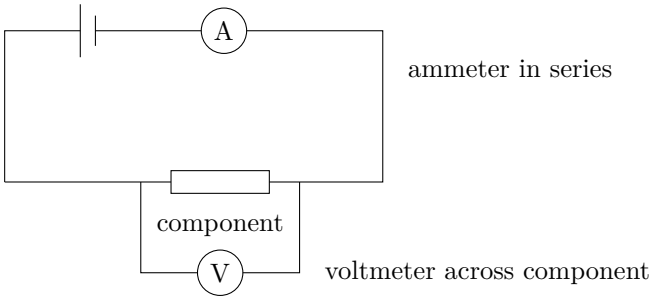
### A stopwatch display is not the timing uncertainty

A 0.01 s display does not remove reaction uncertainty. If the total interval uncertainty is 0.2 s, then $\Delta T = 0.2/20 = 0.01$ s for 20 cycles. Divide both the time and its absolute uncertainty by $N$.

# 5 Circuits and other common apparatus

## Connect the circuit before switching on

Trace the supplied circuit from one battery terminal to the other. An **ammeter** is in series with the measured branch. A **voltmeter** is in parallel across the measured component.




Select d.c. voltage or current and the correct sockets on a multimeter. Start with a safe high range, then lower it for a clearer reading. Never put an ammeter directly across a cell. Switch off before changing sockets or rewiring.

If the reading is zero, check the switch, supply, socket, range, and connections in order. A negative reading may mean reversed leads. Do not alter the circuit just to obtain an expected number.

## Control temperature and position

- For resistance measurements, heating can change the result. Use a low current and switch off between readings when allowed.
- Measure a wire's active length between the electrical contacts. Measure its diameter at several positions; do not include insulation.
- A **rheostat** uses a slider and an end connection to change resistance. Check the circuit diagram and the terminal positions.
- With a light-dependent resistor, keep room lighting and sensor direction unchanged. Keep your hands and body from shading it. Measure distance from the reference stated in the question.

## Read the instrument you actually have

- **Analogue meter** : choose the scale matching the range. For a 0-10 scale on a 0.50 A range, scale value 6.0 means 0.30 A. Read straight on; align the pointer with its mirror image if a mirror is fitted.
- **Balance** : check zero or tare the empty container. Include a hanger, adhesive, or holder if the model requires total mass. Keep the balance level and wait for a stable reading.
- **Newton meter** : check zero in its working orientation. Read force in newtons, not mass in grams. Stay within its range.
- **Protractor** : put its centre at the turning point and its baseline on the reference line. Select the scale starting at zero on that side.
- **Thermometer** : immerse the bulb properly without touching the vessel. Stir gently if appropriate and wait for a steady reading.
- **Measuring cylinder** : place it level and read at eye height. For water, use the bottom of the **meniscus** . Check the scale interval and volume unit.

Use low-voltage supplies as directed. Keep water away from electrical equipment. Support masses over the bench, handle hot water carefully, and keep clear of stretched wires and moving objects.

# 6 Build a table before taking readings

Use one table for the complete data set. Include raw readings, repeats, means, and every requested calculated column. Record the original readings, not only the answer calculated from them.

Keep the paper's symbols: a time called $t$ should not become $T$ without explanation. A trial that permanently changes a sample needs a fresh comparable sample for each repeat.

## Collect a useful range

A **set of values** contains all required readings at one setting, usually one table row. Five sets means five different settings, not five repeats at one setting. Include initial readings when instructed.

For example, November 2025 Paper 31 requires five different masses, with both $T_1$ and $T_2$ at each mass. These are periods for different arrangements: do not average them together. Paper 34 requires six different values of $W$, recording $W$, $N$, and $L$ at each.

Test the allowed low and high settings, then spread measurements across the range. Keep within the question's limits. Reset control variables after each adjustment. A wide range helps reveal the trend and determine its gradient.

## Headings and units

Write quantity and unit as $l/\text{cm}$, $t/\text{s}$, or $I/\text{mA}$. Put units in headings, not in every table cell. A ratio such as $T/T_0$ has no unit. A squared length needs $\text{cm}^2$, not cm.

## Example: a correctly organised timing table

Illustrative extract: three settings, with two timings at each setting. Each total is for 20 cycles. Here $t_1$ and $t_2$ ARE repeats at the same length. Average within each row; never average across lengths. Complete all requested rows.

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

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

## Decimal places and significant figures do different jobs

**Decimal places** describe the recording step for raw readings. A millimetre ruler gives lengths such as 7.0 cm and 12.4 cm. Keep the same precision throughout that column. Do not invent 7.00 cm from that ruler.

**Significant figures** apply to calculated values. For multiplication, division, roots, and powers, use the least number in the input measurements, or one more. Keep extra digits during working and round only for presentation.

For the first row, both times have four significant figures. $T = 1.099\,\text{s}$ and $T^2 = 1.208\,\text{s}^2$ also have four. The length is not used in these calculations. Calculated columns need not all have the same decimal places.

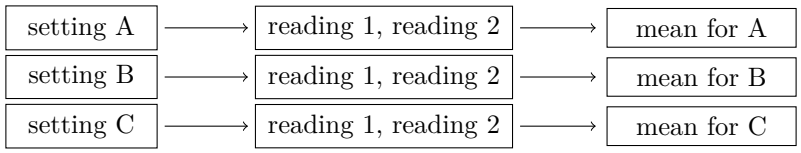
For addition or subtraction, base rounding on input decimal places. If $L = 24.6\,\text{cm}$ and $L_0 = 22.3\,\text{cm}$, write $e = 2.3\,\text{cm}$. This difference has only two significant figures; use the difference's precision in later calculations.

When asked to justify rounding, name the measurements in that calculation and their figures. "My calculator gives this" is not a justification.

Example: "My $V$ has 3 significant figures and $I$ has 2. I give $R = V/I$ to 3 significant figures, one more than the least precise input." Keep trailing zeros that show the precision.

# 7 Decide what to repeat and what to average

**A practical decision:** two students each write six times in their table. One uses six different lengths; the other repeats one length six times. Only the first has six settings for a graph. The second can assess scatter at one setting.




## Use the question to decide

1. Identify the quantity being measured and the setting it belongs to.
2. Follow any required number of readings, settings, or cycles.
3. Repeat a measurement when timing, positioning, release, or shape varies. Reset the measurement properly and record all readings.
4. Average readings of the same quantity under the same conditions. Keep different conditions in separate rows or columns.

**Two readings are a useful starting point, not a rule for every instrument.** Repeated manual timings help assess scatter. Several diameter readings at different positions help assess variation. Simply copying a stable digital display twice adds no evidence. Repeats do not remove a zero error.

## Choose a next action before reading the answers

1. A task asks for six settings including the first. You have three settings, each timed twice. How many settings remain?
2. At one setting, 20 cycles take 24.36 s and 24.52 s. Find the period. May you average this with the period at a different setting?
3. Two 10-cycle timings are 12.20 s and 18.30 s. Should you immediately report their mean? Explain your next action.
4. A diagram labels the unloaded length $L_0$ and loaded length $L$. You measure 22.3 cm and 24.6 cm. Does their mean give the extension?

## Answers and reasons

**1.** Three more settings. The six existing timings represent only three rows.

**2.** Use the mean total for this setting, then divide by the cycle count:

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

Keep the period at the other setting separate; it is a different result.

**3.** Investigate the large disagreement: check cycle counting, release, and starting conditions; reset and time again. Keep the original readings visible. A third result helps diagnose the problem; do not discard a value simply because it is inconvenient.

**4.** Extension is a difference between two conditions:

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

A mean would estimate neither the extension nor either original length.

# 8 Estimate uncertainty from the measurement

**Absolute uncertainty** is the amount after ±: $l = (12.5 \pm 0.1)$ cm uses $\Delta l = 0.1$ cm. It has the same unit as $l$. **Percentage uncertainty** is:

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

Follow a supplied uncertainty. Otherwise estimate it from the instrument, the way the reading is taken, and any repeat scatter. Explain your choice.

### One scale reading and a difference are different cases

- **One clear analogue reading:** with marks 1 mm apart, rounding to the nearest mark gives a reading allowance of ±0.5 mm. This assumes you can locate the point clearly; it is not a rule for every ruler measurement.
- **A length from two ruler readings:** for $l = r_2 - r_1$, each endpoint contributes. If each is uncertain by 0.5 mm, the simple maximum-uncertainty rule gives $\Delta l = \Delta r_2 + \Delta r_1 = 0.5 + 0.5 = 1.0$ mm. Add the amounts even though you subtract the readings.
- **A digital display:** a balance reading 25.4 g changes in steps of 0.1 g. In the absence of a stated accuracy, ±0.1 g is a simple allowance for the display step, not a guarantee of the balance's accuracy. Use stated specifications when provided; fluctuations or the method may require more.

### The apparatus can make the uncertainty larger

A ruler with 1 mm marks does not make a moving endpoint readable to 0.5 mm. Suppose its position is only reproducible within about ±2 mm. Estimate $\Delta h = 2$ mm for that height, and state the reason. Similarly, a stopwatch's 0.01 s display does not remove manual reaction uncertainty.

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

$$u_h = \frac{\Delta h}{h} \times 100\% = \frac{0.2\,\text{cm}}{3.2\,\text{cm}} \times 100\% \approx 6.3\%.$$

Use matching units. This is an example estimate, not a universal 2 mm rule.

### Repeated readings: why half the range?

Readings 12.4, 12.6 and 12.5 cm have mean 12.5 cm. Their **full range** is $12.6 - 12.4 = 0.2$ cm, from lowest to highest. In this example, each extreme is 0.1 cm from the mean:

$$\Delta l = \frac{l_{\max} - l_{\min}}{2} = \frac{12.6\,\text{cm} - 12.4\,\text{cm}}{2} = 0.1\,\text{cm}, \qquad l = (12.5 \pm 0.1)\,\text{cm}.$$

The ±0.1 cm interval has a *total width* of 0.2 cm. Divide by two to express this width as an amount on either side, not because there are two or three readings. Cambridge accepts half-range as a practical estimate where appropriate; it is not an exact statistical uncertainty or a guarantee for future readings. For uneven scatter, the mean need not be the midpoint of the extremes.

Show the repeats and working. Do not claim zero uncertainty for identical readings, or ignore a larger known uncertainty in the instrument or method.

### Carry uncertainty through a calculation

For sums or differences, add absolute uncertainties. For products or quotients, add percentage uncertainties. For $z = a^n$, use $u_z = |n|u_a$. For exact $N$, $T = t/N$ gives $\Delta T = \Delta t/N$ and $u_T = u_t$. Exact constants add none.

Example: $e = 24.6 - 22.3 = 2.3$ cm, each length uncertain by 0.1 cm: $\Delta e = 0.2$ cm and $u_e \approx 8.7\%$. Repeats can improve a mean affected by **random error**; they do not remove a **systematic error** such as a zero error.

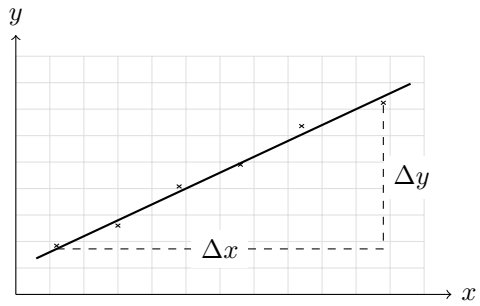
# 9 Draw a graph that can be read accurately

## Set the axes and scales

1. Use exactly the requested quantities. "Plot $L$ against $Z$" means $L$ on the vertical axis.
2. Label quantities and units as in your table. A dimensionless quantity has no unit.
3. Make the data span at least half the grid horizontally and vertically. Check both before plotting.
4. Use easy intervals: 1, 2, or 5 times a power of ten per large square. Number each axis regularly, at least every 2 cm.
5. A **false origin** lets an axis start away from zero. Label its first value clearly. Keep the scale uniform throughout the plotted region.

## Plot every observation

Use small, clear crosses or encircled dots, smaller than 1 mm. Plot to better than 1 mm accuracy. Read both coordinates from the table, including the calculated columns. Do not swap them.




triangle corners on the fitted line, not chosen raw points

## Draw the trend, then measure its gradient

A **line of best fit** balances scatter on both sides along its whole length. Draw one thin straight line with a ruler if asked. Do not join points, choose only the first and last points, or force the line through zero.

An **anomalous point** lies away from the main trend. Check the reading while apparatus is available. If justified, circle and label one point, keeping its original value visible. Do not delete inconvenient data. In a six-point task, retain at least five points when fitting after excluding one. Follow your paper's requirements.

Choose two widely separated points on the fitted line. They need not be measured points. Draw a large triangle whose sloping side exceeds half the drawn line. Record both coordinates, using their actual scale values.

$$G = \frac{y_2 - y_1}{x_2 - x_1}.$$

Use changes in quantities, not a ruler's centimetres on the graph paper. Retain a negative sign for a falling line. Give gradient units: vertical-axis unit divided by horizontal-axis unit.

If the question requests a curve, draw a smooth trend curve. A **tangent** gives its gradient at a particular point; calculate from two distant points on that tangent. Do not replace a requested curve with a straight line.

The sketch above shows the method. Page 15 shows a complete table and a graph with numerical scales; page 16 reads its gradient.

## 10 Find constants from your graph

Let $G$ be the graph gradient and $C$ its **intercept** . Match the supplied equation to $y = Gx + C$ before substituting numbers. The gradient is not always the requested constant itself.

### Worked example: a false origin

Suppose $L = aZ + b$. The graph has $L$/cm vertically and dimensionless $Z$ horizontally. Two points on the fitted line are $(1.20, 4.10)$ and $(2.00, 6.50)$.

$$G = \frac{L_2 - L_1}{Z_2 - Z_1}$$

$$G = \frac{6.50 - 4.10}{2.00 - 1.20} = 3.00\,\text{cm}.$$

Comparing $L = aZ + b$ with $y = Gx + C$ gives $a = G$ and $b = C$.

The displayed left edge might be $Z = 1.00$. Its height is not the intercept. The intercept is the value at $Z = 0$. Use a point on the fitted line:

$$b = L - aZ$$

$$b = 4.10 - 3.00(1.20) = 0.50\,\text{cm}.$$

Thus $a = 3.00\,\text{cm}$ and $b = 0.50\,\text{cm}$. A vertical axis that starts above zero is also acceptable: read the true value at $x = 0$ if visible. Otherwise use $C = y - Gx$.

### Match symbols and units

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

These models are supplied in November 2025 Paper 34, Q1 ($L = aZ + b$), and June 2025 Paper 35, Q1 ($T/T_0 = Ph + Q$). Learn how to match the supplied equation to $y = Gx + C$; you do not need to memorise these particular models.

For $L$/cm against dimensionless $Z$, $a$ and $b$ both have units cm. For $T/T_0$ against $h$/cm, $P$ has unit 1/cm and $Q$ has no unit.

### Use the supplied transformed quantity

A question may ask for $T^2$, $1/l$, $\sqrt{T}$, or a ratio. Calculate and plot that quantity. Do not substitute a more familiar graph. For $\sqrt{T}$, the unit is $\text{s}^{1/2}$; for $1/l$, it is inverse length.

Keep units consistent through the table, graph, and calculation. Convert when the model needs SI units. For the ratio graph, a gradient of 0.0400/cm equals 4.00/m. Its number changes when the horizontal-axis unit changes; see page 16.

Use the fitted equation for a prediction, substituting the requested $x$ value. State when it lies outside the measured range: the trend may not continue there. A straight line alone does not show direct proportionality; that also requires zero intercept within the measurement uncertainty.

# 11 Test a relationship with two data sets

A **hypothesis** may say a calculated quantity $k$ is constant. Rearrange the supplied equation. Calculate $k$ separately for each data set. Compare those values, not the raw readings.

### Worked example: rearrange before calculating

For an illustrative model $t^2 = kx$, the measurements are $(x_1, t_1) = (0.200\,\text{m}, 0.640\,\text{s})$ and $(x_2, t_2) = (0.400\,\text{m}, 0.890\,\text{s})$.

$$k = \frac{t^2}{x}$$

$$k_1 = \frac{0.640^2}{0.200} = 2.048\,\text{s}^2/\text{m}.$$

$$k_2 = \frac{0.890^2}{0.400} = 1.98025\,\text{s}^2/\text{m} \approx 1.980\,\text{s}^2/\text{m}.$$

Three significant figures in each input allow three or four in $k$. Use unrounded calculator values for the comparison. State which measured quantities limit your figures when asked.

### Calculate percentage difference

One clear symmetric convention uses the mean of the two values as the reference:

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

For the positive values above:

$$D = \frac{|2.048 - 1.98025|}{(2.048 + 1.98025)/2} \times 100\% \approx 3.36\%.$$

Show your denominator explicitly and keep that convention throughout. If the question specifies another convention, use it. Here $D$ compares two measurements, not a measurement with a known true value.

### Compare with the stated allowance

If the question gives a 10% allowance, write: "The percentage difference is 3.36%, below 10%. My results support the suggested relationship within this allowance."

If your difference exceeds the allowance, say your results do not support it within that allowance. Do not change measurements to obtain agreement. Do not claim that two values prove a relationship for every possible setting.

**Read the allowance on this paper.** The reviewed 2025 papers use 10%, 20%, and 30%. There is no universal 10% or 20% rule. Use the given value for this comparison; do not silently double it or replace it with an earlier uncertainty estimate.

### Keep the two data sets separate

Use each object's own measurements. Re-measure changing quantities; retain fixed quantities as instructed. Keep a denominator containing a sum inside brackets.

# 12 Write limitations that explain a real problem

A **limitation** is a weakness in measurement or procedure. Name the quantity and explain why its reading or the conclusion is uncertain.

Use this structure: **"It is difficult to measure [quantity] because [specific cause]."** Where helpful, explain the consequence.

## Four useful categories to inspect

1. **Reading:** unclear centres, thick markers, moving endpoints, small heights, an awkward ruler position.
2. **Motion:** unclear timing events, rapidly dying oscillations, unwanted sideways motion, inconsistent release.
3. **Apparatus:** bending track, slipping contacts, friction at a pivot, compression of soft material.
4. **Model and evidence:** an omitted mass, a changing control variable, or only two settings to test a relationship.

Choose independent problems. Four versions of "the ruler is hard to read" may describe only one limitation. Do not claim a problem you did not have or that the method already prevents.

## Examples of wording that carries information

- Weak: "Human error." Useful: "The ball reaches the box quickly, so judging the stop event adds uncertainty to $t$."
- Weak: "Parallax." Useful: "The spring end is separated from the ruler, so its apparent scale position changes with eye position."
- Weak: "Not enough readings." Useful: "Only two diameters were tested, so agreement between two $k$ values is weak evidence for the relationship."
- Weak: "The equipment is inaccurate." Useful: "The caliper jaws compress the rubber, so the measured diameter depends on contact force."

## Repeats and extra settings solve different problems

Repeating the same setting checks scatter and improves a mean. Adding different settings tests the relationship across a range. For a two-setting investigation, write: "Use more different values of the independent variable, then compare more $k$ values or plot the relevant graph."

## Choose changes beyond ordinary correct technique

In the evaluation section, "read at eye level", "repeat the timing", and "tighten the clamp" can be too basic. They may already be possible or required with the supplied apparatus. Normally these are things to do during the experiment, not new improvements earning evaluation credit.

An improvement should change a real weakness in the setup or procedure. Name the apparatus, where it goes, what it measures, and how it helps. You may propose school-laboratory equipment not supplied. Keep the same investigation. A completely different experiment does not improve this method.

## 13 Match each limitation to a workable improvement

These are examples to adapt, not a list to copy into every experiment. Select the pairs that fit your apparatus. Write the same pair number in the limitations and improvements spaces.

### Lengths and shapes

**Problem:** the small height $h$ has a large percentage uncertainty; the ruler's unmarked end makes contact awkward. **Change:** use a suitable depth gauge or calipers between the bench reference and the required surface. Name those contact points.

**Problem:** a moving spring endpoint is difficult to compare with a hand-held ruler. **Change:** clamp the ruler beside the spring and add a pointer marking the required endpoint.

**Problem:** the centre of a mass is hidden. **Change:** measure both edges and average their positions, or use matching edges for equal masses.

**Problem:** a paper cylinder becomes oval near its clips. **Change:** form it around a circular template, secure the seam consistently, and remove the template before testing deformation.

### Timing and motion

**Problem:** start and stop events are difficult to judge for a moving ball. **Change:** use suitable light gates connected to a timer at defined start and end positions. Align the beam with the ball's path. Alternatively, film with a visible timer or known frame rate, then inspect frames.

**Problem:** oscillations die away before many cycles can be timed. **Change:** use video to identify repeated crossings over the visible cycles. A bigger starting amplitude is only suitable if it keeps the model and required motion valid.

**Problem:** an object rolls unevenly because the track bends under it. **Change:** use a rigid track with extra supports underneath, while keeping the required geometry.

### Missing mass, changed samples, and friction

**Problem:** adhesive adds mass that the model ignores. **Change:** weigh the adhesive with the attached masses and use that total, or use a specified lighter attachment.

**Problem:** a paper sample changes shape after getting wet, so it cannot give independent repeat trials. **Change:** prepare fresh identical samples, keeping their dimensions and orientation the same, and repeat the placement and timing.

**Problem:** a suspended card sticks on a thick nail, changing its resting direction. **Change:** use a thinner smooth pin and a suitable smooth hole so the card swings freely.

### Evidence across a range

**Problem:** two settings give too little evidence for a general relationship. **Change:** test more different settings across a wider allowed range; calculate and compare more constants, or plot the graph predicted by the model.

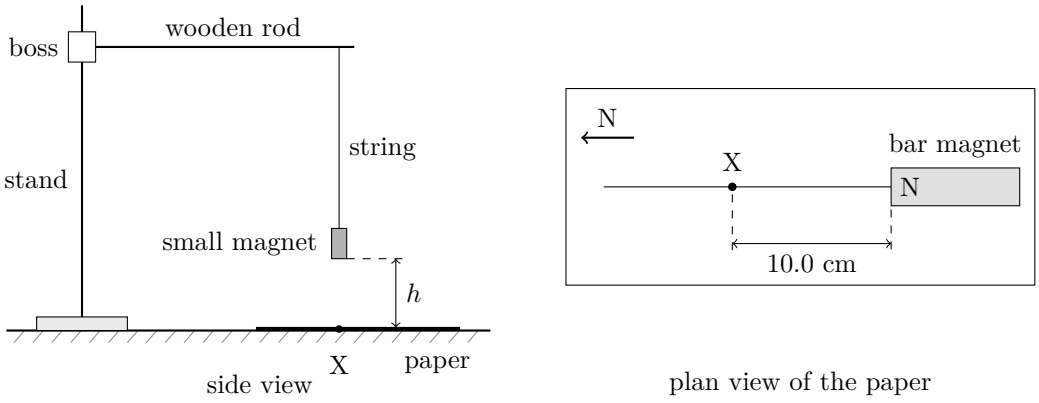
Avoid "use better apparatus", "use a computer", or "be more careful". Each change must address a named problem. More decimal places cannot remove a systematic error or make a flexible object rigid.

# 14 Worked Question 1: set up and plan

**Exam basis: 9702/35 May/June 2025, Q1.** The setup, model, height range and mark points below come from that paper and its published mark scheme. The readings on pages 15–16 are illustrative teaching data, not an official solution.

### The apparatus

A small magnet hangs on a string from a wooden rod clamped in a boss. A sheet of paper is fixed to the bench, its line aligned north–south with a plotting compass; point X is the middle of the line. The bar magnet lies on the line with its N pole 10.0 cm from X.




### Read the supplied model and define the periods

First determine $T_0$ at $h = 3.0$ cm *without* the bar magnet. Then place the bar magnet, draw round it, and never move it. Displace the small magnet a short distance along the line, release it, and find $T$ for each height. The paper supplies

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

Plot $T/T_0$ vertically against $h$ horizontally. Comparing with $y = Gx + C$ gives $P = G$ and $Q = C$. $T_0$ is one fixed reference period; do not average it with $T$.

### Make a collection plan

- Six heights in the stated range $3.0 \leq h/\text{cm} \leq 9.0$, including the first. Spread them: the scheme's range mark needs $h \leq 4.0$ cm and $h \geq 8.0$ cm.
- Record every $h$ to the nearest mm. Re-centre the magnet over X after each change of height.
- Time 20 cycles twice at each height (the scheme asks for at least two timings of five or more cycles). Here $t_1$ and $t_2$ are those repeat totals.
- Check the trend as you go: the bar magnet makes the oscillation faster, so $T < T_0$, and $T$ increases as $h$ increases.

### Where the 20 marks go

| Part | What earns the marks | Marks |
|---|---|---|
| (a), (b) | $T_0$ from repeated timings of many cycles, with unit; $T < T_0$ with the bar magnet | 3 |
| (c) table | six sets (five marks), range, headings, $h$ to the nearest mm, $T/T_0$ correct | 9 |
| (d) graph | axes and scales, plotting, quality, line of best fit, gradient, intercept | 6 |
| (e) | $P$ and $Q$ from your gradient and intercept; $P$ in $\text{cm}^{-1}$, $Q$ no unit | 2 |

# 15 Worked Question 1: table and graph

## Record the reference and the complete table

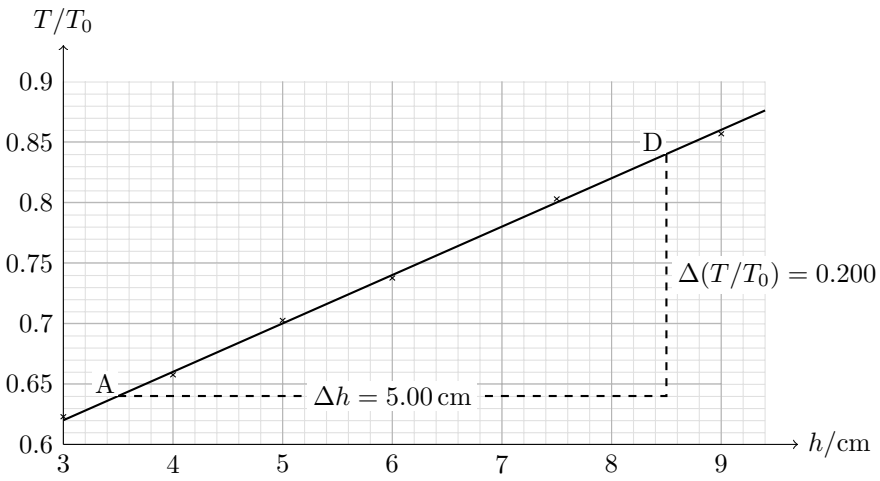
Illustrative reference totals: 23.96 s and 24.04 s for 20 cycles without the bar magnet, so

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

| $h$/cm | $t_1$/s | $t_2$/s | $T$/s | $T/T_0$ |
|---|---|---|---|---|
| 3.0 | 14.88 | 15.02 | 0.7475 | 0.6229 |
| 4.0 | 15.72 | 15.84 | 0.7890 | 0.6575 |
| 5.0 | 16.80 | 16.92 | 0.8430 | 0.7025 |
| 6.0 | 17.64 | 17.76 | 0.8850 | 0.7375 |
| 7.5 | 19.33 | 19.21 | 0.9635 | 0.8029 |
| 9.0 | 20.50 | 20.62 | 1.028 | 0.8567 |

For the first row, $T = (14.88\,\text{s} + 15.02\,\text{s})/(2 \times 20) = 0.7475\,\text{s}$ and $T/T_0 = 0.7475/1.200 = 0.6229$. The ratio has no unit because seconds cancel. Four significant figures match the timings. The repeats differ by up to 0.14 s: a genuine record of scatter, not a copied value.

## Plot and draw the line




Both axes start away from zero: the lower-left corner is (3.0, 0.60), neither the origin nor the $y$-intercept. Heights span 6.0 cm of the 6.4 cm grid; ratios span 0.23 of 0.30. Points alternate either side of the line along its whole length, so the line is balanced.

# 16 Worked Question 1: constants and units

### Read a large triangle on the fitted line

Choose $A = (3.50\,\text{cm},\ 0.640)$ and $D = (8.50\,\text{cm},\ 0.840)$ on page 15. These points are on the fitted line; they need not be measured data points. The hypotenuse is longer than half the line, and both read-offs are exact to half a small square.

$$G = \frac{(T/T_0)_D - (T/T_0)_A}{h_D - h_A} = \frac{0.840 - 0.640}{8.50\,\text{cm} - 3.50\,\text{cm}} = 0.0400\,\text{cm}^{-1}.$$

The vertical quantity has no unit, so the gradient has the unit of $1/h$. Use actual coordinate differences, never ruler distances on the paper.

### Match the model and find the constants

The coefficient of $h$ is $P$, so $P = G = 0.0400\,\text{cm}^{-1}$. The constant $Q$ is the value at $h = 0$, outside the displayed graph, so substitute a point on the line:

$$Q = \left(\frac{T}{T_0}\right)_A - Ph_A = 0.640 - (0.0400\,\text{cm}^{-1})(3.50\,\text{cm}) = 0.500.$$

$Q$ has no unit. It is not the graph's bottom value, 0.60, or its left-edge line value, 0.620. Give $P$ and $Q$ as decimals to at least two significant figures, never as fractions.

### Express a gradient in a different length unit

The scheme accepts $\text{cm}^{-1}$ or $\text{m}^{-1}$, consistent with the readings:

$$P = 0.0400\,\text{cm}^{-1} \times 100\,\frac{\text{cm}}{\text{m}} = 4.00\,\text{m}^{-1}.$$

The same line is described by both. Match the number to its unit when substituting.

### A complete final answer

"$P = 0.0400\,\text{cm}^{-1}$, $Q = 0.500$." Above it on the page: the triangle coordinates, the gradient calculation, and the substitution for $Q$. Your apparatus and readings will give your own values.

### Further practice: use the fitted model

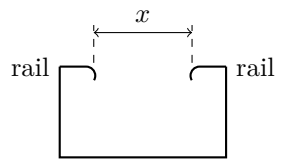
The exam stops at $P$ and $Q$. As practice, predict the period at $h = 6.50$ cm, inside the measured range:

$$T = T_0(Ph + Q) = (1.200\,\text{s})[(0.0400\,\text{cm}^{-1})(6.50\,\text{cm}) + 0.500] = 0.912\,\text{s},$$

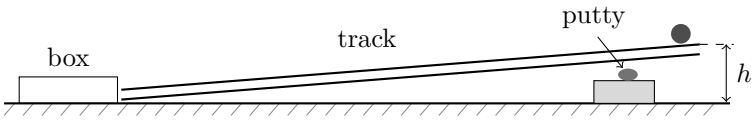
so 20 cycles would take about $20 \times 0.912\,\text{s} = 18.2\,\text{s}$. A prediction at 12 cm would extrapolate beyond the 3.0–9.0 cm range, where the trend may not continue. A nonzero intercept means $T/T_0$ is not directly proportional to $h$.

# 17 Worked Question 2: measure and calculate

**Exam basis: 9702/34 October/November 2025, Q2.** The setup, model, 30% figure and mark points come from that paper and its published scheme; the readings are illustrative teaching data. A sphere rolls down a plastic channel whose two rails are a distance $x$ apart. The raised end rests on a wooden block, fixed with putty, at height $h$; the sphere rolls into a box.




end view of the channel




wooden block

side view: the sphere is released at the raised end

## The readings

$x = 1.60\,\text{cm}$ and $h = 3.2\,\text{cm}$, each to the nearest mm. The block and track stay fixed for both spheres, so $x$ and $h$ are measured once. Each diameter is read with calipers; each time is two releases from the same point.

| sphere | $d$/cm | $1-(x/d)^2$ | $t_1$/s | $t_2$/s | $t$/s |
|---|---|---|---|---|---|
| smaller | 2.00 | 0.360 | 5.14 | 5.26 | 5.20 |
| larger | 2.50 | 0.590 | 4.86 | 4.74 | 4.80 |

The larger sphere takes less time: that trend is a mark in itself, so check it before you leave the apparatus.

## Percentage uncertainty in $h$

A single ruler reading to the nearest mm, at a raised end that is hard to sight against the scale: $\Delta h = 0.1\,\text{cm}$ (the scheme accepts 1 or 2 mm).

$$\frac{\Delta h}{h} \times 100\% = \frac{0.1\,\text{cm}}{3.2\,\text{cm}} \times 100\% = 3\%.$$

With repeated readings, half the range is accepted, but never zero when the readings agree.

## Calculate $k$ for each sphere

The model is $t^2 h = k\left(5 + \dfrac{2}{1-(x/d)^2}\right)$, so $k = t^2 h/F$ with $F = 5 + 2/[1-(x/d)^2]$. The 5 is added after the division.

$$F_1 = 5 + \frac{2}{0.360} = 10.5556, \qquad k_1 = \frac{(5.20\,\text{s})^2(0.032\,\text{m})}{10.5556} = 0.0820\,\text{m s}^2,$$

$$F_2 = 5 + \frac{2}{0.5904} = 8.38753, \qquad k_2 = \frac{(4.80\,\text{s})^2(0.032\,\text{m})}{8.38753} = 0.0879\,\text{m s}^2.$$

$F$ has no unit, so $k$ has the unit of $t^2 h$. Recalculate $F$ for each sphere; keep guard digits until the final answer.

# 18 Worked Question 2: conclusion and evaluation

### Justify the significant figures

"$t$, $x$ and $d$ were recorded to three significant figures and $h$ to two, so I gave $k$ to three." The mark needs the link to the raw readings $t$, $h$, $x$ and $d$; not the exact 5 and 2 in the model, and not "the calculator showed this". Two or three figures are both acceptable here.

### Test the relationship against the stated 30%

$$D = \frac{|k_2 - k_1|}{(k_1 + k_2)/2} \times 100\% = \frac{0.0879019 - 0.0819739}{0.0849379} \times 100\% = 7.0\%.$$

"The percentage difference between my two values of $k$ is 7.0%. This is less than the 30% uncertainty, so my results support the relationship." One mark needs both the calculation and a conclusion consistent with it. Two values within the allowance support the model; they do not prove it.

### Four limitations and four matching improvements

The paper asks for four of each, in separate answer spaces. Write each improvement with the same number as its limitation. Each row below would earn a mark in each column; choose the four that you actually met. This student read $d$ with calipers, so row 4 does not describe their experiment: they would choose from rows 1, 2, 3, 5 and 6.

| | **Limitation: the problem and its cause** | **Improvement that addresses it** |
|---|---|---|
| 1 | Two values of $k$ are not enough to draw a conclusion about the relationship. | Use several more spheres of different diameter; calculate $k$ for each and compare, or plot a graph. |
| 2 | $h$ is small, so a 1 mm reading uncertainty is a large percentage; the ruler's scale does not start at its end. | Measure $h$ with vernier calipers (depth gauge) from the bench to the raised end. |
| 3 | Hard to judge the instant the sphere enters the box, so $t$ is uncertain. | Film the run with a timer in view and step through frame by frame, or put a light gate at the end of the track connected to a timer. |
| 4 | Hard to measure $d$ with a ruler: parallax at a curved surface. | Measure $d$ with a micrometer or vernier calipers, at several orientations. |
| 5 | The smaller sphere ($d$ close to $x$) sinks between the rails and sticks, or the sphere rolls off when the track tilts sideways. | Use spheres of larger diameter, or a narrower track; check the track is level across its width with a spirit level. |
| 6 | The track bends under the heavier sphere, or the box moves when the sphere hits it, so the distance rolled varies. | Use a rigid (metal) track, or add supports along its length; fix the box with putty. |

### What earns nothing

"Human error", "parallax" on its own, "repeat the readings" with no reason, "use a computer", "use more accurate equipment", and "be more careful". Two limitations with the same cause count once. Improvements must be practical school apparatus for this same experiment, not a different investigation.

## 19 Quick practice with checked answers

Cover the answers below. These short tasks check practical decisions, not topic theory.

### Tasks

1. A micrometer reads 2.46 mm. Its zero error is −0.02 mm. Find the corrected thickness.
2. A ruler gives $L = 18.4\,\text{cm}$ and $L_0 = 16.7\,\text{cm}$. Each has uncertainty 0.1 cm. Find extension and percentage uncertainty.
3. Fifteen cycles take 18.30 s and 18.42 s. Find the mean period. Explain why timing one cycle is less useful.
4. You plot $T/T_0$ against $h/\text{cm}$ for $T/T_0 = Ph + Q$. The fitted line passes through $(2.00, 1.120)$ and $(8.00, 1.480)$. Find $P$, $Q$, and their units.
5. Two constants are 0.420 and 0.455 in the same unit. Use the mean-reference percentage difference. Does the relationship pass a 10% allowance? A 5% allowance?
6. A rolling ball bends a plastic track. Write one specific limitation and its matching improvement.

### Answers and reasons

**1.** Subtract the signed zero error:

$$d = d_{\text{obs}} - e_0 = 2.46 - (-0.02) = 2.48\,\text{mm}.$$

**2.** Extension is a difference; absolute uncertainties add:

$$e = L - L_0 = 18.4 - 16.7 = 1.7\,\text{cm}.$$

$$\Delta e = \Delta L + \Delta L_0 = 0.1 + 0.1 = 0.2\,\text{cm}.$$

$$u_e = \frac{\Delta e}{e} \times 100\% = \frac{0.2}{1.7} \times 100\% \approx 12\%.$$

**3.** Divide the mean total time by the exact count:

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

Start and stop reaction has a smaller percentage effect on a longer interval.

**4.** Match the gradient and intercept to the model:

$$P = \frac{y_2 - y_1}{h_2 - h_1} = \frac{1.480 - 1.120}{8.00 - 2.00} = 0.0600\,/\text{cm}.$$

$$Q = y - Ph = 1.120 - 0.0600(2.00) = 1.000.$$

$P$ has inverse-length units; $Q$ has no unit. The plotted left edge need not be $h = 0$.

**5.** $D = |0.455 - 0.420|/0.4375 \times 100\% = 8.0\%$. Supported within 10%; not supported within 5%.

**6.** "The track bends under the ball, changing the slope and the travel time. Use a rigid track with extra supports to keep the slope fixed."

# 20 Turn instructions into practical actions

## Exam English: say what you will do

| Instruction | Action |
|---|---|
| Plot $y$ against $x$ | Put $y$ vertically and $x$ horizontally. |
| Keep $h$ constant | Check and restore $h$ after changing the independent variable. |
| Including your first reading | Count the first complete set towards the required total. |
| Total suspended mass | Include the hanger and attached masses, as defined. |
| Hence determine | Use the result just obtained in the next calculation. |
| Within a stated allowance | Calculate the percentage difference and compare it with that allowance. |

## Explain a limitation and a matching improvement

**Sentence support:** "It is difficult to measure … because …" Then: "Use … at … to measure …; this reduces …"

**Try:** a ball passes two marked positions quickly. A student manually starts and stops a stopwatch. Replace "human error; use a computer" with a useful pair.

**One answer:** judging when the ball crosses each mark adds reaction uncertainty to the travel time. Place a light gate at each marked position, aligned with the ball's path, and connect them to an electronic timer. This measures the interval between the crossings without manual start and stop reactions. Check that the gates measure the same interval defined in the question.

## Practical checkpoints: show the skill yourself

Work with a partner, swapping roles. Each student records their own data and explains their own decisions. Ask a partner or teacher to observe these actions:

1. **Measure:** locate the correct endpoints, align the ruler, and explain your uncertainty estimate.
2. **Time:** show one full cycle, choose a suitable count, repeat a timing, and calculate the period.
3. **Record:** identify settings and repeats in your table; explain which values can be averaged.
4. **Analyse:** plot your own data, choose line points for a gradient, and recover a constant from the supplied model.
5. **Evaluate:** name one problem you actually observed and explain a change that addresses its cause.

**Transfer task:** change the apparatus or geometry and repeat the explanation without the worked example. For example, change from a vertical spring to a twisting oscillator: identify the cycle and timing reference again. Keep the prescribed motion and follow the new model.

# 21 Final Paper 3 checklist

## Before and during measurement

- I know the endpoints and reference surfaces for every length.
- I checked zero, range, units, alignment, and the required setup.
- I recorded the initial measurements in their answer spaces.
- I used the requested number of different settings and a useful allowed range.
- I kept control variables fixed and recorded genuine repeats where appropriate.
- My readings are written immediately, with units and suitable precision.

## Before leaving the graph

- Both axes show the requested quantity and unit; calculated powers and ratios are correct.
- Points fill at least half the grid in both directions; scales are easy and regularly labelled.
- Every table observation is plotted accurately with a small mark.
- My fitted line balances scatter; any ignored anomaly is clearly identified.
- My gradient uses two distant points on the fitted line, with coordinates and a large triangle.
- I found the intercept at $x = 0$, or calculated it using a point on the fitted line.
- I matched the equation to the graph and gave the constants with appropriate units.

## Before finishing Question 2

- My uncertainty estimate names the measurement problem and uses consistent units.
- My significant-figure explanation names the quantities used in the calculation.
- I calculated each constant from its own data set.
- I showed percentage difference and compared it with the allowance printed in this paper.
- My conclusion follows my numbers, without claiming proof from two settings.
- Each limitation names a real cause; each improvement explains a workable change.
- I supplied exactly the requested number of distinct points and checked every answer space.

## Sources and scope

Cambridge International AS & A Level Physics 9702, syllabus for examination in 2025, 2026 and 2027, practical assessment, printed pages 42-48. Check the syllabus for your examination year if using this guide after 2027.

Question papers and mark schemes reviewed: October/November 2025, 9702/31, /34, /35; May/June 2025, 9702/31, /32, /34, /35. These include springs, equilibrium, rolling objects, a light-dependent resistor, paper on water, and balls falling through water.

The magnet model and setup on pages 14-16 are from 9702/35 May/June 2025, Q1; the rolling-sphere question on pages 17-18 is from 9702/34 October/November 2025. Mark points are summarised from the published schemes. Worked readings, fitted lines, predictions and diagrams are newly authored teaching examples. Exact measurements, uncertainty estimates, ranges, and evaluation points depend on the apparatus and question. Follow the live paper's instructions.