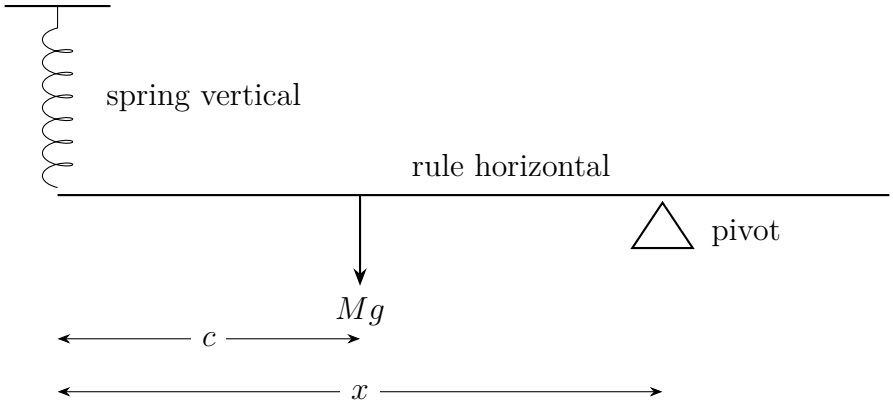
Spring constant from moments

Name: _____ Class: _____ Date: _____

Aim Find a spring constant indirectly by balancing moments. Allow 60–75 minutes.

Key ideas A **moment** is force × perpendicular distance. Below the elastic limit, $F = k(l - l_0)$. Use $g = 9.81\,\mathrm{m\,s^{-2}}$.

Apparatus Metre rule, spring, stand and clamp, string, pivot, taped 100 g mass, millimetre ruler and balance.



Measure c and x from the *same spring attachment point*; $x > c$. The combined weight acts at c. Diagram not to scale.

Safety Weight the stand base and keep masses over the bench. Do not overstretch the spring. Ask the teacher to check the setup before loading it.

1 Set up and measure

1. Balance the unloaded rule on the pivot. Tape the 100 g mass at its balance point. Check the combined rule still balances there. Measure c and total mass M, including tape.
2. Measure the unstretched *coiled section* length l_0. Use the same two coil endpoints in every later reading.
3. Attach the spring near one end. Place the pivot beyond c. Adjust the clamp height until the rule is horizontal and the spring vertical.
4. Measure pivot distance x and coil length l. View scales at right angles. Wait for the rule to stop moving.
5. Choose at least six safe pivot positions spread over the usable range. Restore horizontal balance each time. Repeat l after resetting the balance. Revisit the first position at the end to check for spring drift.

Processing check (synthetic data) A fitted gradient is $s = -0.0500 \pm 0.0025\,\mathrm{m^2}$, with $M = 0.200$ kg and $c = 0.500$ m. Taking M, c, g as exact for this check, calculate $k = -Mgc/s$ and its approximate uncertainty.

2 Record measurements

$M =$ _____ kg $c =$ _____ m $l_0 =$ _____ m

Instrument resolution: rule _____; balance _____.

Convert lengths to metres before processing. A 1 mm rule reading is recorded to 0.001 m. Keep guard digits when calculating $1/x$. Repeats belong in the table, not only in a mean.

x/m	l_1/m	l_2/m	$\bar{l}$/m	$(1/x)$/m^{-1}

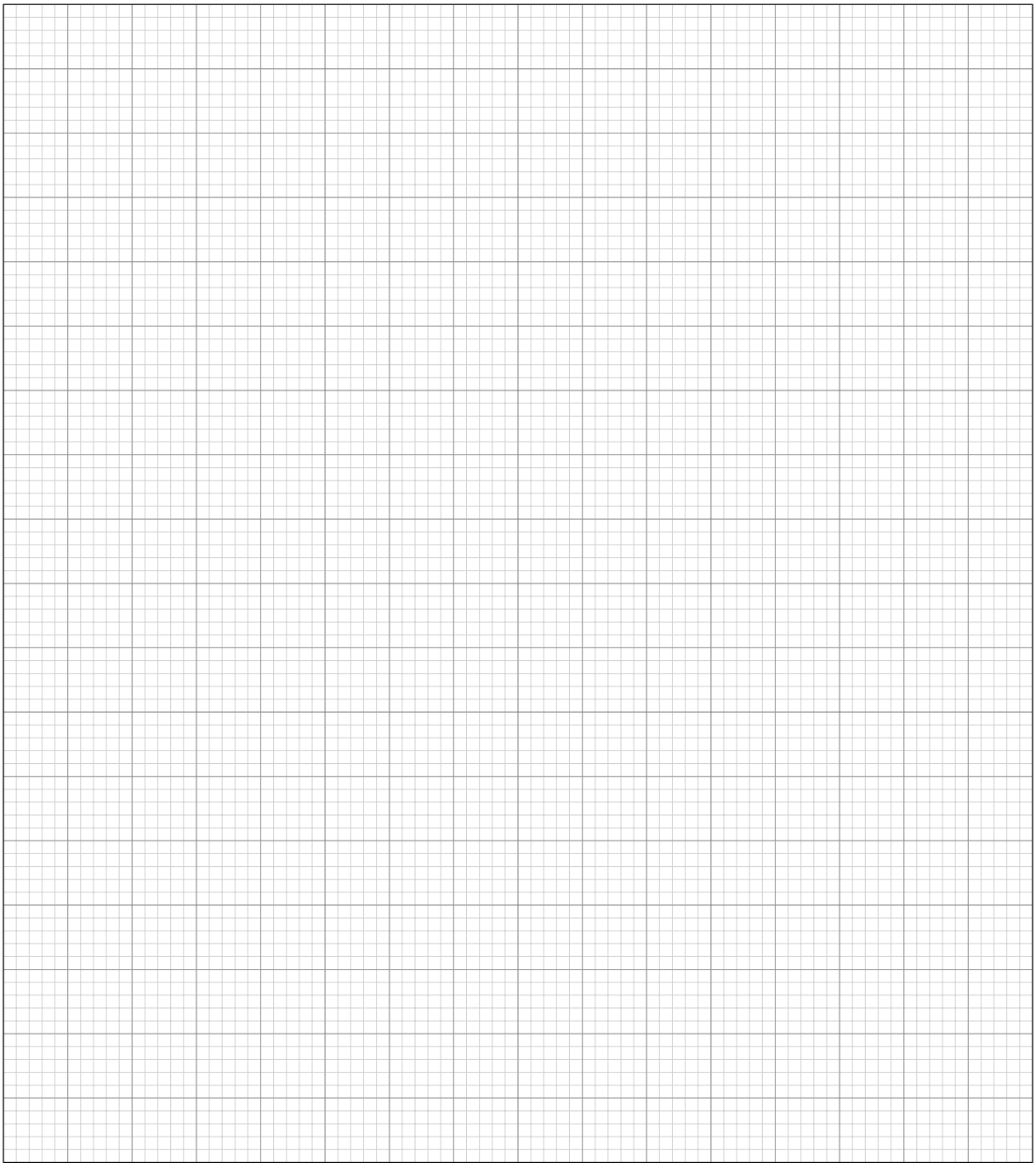
Controls Why must the rule remain horizontal and the spring vertical?

Pilot check Record your usable range and explain why the smallest x must remain greater than c.

Uncertainty Record resolution and estimate Δl and Δx. Consider two-endpoint readings, coil alignment and the spread of repeats. Explain the estimates.

3 Graph

Plot mean coil length $\bar{l}$ against reciprocal distance $1/x$. Draw a best-fit line; do not force it through the origin. Extension beyond Paper 3: add justified uncertainty bars in both variables and a defensible extreme line; use the gradient difference as an estimate of Δs. If no straight line fits the bars, discuss the model or underestimated errors.



Choose scales and label both axes with quantities and units. Mark a large gradient triangle on the best-fit line where appropriate.

4 Analyse and evaluate

Taking moments about the pivot gives

$$k(l-l_0)x = Mg(x-c), \qquad l = \underbrace{\left(l_0 + \frac{Mg}{k}\right)}_{B} - \underbrace{\frac{Mgc}{k}}_{A}\frac{1}{x}.$$

1. Find gradient s and intercept B. Give their units. For a false origin, use a point on the fitted line and $B = l - s/x$.

2. Use $A = -s$ to calculate $k_1 = Mgc/A$. Separately calculate $k_2 = Mg/(B - l_0)$. Show substitutions and give units.

3. Which estimate is more reliable? Consider extrapolation and subtracting two similar lengths in $B - l_0$. Cite your own graph. Explain why the two estimates are linked through the same fitted line.

4. Identify two specific limitations. For each, give an improvement and explain which reading it improves.

Conclusion Use $\Delta k_1/k_1 \simeq \Delta M/M + \Delta c/c + \Delta s/|s|$. Quote your preferred spring constant with uncertainty and justified precision, and say whether the data support the model.

Before you leave Return the apparatus, clear the bench and submit your recorded data.

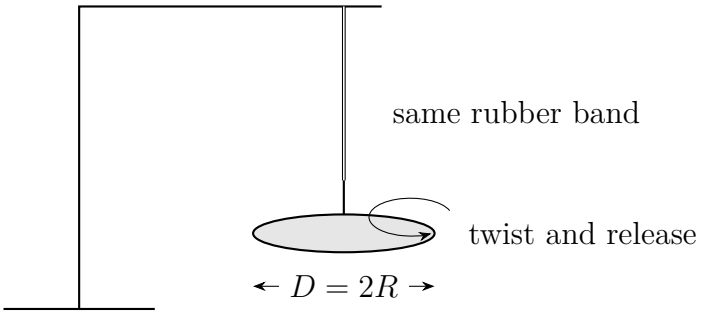
Testing a model with rotational timing

Name: _____ Class: _____ Date: _____

Aim Test a supplied relationship using two rotating mass hangers. Allow 50–60 minutes.

Practical-skills enrichment The rotational theory is beyond AS. You only need the supplied model $T^2 = KmR^2$ and AS measurement skills. Here T is one cycle, m is total mass and R is widest radius. A constant K assumes comparable mass distribution and unchanged band stiffness.

Apparatus Stand, boss and clamp, rubber band, 50 g and 100 g mass hangers, ruler, stopwatch, balance and optional vernier calipers.



Safety Stabilise the stand. Inspect the band for damage and keep the hanger over a tray. Do not stretch or twist the band excessively.

1 Make the comparison fair

1. Measure each hanger's actual mass, including any added load. Measure its widest diameter in two directions and calculate $R = D/2$.
2. Suspend the first hanger from the band. Let it settle. Twist it about half a turn without lifting or pushing it, then release.
3. Use a fixed mark and a fixed direction of crossing. One cycle returns to the same angular position moving in the same direction.
4. Time 10 complete cycles. Repeat three times, resetting the twist angle. Calculate $T = \bar{t}/10$.
5. Repeat with the other hanger using the same band and clamp point. Keep the initial twist angle similar. Recheck the first hanger afterwards to test whether the band has changed.

Before measuring Describe how you will avoid confusing half a cycle with a complete cycle.

Processing check (synthetic data) For 10 cycles, $\bar{t} = 12.0 \pm 0.2$ s; $m = 0.100 \pm 0.001$ kg and $D = 0.0400 \pm 0.0010$ m. Calculate T, R and the fractional uncertainty in K. Does dividing by 10 reduce the fractional timing uncertainty?

2 Record raw and processed data

Resolution: balance _____; ruler/calipers _____; stopwatch _____.

Hanger	m/kg	D_1/m	D_2/m	R/m

Hanger	t_1/s	t_2/s	t_3/s	$\bar{t}$/s	T/s

Hanger	mR^2/kg m^2	T^2/s^2	K/s^2 kg^{-1} m^{-2}

Observations Describe any sideways swinging, uneven rotation or damping.

Precision Justify the decimal places of your mass, diameter and timing readings.

3 Compare with uncertainty

Calculate $K = T^2/(mR^2)$ for each hanger. Show one complete calculation with SI units.

For this experiment use an absolute timing uncertainty that includes start/stop judgement and repeat scatter. The stopwatch display alone is not a reaction-time estimate.

$$\frac{\Delta K}{K} \approx 2\frac{\Delta T}{T} + \frac{\Delta m}{m} + 2\frac{\Delta R}{R}, \qquad \Delta T = \frac{\Delta \bar{t}}{10}.$$

State and justify $\Delta\bar{t}$, Δm and ΔR for each hanger. If $R = D/2$, then $\Delta R = \Delta D/2$; the fractional uncertainty is unchanged.

Calculate both uncertainty intervals $K - \Delta K$ to $K + \Delta K$. Do they overlap?

Conclusion Are the measurements consistent with a single K? Explain why overlap is evidence of consistency, not proof of the model, and why two values cannot establish a general relationship.

4 Evaluate and design a stronger test

1. Name two specific limitations and match each to a practical improvement. Explain how the improvement changes the uncertainty or fairness of the comparison.

2. The heavier hanger stretches the band more. Explain why this could change K, even if your timing is excellent.

3. Plan a follow-up using at least six values. Explain how to vary mass while keeping the mass distribution and radius comparable. State the axes of a graph that should be straight if the model holds.

Adding modelling clay changes both the mass and its distribution. A large change in shape is a change to the model, not simply another value of m. Ask the teacher to approve your proposed loads.

Exit check Why does timing 10 cycles reduce fractional timing uncertainty?

Before you leave Return the apparatus, clear the bench and submit your recorded data.

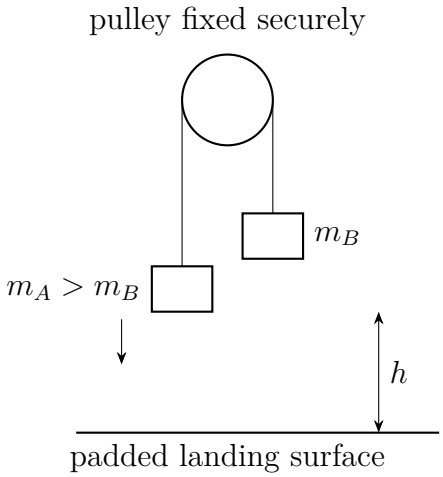
Free fall with connected masses

Name: _____ Class: _____ Date: _____

Aim Estimate g with two connected masses, keeping their total mass constant. Allow 60–75 minutes.

Key ideas For an ideal light string and frictionless pulley, $(m_A - m_B)g = (m_A + m_B)a$. Release from rest so $h = \frac{1}{2}at^2$. Include hanger masses in m_A and m_B.

Apparatus Clamped low-friction pulley, stand, string, two mass hangers, transferable 5 g or 10 g masses, ruler, balance, stopwatch and padded catch tray.



Safety Secure the pulley and stand. Keep feet and fingers out of the fall path. Catch the masses in the tray; stop before a hanger reaches the pulley. Do not stand under a suspended mass.

1 Collect fair measurements

1. Start with each side approximately 0.100 kg. Measure the actual masses. Set a safe fall distance h near 1 m to the landing surface.
2. Transfer a small mass from B to A. Record both totals. Transferring 5 g changes $m_A - m_B$ by 10 g.
3. Release A from the marked start position without a push. Time its fall to the landing surface. Reset and take three readings.
4. Transfer another small mass and repeat. Aim for six useful differences, using small transfers. Do not add fast, unreliable runs merely to reach six points.
5. Check that $m_A + m_B$ and h stay constant. Use smaller transferable masses to spread readings in the slower range.

Processing check (synthetic data) A 5 g mass is transferred from B to A. State the changes in d and S. For $t = 1.50 \pm 0.15$ s, calculate the approximate percentage contribution of timing to the uncertainty in g_i.

2 Results and controls

$h =$ _____ m $S = m_A + m_B =$ _____ kg.

$d = m_A - m_B$. Estimate $\Delta h =$ _____ m and justify it.

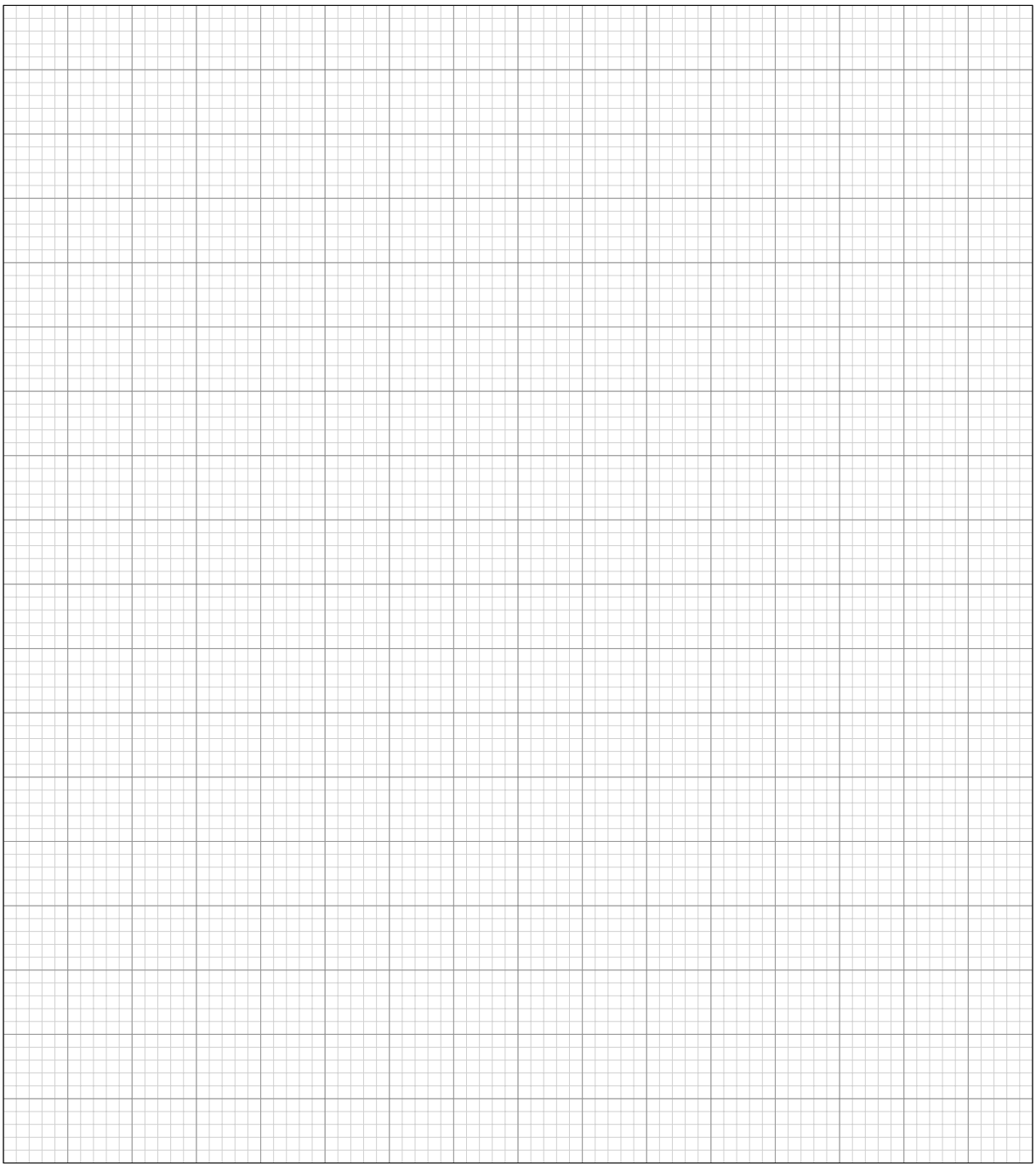
m_A/kg	m_B/kg	d/kg	t_1/s	t_2/s	t_3/s

d/kg	$\bar{t}$/s	$1/\bar{t}^2$/s^{-2}	$K = d\bar{t}^2$/kg s^2

Record the instrument resolutions and the shortest time you considered reliable. Explain the choice.

3 Graph

Plot mass difference $d = m_A - m_B$ against $1/\bar{t}^2$. Draw a best-fit line; do not force it through the origin. Extension beyond Paper 3: add justified uncertainty bars in both variables and a defensible extreme line; use the gradient difference as an estimate of ΔK. If no straight line fits the bars, discuss the model or underestimated errors.



Choose scales and label both axes with quantities and units. Mark a large gradient triangle on the best-fit line where appropriate.

4 Estimate free-fall acceleration

The ideal model predicts

$$d = K\frac{1}{t^2}, \qquad K = \frac{2hS}{g}, \qquad g = \frac{2hS}{K}.$$

1. Determine the graph gradient K and its unit. Use it to calculate g. For the graph result use $\Delta g/g \simeq \Delta h/h + \Delta S/S + \Delta K/|K|$. Show your working.

2. For one row, calculate $K_i = d\bar{t}^2$ and $g_i = 2hS/K_i$. Estimate $\Delta g_i/g_i \simeq \Delta h/h + \Delta S/S + \Delta d/d + 2\Delta t/t$. Justify uncertainties; for $d = m_A - m_B$, conservatively use $\Delta d = \Delta m_A + \Delta m_B$.

3. Calculate the percentage difference from $9.81\,\mathrm{m\,s^{-2}}$. Is your estimate consistent within its uncertainty? Distinguish your one-row uncertainty from the uncertainty of the graph gradient.

4. Explain how pulley inertia changes the gradient and how approximately constant friction can give a positive intercept. Match two limitations to improvements.

Conclusion State what your data support, including whether the fitted intercept is close to zero.

Before you leave Return the apparatus, clear the bench and submit your recorded data.

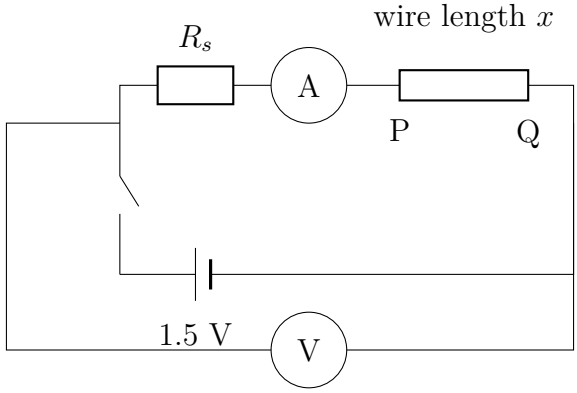
Resistivity from a series circuit

Name: _____ Class: _____ Date: _____

Aim Determine wire **resistivity** using a straight-line graph. Allow 60–75 minutes.

Key ideas $R_{\text{wire}} = \rho x/A$ and $A = \pi d^2/4$. At each reading, $V/I = R_s + \rho x/A$ in the ideal series circuit. Paired V, I readings allow V to change.

Apparatus 1.5 V cell, switch, ammeter, voltmeter, 10 Ω resistor, leads and clips, about 1.1 m of constantan wire taped to a metre rule, micrometer.



The voltmeter is across the *whole resistor-and-wire series branch*, not only the wire. Its current is assumed negligible. x is the distance along the wire between P and Q.

Safety Use low voltage only. Open the switch between readings and before moving clips. Do not short the cell or touch a hot wire. Have the circuit checked before closing the switch.

1 Measure and build

1. Check the micrometer zero. Measure diameter at three positions, in two directions. Use the ratchet gently and correct any zero error.
2. Calculate mean diameter d in metres, then area A. Avoid squeezing the wire.
3. Connect the circuit. Start near $x = 0.50$ m. Close the switch briefly and record I and terminal voltage V.
4. Open the switch. Increase x and repeat for at least six well-spread lengths. Repeat paired V, I readings after resetting a clip.
5. Record V at every length. Process each pair as $R = V/I$; this also allows for changing cell voltage.

Processing check (synthetic data) For $d = 0.230 \pm 0.005$ mm and $s = 11.8 \pm 0.6\,\Omega\,\text{m}^{-1}$, calculate $\rho = s\pi d^2/4$ and its approximate percentage uncertainty. Convert diameter before squaring.

2 Record measurements

Micrometer zero error: _____ mm Resolution: _____ mm.

Position	d_1/mm	d_2/mm

Corrected mean $d =$ _____ m $A =$ _____ m^2.

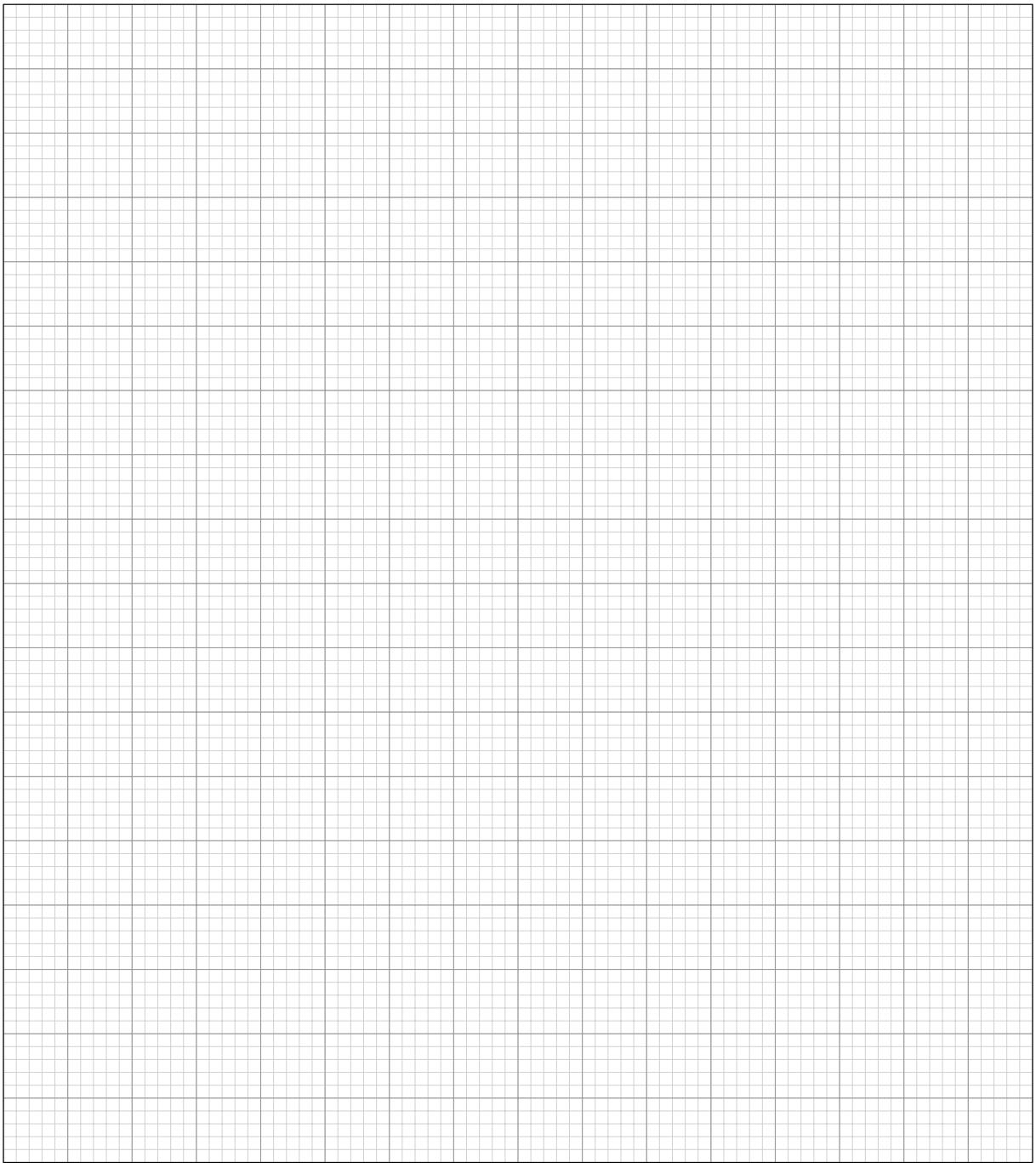
x/m	V_1, V_2/V	I_1/A	I_2/A	$\bar{I}$/A	$\bar{R}$/ Ω

Pilot and controls State the usable length range. How did you limit heating and keep clip contact consistent?

Uncertainty Estimate Δd. Explain why a diameter error matters strongly to the area.

3 Graph

For each length calculate $R_1 = V_1/I_1$, $R_2 = V_2/I_2$ and their mean $\bar{R}$. Plot $\bar{R}$ against x. Draw a best-fit line. Extension beyond Paper 3: add justified uncertainty bars in both variables and a defensible extreme line; use the gradient difference as an estimate of Δs. If no straight line fits the bars, discuss the model or underestimated errors.



Choose scales and label both axes with quantities and units. Mark a large gradient triangle on the best-fit line where appropriate.

4 Analyse the straight line

Using paired voltage and current readings,

$$\bar{R} = \underbrace{\frac{\rho}{A}}_{s} x + b, \qquad \rho = sA.$$

The intercept includes R_s and approximately constant lead, contact and ammeter resistance. For verified constant V, a $1/I$–x graph is an optional alternative.

1. Explain why paired V/I readings account for changing cell voltage. Use your own data.

2. Find gradient and intercept, including units. Calculate ρ in $\Omega\,\mathrm{m}$ and the intercept resistance in Ω. Show substitutions with SI units.

3. Estimate $\Delta\rho/\rho \approx \Delta s/|s| + 2\Delta d/d$. State how you estimated each term. If no gradient uncertainty is available, identify what is missing rather than inventing it.

4. Compare the intercept with 10 Ω and, for constantan, ρ with approximately $4.9 \times 10^{-7}\,\Omega\,\mathrm{m}$. Explain why material and temperature matter.

5. Discuss two specific limitations and matching improvements. Consider clip resistance, heating or diameter variation.

Conclusion State your resistivity with justified precision and the evidence for or against a linear model.

Before you leave Return the apparatus, clear the bench and submit your recorded data.

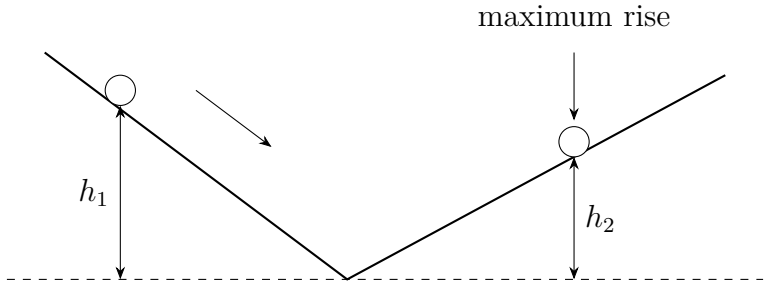
Energy recovery on joined runways

Name: _____ Class: _____ Date: _____

Aim Find how a marble's recovered gravitational potential energy depends on release height. Allow 60 minutes.

Key ideas For the same marble, recovered energy fraction $\eta = \bar{h}_2/h_1$. Percentage recovery is 100η. Measure both heights from one datum. The bottom of the same marble can be used because its radius cancels between equal datum offsets.

Apparatus Two rigid V-groove runways about 40 cm long, two stands and clamps, marble, metre rule, balance and catch tray.



height datum at lowest bottom-of-marble level

Set the zero height at the bottom of the marble when it is at the lowest point of the joined track. Measure height gains from there. A bench datum is equivalent only when that lowest bottom-of-marble level is at bench height.

Safety Clamp the runways securely. Keep the marble contained and catch any escape with a tray. Pick up fallen marbles immediately to prevent slips.

1 Run the experiment

1. Align the grooves so the marble crosses the join smoothly. Check that the tracks stay fixed and the marble cannot roll off the ends.
2. Measure marble mass m and define the height datum. Choose at least six well-spread release heights h_1.
3. Place the marble at the first height. Release without a push. Read the greatest height h_2 reached on the second runway.
4. Repeat three times at the same h_1. One partner releases while the other watches beside the ruler. Alternate roles halfway through.
5. Change h_1 only. Keep the marble, runway angles and join unchanged. Revisit one earlier height to check for drift. Recheck the alignment if the tracks move.

Processing check (synthetic data) For $h_1 = 0.200 \pm 0.002$ m and $\bar{h}_2 = 0.150 \pm 0.005$ m, calculate η and $\Delta\eta$. Can these readings resolve a recovery-fraction change of only 0.01?

2 Results and energy calculations

$m =$ _____ kg Height datum: _____.

h_1/m	h_{2a}/m	h_{2b}/m	h_{2c}/m	$\bar{h}_2$/m	$\eta = \bar{h}_2/h_1$

Worked processing frame Choose one row and complete:

$$E_1 = mgh_1 = _____ \text{ J}$$

$$E_2 = mg\bar{h}_2 = _____ \text{ J}$$

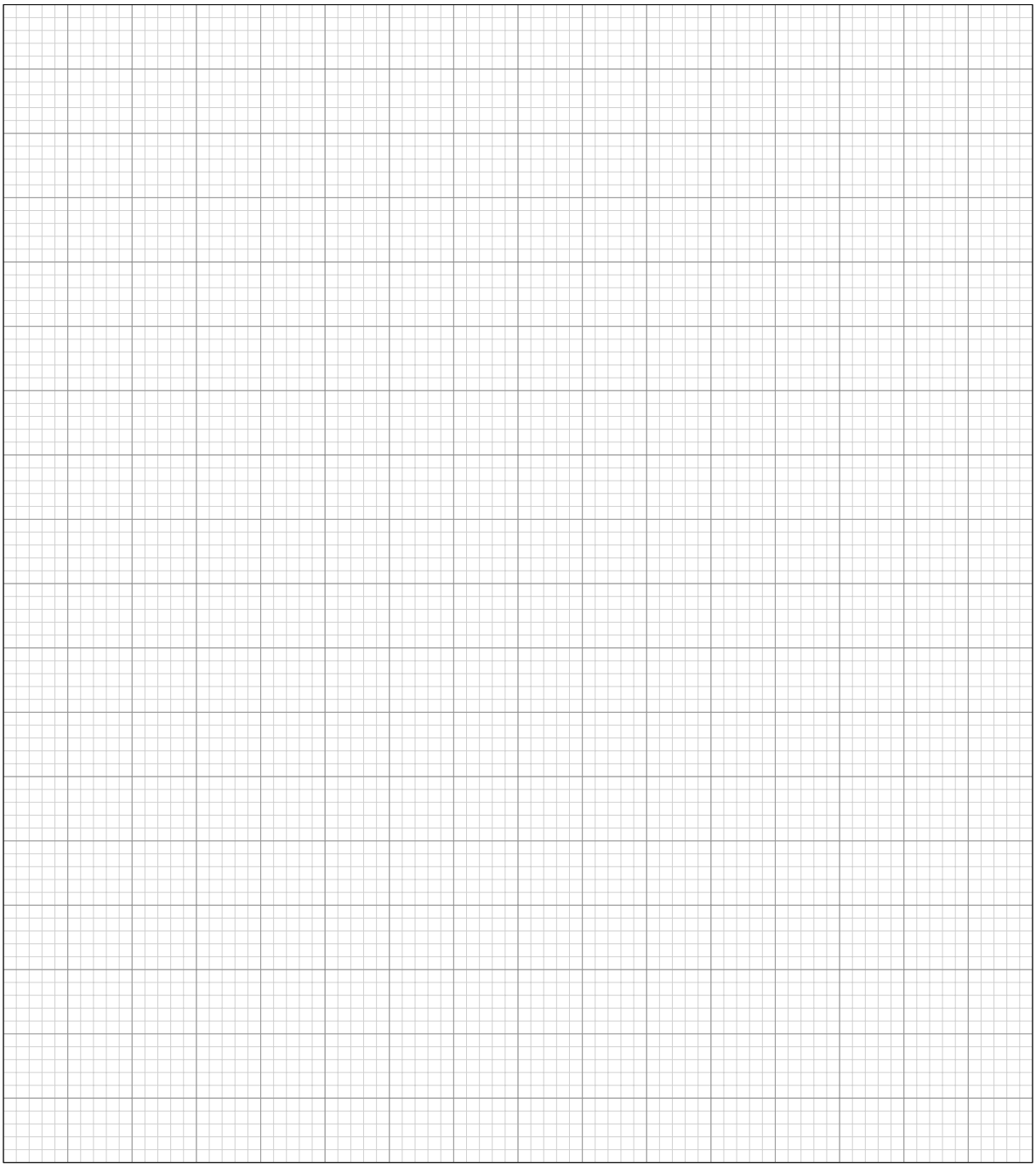
$$\text{Energy not recovered} = mg(h_1 - \bar{h}_2) = _____ \text{ J}$$

Uncertainty Estimate Δh_1 and $\Delta \bar{h}_2$. Include judging the turning point and the spread of repeat readings, not only ruler resolution.

Model check Why should $0 \le \eta \le 1$ for a release from rest? What would $\eta > 1$ tell you to check?

3 Graph

Plot recovered fraction $\eta = \bar{h}_2/h_1$ against release height h_1. Draw a best-fit trend supported by the data; do not assume it must be a straight line.



Choose scales and label both axes with quantities and units. Mark a large gradient triangle on the best-fit line where appropriate.

4 Interpret energy recovery

1. Is recovery fraction constant, increasing or decreasing with release height? Use numerical values and the pattern on your graph.

2. Estimate $\Delta\eta/\eta \approx \Delta\bar{h}_2/\bar{h}_2 + \Delta h_1/h_1$ for two contrasting rows. Is the apparent trend larger than the uncertainties?

3. Explain why rotational kinetic energy is not automatically "lost energy". For rolling without slipping, translation and rotation stop together at maximum rise; identify mechanisms that transfer mechanical energy to the surroundings.

4. Identify two limitations of measuring a moving marble's maximum height. Give an improvement for each and explain how it helps.

5. Plan a further comparison using a different runway angle. State what to change, measure and keep constant.

Conclusion Give the recovered fraction over your tested height range and qualify any trend that is not clear within uncertainty.

Before you leave Return the apparatus, clear the bench and submit your recorded data.

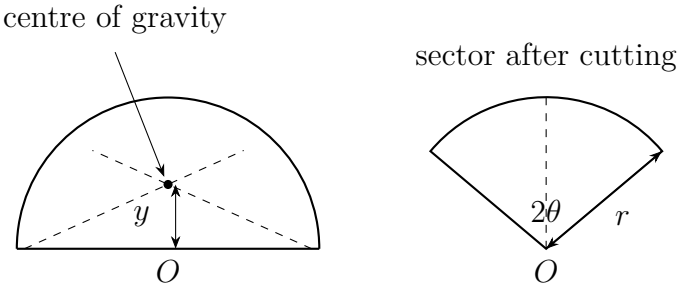
Centre of gravity of circular sectors

Name: _____ Class: _____ Date: _____

Aim Locate the centre of gravity of card sectors and use a graph to estimate their radius. Allow 60–75 minutes.

Key ideas A freely suspended object settles with its **centre of gravity** vertically below the support. Two plumb lines locate it. For a uniform circular sector of total angle 2θ, use the supplied model $y = (120r/\pi)(\sin\theta/\theta)$, with θ entered in degrees. No derivation is required.

Apparatus Uniform semicircular card of radius about 145 mm, scissors, millimetre ruler, protractor, clamped pin and plumb line with a small mass. Keep spare card available.



Left: each dashed line is the vertical through a different suspension hole. Right: cut symmetrically about the same centre line; retain O and the original radius.

Safety Keep the pin clamped with its sharp end away from faces. Handle scissors carefully and keep the plumb mass clear of fingers and the bench edge.

1 Plan before cutting

1. Measure r. Mark O and the symmetry axis. Plan six total sector angles, for example $180°, 160°, 140°, 120°, 100°, 80°$.
2. Suspend the semicircle from a small hole near one corner. Hang the plumb line from the same support; let both settle and mark the vertical on the card.
3. Repeat from a second, separated hole. Their intersection locates the centre of gravity. Measure its distance y from O along the symmetry axis.
4. Cut down to the next smaller angle, symmetrically. Repeat the suspension measurements and label the new lines by angle so you cannot confuse them.
5. Continue through your planned angles. Work largest to smallest: a removed piece cannot be restored. Use a third suspension line at each angle to judge how tightly the lines meet.

Processing check (synthetic data) A fitted gradient is 5.54 ± 0.20 m degree. Calculate r_{graph} and Δr_{graph}. Is this consistent with $r = 0.145 \pm 0.002$ m? Compare intervals.

2 Measurements and processing

Measured $r =$ _____ m Estimated $\Delta r =$ _____ m.

Set the calculator to degrees. θ is *half* the measured sector angle. Divide the numerical value of $\sin\theta$ by the numerical degree value of θ. This degree-based horizontal variable has units degree^{-1}.

2θ/degree	θ/degree	$\sin\theta$	X/degree^{-1}	y/m

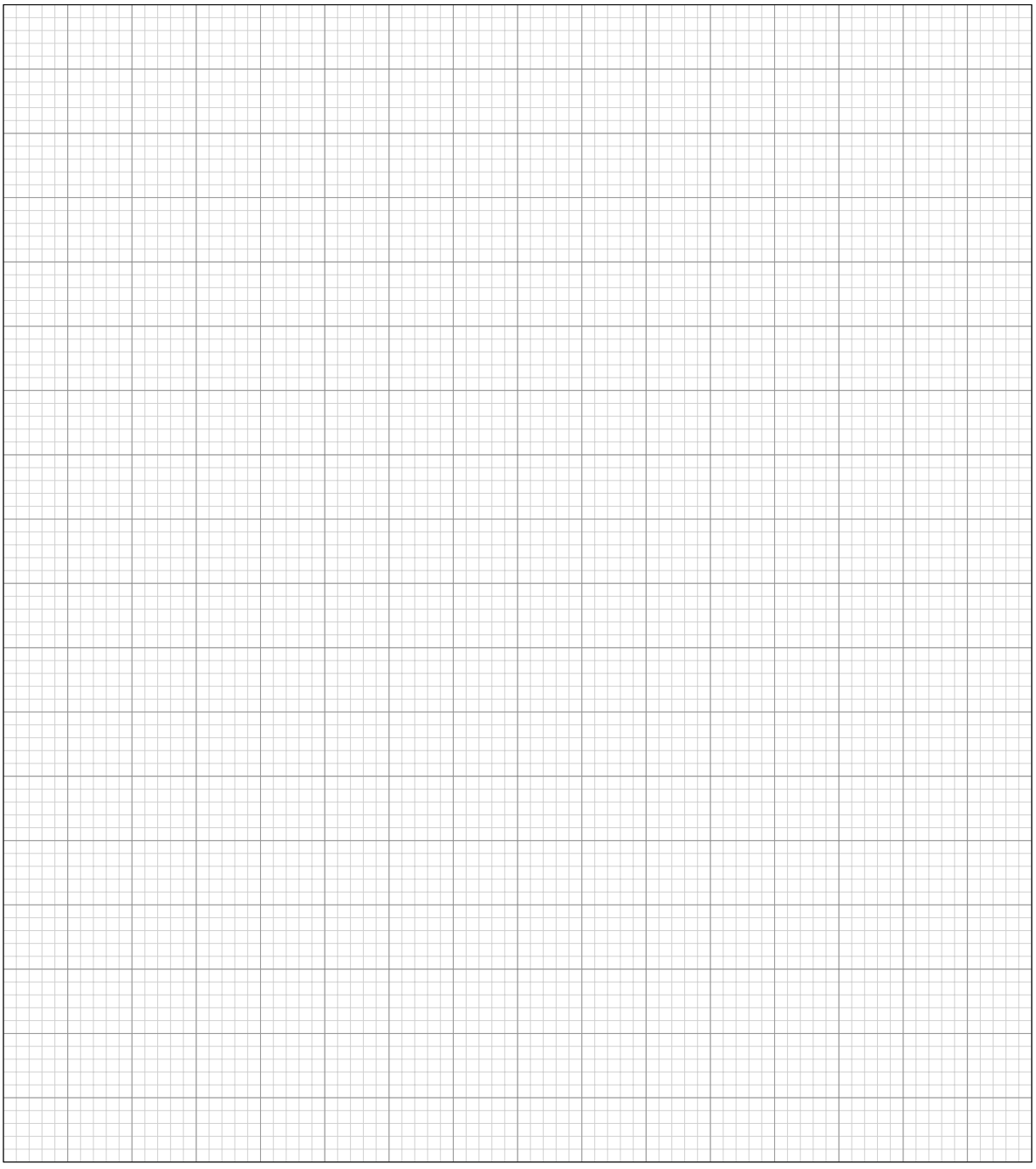
Check one processed value For $2\theta = 180°$, $\theta = 90°$ and $X = 1/90 = 0.01111$ degree^{-1}. Show the processing for another row.

Range Explain why your angle range produces a useful spread in X, even though no point will be near $X = 0$.

Observations Was the centre of gravity on the symmetry axis? How well did the third plumb line agree? Estimate Δy from the intersection region and $\Delta\theta$ from angle marking.

3 Graph

Plot distance y against $X = \sin\theta/\theta$ calculated in degrees. Draw a best-fit line; do not force it through an off-page origin. Extension beyond Paper 3: add justified uncertainty bars in both variables and a defensible extreme line; use the gradient difference as an estimate of Δs. If no straight line fits the bars, discuss the model or underestimated errors.



Choose scales and label both axes with quantities and units. Mark a large gradient triangle on the best-fit line where appropriate.

4 Test the sector model

$$y = sX, \qquad s = \frac{120r}{\pi}, \qquad r_{\text{graph}} = \frac{\pi s}{120}.$$

Here the numerical factor 120 includes the degree-to-radian conversion. Do not use the radian formula with degree data.

1. Use a large triangle on the fitted line to determine s. State its degree-based unit. Calculate r_{graph} in metres.

2. Compare r_{graph} with your directly measured r. Calculate the percentage difference. Judge consistency using Δr and a justified range of graph gradients.

3. What intercept would the ideal model predict? If the origin is off the grid, calculate $b = y - sX$ using a fitted-line point. Discuss what a non-zero b might indicate.

4. Identify two specific limitations, such as thick plumb lines or non-uniform card. Match each to an improvement.

5. Why must you not cut through the centre mark or reuse a line from a different sector angle?

Conclusion State your radius estimate and whether the linear trend supports the supplied model.

Before you leave Return the apparatus, clear the bench and submit your recorded data.