

PREMIUM STUDY NOTES · A2 LEVEL

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Physics

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16 chapters · ~7,040 words of student-ready notes

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Practical 1 – Momentum Conservation (Large Trolleys)

Investigate the principle of conservation of linear momentum using two trolleys colliding inelastically on a runway.

AIM

Show that, in an inelastic head-on collision, the total momentum of the two-trolley system before the collision equals the total momentum of the joined system afterwards – i.e. linear momentum is conserved when no external resultant force acts.

UNDERLYING THEORY

Momentum $p = mv$ is a vector. Newton's third law makes the contact forces during collision an internal action-reaction pair. Internal forces cancel within the system, so only external forces can change the total momentum. Friction is the obvious external force here – we have to compensate for it.

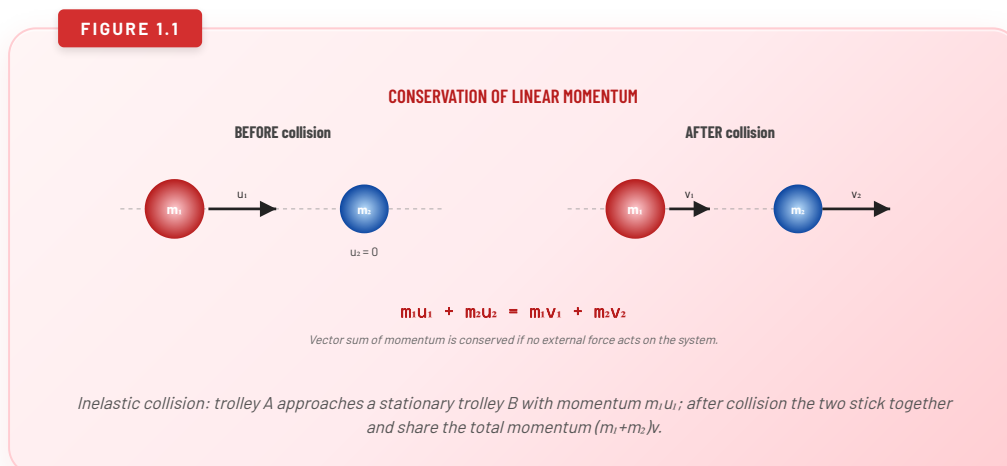
APPARATUS

- Linear runway with adjustable tilt
- Two large dynamics trolleys (one fitted with a drawing pin, the other with Plasticene®)
- Five slotted masses for the moving trolley
- Two light gates connected to a data-logging interface
- Data-logger / interface unit set to record speeds at gates 1 and 2
- Top-pan balance (to mass the trolleys), metre rule, stop-clock

METHOD

- Place the runway on the bench and tilt one end up by a few millimetres until a gentle push on a single trolley produces motion at constant speed between the gates – this is the friction-compensation check.
- Mass each trolley separately with the slotted masses fitted. Record the masses m_1 (incident trolley A) and m_2 (target trolley B).
- Soften a small piece of Plasticene® on the front of trolley B. Fit the drawing pin on the front of trolley A so the pin will embed in the Plasticene® on impact, locking the trolleys together (perfectly inelastic).
- Place the two light gates close together near the collision point, just inside the limits of the trolleys' final motion.
- Configure the data logger to record the speed u_1 of trolley A as it passes the first gate, and the speed v of the joined trolleys as they pass the second gate after collision.
- Push trolley A from rest at the high end of the runway with a single, repeatable shove. Record u_1 and v .
- Repeat for at least five pushes of varying initial speed (different shove strengths). Tabulate u_1 , v , m_1 , m_2 , momentum-before (m_1u_1) and momentum-after ($(m_1+m_2)v$).

FIGURE 1.1



CONSERVATION EQUATION

$m_1u_1 + m_2u_2 = (m_1 + m_2)v$ with $u_2 = 0 \Rightarrow v = m_1u_1 / (m_1 + m_2)$. If conservation holds, your measured v should match this prediction within the uncertainty of u_1 .

SAMPLE RESULTS

M_1 / KG	M_2 / KG	U_1 / M S ⁻¹	V_MEAS / M S ⁻¹	P_BEFORE / KG M S ⁻¹	P_AFTER / KG M S ⁻¹
1.20	1.20	0.42	0.21	0.504	0.504
1.20	1.20	0.55	0.27	0.660	0.648
1.20	1.20	0.68	0.34	0.816	0.816

ANALYSIS

1. For each trial, compute p_{before} and p_{after} .
2. Compute percentage difference: $|p_{\text{before}} - p_{\text{after}}| / p_{\text{before}} \times 100\%$.
3. If the percentage difference lies within your combined uncertainty (typically $\leq 5\%$), conservation is verified.
4. Plot p_{after} vs p_{before} across all trials. A best-fit line of gradient 1 through the origin demonstrates conservation graphically.

RISK ASSESSMENT

Trolleys can roll off the bench – place a buffer or end-stop. Slotted masses must be locked onto the trolley to prevent flyaway. Drawing pin is sharp – cap it or face it away from people during setup.

SOURCES OF ERROR

- Residual friction not fully compensated – small loss of momentum between the gates.
- Gates timed only over the trolley card length, not its centre of mass – introduces a small systematic offset.
- Push not perfectly along the runway axis – component of velocity perpendicular to the gates.
- Plasticene[®] deformation absorbs some kinetic energy (expected) but should not affect momentum (observed).

IMPROVEMENTS

- Use a linear air track (Practical 3) instead of a runway – near-zero friction.
- Use a longer card on each trolley to reduce timing uncertainty at the gates.
- Repeat each push at least three times and average the velocities.
- Use a motion sensor instead of a single light gate to capture the full $v(t)$ curve.

EXAMINER'S TIP

Mark schemes reward you for stating: (i) the assumption of negligible external force (friction-compensated runway), (ii) momentum is a vector and your trolleys move along the same straight line so signs are simple, and (iii) the comparison method (table of p_{before} vs p_{after} with percentage difference). Don't just report 'they're close' – quantify.

Practical 2 – Momentum Conservation (Small Trolleys)

A scaled-down version of Practical 1 using small trolleys with Velcro® coupling – same physics, different apparatus.

This is a methodologically identical experiment to Practical 1 but uses smaller trolleys (often 250–500 g rather than 1–2 kg). Velcro® pads on the front of each trolley provide the inelastic latch – gentler than the pin-and-Plasticene® method and reusable many times without replacement.

AIM

Verify the principle of conservation of linear momentum using small dynamics trolleys joined by Velcro® in a perfectly inelastic collision.

APPARATUS

- Two small dynamics trolleys with Velcro® pads
- Eight washers (four loaded onto each trolley)
- Linear runway with adjustable tilt
- Two light gates and a data-logging interface
- Top-pan balance, metre rule

METHOD

1. Compensate the runway for friction by raising one end until a tapped trolley travels with constant speed between the gates.
2. Mass each trolley with its four washers attached and record m_1 and m_2 .
3. Place trolley B between the two gates, stationary. Place trolley A above gate 1.
4. Configure the data logger to capture u_1 (trolley A through gate 1) and v (joined pair through gate 2).
5. Release trolley A with a controlled push. After the Velcro® latches them together, the joined pair must continue without acceleration to gate 2.
6. Repeat for several initial speeds and tabulate u_1 , v , p_{before} , p_{after} .

ANALYSIS

Identical analysis to Practical 1: compare p_{before} and p_{after} for each trial; plot p_{after} vs p_{before} ; report percentage difference. With smaller trolleys, friction is a proportionally larger external force, so accept tolerance is wider ($\sim 5\text{--}7\%$) than for the linear air track method.

RISK ASSESSMENT

Smaller trolleys are easier to push off the runway – use end-stops. Washers are dense and can fall on toes – tape them in place during runs.

WHY MULTIPLE VERSIONS?

Edexcel deliberately includes three momentum practicals (large trolleys, small trolleys, linear air track) so candidates can be assessed on adapting the same principle across different apparatus. A common exam-paper task is to compare the percentage error between two methods and explain why one performs better.

EXAMINER'S TIP

When asked to compare methods (this practical vs. P1 vs. P3), the marks-winning answer addresses three axes: (i) friction reduction (air track wins), (ii) timing precision (light-gate over a card length), (iii) ease of repeating identical pushes (Velcro® latch lets you reuse trolleys instantly – throughput advantage).

Practical 3 – Momentum Conservation on a Linear Air Track

Near-frictionless apparatus; the gold-standard method for verifying $p_{\text{before}} = p_{\text{after}}$.

A linear air track is a hollow aluminium beam with rows of small holes along its top surface. Compressed air from a blower escapes through the holes and supports a glider (rider) on a thin air cushion – effectively eliminating friction. Two riders coupled by a pin-and-Plasticene® arrangement collide inelastically; the conservation of momentum can be verified to better than 2% under good conditions.

AIM

Verify the conservation of linear momentum in an inelastic collision using a near-frictionless linear air track, and obtain the smallest possible percentage discrepancy between p_{before} and p_{after} .

APPARATUS

- Linear air track (~1.5 m) with air blower
- Two riders (gliders), one with a Plasticene® pellet, the other with a pin attachment
- Two light gates at known positions, data logger
- Top-pan balance, metre rule, spirit level

METHOD

1. Level the air track with a spirit level. Switch on the blower and verify a rider released from rest stays at rest (or drifts only imperceptibly) – this is your zero-friction confirmation.
2. If a residual slope is detectable, adjust until balanced; do NOT compensate for friction by tilting (no friction to compensate).
3. Mass each rider including any pin/pellet attachments. Record m_1 (incident) and m_2 (target).
4. Place rider B between the gates, stationary. Place rider A above gate 1.
5. Set the data logger to capture u_1 through gate 1 and v through gate 2 (joined pair).
6. Give rider A a smooth push. The pin embeds in the Plasticene®, joining the riders.
7. Tabulate u_1 , v , m_1 , m_2 , p_{before} , p_{after} for at least 6 trials at varying u_1 .
8. Plot p_{after} against p_{before} . Best-fit line should pass through origin with gradient 1.

WHY THIS METHOD PERFORMS BETTER

SOURCE OF ERROR	TROLLEY METHODS (P1, P2)	AIR TRACK (P3)
Friction	~3-5% loss between gates	< 0.5% loss
Push direction control	Hand-push, variable axis	Hand-push, but rider centred on track
Repeatability	Plasticene® replaced frequently	Pin and Plasticene® reusable many times
Typical % discrepancy	3-7%	< 2%

RISK ASSESSMENT

Compressed-air supply is loud (~80 dB) – ear defenders for prolonged use. Air-track holes can be sharp; do not run fingers along the surface. Riders can shoot off the end – use rubber stops at both ends.

EXAMINER'S TIP

If asked 'why is the air track better than the runway?' the model answer covers (i) near-zero friction = no external force, (ii) glider mass is supported uniformly (no pivoting), (iii) the track itself provides an automatic constraint to one dimension (no transverse error). All three are mark-scheme bullet points.

Practical 4 – Rate of Change of Momentum (Linear Air Track)

Verify Newton's second law in its modern form, $F = dp/dt$, using a constant-mass + variable-force setup.

AIM

Show that the rate of change of momentum of an accelerating system is directly proportional to the resultant force on it – the modern statement of Newton's second law ($F = dp/dt$). The total mass is held constant; only the accelerating force is varied.

THE MASS-CONSERVATION TRICK

If you simply add masses to the falling weight, you change the total accelerating mass simultaneously – F and m both change and the test is unclear. The clean experimental design moves a small mass between the rider (its mass) and the hanging weight (the accelerating force = its weight, mg). This way the total mass to accelerate stays constant; only the accelerating force varies.

APPARATUS

- Linear air track + blower; rider with hook for thread
- Pulley over the end of the track; light thread; mass hanger + ten 100-g slotted masses
- Two light gates and a data-logging interface
- Top-pan balance, metre rule

METHOD

1. Level the air track. Pass a thread from the rider over the pulley to a mass hanger.
2. Distribute ten 100-g masses: start with six on the rider and four on the hanger (total accelerated mass = rider + 10 masses; accelerating force = weight of 4 masses = ~4 N).
3. Set the data logger to read v_1 (rider through gate 1), v_2 (rider through gate 2), and the time t between the gates.
4. Release the rider from rest above gate 1. Record v_1 , v_2 , t .
5. Compute $\Delta p = m_{\text{total}} \times (v_2 - v_1)$ and rate of change of momentum $\Delta p/t$.
6. Move ONE 100-g mass from the rider to the hanger. The total accelerated mass is unchanged; the accelerating force is now the weight of 5 masses = ~5 N. Repeat the run.
7. Continue, transferring one mass at a time, until only one mass remains on the rider (force = 9 masses worth, ~9 N).
8. Tabulate F (accelerating force = mg of hanging masses), v_1 , v_2 , t , Δp , $\Delta p/t$.

SAMPLE RESULTS

HANGING MASS / KG	F = MG / N	v_1 / M S ⁻¹	v_2 / M S ⁻¹	T / S	ΔP / KG M S ⁻¹	$\Delta P/T$ / N
0.40	3.92	0.22	0.62	0.52	0.62	1.19
0.60	5.88	0.34	0.94	0.45	0.93	2.07
0.80	7.84	0.42	1.16	0.40	1.15	2.88
1.00	9.81	0.51	1.38	0.36	1.35	3.75

ANALYSIS

1. Plot $\Delta p/t$ (y-axis) against F (x-axis).
2. A straight line through the origin verifies $F \propto \Delta p/t$.
3. The gradient should be 1 (since $F = \Delta p/t$ for a constant mass – not strictly required, but a good check).

RISK ASSESSMENT

Falling masses can hit the floor – use a soft cushion or sand tray to break their fall. Pulley axle should be lubricated to minimise pulley friction (which adds a hidden force).
 Air-track noise: ear protection for long sessions.

SOURCES OF ERROR

- Pulley friction adds a small constant resistive force, giving a non-zero intercept on the $\Delta p/t$ -vs-F line.
- Mass hanger oscillates as it falls – releases gently to minimise.
- Air-track levelling drift: re-check between trials.
- Light-gate timing only measures when the rider's card crosses; small offset in v calculation.

EXAMINER'S TIP

If your $\Delta p/t$ -vs-F plot has gradient noticeably different from 1, the most likely culprit is pulley friction or unaccounted hanging-mass air resistance – both reduce the effective accelerating force below mg . Stating this explicitly is worth a method mark in the analysis section.

Practical 5 – Rate of Change of Momentum (Trolley + Runway)

The same Newton's-second-law verification using a friction-compensated runway and twelve washers.

Identical concept to Practical 4 but using a dynamics trolley + runway and twelve 10-g washers as the transferred masses. Cheaper apparatus; slightly more friction (the runway must be tilted to compensate).

APPARATUS

- Linear runway with adjustable tilt; dynamics trolley
- Pulley clamped at the lower end; light thread; 12 washers + small mass hanger
- Two light gates and a data-logging interface
- Top-pan balance, metre rule

METHOD

1. Friction-compensate the runway: tilt until the trolley with no thread attached travels at constant speed between the gates after a gentle push.
2. Tie a thread from the trolley to a small mass hanger and run it over the pulley.
3. Start with ten washers on the trolley and two on the hanger (force = weight of 2 washers).
4. Release; record v_1 , v_2 , t . Compute Δp and $\Delta p/t$.
5. Transfer ONE washer from trolley to hanger and repeat (force = 3 washers).
6. Continue until only two washers remain on the trolley (force = 10 washers).
7. Tabulate F , Δp , $\Delta p/t$.

ANALYSIS

1. Plot $\Delta p/t$ (y) against F (x).
2. Best-fit line should pass through origin with gradient 1.
3. Compare the residual scatter to Practical 4 – the friction-compensated runway gives more scatter than the air track but the relationship is still linear.

RISK ASSESSMENT

Trolley can roll off the runway – place an end-stop or buffer. Falling washers can land on toes – use a sand tray or soft cushion under the hanger. Pulley axle should be lubricated to minimise added friction. Keep the runway away from the table edge so the falling weight does not strike anyone.

SOURCES OF ERROR

- Pulley friction adds a small constant resistive force (positive y-intercept on the $\Delta p/t$ -vs- F line).
- Runway tilt for friction compensation is a single static check – trolley friction may not be perfectly velocity-independent in practice.
- Washer steps of 10 g are smaller than the air-track 100-g steps – reading uncertainty per data point is proportionally larger.
- Light-gate cards have finite width: the timing measures the average velocity over the card length, not at a point.

EXAMINER'S TIP

When asked which method (P4 or P5) is more accurate, the model answer addresses (i) friction floor: air track \ll runway, (ii) mass-transfer granularity: 100-g slotted masses give bigger force differences than 10-g washers; bigger steps reduce the effect of timing uncertainty on each individual point.

Practical 6 – Centripetal Force (Whirling Bung)

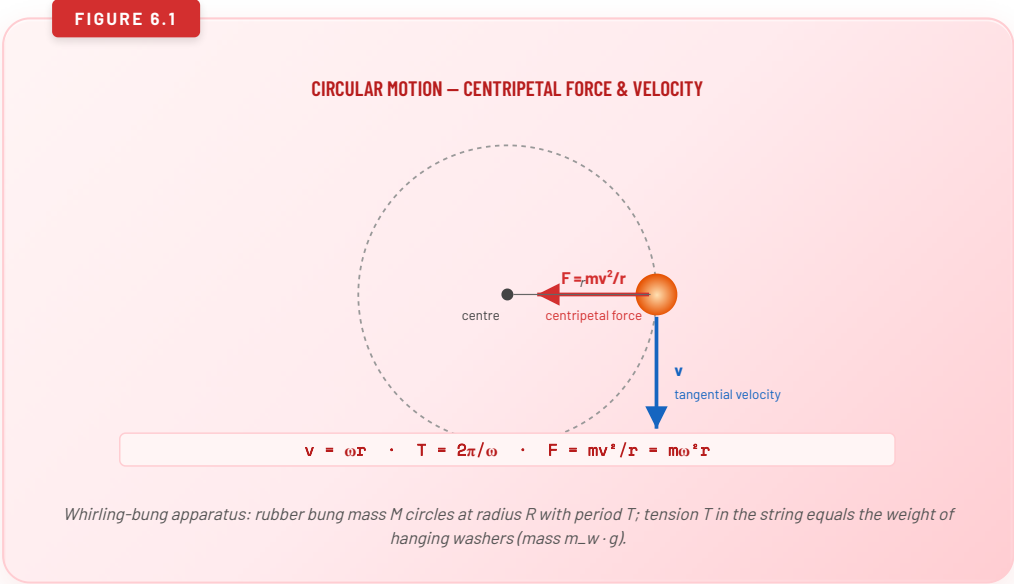
Verify $F = mv^2/r$ by whirling a bung in a horizontal circle while measuring the tension provided by hanging washers.

AIM

Verify experimentally that the centripetal force needed to keep an object in uniform circular motion is given by $F = mv^2/r$ – equivalently, $m\omega^2r$ – where m is the mass of the object, v is its tangential speed, r is the radius of the circle, and $\omega = 2\pi/T$ is its angular velocity.

THEORY

An object moving in a circle is continuously changing direction, so it is accelerating – toward the centre. The resultant inward force is the centripetal force $F = mv^2/r$. In this experiment the centripetal force is supplied by the tension T in a string, which is in turn provided by the weight of hanging washers $W = m_w \cdot g$. Setting $F = W$ lets you predict the rotation period for a given radius.



APPARATUS

- Rubber bung with attached string (1–2 m of strong cord)
- Short glass tube (10 cm) with smoothed ends, threaded onto the cord
- Hanging washers (a few grams more than the bung mass)
- Stopwatch (measure 10 orbits for accuracy)
- Metre rule, top-pan balance
- Marker to fix the radius (a piece of tape on the cord just below the glass tube)

METHOD

1. Tie the string to the bung; thread it through the glass tube; tie the lower end to the washers.
2. Mass the bung (M) and the washers (m_w) on the top-pan balance.
3. Mark the desired radius R on the cord (e.g. 80 cm above the tube).
4. Hold the glass tube vertically. Start whirling the bung in a horizontal circle, gently increasing speed until the marker is just at the top of the tube and the radius is constant.
5. While the orbit radius stays constant, time 10 complete orbits with the stopwatch. Divide by 10 to get the period T .
6. Record M , m_w , R , T . Compute $v = 2\pi R/T$ and predicted $F = mv^2/R$.
7. Compare predicted F with the actual centripetal force = weight of washers = $m_w \cdot g$.

ANALYSIS

1. Theoretical: $F_{\text{centripetal}} = m_w \cdot g$ (the weight of hanging washers, supporting the bung in the orbit).
2. Experimental: $F_{\text{measured}} = M \cdot v^2 / R = M \cdot (2\pi R/T)^2 / R = 4\pi^2 MR/T^2$.
3. Compute percentage difference. Within 5–10% is typical.
4. Vary R (or m_w) and tabulate. A plot of T^2 against $MR/(m_w g)$ should be a straight line with gradient $4\pi^2$ (a good visual check on the inverse-square relation).

⚠ RISK ASSESSMENT

The whirling bung has substantial kinetic energy – clear the area within a 2-metre radius. Stand well back from any windows or fragile equipment. Wear safety glasses. Use thick string that can't snap mid-orbit. Always practice the technique before recording data – you must keep the radius constant throughout the timing run.



SOURCES OF ERROR

- Radius not constant during timing – the orbit drifts wider or narrower as you speed up.
- Glass tube friction on the cord (treat as small).
- Stopwatch reaction time (~0.2 s) – reduced by timing 10 orbits, not 1.
- Bung not orbiting in a perfect horizontal circle – gravitational sag of cord adds an angle θ and the centripetal equation becomes $F = mv^2/r \tan\theta$.

IMPROVEMENTS

- Use a video frame-rate analysis (slow-motion phone camera) to time the orbit instead of stopwatch.
- Replace the bung with a heavier object whose KE-to-air-resistance ratio is bigger.
- Use a force sensor to read tension directly instead of inferring it from $m \cdot w \cdot g$.

EXAMINER'S TIP

'Why time 10 orbits, not 1?' is a stock practical question. The mark-scheme answer: the reaction-time uncertainty (~0.2 s) is divided by 10 in T , so the percentage uncertainty in T drops by a factor of 10 – with no extra effort and no extra apparatus.

Practical 7 – Centripetal Force (Rotating Trolley)

An apparatus-precise alternative to the whirling bung, using a motor-driven rotating arm with calibrated newton-meter.

AIM

Compare the theoretical centripetal force needed to keep a trolley orbiting on a rotating-arm apparatus (mv^2/R) with the actual spring force measured by extending a newton-meter to the same orbital radius.

APPARATUS

- Rotating-arm rig clamped firmly to the bench, with motor-driven turntable
- Trolley with a load mass, attached to the centre of the turntable by a spring + newton-meter assembly
- End stop on the runway portion of the arm (the 'orbit boundary')
- Calibrated newton-meter (10-N range)
- Tachometer or stopwatch, top-pan balance, metre rule

METHOD

1. Clamp the rotating apparatus securely. Mass the trolley including its load (m).
2. Switch on the motor at low speed. Increase speed gradually until the trolley just touches the end stop – this fixes the orbital radius R .
3. Use the tachometer or measure the time for 10 rotations to compute the rotation rate f . Convert to $v = 2\pi Rf$.
4. Calculate the theoretical centripetal force $F_{\text{theory}} = mv^2/R$.
5. With the motor stopped, pull the trolley out manually until the spring extends by the same amount (i.e. the trolley is at the end stop). Read the newton-meter to obtain the actual spring force F_{meas} needed to reach that radius.
6. Compare F_{theory} and F_{meas} . Repeat for several different load masses on the trolley.

ANALYSIS

Plot $F_{\text{theory}} (= mv^2/R)$ against F_{meas} . A straight line of gradient 1 through the origin verifies the centripetal-force equation. Any systematic offset suggests a friction or static-tension component you haven't accounted for.

RISK ASSESSMENT

Rotating apparatus is high-energy; secure ALL clamps and stand at least 1 m from the rotation plane. Switch off and let the system stop before adjusting masses. Loose clothing or hair must be tied back.

EXAMINER'S TIP

If the F_{theory} vs F_{meas} line has gradient slightly above 1, you've probably under-estimated the orbital radius (it's actually larger when the trolley is rotating because of slight outward flex of the apparatus). State this explicitly in your analysis.

CHAPTER 08 / Capacitors

Practical 8 – Charge Stored by a Capacitor

Verify $Q = CV$ experimentally by direct measurement on a coulombmeter.

AIM

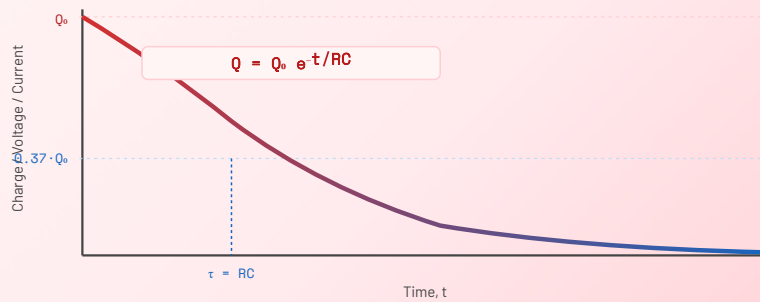
Demonstrate that the charge Q stored on a capacitor is directly proportional to the potential difference V across it ($Q = CV$), and obtain a value for the capacitance C from the gradient of a Q -vs- V graph.

THEORY

Capacitance is defined by $C = Q/V$. For an ideal (linear) capacitor, C is constant: doubling V doubles Q . The graph of Q against V is therefore a straight line through the origin, and the gradient gives C directly. A non-linear graph would indicate a non-ideal capacitor (e.g. a polarised electrolytic operating beyond its linear range, or insulation breakdown).

FIGURE 8.1

CAPACITOR DISCHARGE – EXPONENTIAL DECAY



RC behaviour underpins this practical: the capacitor stores $Q = CV$ when fully charged, and the coulombmeter then measures Q directly when the switch is flipped.

APPARATUS

- Capacitor under test (e.g. $0.1 \mu\text{F}$, then $1 \mu\text{F}$, then $10 \mu\text{F}$ to repeat)
- Variable DC power supply (0–10 V)
- Two-position switch (charge / measure)
- Voltmeter (0–10 V)
- Coulombmeter (0–10 μC)
- Connecting leads

METHOD

1. Wire the circuit: power supply → switch → capacitor → back to supply (charging path); when the switch is in position 2, the capacitor is connected to the coulombmeter (measuring path).
2. With switch in position 1 (charge), set the supply voltage to 0.5 V. Wait a moment for the capacitor to fully charge.
3. Flip the switch to position 2 (measure). Read the coulombmeter and record Q .
4. Reset both: bring switch back to position 1, set supply to 1.0 V, recharge, switch to position 2, record Q .
5. Repeat in 0.5-V steps up to –6 V (or the supply maximum). Tabulate V , Q .
6. Repeat the whole procedure for capacitors of different rated capacitance.

SAMPLE RESULTS

V / V	Q (0.1 MF) / MC	Q (1 MF) / MC	Q (10 MF) / MC
1.0	0.10	1.0	9.8
2.0	0.21	2.1	20.1
3.0	0.30	3.0	30.0
4.0	0.41	4.0	40.2
5.0	0.49	5.1	49.7
6.0	0.61	6.0	59.9

ANALYSIS

1. Plot Q (y-axis) against V (x-axis) for each capacitor.
2. Best-fit line through the origin. Confirm linearity.
3. Read the gradient: gradient = C (in farads if Q in coulombs, V in volts).
4. Compare measured C to rated C . Tolerance is typically $\pm 10\%$ for ceramic, $\pm 20\%$ for electrolytic capacitors – mark schemes accept agreement within this band.

RISK ASSESSMENT

A charged capacitor stores energy and can deliver a sudden discharge through your fingers if you touch both terminals (small risk at $< 6\text{ V}$; significant for higher voltages). Always discharge with a $1\text{ k}\Omega$ resistor across the terminals before handling. Polarised capacitors must be wired correctly – reversing polarity can cause them to vent or explode.

SOURCES OF ERROR

- Charge leakage during the switching delay: the capacitor starts to discharge through the coulombmeter the moment the switch closes.
- Coulombmeter accuracy: typically $\pm 2\text{--}5\%$ of full scale.
- Capacitor rated tolerance: ceramic $\pm 10\%$, electrolytic $\pm 20\%$.
- Voltmeter loading: very-high-impedance digital meters minimise this; analogue meters can draw measurable charge.

EXAMINER'S TIP

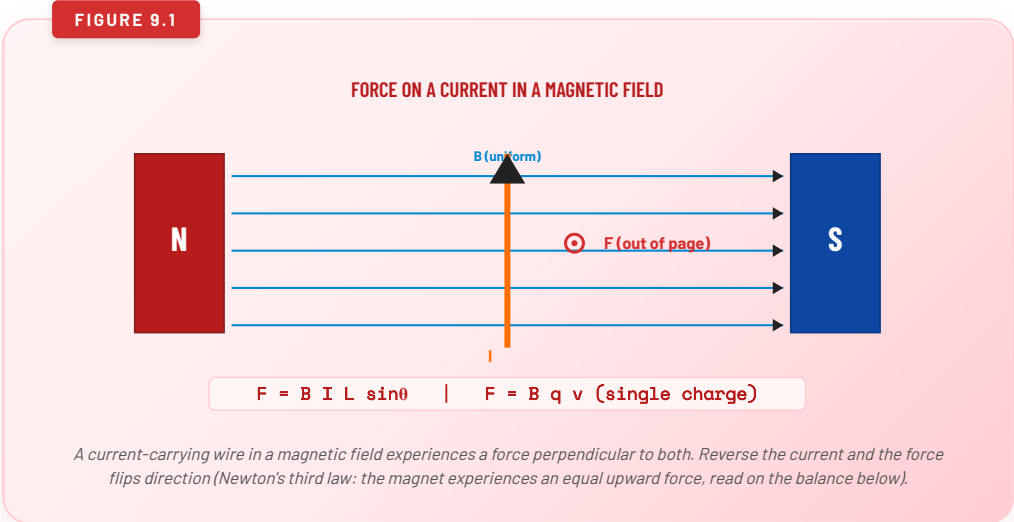
When the gradient of your Q -vs- V plot disagrees with the rated value, the model answer addresses dielectric tolerance, leakage during measurement, AND the choice of capacitor type (electrolytic capacitors have wider tolerance). Don't blame the meter alone.

Practical 9 – Force on a Current-Carrying Wire in a Magnetic Field

Verify $F = BIL$ by varying the current and the wire length and measuring the force on a top-pan balance.

AIM

Investigate how the force F on a horizontal current-carrying conductor in a uniform magnetic field depends on (i) the current I and (ii) the length L of conductor in the field. The expected relationship is $F = BIL$ when the field, current and length are mutually perpendicular.



THEORY AND THE 'NEWTON'S-THIRD-LAW TRICK'

Direct measurement of the force on a hanging current-carrying wire is fiddly. Instead, we exploit Newton's third law: if the magnet exerts an upward force F on the wire ($F = BIL$), the wire exerts an equal and opposite downward force F on the magnet. Place the magnet assembly on a top-pan balance and the apparent change in mass Δm gives $F = (\Delta m)g$ directly.

APPARATUS

- Top-pan balance (resolution 0.01 g)
- C-shaped magnet (or pair of slab magnets on a yoke) producing a uniform field across a 5–10 cm gap
- Stiff wire frame with a U-shaped horizontal limb that fits inside the magnet gap
- Variable DC power supply (0–5 A), ammeter
- Set of wire frames with U-limbs of different known lengths (e.g. 2, 4, 6, 8, 10 cm)
- Connecting leads

METHOD – PART A: F VS I

1. Place the magnet assembly on the top-pan balance. Tare to zero.
2. Position the wire frame so its U-limb lies in the magnet gap, perpendicular to the field.
3. Set the current to zero. Confirm the balance still reads zero.
4. Switch the supply on and set $I = 0.5$ A. Record the new balance reading m . Compute $F = mg$.
5. Increase I in steps of 0.5 A up to 4–5 A. Record F at each current.
6. Plot F (y-axis) against I (x-axis). A straight line through the origin verifies $F \propto I$; the gradient gives BL (since $F = BIL$, gradient = BL with L fixed).

METHOD – PART B: F VS L

1. Fix the current at a chosen value (e.g. 3 A).
2. Replace the wire frame with one of different L . Measure F at the same current.
3. Repeat for at least five different L values (2, 4, 6, 8, 10 cm).
4. Plot F vs L . Linear with gradient BI gives B (since I is known, $B = \text{gradient} / I$).

ANALYSIS

From Part A, gradient = BL . From Part B, gradient = BI . Both give the magnetic flux density B . The two values should agree within experimental uncertainty – this is the cross-check that validates the $F = BIL$ relationship.

RISK ASSESSMENT

Currents above 3 A heat the wire significantly – do not run continuously for more than ~30 s. Strong magnets attract iron objects fiercely and pinch fingers – keep tools and watches away. Set the supply current limit before connecting to avoid surge.

SOURCES OF ERROR

- Field is not perfectly uniform across the wire length – introduces a small systematic offset, larger for longer wires.
- Wire heats up – resistance rises – current drifts unless the supply is current-regulated.
- Balance drift between trials.
- Wire not exactly perpendicular to the field: actual force is $BIL \sin\theta$, and any $\theta < 90^\circ$ reduces F .

EXAMINER'S TIP

When asked to estimate B from this experiment, work in SI units throughout: F in newtons (i.e. balance reading in $\text{kg} \times 9.81$), I in amps, L in metres. Common error: forgetting to convert grams \rightarrow kg, leading to a B that's 1000 \times too small.

Practical 10 – Specific Heat Capacity of a Liquid

Use an electric heater of known power to measure the energy needed to raise water by a measured temperature.

AIM

Determine the specific heat capacity (c) of water by supplying a known amount of electrical energy to a known mass of water and measuring the resulting temperature rise. The relationship $Q = mc\Delta T$ allows c to be extracted.

THEORY

Specific heat capacity is the energy required to raise 1 kg of a substance by 1 K. For water, $c \approx 4180 \text{ J kg}^{-1} \text{ K}^{-1}$. In this experiment we supply $Q = Pt$ joules of electrical energy to a mass m of water and measure the resulting ΔT . Rearranging $Q = mc\Delta T$ gives $c = Pt / (m \Delta T)$.

APPARATUS

- Insulated calorimeter (Styrofoam cup or vacuum flask) of known mass
- Immersion heater (rated 12 V, ~50 W, with known resistance)
- Variable DC power supply, ammeter, voltmeter
- Top-pan balance
- Thermometer (range 0–100 °C, resolution 0.1 °C) or temperature probe + data logger
- Stopwatch
- Water (~250 g)

METHOD

1. Mass the empty calorimeter (m_{cal}). Add water; mass again. The difference is m (mass of water).
2. Insert the immersion heater so it is fully submerged in the water but not touching the calorimeter wall.
3. Insert the thermometer/probe and stir gently. Record the initial temperature T_0 (allow time to reach thermal equilibrium with the heater).
4. Switch on the supply at the rated voltage. Record V and I ; compute power $P = VI$.
5. Start the stopwatch simultaneously. Stir the water gently and continuously throughout the heating period.
6. After a measured time t (typically 5–10 minutes), switch off the supply but keep stirring.
7. Record the maximum temperature reached T_{max} (a few seconds after switch-off as the water continues to mix and reach equilibrium).
8. $\Delta T = T_{max} - T_0$.
9. Compute $c = Pt / (m \Delta T)$.

SAMPLE RESULTS

QUANTITY	SYMBOL	VALUE
Mass of water	m	0.245 kg
Voltage	V	12.0 V
Current	I	4.20 A
Power	$P = VI$	50.4 W
Heating time	t	300 s
Energy supplied	$Q = Pt$	15 120 J
Initial temperature	T_0	21.0 °C
Maximum temperature	T_{max}	35.5 °C
Temperature rise	ΔT	14.5 K
Calculated c	$Q/(m\Delta T)$	4260 J kg ⁻¹ K ⁻¹

ANALYSIS

Compare the measured c to the accepted value ($\sim 4180 \text{ J kg}^{-1} \text{ K}^{-1}$). The expected discrepancy is +2 to +5% – the measurement is biased *high* because some heat is absorbed by the calorimeter and lost to the surroundings, both of which inflate the apparent c when not accounted for.

IMPROVING THE EXPERIMENT

- Account for the calorimeter heat capacity: $c_{\text{eff}} = (Pt - m_{\text{cal}} \cdot c_{\text{cal}} \cdot \Delta T) / (m \cdot \Delta T)$.
- Insulate with a lid and insulating wool to minimise convection/conduction losses.
- Cool the water below room temperature before heating, so it heats *through* room temperature; the heat-loss errors then partially cancel (water gains from the room early in the run, loses to the room late in the run).
- Plot temperature vs time during heating and after switching off – extrapolate back to the moment the heater was switched off to correct for cooling losses (Newton's law of cooling correction).

RISK ASSESSMENT

Hot water can scald – do not heat above 60°C unless required, and never to boiling. Heater elements get extremely hot – never lift them out of the water while the supply is on. Wet hands + electrical apparatus is dangerous – keep the supply unit and meters dry.

EXAMINER'S TIP

If asked 'why is your measured c larger than the accepted value?', the model answer: heat loss to the surroundings AND heat absorbed by the calorimeter and thermometer both reduce the apparent ΔT relative to what the water alone received – so the same Q divided by a smaller ΔT gives a larger calculated c .

Practical 11 – Specific Heat Capacity of a Solid

The same energy-balance method adapted for an aluminium block with drilled wells for the heater and thermometer.

AIM

Determine the specific heat capacity of a solid (typically aluminium or copper) by supplying a known amount of electrical energy via an immersion heater placed in a drilled cavity, and measuring the resulting temperature rise of the block.

APPARATUS

- Aluminium (or copper) block, mass ~1 kg, with two cylindrical wells drilled into it (one for the heater, one for the thermometer)
- Immersion heater (12 V, ~50 W)
- Variable DC power supply, ammeter, voltmeter, stopwatch
- Thermometer or temperature probe
- Top-pan balance, lagging (felt or fibreglass cloth)
- Heat-sink compound (small amount in each well to improve thermal contact)

METHOD

1. Mass the block (m). Note its accepted material (aluminium ~ 900 , copper $\sim 385 \text{ J kg}^{-1} \text{ K}^{-1}$).
2. Apply a small amount of heat-sink compound in each well. Insert the heater into one well, the thermometer into the other.
3. Wrap the block in lagging to minimise heat loss.
4. Record the initial temperature T_0 .
5. Switch on the supply at the rated voltage. Record V and I ; compute $P = VI$.
6. Start the stopwatch. Heat for a measured time t (typically 5–10 minutes).
7. Switch off and continue to monitor the thermometer; the maximum temperature T_{max} is reached typically 30–60 seconds after switch-off as heat diffuses through the block.
8. $\Delta T = T_{\text{max}} - T_0$. Compute $c = Pt / (m \Delta T)$.

WHY SOLIDS NEED A 'SOAK TIME'

Unlike water (where stirring distributes heat uniformly within seconds), heat in a solid block must *conduct* from the heater well outward. Until the temperature gradient inside the block has equalised (the 'soak time'), the thermometer reading lags the actual peak. Always wait until T_{max} stops rising before recording – otherwise you under-estimate ΔT and over-estimate c .

EXAMINER'S TIP

Compare your measured c to the accepted value. For aluminium, expect $900 \pm 50 \text{ J kg}^{-1} \text{ K}^{-1}$. If your value is significantly higher, heat losses to the lagging or surroundings are the most likely cause; if much lower, you may have read T_{max} too early before the block reached thermal equilibrium internally.

Practical 12 – Pressure-Temperature Relationship for a Gas

Verify the Pressure Law ($P \propto T$ at constant volume) and infer absolute zero by extrapolation.

AIM

Verify experimentally that, for a fixed volume of gas, pressure is directly proportional to absolute (kelvin) temperature, $P \propto T$, and use the data to infer the value of absolute zero by extrapolating P -vs- θ (in $^{\circ}\text{C}$) to $P = 0$.

THEORY

For a fixed mass of ideal gas at constant volume, the pressure is proportional to absolute temperature: $P = nRT/V$ (with n, V constant). On a P -vs- θ graph (Celsius), the line should extrapolate to $P = 0$ at $\theta = -273.15^{\circ}\text{C}$ – absolute zero.

APPARATUS

- Round-bottomed flask ($\sim 250\text{ cm}^3$) sealed with a stopper, connected via narrow tubing to a Bourdon pressure gauge
- Large beaker / water bath
- Heat source (Bunsen burner or hotplate), tripod, gauze
- Thermometer or temperature probe (range -10 to 110°C)
- Ice (to start at low temperature)
- Stirrer

METHOD

1. Set up the apparatus with the flask immersed in a water bath. Ensure the flask is fully submerged (so the gas inside reaches the bath temperature).
2. Add ice to start at $-0-5^{\circ}\text{C}$. Stir to ensure thermal equilibrium between bath and flask gas.
3. Record the temperature θ from the thermometer and the pressure P from the gauge.
4. Heat the bath gradually (slow heating, stirring continuously). Pause every 10–15 K to allow equilibrium and record (θ, P) pairs up to 90°C .
5. Aim for at least 6–8 data points spread over the range.

ANALYSIS

1. Plot P (y -axis) against θ in $^{\circ}\text{C}$ (x -axis).
2. Best-fit a straight line and extrapolate it backward to $P = 0$. Read the x -intercept – this should be approximately -273°C .
3. Convert θ to $T(\text{K}) = \theta + 273$. Plot P against $T(\text{K})$. The line should pass through the origin, confirming $P \propto T$.

RISK ASSESSMENT

Heating a sealed glass flask is dangerous if the seal fails – flask can crack from thermal shock if the bath water is much hotter than the glass. Never heat past 95°C in this setup. Wear safety glasses; use tongs or thermal gloves. Bunsen burner: tie back hair, no loose clothing.

EXAMINER'S TIP

Extrapolating to absolute zero is the marquee result of this experiment. Expect to find a value around -270 to -280°C – close to the accepted -273.15°C . If your extrapolated value is significantly off, the most likely cause is failure to keep volume constant (i.e. the rubber tubing connecting the flask to the gauge expanded slightly with pressure).

Practical 13 – Pressure-Volume Relationship (Boyle's Law)

Verify $P \times V = \text{constant}$ at fixed temperature using a syringe + pressure gauge – inverse-proportionality between pressure and volume.

AIM

Verify Boyle's law: at fixed temperature and fixed amount of gas, the pressure of a gas is inversely proportional to its volume, $P \propto 1/V$. Equivalently, $PV = \text{constant}$.

APPARATUS

- Sealed-end syringe (50 cm³, with a movable plunger) connected to a Bourdon pressure gauge
- Stand and clamp to hold the syringe vertically
- Slow-pumping mechanism (e.g. screw-thread plunger) so the gas can be compressed slowly
- Set of small masses (or a hand pump with calibrated stops)
- Thermometer (to confirm temperature is constant throughout)

METHOD

1. Open the syringe to atmospheric and allow it to fill to its maximum volume (e.g. 50 cm³). Record the ambient pressure P_0 and volume V_0 .
2. Compress the plunger slowly (over ~10 seconds – slow enough for the gas to remain at room temperature; rapid compression heats the gas adiabatically).
3. Stop at a measured smaller volume V_1 . Wait for thermal equilibrium with the room (~30 seconds). Record P_1 .
4. Repeat for V values of 45, 40, 35, 30, 25, 20, 15 cm³.
5. Tabulate V , P , PV (column 4), and $1/V$ (column 5).

ANALYSIS

1. Plot P (y -axis) against $1/V$ (x -axis). A straight line through the origin verifies $P \propto 1/V$.
2. Compute PV at each point. PV should be constant within experimental uncertainty ($\sim 3\text{-}5\%$).
3. If PV drifts upward with decreasing V , the gas is heating during compression (adiabatic warming); slow the compression and try again.

RISK ASSESSMENT

High pressure can cause the syringe's seal to blow out – do not exceed the gauge's rated maximum (typically 5 atm absolute). Eye protection. Slow compression also reduces the risk of mechanical kickback if the seal fails.

EXAMINER'S TIP

If your P -vs- $1/V$ graph has a small positive y -intercept, the volume V you read off the syringe doesn't include the 'dead volume' in the connecting tube. Account for this offset by adding a constant V_{dead} to each V reading; the corrected line will pass through the origin. Marking schemes often credit candidates who identify and correct for the dead volume.

Practical 14 – Activity of a Radioactive Source

Measure the count rate from a low-activity source as a function of distance – and verify the inverse-square law.

AIM

Measure the corrected count rate of gamma radiation from a sealed source as a function of distance from a Geiger-Müller (GM) tube and verify that intensity follows an inverse-square law: $I \propto 1/d^2$.

THEORY

Gamma rays from a point source spread out spherically. The intensity at distance d falls as $I = A / (4\pi d^2)$, where A is the source activity. Hence the count rate $C \propto 1/d^2$. Plotting C against $1/d^2$ gives a straight line through the origin, confirming the inverse-square law.

APPARATUS

- Sealed gamma source (e.g. Co-60, ~10 kBq – school-grade)
- GM tube + ratemeter (or scaler with timer)
- Lead castle or shielded source holder
- Metre rule or optical bench for accurate distance measurement
- Stopwatch (if using a scaler rather than a ratemeter)

METHOD

1. Measure the background count rate B by counting for 5 minutes with no source present. Record total counts, divide by 300 s to get B (counts s^{-1}).
2. Place the source at distance $d_1 = 5$ cm from the GM tube window. Count for 60 s. Record total counts and compute C_1 (counts s^{-1}).
3. Compute corrected count rate $C_{\text{corr}} = C_1 - B$.
4. Repeat for $d = 10, 15, 20, 25, 30, 40, 50$ cm. At each distance, count for 60 s.
5. Tabulate $d, C, C_{\text{corr}}, 1/d^2$.

ANALYSIS

1. Plot C_{corr} (y-axis) against $1/d^2$ (x-axis).
2. A straight line through the origin verifies the inverse-square law.
3. From the gradient ($= A / 4\pi$), estimate the source activity A . Compare with the rated activity on the source label.

RISK ASSESSMENT

Even school-grade gamma sources require careful handling. **Maximum exposure time, minimum distance, maximum shielding** – the 'ALARA' principle (As Low As Reasonably Achievable). Use tongs to handle the source – never bare hands. Return the source to its lead castle immediately after each run. Pregnant students and any student with an open wound on the hands should not handle the source.

SOURCES OF ERROR

- GM tube has a finite dead time ($\sim 100 \mu\text{s}$ after each pulse) – saturates at high count rates. Stay below ~ 500 counts s^{-1} for accurate readings.
- Background varies slightly during the experiment – record it again at the end and average.
- Source is not a perfect point – finite-size correction matters at very small d .
- Air absorbs some gamma radiation – small effect for low-energy gammas, negligible for Co-60.

EXAMINER'S TIP

Subtracting the background is mandatory for full marks. Mark schemes typically deduct 1-2 marks for any analysis that uses raw count rate without background correction. Always state the corrected count rate explicitly.

Practical 15 – Simulation of Radioactive Decay

Use dice (or wooden cubes with one marked face) to simulate the random nature of radioactive decay and verify the exponential decay law.

AIM

Use a population of dice to simulate the random decay of unstable nuclei, and verify experimentally that the number of 'undecayed' dice falls exponentially with the number of throws. Each throw represents one unit of time. The simulation lets you see decay statistics for population sizes (~100–200 dice) where real radioactive sources of similar activity would be invisible.

THEORY

If on each throw a fraction p of the remaining dice is 'decayed' (e.g. those showing a 6, $p = 1/6 \approx 0.167$), then after n throws the expected number of undecayed dice is $N(n) = N_0(1-p)^n$. For large N_0 , this matches the radioactive decay law $N(t) = N_0 e^{-\lambda t}$ with decay constant $\lambda = -\ln(1-p)$ per throw.

APPARATUS

- 100–200 standard six-sided dice (or wooden cubes with one face marked)
- Large tray or shallow box for throwing the dice
- Recording sheet

METHOD

1. Count the initial population N_0 (e.g. 200 dice) and record at throw $n = 0$.
2. Throw all the dice into the tray. Remove every die that lands on a 6 – these have ‘decayed’.
3. Count the remaining dice; record N_1 . This is throw $n = 1$.
4. Repeat: throw the remaining dice, remove all sixes, count, record N_2 . Continue until $N < 5$ (typically ~25 throws for $N_0 = 200$).
5. Tabulate n vs $N(n)$.

ANALYSIS

1. Plot $N(n)$ against n . Curve should be a falling exponential.
2. Plot $\ln N(n)$ against n . The plot should be a straight line with negative gradient $-\lambda$.
3. Theoretical $\lambda = -\ln(1-1/6) = -\ln(5/6) \approx 0.182$ per throw. Compare to your measured gradient; agreement within 10% is typical for $N_0 = 200$.

WHY A SIMULATION?

The decay of any individual die (or nucleus) is genuinely random – no measurement on the die before the throw can predict whether it will land on a 6. But the bulk behaviour of a large population is predictable, with smaller statistical fluctuations as N_0 grows. This is a vivid demonstration of how randomness at the individual level produces deterministic-looking laws at the population level – the philosophical heart of statistical physics.

EXAMINER'S TIP

When asked ‘why does the experimental decay constant differ slightly from the theoretical 0.182?’, the model answer addresses statistical fluctuations: with $N_0 = 200$, the number of sixes per throw fluctuates around the expected value with standard deviation $\sqrt{Np(1-p)} \approx 5$. The observed gradient therefore has a small uncertainty inherent to the finite sample size.

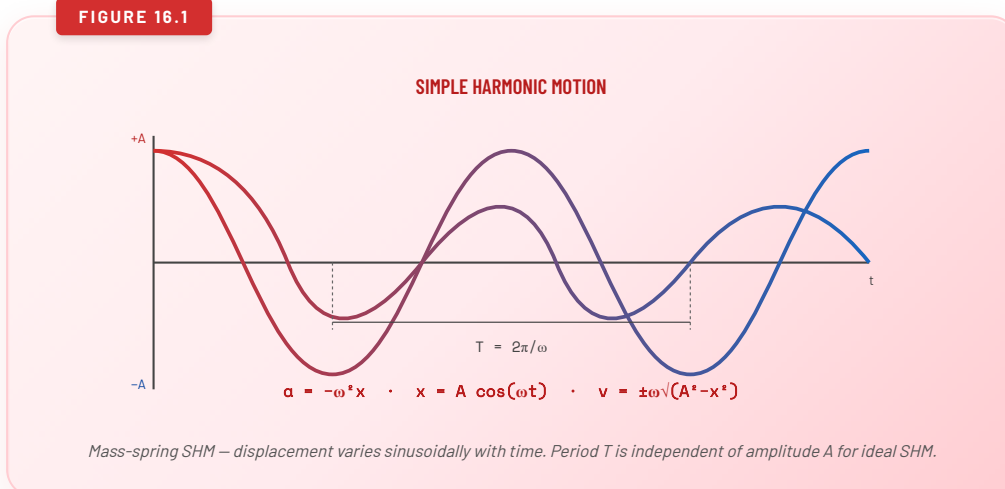
Practical 16 – Graphical Representation of Simple Harmonic Motion

Use a motion sensor (or video frame analysis) to capture the displacement-time curve of a mass-spring system and extract period, amplitude, and angular frequency.

AIM

Record the displacement of a mass on a vertical spring against time, plot the resulting graph, and demonstrate that the motion is simple harmonic by (i) the sinusoidal shape of the displacement-time curve, (ii) the relation $T = 2\pi\sqrt{m/k}$, and (iii) the independence of period from amplitude (isochronous).

FIGURE 16.1



APPARATUS

- Helical spring with known spring constant k (or to be determined)
- Set of slotted masses (50–500 g)
- Stand, clamp, retort rod – for hanging the spring
- Motion sensor positioned above (or below) the mass, connected to a data logger
- Stopwatch (backup measurement of period for at least one run)

METHOD

1. Hang the spring vertically. Attach a mass m at the bottom.
2. Determine the static extension x of the spring under the load. Compute $k = mg/x$. (This calibrates the spring constant for the SHM equation $T = 2\pi\sqrt{m/k}$.)
3. Position the motion sensor so it can detect the mass throughout its oscillation range.
4. Pull the mass down by a measured small displacement A (no more than $\sim 10\%$ of the natural length, to keep the spring in its elastic regime).
5. Release. Start data logging immediately.
6. Record displacement vs. time for at least 10 oscillations.
7. Repeat for different amplitudes A (5, 10, 20 mm). Period should be unchanged.
8. Repeat for different masses m (50, 100, 200, 300 g). Plot T^2 vs m ; expect a straight line of gradient $4\pi^2/k$.

ANALYSIS

1. From the displacement-time graph, identify the period T (time between consecutive peaks).
2. Verify the curve is sinusoidal – if you plot acceleration (the second derivative computed by the data logger) against displacement, you get a straight line through the origin with negative gradient $= -\omega^2$.
3. From the gradient of T^2 vs m : gradient $\times k / 4\pi^2$ should equal 1 (or, equivalently, the gradient gives $4\pi^2/k$).
4. Compute $\omega = 2\pi/T$. Compute $v_{\text{max}} = A\omega$ and $a_{\text{max}} = A\omega^2$; compare to the data-logger's peaks.

RISK ASSESSMENT

Slotted masses can fall – secure them onto the hanger. Stand and clamp must be stable – weight the base. Avoid extending the spring beyond its elastic limit (you'll see permanent stretch and the SHM equation no longer applies). Eye protection if the spring snaps.

WHAT THE GRAPH REVEALS

- **Displacement-time:** pure sine wave, period T , amplitude A .
- **Velocity-time:** cosine wave, $\pi/2$ ahead in phase. Maximum at the equilibrium position; zero at the extremes.
- **Acceleration-time:** negative sine wave, π out of phase with displacement. Maximum at the extremes (where the restoring force is greatest); zero at equilibrium.
- **Acceleration vs displacement:** $a = -\omega^2 x$ – straight line through origin with negative gradient. Confirms the defining condition of SHM.

EXAMINER'S TIP

When asked 'how do you confirm the motion is SHM?' the model answer addresses TWO independent tests: (i) the displacement-time graph is sinusoidal, and (ii) the acceleration-vs-displacement plot is linear with negative gradient through the origin. One test alone could match other periodic motions; both together uniquely identify SHM.

Synopsis, Glossary & Examiner's Tips

A final pass over the most exam-critical concepts from across the WPH14/WPH15 syllabus.

SYNOPSIS

A2 Physics builds on the GCSE foundation by adding two ideas that change everything: **vector reasoning** and **field thinking**. The Further Mechanics block trains you to track *momentum* as a vector through collisions and explosions, and to recognise that any object moving in a curve has an unbalanced (centripetal) force. The Electric, Magnetic, and Gravitational Fields block teaches you that all three follow inverse-square or $1/r^2$ laws and can be analysed with the same toolkit (field strength = force per unit test object). Capacitors, RC circuits, and electromagnetic induction extend this into time-dependent behaviour governed by the exponentials $Q = Q_0 e^{-t/RC}$ and $\epsilon = -d\Phi/dt$. Particle Physics introduces the Standard Model and the experimental devices (linear accelerators, cyclotrons, cloud and bubble chambers) that revealed it. The Thermal block treats internal energy, specific heat, and the kinetic theory of ideal gases. Nuclear Physics adds radioactive decay, half-life, mass defect, and the energetics of fission and fusion. Oscillations re-uses circular-motion mathematics to describe simple harmonic motion, damping, and resonance. Astrophysics and Cosmology close the course by mapping stellar evolution on the H-R diagram and explaining the Big Bang via Hubble's law. Master the equations, master the units, and the exam writes itself.

EXAMINER'S TIPS (THE MARKS-WINNING SHORTLIST)

- **Always quote the equation first**, then substitute, then simplify, then state the answer with its *SI unit* and an appropriate number of significant figures (3 s.f. is usually the safe default).
- **Vectors vs scalars**: momentum, velocity, force, electric/magnetic field strength, acceleration are vectors. Always state direction (sign or compass) for full marks.
- **Free-body diagrams earn marks**. Sketch all forces acting *on* the body, label each, then resolve along useful axes (radial / tangential for circular motion; horizontal / vertical for projectiles).
- **Use absolute values for charges** in Coulomb's law to find the magnitude, then state the direction separately. Sign errors are the #1 way A-grade scripts drop marks.
- **Capacitor exponential decay**: at one time-constant $t = RC$, the quantity has fallen to $1/e \approx 37\%$ of its initial value (or risen to 63% during charging). Remember 5τ for 'fully' charged/discharged.
- **Lenz's law gives the sign**: induced emf opposes the change that produced it. The minus sign in $\epsilon = -dN\Phi/dt$ is not optional.
- **SHM clue words**: "acceleration is proportional to displacement and directed towards equilibrium" ($a = -\omega^2 x$) is the mark-scheme test. Period $T = 2\pi/\omega$ and is independent of amplitude.
- **Half-life vs decay constant**: $t_{1 \rightarrow 2} = \ln 2 / \lambda$. Use the smaller of two unknowns to keep arithmetic simple.

COMPACT GLOSSARY

Momentum (p)

Product of mass and velocity, $p = mv$. A vector.

Impulse

Change in momentum, $\Delta p = F\Delta t$. Equal to area under a force-time graph.

Centripetal force

Resultant inward force keeping a body in circular motion: $F = mv^2/r = m\omega^2 r$.

Angular velocity (ω)

Rate of change of angular displacement, in rad s^{-1} . $\omega = 2\pi/T = 2\pi f$.

Electric field strength (E)

Force per unit positive charge, $E = F/Q$. Unit: N C^{-1} or V m^{-1} .

Coulomb's law

$F = k_0 Q_1 Q_2 / r^2$ with $k = 1/(4\pi\epsilon_0) \approx 8.99 \times 10^9 \text{ N m}^2 \text{ C}^{-2}$.

Capacitance (C)

Charge stored per volt, $C = Q/V$. Unit: farad (F).

Time constant (τ)

Product RC. Time for the charge on a discharging capacitor to fall to 37% of its initial value.

Magnetic flux density (B)

Force per unit length per unit current on a perpendicular conductor. Unit: tesla (T).

Magnetic flux (Φ)

$\Phi = BA \cos\theta$ for a coil of area A in field B. Unit: weber (Wb).

Faraday's law

Induced emf is proportional to the rate of change of flux linkage, $\epsilon = -dN\Phi/dt$.

Lenz's law

The induced current flows in the direction that opposes the change causing it.

Standard Model

Catalogue of fundamental particles – six quarks, six leptons, gauge bosons.

Decay constant (λ)

Probability per unit time of a nucleus decaying. $A = \lambda N$.

Half-life ($t_{1 \rightarrow 2}$)

Time for the activity (or N) to fall by half. $t_{1 \rightarrow 2} = \ln 2 / \lambda$.

Mass defect

Difference between the mass of separated nucleons and the mass of the bound nucleus. Equates to binding energy via $E = \Delta mc^2$.

SHM

Motion in which acceleration is proportional to displacement and directed back to equilibrium.

Resonance

Maximum amplitude when driving frequency matches natural frequency of a system.

Gravitational field strength (g)

Force per unit mass, $g = F/m$. Near Earth: 9.81 N kg^{-1} . Far field: $g = GM/r^2$.

Hubble's law

Recession speed $v = H_0 d$. Implies an expanding universe; $1/H_0$ estimates its age.

H-R diagram

Plot of stellar luminosity vs. surface temperature. Reveals the main sequence, giants, and white dwarfs.

STUDENT NAME

STUDENT ID

SUBJECT

Physics

SUBJECT CODE

WPH14

CURRICULUM

Pearson Edexcel IAL (A2 Levels)

ACADEMIC SESSION

DECLARATION OF AUTHENTICITY

I hereby declare that this study notes document is my own original work prepared under the guidance of my instructor at Neuratech Academy. All content contained herein is accurate to the best of my knowledge and has been prepared with academic integrity in accordance with the institution's code of conduct and scholarly standards.

STUDENT SIGNATURE

INSTRUCTOR SIGNATURE

DATE