Raffles Institution
Year 5-6 Physics Department

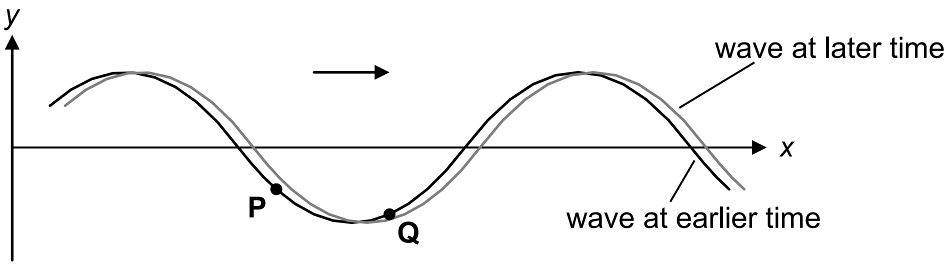
2024 H2 Physics Preliminary Examination Solution

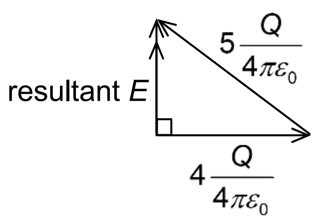
Paper 1

Qn	Ans	Solution
1	**A**	units of $\Delta P = \dfrac{\text{kg m s}^{-2}}{\text{m}^2} = \text{kg m}^{-1}\ \text{s}^{-2}$ units of $\rho = \text{kg m}^{-3}$ units of $\left(\dfrac{\Delta P}{\rho}\right)^n = \left(\dfrac{\text{kg m}^{-1}\ \text{s}^{-2}}{\text{kg m}^{-3}}\right)^n = \left(\text{m}^2\ \text{s}^{-2}\right)^n$ units of $v = \text{m s}^{-1}$ For equation to be homogeneous, units of $\left(\dfrac{\Delta P}{\rho}\right)^n$ = units of v $\text{m}^{2n}\ \text{s}^{-2n} = \text{m s}^{-1}$ comparing indices of m: $2n = 1 \quad \Rightarrow \quad n = \dfrac{1}{2}$
2	**D**	$d = d_2 - d_1 = 16.24 - 12.78 = 3.46$ mm $\Delta d = \Delta d_2 + \Delta d_1 = 0.03 + 0.02 = 0.05$ mm $\dfrac{\Delta d}{d} \times 100\% = \dfrac{0.05}{3.46} \times 100\% = 1.4451 = 1.4\%$
3	**C**	From *a*-*t* graph: From $t = 0$ to $t = t_1$, acceleration is constant which implies that the object's velocity is increasing at a constant rate. From $t = t_1$ to $t = t_2$, acceleration is decreasing which implies that the object's velocity is increasing at a decreasing rate. From $t = t_2$ to $t = t_3$, acceleration is zero which implies that the object's velocity is constant. Since $a = \dfrac{dv}{dt}$, the gradient of the *v*-*t* graph, which gives acceleration, in Option C follows the description above.
4	**D**	Option A: Possible, if lift is decelerating / decreasing in speed on its way up. Option B: Possible, if lift is moving upwards at a constant speed. Option C: Possible, if lift is accelerating / increasing in speed on its way up. Option D: Hence, all the options above are possible, depending on the lift's acceleration.

5	**C**	Applying Newton's second law on the system of both crates, $F_{net,both} = m_{both}a$ $100-(2.0+3.0)(9.81)=(2.0+3.0)\times a$ $a=\dfrac{100-(2.0+3.0)(9.81)}{(2.0+3.0)}=10.19\text{ m s}^{-2}$ Applying Newton's second law on the 2.0 kg crate, $F_{net,2kg} = m_{2kg}a$ $100-2.0(9.81)-T=2.0(10.19)$ $T=60\text{ N}$ OR $F_{net,3kg} = m_{3kg}a$ $T-3.0(9.81)=3.0(10.19)$ $T=60\text{ N}$
6	**B**	Motorcycle travels in the same direction during the whole duration. Impulse or the change in momentum is the area under the force-time graph. $\Delta p=\int F dt$ $(400)(v-4.5)=\frac{1}{2}(1.0)(400)-\frac{1}{2}(2.0)(800)$ $v-4.5=-1.5$ $v=4.5-1.5=3.0\text{ m s}^{-1}$
7	**D**	Since cube is floating, there is vertical equilibrium. $U_1+U_2=W_{cube}$ $V_1\rho_1 g+V_2\rho_2 g=(V_1+V_2)\rho_c g$ $V_1\rho_1+V_2(3\rho_1)=(V_1+V_2)(2\rho_1)$ $3V_2-2V_2=2V_1-V_1$ $V_2=V_1$ $\dfrac{V_1}{V_2}=1$
8	**A**	Work done by the force to extend the spring is given by the area under force-extension graph i.e. the area bounded by the graph and the vertical axis of the graph given. This work done goes to increase the potential energy of the spring. The potential energy represented by area *P* is released upon the removal of the force. The potential energy represented by area *Q* is retained in the spring that is permanently stretched i.e. the energy used to separate the particles of the spring further apart.

9	**D**	At constant speed, engine force = resistive force rate at which energy is delivered = rate at which energy is dissipated $P = Fv$ $12\times10^3 = F\left(\dfrac{72\times10^3}{60\times60}\right)$ $F = 600$ N $E_{\text{from fuel}} = E_{\text{to car}}$ $(0.30)(40\times10^6)(m) = (12\times10^3)(1\times60\times60)$ $m = 3.6$ kg
10	**C**	The minute hand takes 1 hour to go round the clock once. $\omega_m = \dfrac{2\pi}{60\times60}$ rad s^{-1} The hour hand takes 12 hours to go round the clock once. $\omega_h = \dfrac{2\pi}{12\times60\times60}$ rad s^{-1} $\dfrac{v_m}{v_h} = \dfrac{r_m\omega_m}{r_h\omega_h} = \left(\dfrac{1.5r_h}{r_h}\right)\left(\dfrac{12\times60\times60}{60\times60}\right) = 18$
11	**C**	Option C (correct): $g = -\dfrac{d\phi}{dr} \quad\Rightarrow\quad d\phi = -\int g\,dr$ Hence, the area under the *g-r* graph gives the change in the gravitational potential ϕ. Options A and B (incorrect): The total gravitational potential between the two planets is always negative. Gravitational potential is zero only at infinity. Option D (incorrect): The gradient of the graph does not give any meaningful quantity.
12	**A**	The gravitational force on each star provides the centripetal force for the star to orbit about the common centre of mass of the system. For two stars, mass *M* and *m*, at a distance *d* apart, $\dfrac{GMm}{d^2} = mr\omega^2 = MR\omega^2$ $mr\omega^2 = MR\omega^2$ $mr = MR$ *R* and *r* are the orbital radii of the stars of masses *M* and *m* respectively. The gravitational force on each star is always directed towards the common centre of mass of the system as the stars orbit. Hence the stars should be on opposite sides of their orbital path, lying along the same straight line through the common centre between them. To maintain this, the stars must also have the same angular velocity ω. Hence star X having a larger mass should have a smaller orbital radius.

13	**D**	From $\frac{1}{2}m\langle c^2\rangle = \frac{3}{2}kT \quad \Rightarrow \quad m = \frac{3kT}{c_{rms}^2} \quad \Rightarrow \quad m \propto \frac{T}{c_{rms}^2}$ $\frac{m_X}{m_Y} = \frac{T_x}{T_y}\left(\frac{c_{rms,Y}}{c_{rms,X}}\right)^2 = \left(\frac{T_x}{2T_x}\right)\left(\frac{3c_{rms,X}}{c_{rms,X}}\right)^2 = \frac{9}{2} = 4.5$
14	**B**	Both the inlet and outlet temperatures and the room temperature must be kept the same so that the rate of heat loss to the surrounding is kept constant for both experiments and can be eliminated.
15	**D**	$v = v_0 \cos \omega t$ $4.0 = v_0 \cos\left(\frac{2\pi}{9.0} \times 3.0\right)$ $v_0 = -8.0 \text{ m s}^{-1}$ $E_K = \frac{1}{2} \times 0.020 \times (-8.0)^2 = 0.64 \text{ J}$
16	**C**	Oil is more viscous than water hence has a greater damping effect on the oscillating mass compared to water. With greater damping, the frequency response curve when the mass is in oil will have smaller amplitudes at all frequencies and the frequency at which resonance occurs will be smaller.
17	**B**	
18	**B**	For astronaut to see the light sources, $P_{\text{received}} = \frac{P_{\text{source}}}{4\pi r^2} \times A_{\text{pupil}} \geq P_{\text{min}}$ $r \leq \sqrt{\frac{P_{\text{source}} A_{\text{pupil}}}{4\pi P_{\text{min}}}} = \sqrt{\frac{10\pi(0.0050/2)^2}{4\pi(2.0 \times 10^{-13})}} = 8838.8 \text{ m}$ $r_{\text{max}} = 8800 \text{ m}$
19	**A**	Diffraction is pronounced when the wavelength of the wave is comparable to the width of the obstacle. Sound waves with a longer wavelength than the diameter of the pillar can bend around the pillar. Light waves with a much shorter wavelength than the diameter of the pillar cannot bend around the pillar.

20	**A**	For light sources to be resolved, angle of separation of the 2 sources $\geq$ minimum angle of separation by Rayleigh criterion $\theta \geq \theta_{\text{min}}$ $\dfrac{S}{D} \geq \dfrac{\lambda}{d}$ where S is the distance between the 2 sources $S \geq \dfrac{\lambda D}{d}$ The best combination is the one that can resolve the smallest distance S between the two sources i.e. shorter λ and D and larger d.
21	**D**	Charge of sphere is Q. $V = \dfrac{Q}{4\pi\varepsilon_0 R} \quad \Rightarrow \quad Q = 4\pi\varepsilon_0 RV$ $F = \dfrac{Qq}{4\pi\varepsilon_0 r^2} = \dfrac{4\pi\varepsilon_0 RVq}{4\pi\varepsilon_0 r^2} = \dfrac{qVR}{r^2}$
22	**B**	magnitude of E at P due to +64Q $= \dfrac{64Q}{4\pi\varepsilon_0 (4.0)^2} = 4\dfrac{Q}{4\pi\varepsilon_0}$ magnitude of E at P due to $-125Q$ $= \dfrac{125Q}{4\pi\varepsilon_0 (5.0)^2} = 5\dfrac{Q}{4\pi\varepsilon_0}$  These two E vectors form a right-angle triangle, with the resultant E pointing upwards with magnitude $\sqrt{\left(5\dfrac{Q}{4\pi\varepsilon_0}\right)^2 - \left(4\dfrac{Q}{4\pi\varepsilon_0}\right)^2} = 3\dfrac{Q}{4\pi\varepsilon_0}$.
23	**A**	$I = \dfrac{E}{R} = \dfrac{E}{\frac{\rho L}{A}} = \dfrac{EA}{\rho L} = \dfrac{E\pi (d/2)^2}{\rho L} = \dfrac{\pi d^2 E}{4\rho L}$ Hence $I \propto \dfrac{d^2}{\rho}$ since L and E across the wires in parallel are constants. $\dfrac{I_X}{I_Y} = \dfrac{{d_X}^2}{\rho_X} \times \dfrac{\rho_Y}{{d_Y}^2} = \dfrac{\left(\frac{1}{4}d_Y\right)^2 \times \rho_Y}{{d_Y}^2 \times \frac{1}{2}\rho_Y} = \dfrac{2}{16} = \dfrac{1}{8}$ $\dfrac{I_X}{I_{total}} = \dfrac{1}{9}$

24	**D**	Since ammeter reading is zero, there is also no current in the middle wire joining the circuits on the left and right. There is no potential difference between the two ends of this wire and there is no current exchange between the two circuits. 50 Ω and 100 Ω resistors are in series. *R* and 200 Ω resistors are in series. Potential difference across the 100 Ω and 200 Ω resistors is the same. $V_R = 24 - V_{200}$ $V_R = 24 - V_{100}$ $\frac{R}{R+200} \times 24 = 24 - \frac{100}{100+50} \times 12$ $\frac{R}{R+200} \times 24 = 16$ $R = 400\ \Omega$
25	**C**	The current in X produces a magnetic field along the circumference of coil Y in the clockwise direction. This magnetic field produced is parallel to the current in each part of coil Y, hence there is no magnetic force induced on coil Y in all directions.
26	**B**	As the wire is raised vertically, it cuts the horizontal component of the Earth's magnetic flux density. $E = B_H L v$ $= (B\cos 50°) L \left(\frac{d}{t}\right)$ $= (3.0 \times 10^{-5}) \cos 50° \times 15 \times \frac{5.0}{150 \times 10^{-3}}$ $= 0.0096418\ \text{V}$ $= 9.6\ \text{mV}$
27	**A**	For an ideal transformer, $I_p V_p = I_s V_s$ $I_s = \frac{I_p V_p}{V_s}$ $= \frac{50 \times 240}{50 \times 10^3}$ $= 0.24\ \text{A}$ $\%\ \text{power loss} = \frac{P_{\text{loss}}}{P_{\text{supplied}}}$ $= \frac{I_s^2 R}{I_p V_p}$ $= \frac{0.24^2 (100)}{50(240)} \times 100\%$ $= 0.048\%$

28	**C**	Momentum of particle, $p = \sqrt{2mE}$ Uncertainty in momentum, $\Delta p = 0.010\sqrt{2mE}$ Minimum uncertainty in position, $\Delta x = \frac{h}{\Delta p} = \frac{h}{0.010\sqrt{2mE}} \quad \Rightarrow \quad \Delta x \propto \frac{1}{\sqrt{mE}}$ $\frac{\Delta x_{electron}}{\Delta x_{baseball}} = \sqrt{\frac{m_{baseball} E_{baseball}}{m_{electron} E_{electron}}} = \sqrt{\frac{0.150 \times 100}{(9.11\times10^{-31})(1.0\times10^{6} \times 1.60\times10^{-19})}} = 1.01\times10^{22}$ Order of magnitude: 10^{22} Note: The mass of the electron is in the data sheet. The mass of the baseball needs to be estimated to the correct order of magnitude.
29	**C**	An isotope of the parent nuclide will have the same number of protons but different number of neutrons. Hence the <u>atomic number of the isotope is the same</u> as the parent nuclide while its <u>mass number is different</u> after the decays. alpha particle – ${}^{4}_{2}He^{2+}$, beta particle – ${}^{0}_{-1}e$, gamma particle – massless, no charge Option C (correct): One alpha decay – mass number decreases by 4, atomic number decreases by 2 Two beta decays – mass number remains the same, atomic number increases by 2 Overall – daughter nuclide <u>mass number decreases</u> by 4, <u>atomic number remains the same</u> Option A (incorrect): The release of a gamma photon does not affect the atomic and mass numbers. Option B (incorrect): One alpha decay – mass number decreases by 4, atomic number decreases by 2 One beta decay – mass number remains the same, atomic number increases by 1 Overall – daughter nuclide mass number decreases by 4, atomic number decreases by 1 Option D (incorrect): Two alpha decays – mass number decreases by 8, atomic number decreases by 4 One beta decay – mass number remains the same, atomic number increases by 1 Overall – daughter nuclide mass number decreases by 8, atomic number decreases by 3
30	**B**	For X: $\left(\frac{1}{2}\right)^{\frac{t}{T_X}} = \frac{1}{8} \quad \Rightarrow \quad \frac{t}{T_X} = \frac{\lg(1/8)}{\lg(1/2)} = 3 \quad \Rightarrow \quad T_X = \frac{t}{3}$ For Y: $\left(\frac{1}{2}\right)^{\frac{t}{T_Y}} = \frac{1}{4} \quad \Rightarrow \quad \frac{t}{T_Y} = \frac{\lg(1/4)}{\lg(1/2)} = 2 \quad \Rightarrow \quad T_Y = \frac{t}{2}$ $\frac{T_X}{T_Y} = \frac{2}{3} = 0.66667 = 0.67$

2024 H2 Physics Preliminary Examination Solution and Comments

Paper 2

1 (a) (i) Take direction up the slope as positive.

$$v^2 = u^2 + 2as_0$$
$$0 = 7.0^2 + 2(-9.81\sin 30°)s_0$$
$$s_0 = 4.9949 = 4.99 \text{ m}$$

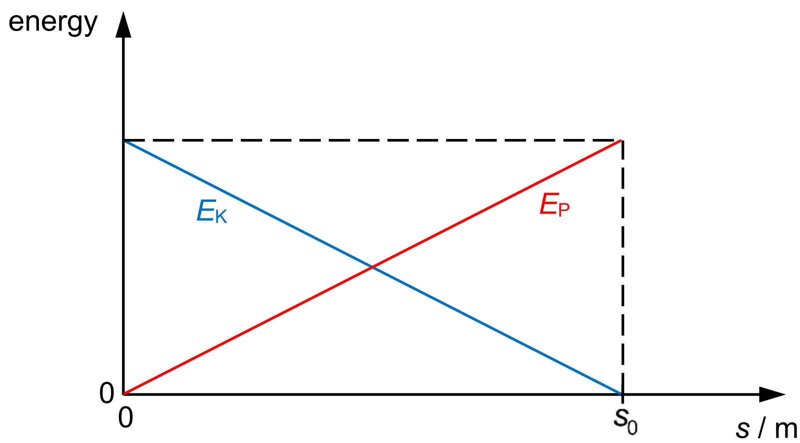
OR

By the principle of conservation of energy,
increase in G.P.E. = decrease in K.E.

$mg(\Delta h) = \frac{1}{2}mv^2 - 0,$ where Δh is the max. vertical height from ground

$$\Delta h = \frac{v^2}{2g} = \frac{7.0^2}{2(9.81)}$$
$$s_0 = \frac{\Delta h}{\sin 30°} = \frac{7.0^2}{2(9.81)} \div \sin 30° = 4.9949 = 4.99 \text{ m}$$

(ii)



*Both graphs aligned at the same total energy and s_0 and clearly labelled.

1. $E_K = \frac{1}{2}mv^2 = \frac{1}{2}m\left(u^2 + 2[-g\sin\theta]s\right)$

$E_K = \frac{1}{2}mu^2 - (mg\sin\theta)s$

Graph of E_K-s is a straight line with negative gradient and vertical intercept $\frac{1}{2}mu^2$.

2. $E_P = mg(\Delta h) = mg(s\sin\theta)$

$E_P = (mg\sin\theta)s$

Graph of E_P-s is a straight line through the origin with positive gradient.

(b) **(i)** $v^2 = u^2 + 2as$

$v^2 = 14.0^2 + 2(-9.81\sin 30°)\left(\dfrac{4.0}{\sin 30°}\right)$

$v = 10.841 = 10.8 \text{ m s}^{-1}$ (shown)

OR

decrease in K.E. = increase in G.P.E.

$\frac{1}{2}mu^2 - \frac{1}{2}mv^2 = mg(\Delta h)$

$v^2 = u^2 - 2g(\Delta h) = 14.0^2 - 2(9.81)(4.0)$

$v = 10.841 = 10.8 \text{ m s}^{-1}$ (shown)

(ii) Take directions to the right and upwards as positive.

Time of flight after the ball leaves the top of the slope to the ground:

$s_y = u_y t + \frac{1}{2}a_y t^2$

$-4.0 = (10.8\sin 30°)t + \frac{1}{2}(-9.81)t^2$

$t = 1.6080 \text{ s or } -0.50713 \text{ s (NA)}$

Horizontal distance travelled:

$s_x = u_x t + \frac{1}{2}a_x t^2$

$= (10.8\cos 30°)(1.6080) + 0$

$= 15.040 = 15.0 \text{ m}$

*State both values of *t* and reject the negative one.

2 **(a)** The initial total momentum of both balls is not zero.

Since there is no net external force acting on the balls as a system, by the principle of conservation of momentum, the total momentum of both balls must remain unchanged and cannot be zero.

Hence, the balls could not be stationary at the same time.

(b) By the principle of conservation of momentum,

$$m_A u_A + m_B u_B = m_A v_A + m_B v_B$$
$$u_A + u_B = v_A + v_B$$
$$4.0 + (-1.0) = v_A + v_B$$
$$v_A + v_B = 3.0 \qquad \text{----- (1)}$$

Since collision is elastic,

$$u_B - u_A = v_A - v_B$$
$$(-1.0) - 4.0 = v_A - v_B$$
$$v_A - v_B = -5.0 \qquad \text{----- (2)}$$

$$(1) - (2) \qquad 2v_B = 3.0 - (-5.0)$$
$$v_B = 4.0 \text{ m s}^{-1} \text{ (shown)}$$

(c) By Newton's second law, the average force on ball B by ball A is

$$F_{net,B} = \frac{\Delta p_B}{\Delta t}$$
$$= \frac{0.50\left(4.0 - (-1.0)\right)}{0.25}$$
$$= 10 \text{ N}$$

By Newton's third law, the average force on ball A by ball B has the same magnitude of 10 N.

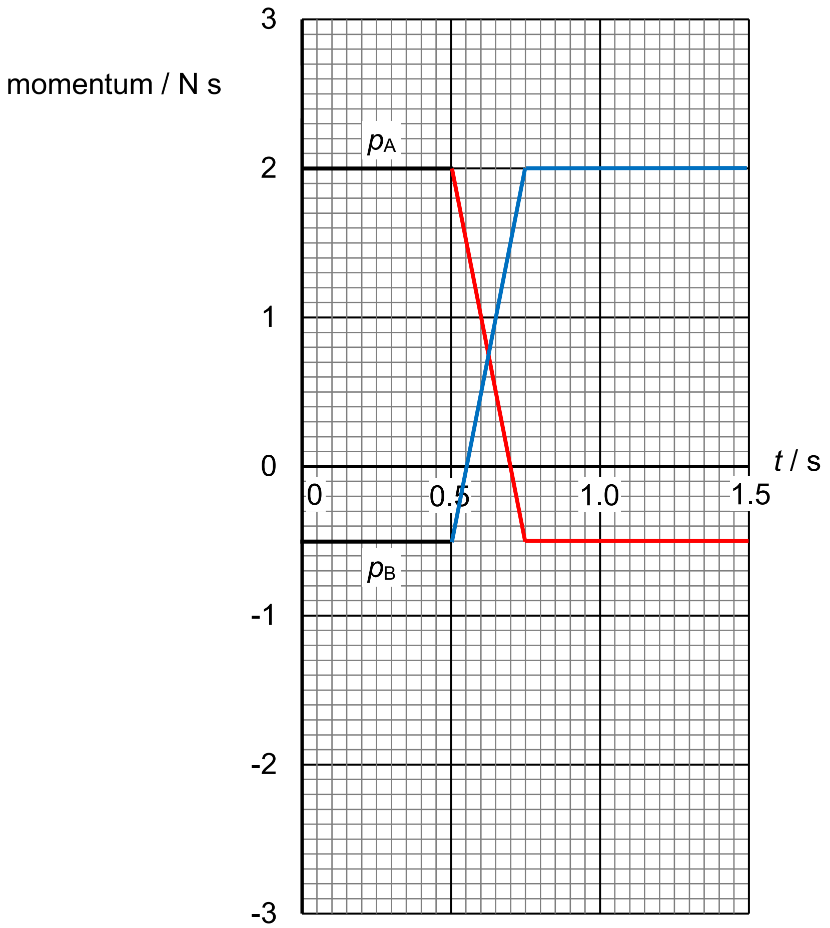
OR

From equation (1) or (2) in part (b), $v_A = 3.0 - v_B = 3.0 - 4.0 = -1.0$ m s^{-1}.

By Newton's second law, the average force on ball A by ball B is

$$F_{net,A} = \left|\frac{\Delta p_A}{\Delta t}\right|$$
$$= \left|\frac{0.50\left((-1.0) - 4.0\right)}{0.25}\right|$$
$$= 10 \text{ N}$$

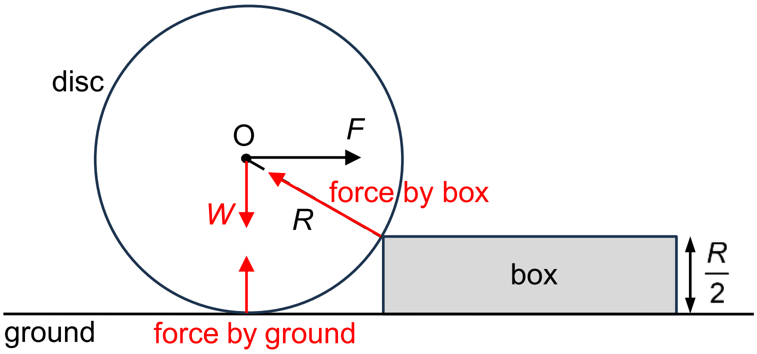
(d)



Balls A and B will exchange velocities and momenta as both balls have the same mass. From (b), $p_{B,f} = (0.50)(4.0) = 2.0$ N s.

Since duration of collision is 0.25 s, constant final momenta to start from 0.75 s to 1.5 s, with lines joining 0.50 s to 0.75 s during the collision.

3 **(a)**



When the disc is just about to rotate, the contact force by the ground just becomes zero.

Perpendicular distance from corner of box to line-of-action of F is $\frac{R}{2}$.

Perpendicular distance from corner of box to line-of-action of W is $\sqrt{R^2-\left(\frac{R}{2}\right)^2}=\frac{\sqrt{3}}{2}R$.

Applying the principle of moments about the corner of box,

$$F\times\frac{R}{2}=W\times\frac{\sqrt{3}}{2}R$$

$$\frac{F}{W}=\sqrt{3}=1.7321=1.73$$

(b) F acting at O needs to be <u>inclined upwards</u> such that it is at an angle <u>above the horizontal</u> to <u>produce a clockwise moment</u> about the corner to <u>overcome the anticlockwise moment due to the weight</u>.

OR

F acting at O needs to be <u>inclined upwards</u> so that there is an <u>upward vertical component to produce a clockwise moment</u> about the corner to <u>overcome the anticlockwise moment due the weight</u>.

OR

F needs to be <u>shifted upwards above O</u> so that there is a <u>moment arm from the corner of the box to the line-of-action of F</u>, to <u>produce a clockwise moment</u> about the corner to <u>overcome the anticlockwise moment due to the weight</u>.

Note: Increasing the magnitude of the horizontal force F acting at O will not cause any rotation as F has no moment about the corner of the box because the perpendicular distance from the corner to the line-of-action of F is zero.

4 **(a)** **(i)** At the top of the circle,

$$T_T + mg = \frac{mv_T^2}{L}$$

For the ball to just complete the vertical circle, the tension T_T at the top of the circle is zero.

$$mg = \frac{mv_T^2}{L}$$
$$v_T^2 = gL$$
$$v_T = \sqrt{gL}$$

(ii) By the principle of conservation of energy, as the ball moves from the top to the bottom of the circle, its gravitational potential energy decreases and its kinetic energy increases. This means the speed at the bottom is greater than the speed at the top. Hence $\frac{v_B}{v_T} > 1$.

(iii) $$\frac{v_B}{v_T} = 3$$
$$v_B = 3v_T$$

As the ball moves from the top to the bottom,
increase in K.E. = decrease in G.P.E.

$$\frac{1}{2}mv_B^2 - \frac{1}{2}mv_T^2 = mg(2L)$$
$$\frac{1}{2}m(3v_T)^2 - \frac{1}{2}mv_T^2 = mg(2L)$$
$$\frac{9}{2}mv_T^2 - \frac{1}{2}mv_T^2 = 2mgL$$
$$4mv_T^2 = 2mgL$$
$$v_T = \sqrt{\frac{1}{2}}\sqrt{gL}$$

As $\sqrt{\frac{1}{2}}\sqrt{gL} < \sqrt{gL}$, where $\sqrt{gL}$ is the value of v_T at which the string just goes slack, the ball will not be able to complete a full circle if $\frac{v_B}{v_T} = 3$. Hence, $\frac{v_B}{v_T} = 3$ is not possible to achieve.

(b) Considering forces along the radial direction,
$$T\sin\theta = mr\omega^2$$

Since $r = L\sin\theta$,
$$T\sin\theta = m(L\sin\theta)\omega^2$$
$$T = mL\omega^2$$
Since m and L are constants, $T \propto \omega^2$. Hence when the angular velocity is doubled, the tension in the string is $4T$.

5 (a) (i) Gravitational potential at a point in a gravitational field is the work done per unit mass by an external force in bringing a small test mass from infinity to that point.

(ii) Gravitational potential at infinity is zero.

Since gravitational force is attractive in nature, to bring a mass from infinity to a point in the gravitational field, the direction of the external force is opposite to the direction of displacement of the mass. This results in negative work done per unit mass by the external force.

Hence, based on its definition, gravitational potential is a negative value.

(b) (i)

$$\Delta E_P = \left(-\frac{GM_E m}{x}\right) - \left(-\frac{GM_E m}{R_E}\right)$$

$$= GM_E m\left(\frac{1}{R_E} - \frac{1}{x}\right)$$

$$= \left(6.67\times10^{-11}\right)\left(6.0\times10^{24}\right)(1600)\left(\frac{1}{6400\times10^3} - \frac{1}{\left(6400\times10^3\right)+\left(2.1\times10^7\right)}\right)$$

$$= 7.6681\times10^{10} = 7.67\times10^{10}\text{ J}$$

(ii) 1. Gravitational force provides the centripetal force on the satellite.

$$\frac{GM_E m}{r^2} = \frac{mv^2}{r} \quad \text{where } m \text{ is the mass of the satellite}$$

$$v = \sqrt{\frac{GM_E}{r}}$$

2. By the principle of conservation of energy, if the satellite has just enough energy to escape to infinity, its total energy is zero.

Let E_{K1} be the kinetic energy of satellite just after the boost.

$$E_P + E_{K1} = 0$$

$$-\frac{GM_E m}{r} + E_{K1} = 0$$

$$E_{K1} = \frac{GM_E m}{r}$$

Just before the boost, kinetic energy of satellite in orbit,

$$E_K = \frac{1}{2}mv^2$$

$$= \frac{1}{2}m\left(\sqrt{\frac{GM_E}{r}}\right)^2$$

$$= \frac{GM_E m}{2r}$$

$$\text{ratio} = \frac{E_{K1}}{E_K} = \frac{GM_E m}{r}\Big/\frac{GM_E m}{2r} = 2$$

6 **(a)** **(i)** Effective resistance of Q and LDR,

$$R_{eff} = \left(\frac{1}{R_Q} + \frac{1}{R_{LDR}}\right)^{-1}$$

$$= \left(\frac{1}{6.0} + \frac{1}{8.0}\right)^{-1}$$

$$= 3.4286 \text{ k}\Omega$$

$$I_{A_1} = \frac{E}{R_T}$$

$$= \frac{9.0}{(3.4286 + 4.0) \times 10^3}$$

$$= 1.2115 \times 10^{-3} \quad = 1.21 \times 10^{-3} \text{ A}$$

(ii) Potential difference across Q and LDR,

$$V_{eff} = \frac{R_{eff}}{R_{eff} + R_P} \times E$$

$$= \left(\frac{3.4286}{3.4286 + 4.0}\right) \times 9.0$$

$$= 4.1539 \text{ V}$$

$$I_{A_2} = \frac{V_{LDR}}{R_{LDR}}$$

$$= \frac{4.1539}{8.0 \times 10^3}$$

$$= 5.1924 \times 10^{-4} \quad = 5.19 \times 10^{-4} \text{ A}$$

(b) **(i)** <u>Resistance of the LDR increases</u> when light intensity is lowered. The <u>effective resistance of Q and the LDR increases</u>.

Since the potential difference across P and Q is the same at 9.0 V, by the potential divider principle, the <u>potential difference across Q is a larger proportion of the 9.0 V</u>. Hence the potential difference across Q increases.

OR

<u>Resistance of the LDR increases</u> when light intensity is lowered. The <u>overall resistance</u> of the circuit <u>increases</u>.

<u>Current from the battery decreases</u>. As the resistance of P is the same, the <u>potential difference across P decreases</u>. Since the <u>potential difference across P and Q remains the same at 9.0 V</u>, this means the potential difference across Q increases.

(ii) Since the potential difference across Q increases, the <u>current through Q increases</u> for the same resistance of Q.

<u>Total current in the circuit is the sum of the current through Q and the LDR</u>. Since the <u>total current from the battery decreases</u> due to overall increase in resistance, and the <u>current in Q increases</u>, this means the current through the LDR decreases. Hence the current reading on ammeter A_2 decreases.

7 **(a)** In a nuclear fusion reaction, two low nucleon number (OR lighter) nuclei combine into a high nucleon number (OR heavier) nucleus.

(b) Since fusion occurs when the two nuclei touch each other, the distance at which the two nuclei fuse is $d = 2\times\left(1.2\times10^{-15}\right) = 2.4\times10^{-15}$ m .

Both nuclei must possess sufficient kinetic energy to overcome the electrostatic repulsion as they approach each other to fuse.

Minimum K.E. needed is when both nuclei just <u>come to rest</u> when they start to fuse.

By the principle of conservation of energy, as the two hydrogen nuclei approach each other,
decrease in K.E. = increase in E.P.E.

$$2\times E_{k,\min} - 0 = \frac{e^2}{4\pi\varepsilon_0 d}$$

$$E_{k,\min} = \frac{e^2}{8\pi\varepsilon_0 d}$$

$$= \frac{\left(1.60\times10^{-19}\right)^2}{8\pi\left(8.85\times10^{-12}\right)\left(2.4\times10^{-15}\right)}$$

$$= 4.7956\times10^{-14}\ \text{J}$$

$$= \frac{4.7956\times10^{-14}}{10^6\left(1.60\times10^{-19}\right)}\ \text{MeV}$$

$$= 0.299725\ \text{MeV} = 0.30\ \text{MeV} \quad \text{(shown)}$$

(c)

$$E_{k,\min} = \frac{3}{2}kT$$

$$T = \frac{2E_{k,\min}}{3k}$$

$$= \frac{2\left(4.7956\times10^{-14}\right)}{3\left(1.38\times10^{-23}\right)}$$

$$= 2.3167\times10^9 = 2.32\times10^9\ \text{K}$$

(d) **(i)** ${}^{0}_{1}\text{X}$
Particle X is a positron.

(ii) Since deuteron ${}^{2}_{1}\text{H}$ is more readily found, it suggests that reaction (2) is more probable than reaction (1) and that ${}^{2}_{1}\text{H}$ is <u>more stable</u> than ${}^{2}_{2}\text{He}$.
Hence, reaction (2) <u>releases more energy</u> than (1).

(e) Energy released,

$$E = \Delta m c^2$$
$$= (\text{mass of reactants} - \text{mass of products})c^2$$
$$= (2 \times 1.007825 - 2.014102 - 0.000549)(1.66 \times 10^{-27}) \times (3.00 \times 10^{8})^2$$
$$= 1.4925 \times 10^{-13} = 1.49 \times 10^{-13}\ \text{J}$$

(f) Nuclear fission reaction of heavy nuclei requires much less energy to trigger (initiate) and can occur at a lower (room) temperature while the nuclear fusion reaction of light nuclei requires an extremely high temperature to trigger.

8 **(a)** This is to <u>reduce collisions between protons and any gas molecules</u> in the beam pipes, so <u>that less harmful ionising radiation is produced</u>.

OR

This is to <u>reduce collisions between protons and any gas molecules</u> in the beam pipes, so that <u>the proton beam can remain focused and not get scattered by these collisions</u>.

OR

This is to <u>reduce collisions between protons and any gas molecules</u> in the beam pipes, so that there is <u>less energy loss and the protons can reach the high speed</u> required.

(b) No. As neutrons are <u>neutral</u> and uncharged, their <u>trajectories cannot be bent / curved by the presence of magnetic fields</u>.

OR

No. As neutrons are <u>neutral</u> and uncharged, they <u>cannot be accelerated by electric fields</u>.

(c) **(i)**

$$E = (\gamma - 1) m_0 c^2$$

$$(7.0 \times 10^{12})(1.60 \times 10^{-19}) = (\gamma - 1)(1.67 \times 10^{-27})(3.00 \times 10^8)^2$$

$$1.12 \times 10^{-6} = (\gamma - 1)(1.67 \times 10^{-27})(3.00 \times 10^8)^2$$

$$\gamma = 7452.8$$

$$\frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} = 7452.8$$

$$v = \sqrt{\left[1 - \left(\frac{1}{7452.8}\right)^2\right] c^2} = 0.999999991\, c \quad \text{(shown)}$$

(ii) Since beam current is defined as the average rate of flow of charge,

$$\text{beam current} = \frac{\text{total charge in the ring}}{\text{period}} = \frac{Q}{T}$$

$$T = \frac{\text{distance travelled along the ring}}{\text{speed of protons}} = \frac{26659}{0.999999991\, c} = 8.8863 \times 10^{-5} \text{ s}$$

$$0.58 = \frac{Q}{8.8863 \times 10^{-5}}$$

$$Q = 5.1541 \times 10^{-5} \text{ C}$$

number of protons per proton beam,

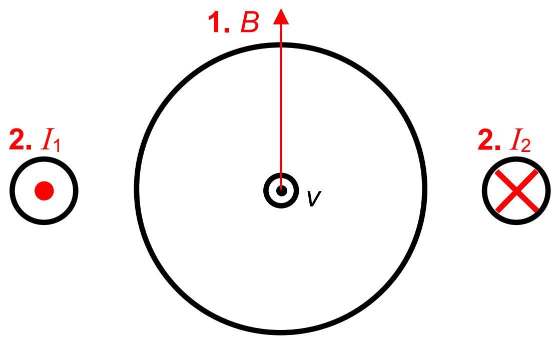
$$N = \frac{Q}{e} = \frac{5.1541 \times 10^{-5}}{1.60 \times 10^{-19}} = 3.22 \times 10^{14}$$

Since there are 2808 bunches per proton beam,

$$\text{number of protons in each bunch} = \frac{3.22 \times 10^{14}}{2808}$$

$$= 1.1467 \times 10^{11} = 1.15 \times 10^{11} \quad \text{(shown)}$$

(d) (i) 1.
2.



1. Since proton velocity is out of the page, beam current is out of the page. Since centre of circular path of the proton's trajectory is on the left, the magnetic force on the proton that provides the centripetal force points to the left.
Using Fleming's left-hand rule, direction of B is upwards.

*Straight line with arrowhead pointing upwards at the centre of pipe.

2. Since each combined cable carries current of the same magnitude, the direction of the current in each cable must be such that each produces a magnetic flux density that points upwards at the centre of the pipe, giving a resultant magnetic flux density as deduced in **(d)(i)1.**

Using the right-hand grip rule, I_1 points out of the page and I_2 points into the page.

*Correct directions, positions and symbols of both currents.

(ii) 1.

$$B = \frac{\mu_0 I_1}{2\pi d} + \frac{\mu_0 I_2}{2\pi d}$$

$$8.33 = \frac{(4\pi \times 10^{-7})(I_1 + I_2)}{2\pi\left(\frac{88}{2} \times 10^{-3}\right)}$$

$$I_1 + I_2 = 1832600 \text{ A}$$

Since $I_1 = I_2$,

$$I_1 = \frac{1832600}{2}$$

$$= 916300 \text{ A} = 9.16 \times 10^5 \text{ A}$$

2. Since current in each cable is 11850 A,

$916300 = N(11850)$ where N is the number of cables

$N = 77.3 \approx 77$

3. Force on combined cable 2 by combined cable 1,

$$F = B_1 I_2 L$$
$$= \frac{\mu_0 I_1}{2\pi d} I_2 L$$
$$= \frac{\left(4\pi \times 10^{-7}\right)(916300)}{2\pi\left(88 \times 10^{-3}\right)}(916300)(14.3)$$
$$= 2.7287 \times 10^{7} = 2.73 \times 10^{7} \text{ N}$$

By Newton's third law, force on combined cable 1 by combined cable 2 is equal in magnitude and opposite in direction.

The cables in the dipole magnet setup experience an <u>extremely large repulsive force away from each other</u>. Hence, the stainless-steel collars are used to <u>keep the cables from moving away from the beam pipe</u>.

(e) (i) average volume occupied by one proton

$$= \frac{\text{volume of one bunch}}{\text{no. of protons in one bunch}}$$
$$= \frac{\left(7.48 \times 10^{-2}\right)\left(1.0 \times 10^{-6}\right)}{1.15 \times 10^{11}}$$
$$= 6.5043 \times 10^{-19} \text{ m}^3$$

Approximating volume occupied by a proton to be volume of a cube with sides of length *d*:

$$d = \sqrt[3]{6.5043 \times 10^{-19}} = 8.6643 \times 10^{-7} \text{ m}$$

average electric force of repulsion between 2 protons,

$$F_E = \frac{e^2}{4\pi\varepsilon_0 d^2}$$
$$= \frac{\left(1.60 \times 10^{-19}\right)^2}{4\pi\left(8.85 \times 10^{-12}\right)\left(8.6643 \times 10^{-7}\right)^2}$$
$$= 3.0663 \times 10^{-16} = 3.07 \times 10^{-16} \text{ N}$$

(ii) Initial velocity v of proton is horizontal along the central axis of the beam pipe.

displacement of proton from centre of beam pipe to bottom of beam pipe,

$$s_y = u_y t + \frac{1}{2}gt^2$$

$$\frac{1}{2}\left(56\times10^{-3}\right) = 0 + \frac{1}{2}(9.81)t^2$$

$t = 0.075554$ s or -0.075554 s (NA)

total horizontal displacement travelled by proton,

$$\begin{aligned} s_x &= vt \\ &= (0.999999991)\left(3.00\times10^8\right)(0.075554) \\ &= 22666199.8 \text{ m} \end{aligned}$$

$$\begin{aligned} \text{number of rounds} &= \frac{s_x}{\text{circumference of ring}} \\ &= \frac{22666199.8}{26659} \\ &= 850.23 = 850 \end{aligned}$$

(iii) The radiation produced from the accelerating protons will cause the protons to lose energy, resulting in the protons straying away from their original path as the radius of curvature of their trajectory will decrease.

Hence, the quadrupole magnets are needed to help keep the protons travelling along the central axis of the beam pipe.

(f) Advantages:

- Linear accelerators are less expensive to build as they do not require large numbers of electromagnets to keep the particles in a circular path, which need to be kept at extremely low temperatures with large amounts of liquid nitrogen and helium.
- Synchrotron radiation due to the particles accelerating is a lot less as particles are not constantly accelerating unlike when they are travelling in circular paths where they experience centripetal acceleration.
- Synchrotron radiation due to the particles accelerating is a lot less as particles are not constantly changing direction unlike when they are travelling in circular paths.

Disadvantages:

- The chances for collisions to happen is much lower because there is only one collision point in a linear accelerator, whereas there can be multiple collision points in a circular accelerator.
- Linear accelerators are not able to reach the same high energies as a circular accelerator without being unfeasibly long, because particles in a circular accelerator can circulate many times, getting boosts in energy many times before colliding.
- For linear accelerators to reach the same high energies as a circular accelerator they need to be extremely long which is very expensive to build.

2024 H2 Physics Preliminary Examination Solution

Paper 3

1 **(a)** The internal energy of an ideal gas is just the <u>sum of the microscopic kinetic energy</u>, due to the <u>random motion</u> of its molecules since the microscopic potential energy of an ideal gas is zero.

Its internal energy <u>depends only on its state</u> (pressure, volume, temperature) and amount of gas.

(b) **(i)** **1.** $\Delta U = Q + W$

Since volume is constant, $W = 0$.

$$\begin{aligned} Q &= \Delta U \\ &= \frac{3}{2}p_2V - \frac{3}{2}p_1V \\ &= \frac{3}{2}V\left(p_2 - p_1\right) \\ &= \frac{3}{2}\left(2.0\times10^{-2}\right)\left(1.5\times10^{5} - 1.0\times10^{5}\right) \\ &= 1500.0 = 1500 \text{ J (shown)} \end{aligned}$$

2. Since

$$E_k = \frac{3}{2}kT_1 = 6.2\times10^{-21}\text{ J}$$

$$T_1 = \frac{2}{3}\left(\frac{6.2\times10^{-21}}{1.38\times10^{-23}}\right) = 299.52\text{ K}$$

From $p = \frac{nR}{V}T$, since volume is constant,

$$\Delta p = \frac{nR}{V}\Delta T = \frac{p_1}{T_1}\Delta T$$

$$\begin{aligned} \Delta T &= \frac{\Delta p}{p_1}T_1 \\ &= \frac{0.5\times10^{5}}{1.0\times10^{5}}\left(299.52\right) \\ &= 149.76 = 150\text{ K} \end{aligned}$$

OR

$$E_k = \frac{3}{2}kT_1$$

$$T_1 = \frac{2}{3}\frac{E_k}{k}$$

Since volume is constant,

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

$$T_2 = \frac{p_2}{p_1}T_1 = \frac{p_2}{p_1}\left(\frac{2}{3}\frac{E_k}{k}\right)$$

$$\begin{aligned} T_2 - T_1 &= \frac{p_2}{p_1}\left(\frac{2}{3}\frac{E_k}{k}\right) - \frac{2}{3}\frac{E_k}{k} \\ &= \frac{2}{3}\frac{E_k}{k}\left(\frac{p_2}{p_1} - 1\right) \\ &= \frac{2}{3}\left(\frac{6.2\times10^{-21}}{1.38\times10^{-23}}\right)\left(\frac{1.5\times10^{5}}{1.0\times10^{5}} - 1\right) \\ &= 149.76 = 150\text{ K} = 150\ ^\circ\text{C} \end{aligned}$$

OR

$U_1 = NE_k$ where N is the number of gas molecules

$$N = \frac{U_1}{E_k}$$

$$\begin{aligned} \Delta U &= U_2 - U_1 \\ &= \frac{3}{2}NkT_2 - \frac{3}{2}NkT_1 \\ &= \frac{3}{2}Nk\left(T_2 - T_1\right) \end{aligned}$$

$$\begin{aligned} T_2 - T_1 &= \frac{2}{3}\frac{\Delta U}{Nk} \\ &= \frac{2}{3}\frac{\Delta U}{\left(U_1/E_k\right)k} \\ &= \frac{2}{3}\frac{E_k\Delta U}{\left(\frac{3}{2}p_1V\right)k} \\ &= \frac{4}{9}\frac{\left(6.2\times10^{-21}\right)(1500)}{\left(1.0\times10^{5}\right)\left(2.0\times10^{-2}\right)\left(1.38\times10^{-23}\right)} \\ &= 149.76 = 150\text{ K} = 150\ ^\circ\text{C} \end{aligned}$$

(ii) The first law of thermodynamics states that the increase in internal energy ΔU is equal to the sum of the work done on the system W and the heat supplied to the system Q, i.e. $\Delta U = Q + W$. Hence $Q = \Delta U - W$.

When a unit mass of the gas, heated under constant volume or under constant pressure, experiences a unit rise in temperature, ΔU will be the same since $\Delta U \propto \Delta T$.

When the gas is heated at constant volume, there is no work done. W is zero and $Q_V = \Delta U$.

When the gas is heated at constant pressure, work is done by the gas as it expands. W is negative and $Q_p > \Delta U$.

The specific heat capacity of a gas is the heat supplied to a unit mass of the gas to cause a unit rise in its temperature i.e. $c = \dfrac{Q}{m(\Delta T)}$. Since $Q_p > Q_V$ the specific heat capacity at constant pressure is higher than that at constant volume.

2 **(a)** Since <u>k and m are constant</u>, $a \propto -x$.
This implies that the block's <u>acceleration is proportional to its displacement from</u> the <u>equilibrium position</u>.

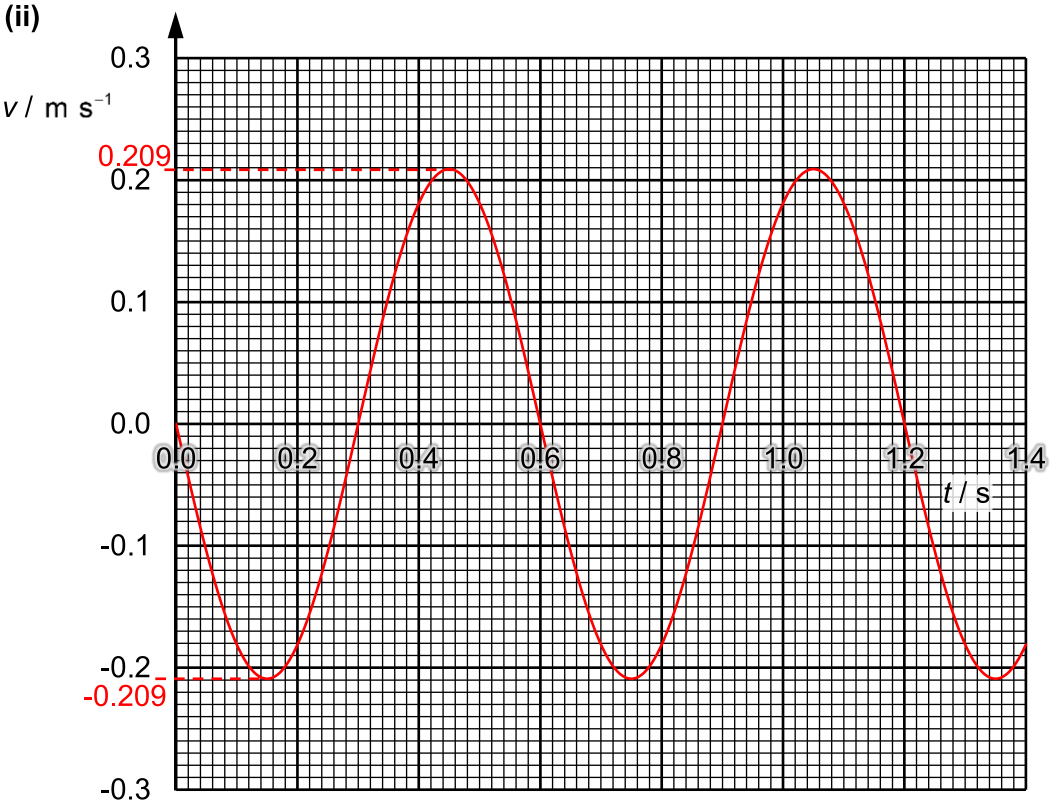
The <u>negative sign</u> implies that the <u>direction of its acceleration is always opposite to its displacement</u>, pointing towards the equilibrium position.

This satisfies the definition for simple harmonic motion.

(b) **(i)** From the graph, $T = 0.60$ s, $x_0 = 2.0 \times 10^{-2}$ m

$$v_0 = \omega x_0$$
$$= \frac{2\pi}{T} x_0$$
$$= \frac{2\pi}{0.60}\left(2.0 \times 10^{-2}\right)$$
$$= 0.20944 = 0.209 \text{ m s}^{-1}$$

(ii)



(iii) $E_K = \frac{1}{2}mv^2 = \frac{1}{2}m\left(\pm\omega\sqrt{x_0^{\,2} - x^2}\right)^2 = \frac{1}{2}m\omega^2\left(x_0^{\,2} - x^2\right)$

$E_P = E_T - E_K = \frac{1}{2}m\omega^2 x_0^{\,2} - \frac{1}{2}m\omega^2\left(x_0^{\,2} - x^2\right) = \frac{1}{2}m\omega^2 x^2$

$$E_P = E_K$$

$$\frac{1}{2}m\omega^2 x^2 = \frac{1}{2}m\omega^2\left(x_0^{\,2} - x^2\right)$$

$$2x^2 = x_0^{\,2}$$

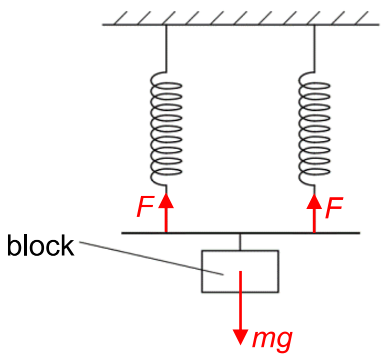
$$x = \pm\frac{x_0}{\sqrt{2}} = \pm\frac{2.0\times10^{-2}}{\sqrt{2}} = \pm 0.014142 \text{ m} = \pm 1.4142 \text{ cm}$$

At equilibrium, $L = 16.0$ cm.
When $E_P = E_K$,
$L = 16.0 + 1.4142 = 17.4142 = 17.4$ cm (block is below equilibrium)
OR
$L = 16.0 - 1.4142 = 14.5858 = 14.6$ cm (block is above equilibrium)

(c) $F_{eff} = 2F = mg$

$k_{eff}e = 2ke = mg$

$k_{eff} = 2k$



The <u>same mass results in half the extension</u> in each spring at equilibrium compared to a single spring in Fig. 2.1. Hence the <u>effective force constant is twice</u> the force constant of one spring ($k_{eff} = 2k$).

From $a = -\frac{k}{m}x$, angular frequency $\omega = \frac{2\pi}{T} = \sqrt{\frac{k}{m}}$. Hence period $\underline{T = 2\pi\sqrt{\frac{m}{k}}}$.

When the force constant is twice that in (a), the <u>period decreases to $\frac{1}{\sqrt{2}}$ the period in (a)</u>.

3 **(a)** amplitudes:
Particles in a progressive wave have the same amplitude.
Particles in a stationary wave have amplitudes ranging from zero at the nodes to maximum amplitude at the antinodes.

phases:
Particles within a wavelength in a progressive wave have different phases.
Particles in a stationary wave between adjacent nodes oscillate with the same phase and particles between adjacent segments oscillate π rad out-of-phase.
Particles at the node do not oscillate.

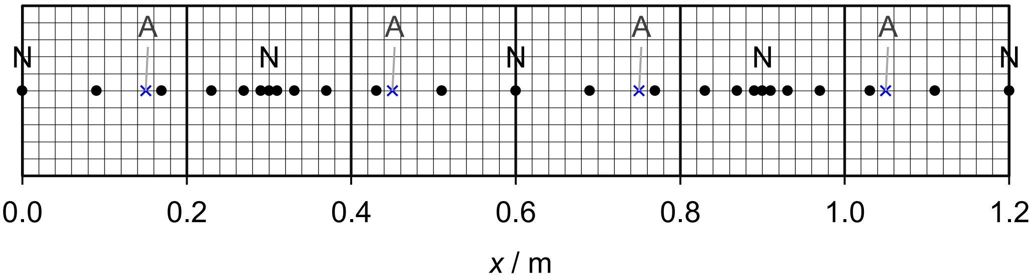
(b) **(i)** Wavelength is the distance between two adjacent particles that oscillate in phase.

$2\lambda = 1.20$ m (2 d.p.)
$\lambda = 0.600$ m (3 s.f.)

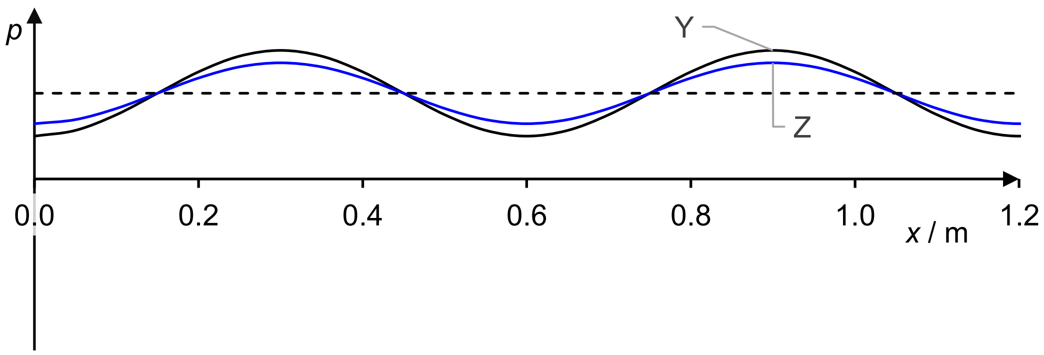
(ii) There are 6 intervals between 0.00 m and 0.30 m (1/2 wavelength) indicating that the separation between particles when they are at equilibrium is 0.05 m. The particle with equilibrium position at 0.15 m is at the amplitude position of 0.19 m at t_0 .

$x_0 = 0.19 - 0.15 = 0.04$ m (2 d.p.)

(c) **(i)**



(ii)



1. Pressure at the nodes is highest or lowest compared to the initial atmospheric pressure.
*Correct high and low pressure positions.

2. For stationary waves, energy is not transferred and the waveform does not progress forward. Positions of nodes and antinodes remain unchanged. Only the displacement of the particles between the nodes changes.
*Graph of smaller amplitude at $t_1 + \frac{T}{8}$ compared to at t_1.

(d) **(i)** Stationary wave is formed in the air column in the tube when an anitnode is at the mouth of the tube and a node is at the water surface.

When first loud note is heard,

$$L_1 + c = \tfrac{1}{4}\lambda$$

$$\begin{aligned} c &= \frac{1}{4}\lambda - L_1 \\ &= \frac{1}{4}(0.600) - 0.144 \\ &= 0.150 - 0.144 \\ &= 0.006 \text{ m} \quad \text{(3 d.p.)} \end{aligned}$$

(ii) When the next loud note is heard,

$$L_2 + c = \tfrac{3}{4}\lambda$$

$$\begin{aligned} L_2 &= \frac{3}{4}\lambda - c \\ &= \frac{3}{4}(0.600) - 0.006 \\ &= 0.444 \text{ m} \quad \text{(3 d.p.)} \end{aligned}$$

4 (a) (i) The electric field strength due to each particle is directed towards the left. As the resultant electric field strength at any point is the vector addition of the individual electric field strengths of A and B, it is always towards the left. Hence there will be no point where the electric field strength is zero.

(ii) The electric potential due to A is negative while that due to B is positive. The total electric potential at any point is the scalar addition of the individual electric potentials of A and B. Hence, there will be a point in between the charges where electric potential is zero.

(b) (i) By the principle of conservation of energy, considering energy changes of particle from the point it enters the electric field to the point it hits point P,

increase in kinetic energy = decrease in electric potential energy

$$\frac{1}{2}m\left(v_f^{\,2}-v_i^{\,2}\right)=q\left(\frac{1}{2}\Delta V\right)$$

$$\begin{aligned}\Delta V &= \frac{m}{q}\left(v_f^{\,2}-v_i^{\,2}\right)\\ &= \frac{\left(6.6\times10^{-27}\right)}{\left(3.2\times10^{-19}\right)}\left[\left(6.5\times10^{5}\right)^2-\left(4.1\times10^{5}\right)^2\right]\\ &= 5247 = 5250\text{ V}\end{aligned}$$

Since the negatively charged particle accelerates towards plate Y which is at 0 V, plate X must be at a lower potential with respect to plate Y.

$V = -5250$ V

(ii)

$$\begin{aligned}F_E &= ma\\ q\left(\frac{\Delta V}{d}\right) &= ma\\ a &= \frac{q\Delta V}{md}\\ &= \frac{\left(3.2\times10^{-19}\right)(5250)}{\left(6.6\times10^{-27}\right)\left(3.6\times10^{-2}\right)}\\ &= 7.0707\times10^{12} = 7.07\times10^{12}\text{ ms}^{-2}\end{aligned}$$

(iii) Take direction to the right and downwards as positive.
consider horizontal motion,

$$s=-\left(u\sin\theta\right)t+\frac{1}{2}at^2$$

$$0.5\times3.6\times10^{-2}=-\left(4.1\times10^{5}\sin32^\circ\right)t+\frac{1}{2}\left(7.07\times10^{12}\right)t^2$$

$$t=1.0842\times10^{-7}\text{ s} \quad\text{or}\quad -4.6963\times10^{-8}\text{ s (NA)}$$

consider vertical motion,

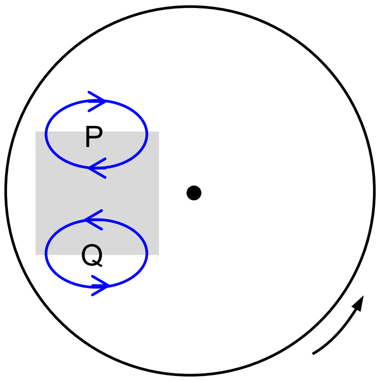
$$\begin{aligned}d &= \left(u\cos\theta\right)t\\ &= \left(4.1\times10^{5}\cos32^\circ\right)\left(1.0842\times10^{-7}\right)\\ &= 0.037698 = 0.0377\text{ m}\end{aligned}$$

5 **(a)** The sections of the disc moving towards or away from the magnets experience a change in magnetic flux linkage. There will be induced e.m.f. and induced currents in the conducting disc.

By Lenz's law, the direction of the induced currents in the disc will oppose the change in the magnetic flux linkage. This produces a force that opposes the direction of the spin of the disc, causing it to slow down.

In slowing down, the mechanical / kinetic energy of the disc is converted to electrical energy as induced currents and eventually converted to thermal energy which is dissipated to the surroundings. This obeys the law of conservation of energy.

(b)



*At least one closed loop drawn at each region P and Q.
*Correct direction of eddy current for each loop.
*For each loop, part of loop in the magnetic field, part of it outside the magnetic field.

(c) As the disc is slowing down, its angular velocity is decreasing. This leads to a rate of change of magnetic flux linkage that is decreasing which produces a decreasing induced e.m.f.

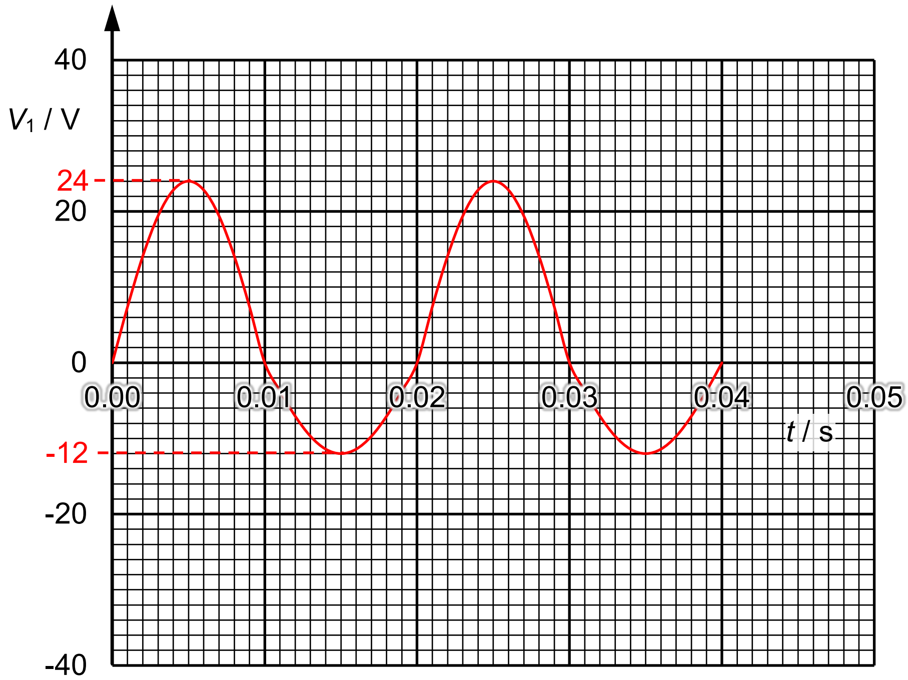
The decreasing induced current produces an opposing / decelerating force that is decreasing in magnitude.

This causes the angular velocity of the disc to decrease at a decreasing rate. Hence its decrease is not linear (does not decrease at a constant rate).

(Angular deceleration is decreasing in magnitude.)

6 **(a)** The root-mean-square value of an alternating current is that value of the direct current that would produce thermal energy at the same rate in the same resistor.

(b) **(i)**



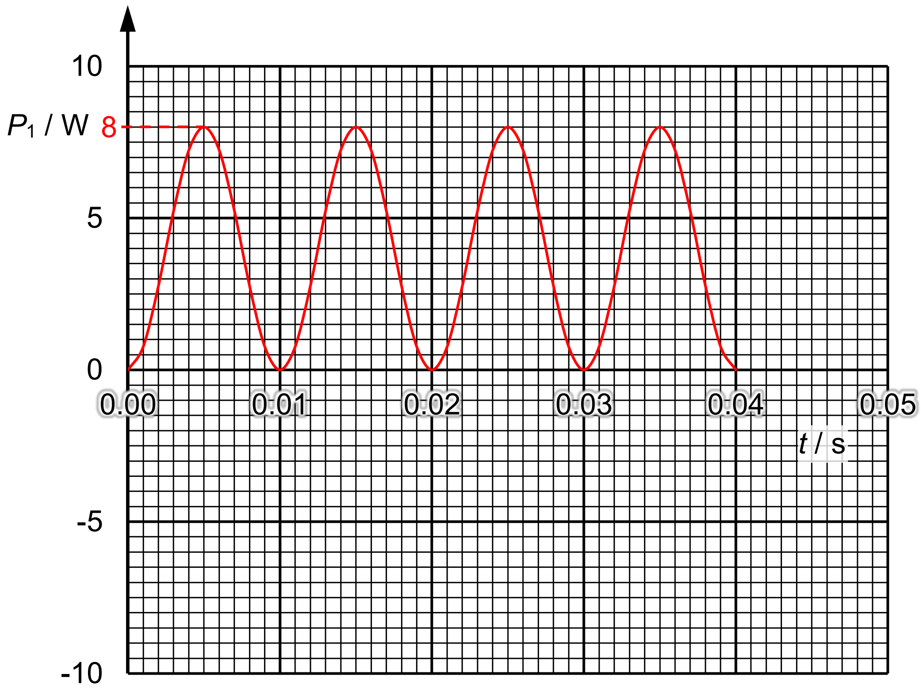
With S closed, current passes through the diode and R_1 in the forward bias direction. In the reverse bias direction, current passes through R_1 and R_2.

Forward bias: peak V_1 = peak V = 24 V
Reverse bias: peak V_1 = 12 V

period $T = \dfrac{2\pi}{\omega} = \dfrac{2\pi}{314} = 0.02$ s

*Sine graph with correct period.

(ii)



With S opened, current passes through R_1 and R_2 all the time and does not pass through the diode.
Since V and I of the alternating supply is sinusoidal, power graph will be a sine^2 graph.

$$\text{peak } P_1 = \frac{(\text{peak } V_1)^2}{R_1} = \frac{(24/2)^2}{18} = 8 \text{ W}$$

*Correct shape (smooth curve, sine squared) with correct period.

7 **(a)** The emission line spectrum consists of a series of distinct lines of specific colours/ wavelengths/ frequencies on a dark background.

Each line is produced by the emission of photons of a specific quantum of energy. Since the photons have specific energy, they must be emitted when electrons in the atoms de-excites between discrete energy levels.

(b) **(i)** The characteristic K_α and K_β lines are due to X-ray photons produced from electron transitions from shell L to K and shell M to K, respectively (or from energy level n = 2 to n = 1 and n = 3 to n = 1, respectively).

Since shell L is nearer to shell K than shell M to shell K, K_α photons have smaller energy E than K_β photons. As energy E is inversely proportional to the wavelength λ, K_α photons have a longer wavelength than K_β photons.

(ii) X-ray photons are emitted when high speed electrons collide with the target atom and undergo many rapid decelerations. The kinetic energy lost by an incident electron is converted into the energy of an X-ray photon. The amount of energy lost varies since an electron can undergo multiple collisions resulting in X-ray photons of varying energies.

The most energetic X-ray photon is produced when an incident electron loses all its kinetic energy in one collision. Since the energy of a photon is given by $E = \dfrac{hc}{\lambda}$, this most energetic X-ray photon has the shortest wavelength.

8 **(a)** **(i)**

$$\phi = B_H A$$
$$= \left(5.2\times10^{-5}\cos70^\circ\right)\left(0.80\times0.55\right)$$
$$= 7.8254\times10^{-6} = 7.83\times10^{-6}\ \text{Wb}$$

(ii) **1.** When the window is opening, the aluminium frame cuts the Earth's magnetic field lines and the <u>magnetic flux through the window decreases</u>. This causes a rate of change of magnetic flux linkage in the frame.

<u>By Faraday's law, there will be an induced e.m.f.</u> in the frame.

Since the frame is a closed loop, this induced e.m.f. produces an induced current in the frame.

<u>By Lenz's law, the direction of the induced current is such as to produce an effect to oppose the decrease in the magnetic flux</u>. Current will flow from ADCB to increase the magnetic flux.

2.

$$\Delta\phi = \phi_f - \phi_i$$
$$= 0 - 7.83\times10^{-6}$$
$$= -7.83\times10^{-6}\,\text{Wb}$$

3.

$$|E| = \left|-\frac{\Delta\phi}{\Delta t}\right|$$
$$= \left|-\frac{-7.83\times10^{-6}}{0.30}\right|$$
$$= 2.61\times10^{-5}\ \text{V}$$

(b) **(i)** Since the velocity of the charged particles is perpendicular to the magnetic field, the <u>magnetic force acting on the charged particles is always perpendicular to their velocity</u>. The magnetic force <u>only changes the direction of the velocity</u> while the speed remains constant.

As the <u>magnitude of the magnetic force is constant</u>, it points towards a fixed point, causing the particles to move in a <u>circular motion about the fixed point with a constant radius</u>.

(ii) The magnetic force acting on the particle provides the centripetal force.

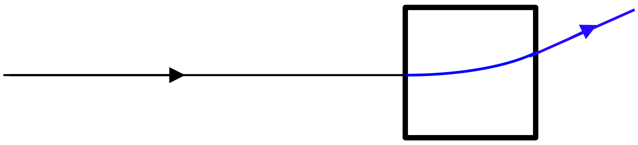
$$Bqv = m\frac{v^2}{r}$$
$$r = \frac{mv}{Bq}$$

Since the particles travel at the same speed in the field of the same magnetic flux density,

$$\frac{r_\alpha}{r_e} = \frac{m_\alpha}{m_e}\frac{q_e}{q_\alpha}$$
$$= \frac{\left(4\times1.66\times10^{-27}\right)}{9.11\times10^{-31}}\times\frac{1}{2}$$
$$= 3644.3$$

$r_\alpha = 3.6\times10^3 r_e$ (shown)

(iii)



*Slight curve (due to large radius) in *B* field.
*Straight path after it exits *B* field from the right edge of the field.

(iv) **1.**

$$R = \frac{mv}{Bq}$$
$$= \frac{(9.11\times10^{-31})(1.2\times10^{6})}{(0.70\times10^{-3})(1.60\times10^{-19})}$$
$$= 9.7607\times10^{-3} = 9.8 \text{ mm} \quad \text{(shown)}$$

2.

$$T = \frac{2\pi R}{v}$$
$$= \frac{2\pi(9.8\times10^{-3})}{1.2\times10^{6}}$$
$$= 5.131\times10^{-8} = 5.13\times10^{-8} \text{ s}$$

3. The electron moves in a circular path in a clockwise direction (viewed from top).

From 0 ms to 1.2 ms, the radius of curvature of its path decreases and increases from 1.2 ms to 3.2 ms.

After 3.2 ms, the direction of its circular path will change to an anti-clockwise direction.

From 3.2 ms to 4.0 ms, the radius of curvature of its path decreases.

4. State any time from 2.4 ms to just before 3.2 ms (from $B = 0.70$ mT and decreasing to zero).

As the magnetic flux density of the field decreases, the radius of curvature of the electron's path increases and leaves the magnetic field due to the high speed of the electron.

9 **(a)** The maximum kinetic energy of the photoelectrons is dependent only on the frequency, but not on the intensity of the incident radiation.

In the particulate theory of light, electromagnetic radiation is made up of discrete quanta of energy known as photons. Each photon has energy $E_{photon} = hf$ where h is the Planck constant and f is the frequency. Emission of a photoelectron is only possible when a single photon is absorbed by an electron on the surface of the metal in a one-to-one interaction.

The maximum kinetic energy of the photoelectron is given by $\text{K.E.}_{max} = hf - \Phi$ where Φ is the work function of the metal. The equation shows that the maximum kinetic energy is a function of the photon's energy and hence frequency for the same metal with constant Φ.

Increasing the intensity of light only increases the rate of incident photons on the metal and has no effect on E_{photon} which is dependent only on frequency. Therefore, there is no effect of intensity on the maximum kinetic energy which provides evidence for the particulate nature of electromagnetic radiation.

OR

There is a threshold frequency below which there is no emission of photoelectrons regardless of the intensity of the incident radiation.

In the particulate theory of light, electromagnetic radiation is made up of discrete quanta of energy known as photons. Each photon has energy $E_{photon} = hf$ where h is the Planck constant and f is the frequency. Emission of a photoelectron is only possible when a single photon is absorbed by an electron on the surface of the metal in a one-to-one interaction.

The maximum kinetic energy of the photoelectron is given by $\text{K.E.}_{max} = hf - \Phi$ where Φ is the work function of the metal. The emission of a photoelectron is only possible if the maximum kinetic energy is greater than zero hence $hf \geq \Phi$. If the photon energy is less than Φ i.e. $f < f_0$ where $f_0 = \dfrac{\Phi}{h}$ is the threshold frequency, there will be no emission of photoelectrons.

Increasing the intensity of light only increases the rate of incident photons on the metal and has no effect on E_{photon} which is dependent only on frequency. Therefore, there is no effect of intensity on the threshold frequency which provides evidence for the particulate nature of electromagnetic radiation.

(b) **(i)**

$$\Phi = \frac{hc}{\lambda_0}$$

$$\lambda_0 = \frac{(6.63\times10^{-34})(3.00\times10^{8})}{(4.33)(1.60\times10^{-19})}$$

$$= 2.8709\times10^{-7} = 287 \text{ nm}$$

(ii) $$E_{K,\max} = \frac{1}{2}mv_{\max}^2 = \frac{hc}{\lambda} - \Phi$$

$$v_{\max} = \sqrt{\frac{2}{m}\left(\frac{hc}{\lambda} - \Phi\right)}$$

$$= \sqrt{\frac{2}{9.11\times10^{-31}}\left(\frac{(6.63\times10^{-34})(3.00\times10^{8})}{210\times10^{-9}} - (4.33)(1.60\times10^{-19})\right)}$$

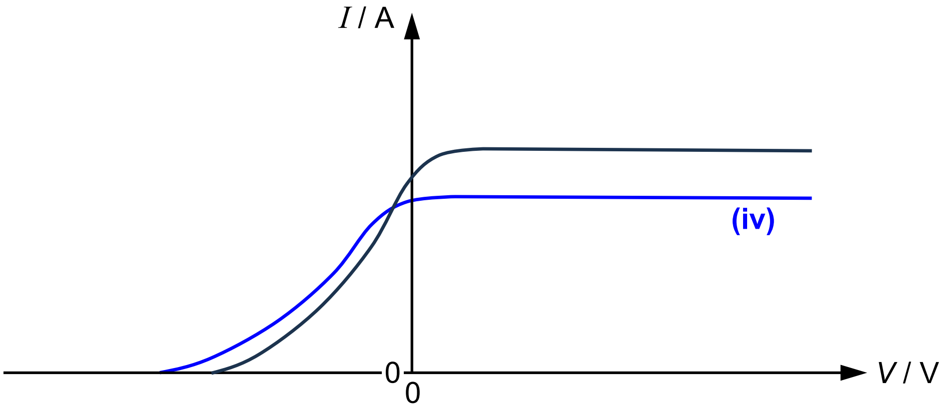
$$= 7.4725\times10^{5} = 7.47\times10^{5}\ \text{m s}^{-1}$$

(iii) When $V = 0$ V, there is no electric force on the emitted photoelectrons and they travel at a constant speed along a straight line perpendicular to the collector plate.

When $V = +3.0$ V, the electric force, $F_e = eE = \frac{eV}{d} = \frac{3e}{d}$, is the resultant force on the photoelectron and it acts in the same direction as its velocity.

Since the resultant electric force is constant, acceleration, $a = \frac{3e}{m_e d}$, is constant, and the speed of the emitted photoelectron increases at a constant rate as it moves along a straight line perpendicular to the collector plate.

(iv)



Shorter wavelength, higher photon energy, higher maximum kinetic energy, hence larger stopping potential.

Since intensity $i = \frac{hc}{\lambda A}\left(\frac{dN_p}{dt}\right)$ remains the same, the rate of incident photons $\frac{dN_p}{dt}$ decreases with a decrease in wavelength or an increase in photon energy. Hence the saturated photocurrent decreases.

(c) (i) The electrons behave as waves with de Broglie's wavelength λ which is related to its momentum p by $\lambda = \frac{h}{p}$. The graphite film, having atoms that are regularly spaced at distances comparable to the wavelength of the electrons, acts as a diffraction grating resulting in a diffraction pattern of concentric rings when the electrons pass through the graphite film.

The maximum and minimum intensities of the concentric rings are a result of electron waves undergoing constructive and destructive interference similar to how light waves interfere.

(ii) $E_k = \frac{1}{2}mv^2 = \frac{1}{2}\frac{(mv)^2}{m} = \frac{p^2}{2m} = \frac{(h/\lambda)^2}{2m} = \frac{h^2}{2m\lambda^2}$

increase in kinetic energy = decrease in electric potential energy

$$\frac{h^2}{2m\lambda^2} - 0 = q\Delta V$$

$$\lambda = \frac{h}{\sqrt{2mq\Delta V}}$$

$$= \frac{6.63\times10^{-34}}{\sqrt{2\left(9.11\times10^{-31}\right)\left(1.60\times10^{-19}\right)(5.0\times10^{3})}}$$

$$= 1.7366\times10^{-11} = 1.74\times10^{-11}\text{ m}$$

(iii) According to Rayleigh criterion, the limiting angle of resolution $\theta_{\min} \approx \frac{\lambda}{b}$ where b is the size of the aperture. For the electrons, $\theta_{\min}$ is approximately four orders of magnitude smaller ($\theta_{\min} \propto \lambda$) than for visible light.

Hence, an electron microscope has a much higher resolving power compared to an optical microscope allowing it to resolve structures at the atomic scale which the optical microscope is unable to.

Centre Number	Class Index Number	Name	Class
S3016			

RAFFLES INSTITUTION

2024 Preliminary Examination

PHYSICS **Higher 2** Paper 4 Practical	**9749/04** **12 August 2024** **2 hours 30 minutes**

READ THESE INSTRUCTIONS FIRST

Write your index number, name and class in the spaces provided at the top of this page.

Write in dark blue or black pen on both sides of the paper.

You may use an HB pencil for any diagrams, graphs or rough working.

Do not use staples, paper clips, glue or correction fluid.

Answer **all** questions.

Candidates answer on the Question Paper.

You will be allowed a maximum of one hour to work with the apparatus for Questions 1 and 2, and maximum of one hour for Question 3. You are advised to spend approximately 30 minutes for Question 4.

Write your answers in the spaces provided on the question paper.

The use of an approved scientific calculator is expected, where appropriate.

You may lose marks if you do not show your working or if you do not use appropriate units.

Give details of the practical shift and laboratory in the boxes provided.

At the end of the examination, fasten all your work securely together.

The number of marks is given in brackets [ ] at the end of each question or part question.

Shift
Laboratory

For Examiner's Use	
1	/ 12
2	/ 10
3	/ 22
4	/ 11
Total	/ 55

1 In this experiment, you will investigate the force required to lift different masses.

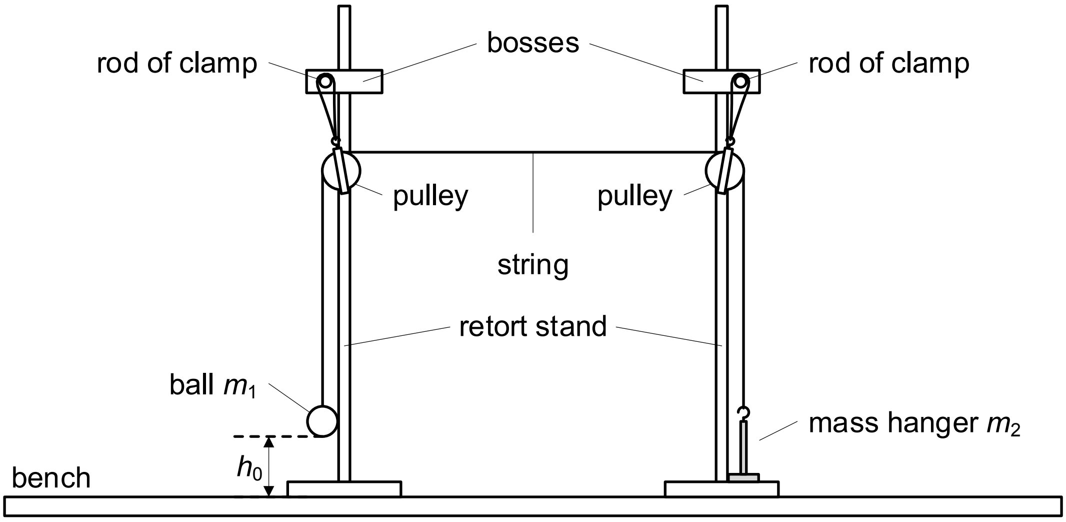


Fig. 1.1

(a) Set up the apparatus as shown in Fig. 1.1. Hang the pulleys to the rods of the clamps. The top of the pulleys should be approximately 42 cm above the bench.

Pass the string through the pulleys. Attach the end of the string with a small loop to the mass hanger and the other end to a ball of modelling clay.

The mass of the ball is m_1 and the mass of the mass hanger is m_2.

Ensure that the ball is suspended above the bench while the mass hanger is resting on the base of the retort stand with the string taut.

Adjust the distance between the retort stands until h_0 is about 5 cm above the bench.

Measure and record h_0.

h_0 = 0.050 m or 5.0 cm ....

(b) Raise the ball to a height h above the bench as shown in Fig. 1.2.

Release the ball such that it moves in a circular path.

Ensure that the string is taut and the mass hanger is resting on the base of the retort stand at the point of release of the ball.

The **minimum** height of the ball required **to just lift** the mass hanger off the base of the retort stand is h.

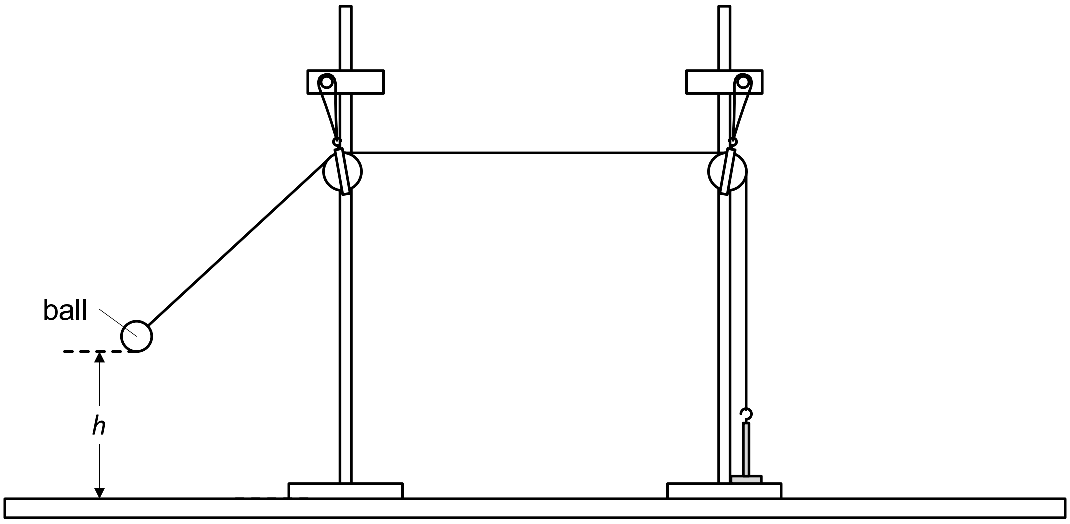


Fig. 1.2

Measure and record h.

Calculate Δh where $\Delta h = h - h_0$.

Minimum height

$h_1 = 0.074$ m; $h_2 = 0.075$ m

$\langle h \rangle = \frac{1}{2}(0.074 + 0.075) = 0.075$ m

$\Delta h = \langle h \rangle - h_0 = 0.075 - 0.050 = 0.025$ m

h = 0.075 m or 7.5 cm ....

Δh = 0.025 m or 2.5 cm ....

[1]

(c) Using the same ball of mass m_1, vary m_2 by adding slotted masses to the mass hanger and repeat **(b)**.

Present your results clearly.

m_2 / kg	h_1 / m	h_2 / m	$\langle h \rangle$ / m	Δh / m
0.050	0.074	0.075	0.075	0.025
0.060	0.103	0.101	0.102	0.052
0.070	0.133	0.132	0.133	0.083
0.080	0.162	0.158	0.160	0.110
0.090	0.202	0.196	0.199	0.149

[3]

(d) Δh and m_2 are related by the expression:

$$\Delta h = \frac{a\, m_2}{m_1} - a$$

where a and m_1 are constants.

(i) Plot a graph of Δh against m_2 to determine a and m_1.

Plot a graph of Δh against m_2 where the gradient is a/m_1 and the vertical intercept is $-a$.

Using the points (0.05450,0.036) and (0.08900,0.142),

$$\text{gradient} = \frac{0.142 - 0.036}{0.08900 - 0.05450} = \frac{0.106}{0.0345} = 3.07 \qquad \text{(3 s.f.)}$$

$$\text{vertical intercept} = 0.142 - 3.07 \times 0.08900 = 0.142 - 0.273 = -0.131$$

$$a = -\text{vertical intercept} = 0.131 \text{ m}$$

$$m_1 = \frac{a}{\text{gradient}} = \frac{0.131}{3.07} = 0.0427 \text{ kg}$$

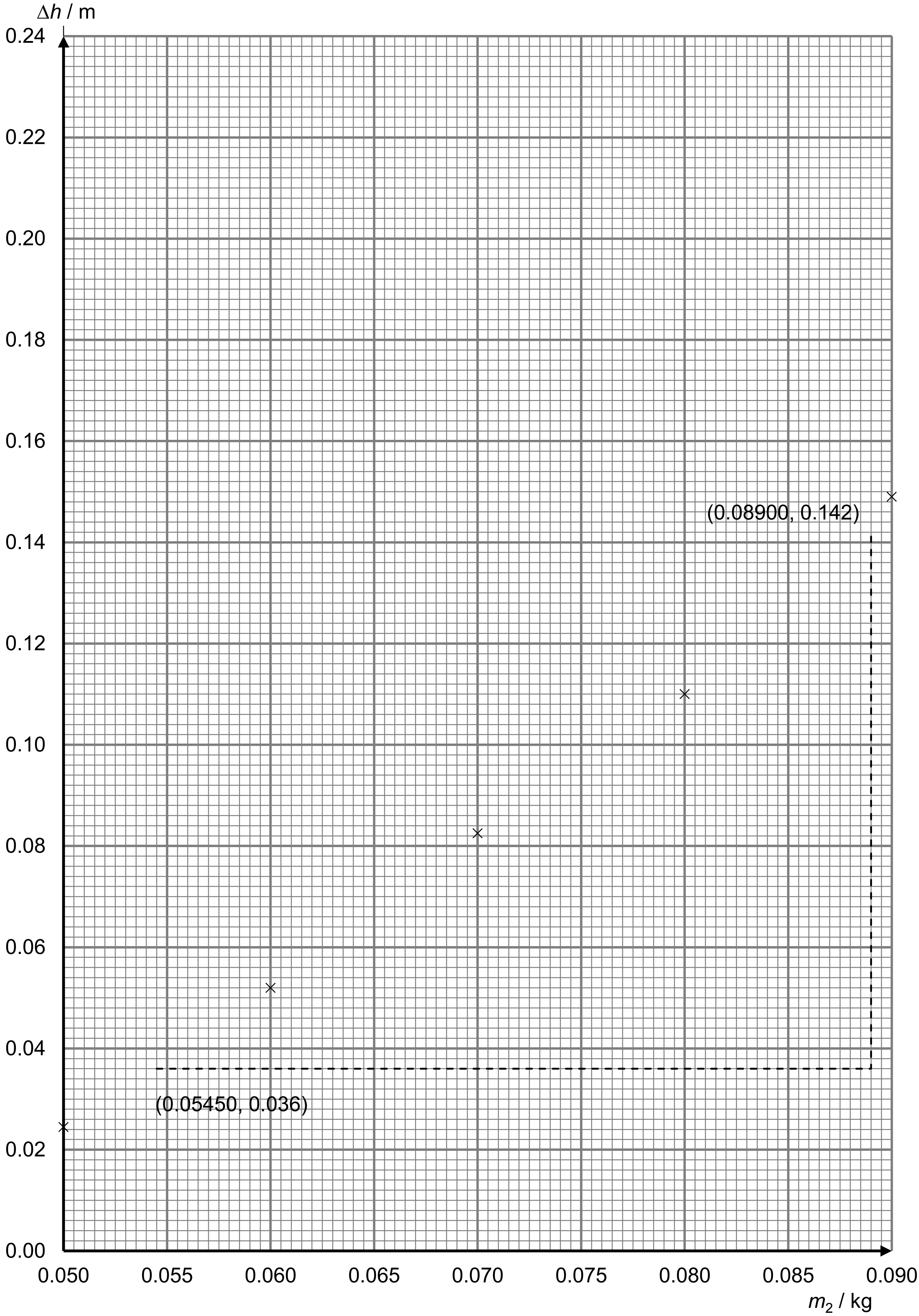
a = 0.131 m

m_1 = 0.0427 kg

[5]

(ii) Explain the significance of the horizontal intercept of the graph.

The horizontal intercept ($\Delta h = 0$) represents the mass of the load (m_2) that is equal to the mass of the ball, i.e., $m_2 = m_1$. [1]


Δh / m
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.00
(0.08900, 0.142)
(0.05450, 0.036)
0.050
0.055
0.060
0.065
0.070
0.075
0.080
0.085
0.090
m2 / kg

(e) **(i)** Suggest one significant source of uncertainty in this experiment.

1. The tension supporting the ball and the mass hanger are not equal as the pulleys are not smooth. This affects the accuracy of h or Δh .

2. The tension supporting the ball and the mass hanger are not equal as the pulleys accelerates/moves when the ball is released. This affects the accuracy of h or Δh .

3. Imprecise to judge when m_2 just lift off affecting the precision of h or Δh .

4. The inability to steadily handhold the ruler and the ball affects the accuracy of h or Δh .

[1]

(ii) Suggest an improvement that could be made to the experiment to reduce the uncertainty identified in **(e)(i)**.

You may suggest the use of other apparatus or a different procedure.

1. Lubricate the axles of the pulleys so that friction is reduced.

2. Fix the pulleys to the rods of the clamps by tying them tightly to the rods.

3. Use of electronic balance to monitor when contact force becomes zero.

4. Support the ruler with retort stand and clamp. The ball can be displaced by pulling the excess string (at lower end of ball). This also ensures that the string supporting the ball is always under tension.

[1]

[Total: 12]

2 In this experiment, you will investigate the properties of a dry cell.

(a) Set up the circuit as shown in Fig. 2.1.

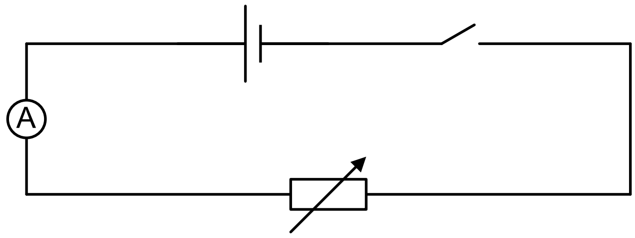


Fig. 2.1

(b) **(i)** Close the switch. Adjust the resistance of the variable resistor until the ammeter reading I is as close to 0.5 A as possible. Measure and record the ammeter reading I.

I = 0.501 A ....

(ii) Open the switch.

(c) A resistor of resistance R is made using three $1.0\ \Omega$ resistors connected as shown in Fig. 2.2.

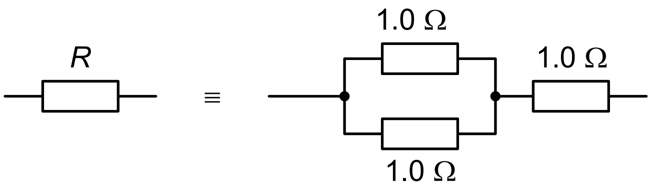


Fig. 2.2

Set up the circuit as shown in Fig. 2.3. The resistance of the variable resistor should be the same as that in **(b)(i)**.

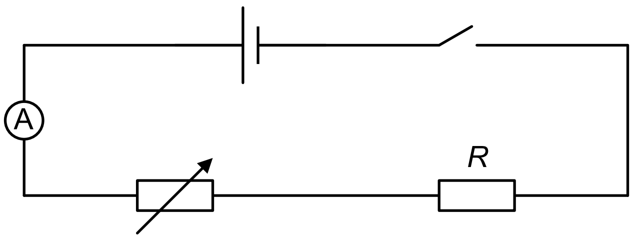


Fig. 2.3

(i) Record the effective resistance R.

R = $1.5\ \Omega$ ....

(ii) Close the switch.

Measure and record the ammeter reading I.

I = 0.330 A ....

(iii) Open the switch.

(d) Vary R by re-arranging the $1.0\ \Omega$ resistors and repeat **(c)**.

You may use any number of the $1.0\ \Omega$ resistors.

Present your results clearly.

$R\ /\ \Omega$	$I\ /\ \text{A}$	$I^{-1}\ /\ \text{A}^{-1}$
0.33	0.450	2.22
0.50	0.430	2.33
0.67	0.410	2.44
1.0	0.373	2.68
1.5	0.330	3.03
2.0	0.295	3.39
3.0	0.244	4.10

[3]

(e) R and I are related by the expression:

$$\frac{1}{I} = \frac{R}{E} + \frac{r}{E}$$

where E is the electromotive force (e.m.f.) of the dry cell and r is the sum of the resistance of the variable resistor and the internal resistance of the dry cell.

Plot a suitable graph to determine a value for E and r.

Plot a graph of $\frac{1}{I}$ against R where the gradient is $\frac{1}{E}$ and the vertical intercept is $\frac{r}{E}$.

Using the points (0.250,2.150) and (2.800,3.950),

$$\text{gradient} = \frac{3.950 - 2.150}{2.800 - 0.250} = \frac{1.800}{2.550} = 0.7059 \quad \text{(3 s.f.)}$$

$$\text{vertical intercept} = 3.950 - 0.7059 \times 2.800 = 3.950 - 1.977 = 1.973$$

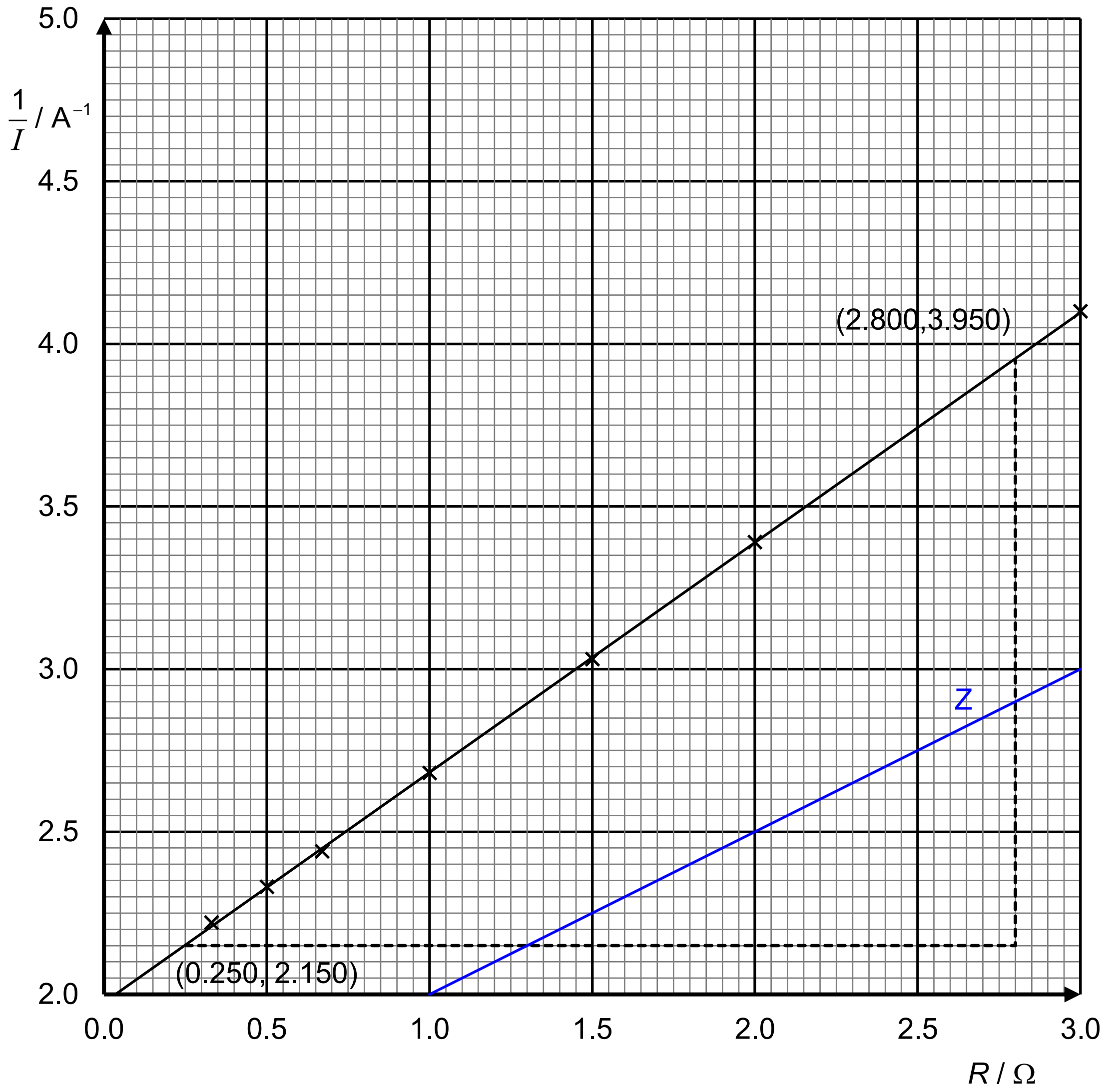
$$E = \frac{1}{\text{gradient}} = \frac{1}{0.7059} = 1.417\ \text{V}$$

$$r = E \times \text{vertical intercept} = 1.417 \times 1.973 = 2.796\ \Omega$$

E = 1.417 V ....

r = 2.796 Ω ....

[6]



(f) Without taking further readings, sketch a line on your graph to show the results you would expect if the experiment was repeated with a dry cell with a larger e.m.f. and a smaller internal resistance than the one used.

Label this line Z. [1]

A larger e.m.f. implies a lower gradient.

A smaller internal resistance and a larger e.m.f. implies a lower vertical intercept.

[Z should not intersect Y.]

[Total: 10]

3 An interrupted pendulum is a simple pendulum which strikes a rod below its pivot during its oscillation, causing the pendulum to deviate from its original trajectory into a trajectory of a smaller radius.

In this experiment, you will investigate how the behaviour of an interrupted pendulum depends on the position of the rod and the initial angle of release.

You have been provided with a simple pendulum and a wooden rod.

(a) Set up the apparatus as shown in Fig. 3.1.

Attach the wooden rod to the retort stand with the boss. Ensure that the wooden rod is below the pivot such that the string of the pendulum is just touching the rod, with the string remaining vertical.

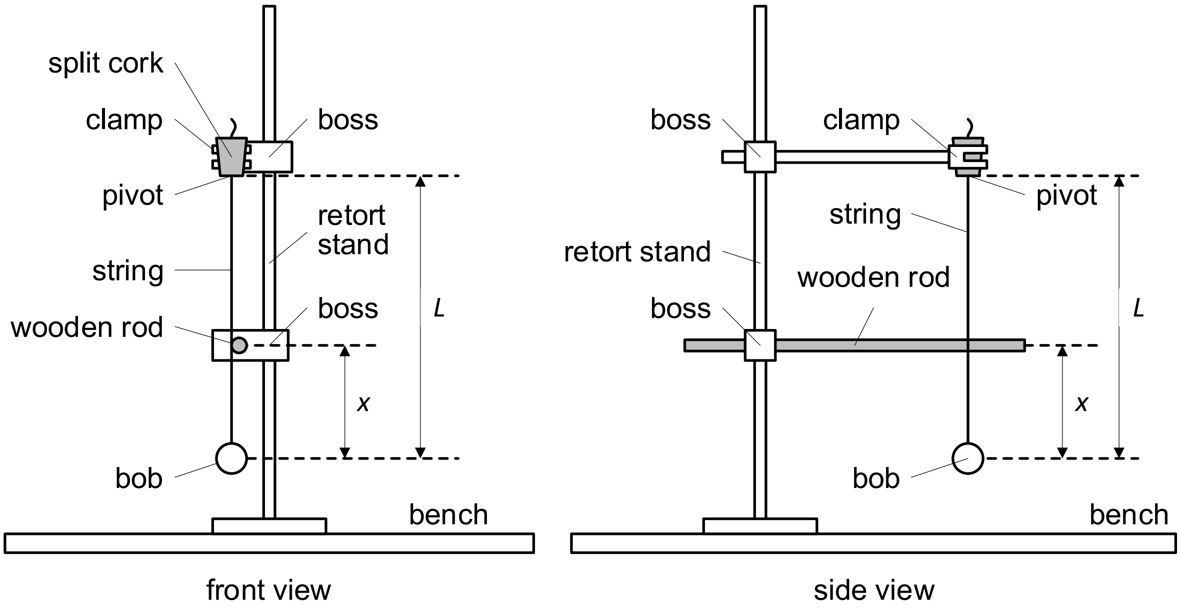


Fig. 3.1

The length of the pendulum is L. The distance between the rod and the pendulum bob is x.

Adjust the positions of the pendulum and the rod so that L is approximately 50 cm and x is approximately 10 cm.

(i) Measure and record L and x.

L = 50.1 cm ....

x = 10.0 cm ....

[1]

(ii) Estimate the percentage uncertainty in your value of *L*.

Percentage uncertainty in *L*

$$\frac{\Delta L}{L} \times 100\% = \frac{0.3}{50.1} \times 100\% = 0.60\%$$

percentage uncertainty in *L* = 0.60% ....

[1]

(iii) Estimate the percentage uncertainty in your value of *x*.

Percentage uncertainty in *x*

$$\frac{\Delta x}{x} \times 100\% = \frac{0.4}{10.0} \times 100\% = 4.0\%$$

percentage uncertainty in *x* = 4.0% ....

[1]

(b) **(i)** Displace the pendulum by a small angle θ away from the rod, as shown in Fig. 3.2. Ensure that θ does not exceed $5°$.

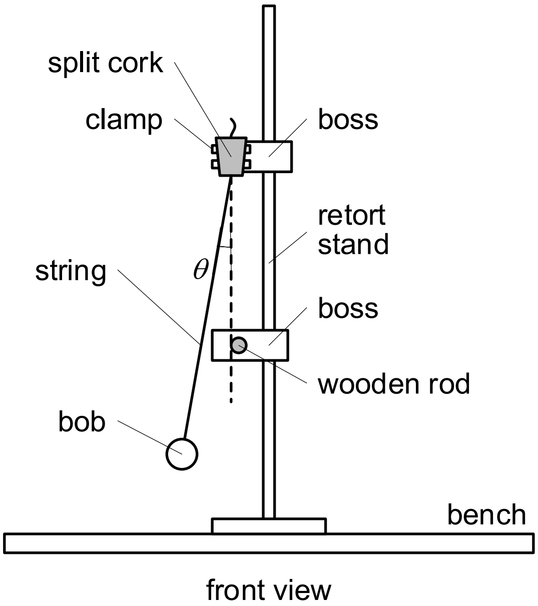


Fig. 3.2

Release the pendulum from this angle. It will swing and oscillate, with the string striking the rod halfway through its oscillation.

Record your value of θ.

Determine the period T of these oscillations.

Timing for 20 oscillations

$$t_1 = 20.66 \text{ s}; \; t_2 = 20.64 \text{ s}$$

$$\langle t \rangle = \frac{20.66 + 20.64}{2} = 20.65 \text{ s}$$

Period

$$T = \frac{\langle t \rangle}{20} = \frac{20.65}{20} = 1.033 \text{ s}$$

θ = 5° ....

T = 1.033 s ....

[2]

(ii) Adjust the wooden rod so that x is approximately 30 cm.

Measure and record your value of x. Repeat **(b)(i)**, using the same value of θ.

Timing for 20 oscillations

$$t_1 = 25.18 \text{ s} ; \; t_2 = 25.20 \text{ s}$$

$$\langle t \rangle = \frac{25.18 + 25.20}{2} = 25.19 \text{ s}$$

Period

$$T = \frac{\langle t \rangle}{20} = \frac{25.19}{20} = 1.260 \text{ s}$$

x = 30.0 cm

T = 1.260 s

[1]

(c) It is suggested that

$$T = p\sqrt{x} + q$$

where p and q are constants.

Use your values in **(a)(i)**, **(b)(i)** and **(b)(ii)** to determine a value for p.

Using the periods from **(b)(i)** and **(b)(ii)**,

$$1.033 = p\sqrt{0.100} + q$$

$$1.260 = p\sqrt{0.300} + q$$

Solving,

$$p = \frac{1.260 - 1.033}{\sqrt{0.300} - \sqrt{0.100}} = \frac{0.227}{0.231} = 0.983 \text{ s m}^{-1/2}$$

p = $0.983 \text{ s m}^{-1/2}$

[2]

(d) At larger angles of oscillation, the period T of an interrupted pendulum is thought to be dependent on the angle of release θ. You will now investigate this dependency.

In the following experiment, you will use the **same value** of x throughout.

(i) Choose **one** value of x from your values in either **(a)(i)** or **(b)(ii)** to use in the following experiment.

Record your choice of x and the period T_x of the oscillation of the pendulum at this value of x from your values in either **(b)(i)** or **(b)(ii)**.

x = 30.0 cm ....

T_x = 1.260 s ....

Explain your choice of x.

Using a larger x results in a longer period T, which reduces the percentage uncertainty ....

in both x and T. ....

....

[1]

(ii) Displace the pendulum away from the rod by an angle θ, as shown in Fig. 3.2, where θ is approximately $30°$.

Measure and record θ.

θ = 30° ....

(iii) Estimate the percentage uncertainty in your value of θ.

Percentage uncertainty in θ

$$\frac{\Delta\theta}{\theta} \times 100\% = \frac{3}{30} \times 100\% = 10\%$$

percentage uncertainty in θ = 10% ....

[1]

(iv) Release the pendulum from this angle, allowing it to oscillate.

Determine the period T of these oscillations.

For $\theta = 30°$, timing for 20 oscillations

$t_1 = 25.56$ s ; $t_2 = 25.65$ s

$$\langle t \rangle = \frac{25.56 + 25.65}{2} = 25.61 \text{ s}$$

Period

$$T = \frac{\langle t \rangle}{20} = \frac{25.61}{20} = 1.281 \text{ s}$$

T = 1.281 s ....

(e) Repeat steps **(d)(ii)** and **(d)(iv)** with a larger value of θ where $\theta \le 60°$.

For $\theta = 60°$, timing for 20 oscillations

$t_1 = 26.78$ s ; $t_2 = 26.73$ s

$$\langle t \rangle = \frac{26.78 + 26.73}{2} = 26.76 \text{ s}$$

Period

$$T = \frac{\langle t \rangle}{20} = \frac{26.76}{20} = 1.338 \text{ s}$$

θ = 60° ....

T = 1.338 s ....

[1]

(f) It is suggested that

$$t = k\sqrt{\frac{L}{x}}\,\theta^2$$

where k is a constant, θ is in radians, and t is given by

$$t = \frac{T}{T_x} - 1$$

(i) Use your value of L in **(a)(i)** and your values of x, T_x, θ and T in **(d)** and **(e)** to determine two values of k.

Rearranging the equation,

$$k = \frac{T/T_x - 1}{\sqrt{L/x}\cdot\theta^2}$$

$$k_1 = \frac{T_1/T_x - 1}{\sqrt{L/x}\cdot\theta^2} = \frac{1.281/1.260 - 1}{\sqrt{0.500/0.300}\cdot(\pi/6)^2} = 0.0471\ \text{rad}^{-2}$$

$$k_2 = \frac{T_2/T_x - 1}{\sqrt{L/x}\cdot\theta^2} = \frac{1.338/1.260 - 1}{\sqrt{0.500/0.300}\cdot(\pi/3)^2} = 0.0437\ \text{rad}^{-2}$$

first value of k = $0.0471\ \text{rad}^{-2}$ ....

second value of k = $0.0437\ \text{rad}^{-2}$ ....

[2]

(ii) State whether or not the results of your experiment support the suggested relationship. Justify your conclusion by referring to your values in **(a)(ii)**, **(a)(iii)** and **(d)(iii)**.

Percentage uncertainty $= \dfrac{\frac{1}{2}(k_1 - k_2)}{\frac{1}{2}(k_1 + k_2)}\times 100 = \dfrac{\frac{1}{2}(0.0471 - 0.0437)}{\frac{1}{2}(0.0471 + 0.0437)}\times 100\% = 3.7\%$

Since the percentage uncertainty in k (3.7%) is smaller than the sum of the percentage uncertainties of 22% due to L, x and θ ($\frac{1}{2}\times 0.60 + \frac{1}{2}\times 4.0 + 2\times 10 = 22\%$), the results support the suggested relationship.

[1]

(g) Remove the wooden rod so that the pendulum is now able to swing freely as a simple pendulum.

Vary L and determine the period of oscillation T, using the same value of θ in **(b)(i)**.

Present your results clearly.

Use your results to estimate a value of L for the simple pendulum where the value of T is the same as your answer in **(b)(i)**.

L / m	Timing for 20 oscillations			T / s
	t_1 / s	t_2 / s	$\langle t \rangle$ / s	
0.500	28.50	28.51	28.51	1.426
0.300	22.04	22.00	22.02	1.101

Assuming $T = m\sqrt{L} + c$,

$$m = \frac{1.426 - 1.101}{\sqrt{0.500} - \sqrt{0.300}} = \frac{0.325}{0.159} = 2.04$$

$$c = 1.426 - 2.04 \times \sqrt{0.500} = 1.426 - 1.44 = -0.01$$

$$L = \left(\frac{T - c}{m}\right)^2 = \left[\frac{1.033 - (-0.01)}{2.04}\right]^2 = 0.261 \text{ m}$$

Assuming $T = mL + c$,

$$m = \frac{1.426 - 1.101}{0.500 - 0.300} = \frac{0.325}{0.200} = 1.63$$

$$c = 1.426 - 1.63 \times 0.500 = 1.426 - 0.815 = 0.611$$

$$L = \frac{T - c}{m} = \frac{1.033 - 0.611}{1.63} = 0.259 \text{ m}$$

Both methods above are equivalent to $\Delta T = m\sqrt{L} + c$ or $\Delta T = mL + c$.

L = 0.261 m ....

[3]

(h) An engineer wishes to design an amusement park ride based on an interrupted pendulum, with the bob representing the ride carriage.

However, instead of getting the carriage to oscillate, the engineer wants the carriage to swing and make a full circle around the rod, with the string looping around the rod.

It is suggested that the ratio $\frac{x}{L}$ is directly proportional to $1-\cos\theta_0$, where θ_0 is the minimum angle of release from the vertical for the carriage to complete a full circle around the rod.

Explain how you would investigate this relationship.

Your account should include:

- your experimental procedure
- control of variables
- how you would use your results to show direct proportionality
- how you would use your results to find the minimum angle of release for an amusement park ride where $L = 100$ cm and $x = 70$ cm.

1. Set up the apparatus as shown in Fig. 3.2.

2. Measure the length L of the pendulum with a metre rule.

3. Measure the distance between the bob and the wooden rod x with a metre rule.

4. Displace and release the pendulum at angle θ (from downward vertical) and observe whether the bob is able to make full revolution around the rod. Measure this angle with a protractor.

5. Increase the angle θ (til minimum angle θ_0) and repeat step 4 if the pendulum is unable to make full revolution. Conversely, decrease the angle θ (til minimum angle θ_0) if the pendulum is able to make full revolution.

6. Repeat steps 2 to 5 for 8 sets of x and θ_0 by adjusting the height of the wooden rod.

7. Since $\frac{x}{L} = k(1-\cos\theta_0)$, plot a graph of $\frac{x}{L}$ against $1-\cos\theta_0$. If the suggested relationship is true, then a straight-line graph will be obtained with a gradient of k and a vertical-intercept of zero.

Alternatively, plot a graph of $\frac{x}{L}$ against $\cos\theta_0$. If the suggested relationship is true, then a straight-line graph will be obtained with a gradient of $-k$ and a vertical-intercept of k.

8. From the straight-line graph drawn, determine the value of $X = 1-\cos\theta_0$ for which $x/L = 0.70$. Then, $\theta_0 = \cos^{-1}(1-X)$.

[5]

[Total: 22]

4 A thermoelectric cooler is made up of pairs of n- and p-type semiconductors sandwiched between two metal contact plates. This arrangement enables the semiconductor pairs to be electrically connected in series. The metal contact plates are in turn glued to flat ceramic substrates.

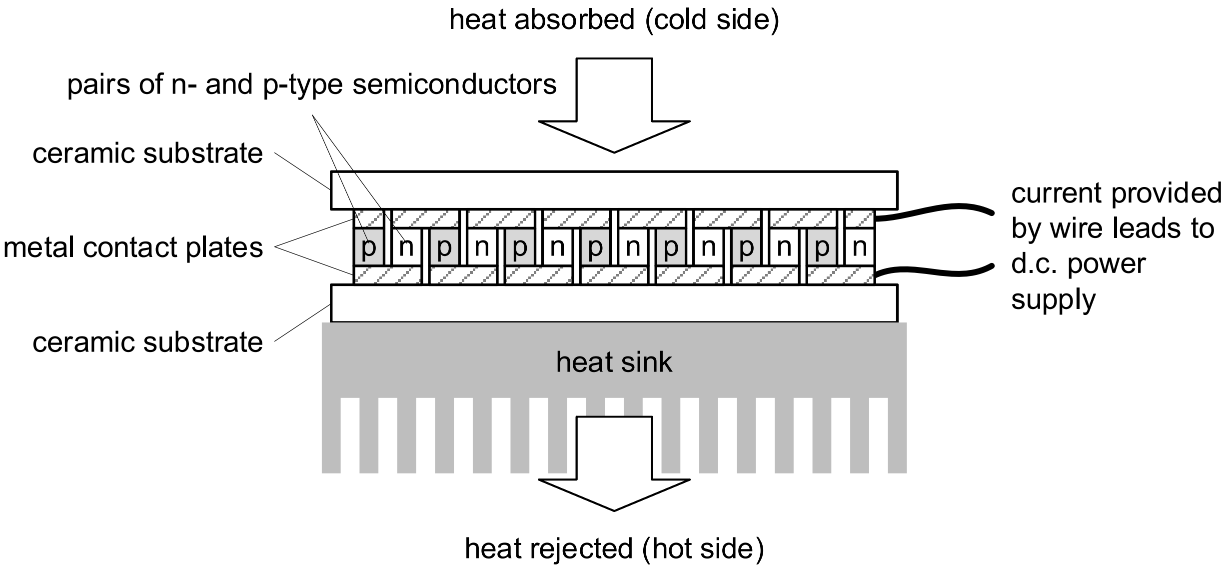


Fig. 4.1 Cross section of a thermoelectric cooler.

When current flows through the semiconductors, heat is absorbed by the thermoelectric cooler at the cold side and rejected by the heat sink at the hot side as shown in Fig. 4.1.

The thermoelectric cooler unit can be used to cool a beaker of water. The rate of heat transfer P across the thermoelectric cooler depends on the current I through the thermoelectric cooler and the N number of pairs of n- and p-type semiconductors.

The rate of heat transfer P is given by

$$P = k\, I^{\alpha}\, N^{\beta}$$

where k, α and β are constants.

Design an experiment to determine the values of α and β.

You are provided with thermoelectric coolers of different number of pairs of n- and p-type semiconductors with heat sinks attached.

Draw a diagram to show the arrangement of your apparatus. You should pay particular attention to:

- the equipment you would use
- the procedure to be followed
- the control variables
- any precautions that would be taken to improve the accuracy of the experiment.

Diagram

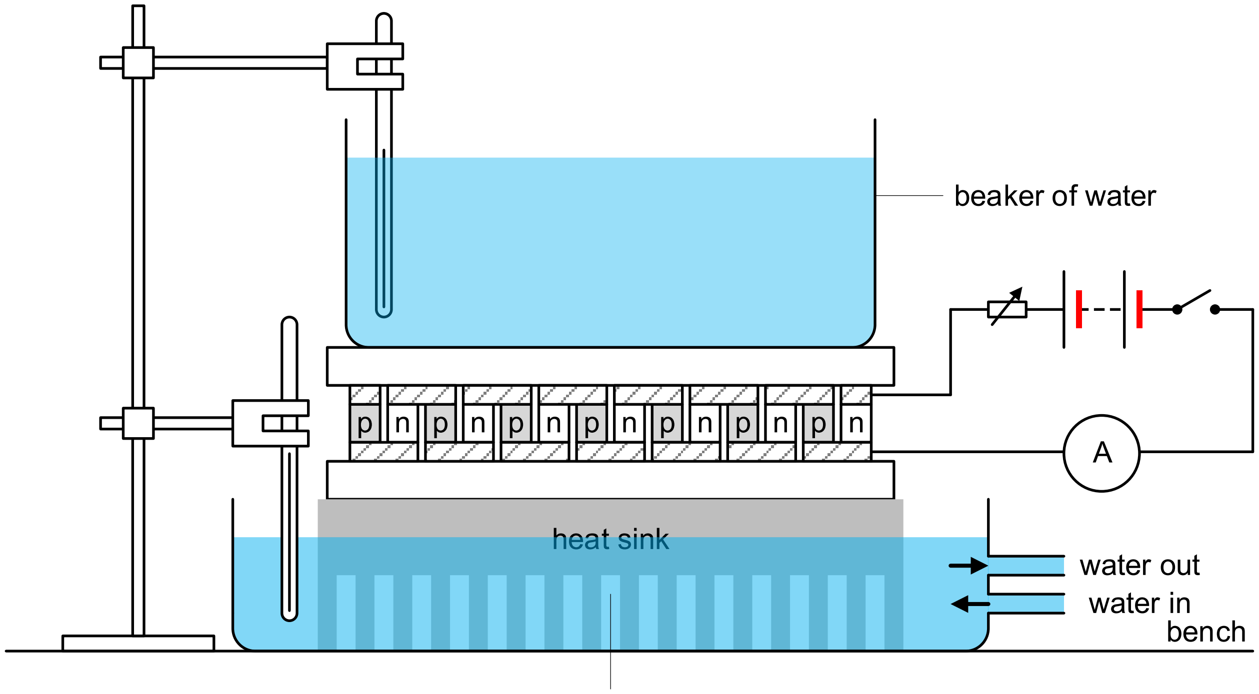


Fig. 1

1. Measure the mass m_0 of an empty beaker with an electronic balance. Fill up the beaker and measure the mass m_1 of beaker and water with the electronic balance.

   Mass of water $m = m_1 - m_0$.

2. Set up the apparatus as shown in Fig. 1.

   Place the beaker of water on the "cold" side of the thermoelectric cooler. Place a thermometer in the beaker to measure its temperature.

   The fins of the heat sink are fully immersed in a water bath. Place a thermometer in the water bath to monitor its temperature. A constant flow of water into and out of the water bath ensures that the temperature of the water bath remains constant.

   Connect the thermoelectric cooler to a power supply, switch, variable resistor and ammeter.

3. Set the rheostat to its maximum resistance and close the switch. Adjust the resistance of the rheostat to obtain a suitable current. Measure the current I through the thermoelectric cooler with an ammeter.

4. Measure the temperature θ of the beaker of water with a thermometer.

5. Measure the time taken t for the temperature of beaker of water to fall from room temperature θ_i to a lower temperature θ_f with a stopwatch. Open the switch once final temperature is reached.

6. The rate of heat transfer by the thermoelectric cooler $P = \dfrac{mc(\theta_f - \theta_i)}{t}$ where c is the specific heat capacity of water.

7. Pour away the water and allow the beaker to return to room temperature θ_i.

Experiment 1

8. Repeat steps 2 to 7 for 8-10 sets of I and P by varying the resistance of the rheostat or e.m.f. of the power supply.

9. The N number of pairs of n- and p-type semiconductor is kept constant by using the same thermoelectric cooler.

Experiment 2

10. Repeat steps 2 to 7 for 8-10 sets of N and P by using thermoelectric cooler with different number of pairs of n- and p-type semiconductor.

11. The current I through the thermoelectric cooler is kept constant by adjusting the rheostat if necessary.

    Note: Current I will vary even for same e.m.f./rheostat setting when a different thermoelectric cooler is used.

12. For both experiments 1 and 2, the temperature of the water bath is kept constant by constant flow of cool water into and warm water out of the water bath.

    Note: The rate of heat transfer by the thermoelectric cooler is also dependent on the temperature of the heat sink. So, it is important to keep the temperature of the heat sink constant using water bath with continuous flowing water.

Analysis [2]

$P = k\, I^{\alpha}\, N^{\beta}$

$\lg P = \alpha \lg I + \lg\left(kN^{\beta}\right)$	$\lg P = \beta \lg N + \lg\left(kI^{\alpha}\right)$
Plot a graph of $\lg P$ against $\lg I$.	Plot a graph of $\lg P$ against $\lg N$.
If the relationship is true, a straight line will be obtained where α is the gradient and $\lg\left(kN^{\beta}\right)$ is the vertical intercept.	If the relationship is true, a straight line will be obtained where β is the gradient and $\lg\left(kI^{\alpha}\right)$ is the vertical intercept.

Additional Details for Reliability [2]

1. Conduct a preliminary experiment to determine the minimum current for the lowest numbers of pairs of n- and p-type semiconductors which can produce an appreciable temperature drop of the water and beaker over a reasonable duration of time.

2. Ensure that the maximum current rating of the thermoelectric cooler is not exceeded to protect it from damage.

3. Ensure good thermal contact between the beaker and the thermoelectric cooler by applying thermal paste between the two surfaces.

4. Account for the heat capacity of the beaker to more accurately calculate the rate of heat transfer by the thermoelectric cooler.

5. Insulate the walls of the beaker and cover up the beaker with insulating material to prevent heat gain from surrounding air. This ensures that the decrease in temperature of water and beaker is due to heat transferred by the thermoelectric cooler.

6. Gently stir the water in the beaker with a stirrer to ensure that temperature is uniform throughout the water in the beaker.

7. Allow thermoelectric cooler/heat sink to cool down after every experiment to reduce the effect of residual thermal energy on subsequent experiments.

8. Account for rate of heat loss to (for $\theta > \theta_{\text{room}}$) rate of heat gain (for $\theta < \theta_{\text{room}}$) from the surrounding by measuring $P = \dfrac{mc(\theta_i - \theta_f)}{t}$ without the themoelectric cooler.

[Total: 11]