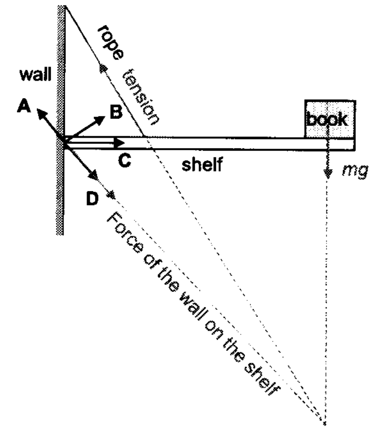
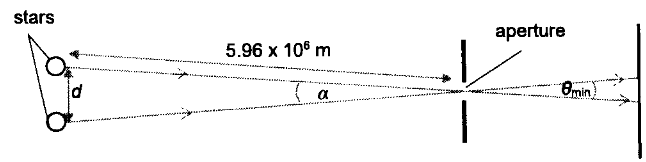
2025 C2 H2 Physics Prelim Exams Paper 1 Suggested Solutions

1	C	6	D	11	C	16	A	21	A	26	D
2	B	7	D	12	A	17	B	22	C	27	B
3	D	8	C	13	B	18	B	23	A	28	C
4	B	9	D	14	B	19	D	24	D	29	A
5	C	10	D	15	C	20	B	25	B	30	D

1	C	volume $= \frac{4}{3}\pi r^3 = \frac{4}{3}\pi(12)^3 = 7200 \text{ cm}^3$
2	B	Upwards direction is taken as negative. Sandbag when released will continue to move upwards but with acceleration downwards. Sandbag will move vertically upwards till it slows down to zero velocity and then it will accelerate downwards.
3	D	Since trolley A is faster than B, and they have the same mass, the net momentum before collision is towards the right and non-zero. Hence Option **A** is true. Option **B** is true by Newton's Third Law. Option **C** is true. If B is moving to the left then so must be A (as A cannot pass through B) and net momentum will be towards the left which is not possible if momentum is conserved. Option **D** is false. Whether a collision is elastic or not depends on whether kinetic energy is conserved and not on the duration of the collision.
4	B	Taking moments about the left end of the ruler, $k_2x = (0.250)(0.200)g + (0.500)(0.0500)g = 0.075g$ —— (1) Taking moments about the right end of the ruler, $k_1x = (0.750)(0.200)g + (0.500)(0.0500)g = 0.175g$ —— (2) Dividing (1) by (2): $\frac{k_2}{k_1} = \frac{0.075}{0.175} = \frac{3}{7} = 0.43$ Distractors (remove from suggested solution for students): A: 1/3 → forget to account for mass of ruler B: 3/7 → Correct C: 7/3 → flipped B D: 3/1 → flipped A
5	C	By the Principle of Floatation (or by considering the net force on the cube), the upthrust on the cube is equal to the weight of the cube. weight of cube $= mg = \rho_0 Vg = \rho_0 L^3 g$
6	D	The shelf is light, so its weight can be neglected. The centre of gravity of the system is thus at the centre of the book.

		When the system is in rotational equilibrium, the lines of action of the forces must meet at a point:  The three forces must form a closed vector triangle, so that net force is zero.
7	D	$F = -\frac{dU}{dx} = -\frac{d(kx^2)}{dx} = -2kx$ The negative sign indicates that direction of force is towards the reference point O.
8	C	$(\uparrow): N\sin\theta = mg$ $(\rightarrow): N\cos\theta = F_c = ma_c = m(0.8g)$ $\tan\theta = 1.25$ $\theta = 51.3°$ Option A: shift cos (0.8) Option B: swap the angles in resolving Option D: shift sin (0.8)
9	D	The rotation of the Earth results in the acceleration of free fall being smaller than the gravitational field strength at the Earth's surface, except at the poles where they are equal.
10	D	As the orbital radius r increases, $GPE = -\frac{GMm}{r}$ becomes less negative (i.e. increases). Kinetic energy of the satellite decreases since the orbital speed drops as the gravitational pull provides less centripetal acceleration; or by $KE = \frac{GMm}{2r}$, KE decreases.

11	C	From kinetic theory of gas, $p = \frac{1}{3}\rho\langle c^2\rangle$ Since the oxygen gas is 16 times as dense as hydrogen gas, the corresponding root-mean-square speed of its molecules must be 4 times as slow, meaning that the root-mean-square speed of the hydrogen molecules are 4 times as fast.
12	A	By First law of thermodynamics, besides cooling, the internal energy can also be decreased by mechanical work through expanding the gas, as it does work on its surroundings. Option D is true only for ideal gas, which has zero microscopic PE. Option B is true, except during change of state. E.g. when ice melts, its internal energy is increased because of the increase in its microscopic PE. But there is no change in its microscopic KE, and thus no temperature change. Option C Temperature is a measure of the <u>average</u> (microscopic) KE (not KE+PE).
13	B	By Newton's 2nd law, F_{net} on piston = ma Since gas exerts an upward force $F_{net} = F_{gas} - mg$ where mg is the piston's weight Hence $F_{net} = F_{gas} - mg = ma$ $F_{gas} = m(g + a) = 0.75\ (9.81 + 3.5) = 9.983$ N Work done by the gas = $F_{gas} \times s = 9.983 \times 0.12 = 1.20$ J
14	B	Using $v_0 = \omega x_0$, $3 = \frac{2\pi}{12}x_0$ giving $x_0 = 5.730$ cm Using $\lvert a_0\rvert = \omega^2 x_0$, $a_0 = \left(\frac{2\pi}{12}\right)^2 \times 5.730 = 1.571$ cm s^{-1} Hence maximum restoring force = 3.0 x $1.571\times10^{-2} = 4.7\times10^{-2}$ N Option C: wrong T = 15/1.5 = 10 s Option D: forgot to square omega, and mass multiply by max v = 3.0 x 0.03
15	C	Since the wave pulse is travelling to the right, the last point on the displacement time graph will be the first point on the displacement position graph. Correspondingly, the first point on the displacement time graph will be the last point on the displacement position graph. The sequence follows through for the points in between.
16	A	As the light passes through the first sheet half of the intensity of the light is lost. The second sheet will need to reduce the intensity by another half in order for the emerging light to be $0.25I_o$. So,

		$\frac{I_o}{2}\cos^2\theta = \frac{I_o}{4}$ $\cos^2\theta = \frac{1}{2}$ $\cos\theta = \sqrt{\frac{1}{2}}$ $\theta = \cos^{-1}\sqrt{\frac{1}{2}} = 45°$ Either sheet could be moved as both will reduce the intensity by half each time the light passes through.
17	B	Using small angle approximation,  $\alpha \approx \theta_{min}$ $\frac{d_{\text{between the stars}}}{D_{\text{from telescope}}} = \frac{\lambda}{b}$ $d_{\text{between the stars}} = \frac{\lambda D_{\text{from telescope}}}{b}$ $= \frac{(630\times10^{-9})(5.9\times10^{16})}{45\times10^{-2}}$ $= 8.3\times10^{10}$ m
18	B	The distance from the node to the end of the tube is $\frac{\lambda}{4}$. Since $\frac{\lambda}{4} = 0.17 \rightarrow \lambda = 0.68$ m. The frequency to generate this stationary wave is $f = \frac{v}{\lambda} = \frac{340}{0.68} = 500$ Hz The wavelengths of $\frac{\lambda}{4}, \frac{3\lambda}{4}, \frac{5\lambda}{4}, \frac{7\lambda}{4}$.... are equal to 0.17 m to obtain a next node at the same position. The corresponding resonant frequencies would then be 500 Hz, 1500 Hz, 2500 Hz, 3500 Hz, 4500 Hz, 5500 Hz... etc.
19	D	We cannot use Coulomb's Law because that is for point charges (or charge distributions with spherical symmetry), but we have metal plates. Uniform electric field strength between the metal plates, $E = \frac{\Delta V}{d} = \frac{3V}{r_1 + r_2}$

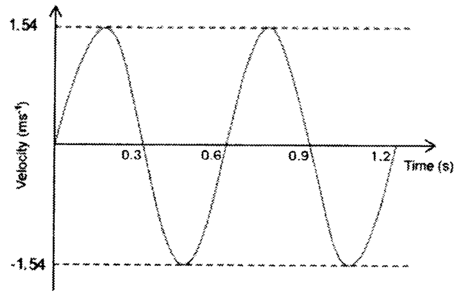
		Electric force on charged oil drop $= qE = q(\frac{3V}{r_1 + r_2})$ Distractors (remove from suggested solution for students): A → formula for electric potential energy if the plates were point charges B → formula for electric force if the plates were point charges C → calculated electric field strength due to each plate separately D → correct
20	B	work done by external force $= \Delta U = q\Delta V$ The net potential at a point is the scalar sum of the potentials due to the first two point charges. ΔU is independent of the path. Since the charges have opposite polarity, • the electric potential is positive near $+2q$ and negative near $-q$. • the point where the electric potential is zero is between the two charges, and nearer to $-q$. A: always equidistant from $+2q$, starts and ends about the same distance from $-q$. $\Delta V \approx 0$ C: starts and ends about equidistant from both $+2q$ and $-q$. $\Delta V \approx 0$ D: $V_{initial}$ is a large negative number, and V_{final} is a smaller negative number. ΔV is positive. B: $V_{initial}$ is a large negative number, and V_{final} is a large positive number. ΔV is the greatest.
21	A	Resistance R is the ratio of V to I. To determine the change of R, analyse the ratio $\frac{I}{V}$ i.e. the **gradient of the line from origin to the desired point on the graph.** From W to X: $\frac{I}{V}$ is constant, thus the inverse of the ratio, R is constant. From X to Y: $\frac{I}{V}$ is increasing, thus the inverse of the ratio, R is decreasing. From Y to Z: $\frac{I}{V}$ is decreasing, thus the inverse of the ratio, R is increasing.
22	C	The readings of V_2 and V_3 are both zero. No current flows through the resistor that V_2 is connected across and the resistance of a diode is zero.
23	A	When the ammeter is zero, p.d. across the section of the wire on the left of the sliding contact is equal to that of the p.d. across the fixed resistor on the left. p.d. across the section of the wire on the right of the sliding contact is equal to that of the p.d. across the LDR on the right. (LDR is in bright light, its resistance is low) LDR in the dark has higher resistance, thus by potential divider principle, the p.d. across it will become higher. To return the ammeter reading to zero, we have to move the sliding contact to the left

24	D	The current in P produces a magnetic field along the circumference of coil Q in the clockwise direction. This magnetic field produced is parallel to the current in each part of coil Q, hence by Fleming's left hand rule, there is no magnetic force induced on coil Q in all directions. Options A and B: wrongly use 'Like currents attract' concept.
25	B	n is the number of turns per unit length of solenoid. $n = \frac{N}{\text{solenoid length}} = \frac{4000}{200 \times 10^{-3}} = 20000$ turns per unit length $B = \mu_0 nI = \mu_0 n\left(\frac{V}{R}\right)$ $= (4\pi \times 10^{-7})(20000)\frac{6.0}{(3.26 \times 10^3)}$ $= 4.6 \times 10^{-5}$ T Option A: uses R = 3.26 Ω instead of R = 3.26 kΩ Option C: wrong n, use n = 4000 turns and wrong R = 3.26 Ω instead of R = 3.26 kΩ Option D: wrong n, use n = 4000 turns.
26	D	By Faraday's Law, e.m.f. induced, $\varepsilon = \frac{d\phi}{dt}$ $\varepsilon \approx \frac{\Delta\phi}{\Delta t} = \frac{1.2 \times (\pi(0.2)^2 - \pi(0.1)^2)}{0.1} = 1.2 \times \pi(0.04 - 0.01) \times 10$ V
27	B	V_o = 320 V $V_{rms} = \frac{320}{\sqrt{2}} = 226 = 230\text{V}$ The root-mean-square voltage is the equivalent d.c. voltage that would give the same average power.
28	C	From photoelectric equation, $eV_s = hf - \Phi$ Using the same ultraviolet source is used, the energy of each photon remains the same, thus the stopping potential remains the same. Lower intensity implies that the rate of photons incident on the metal is less. The rate of electron emission is less, and the rate of electrons reaching the collector plates also decreases. Thus, the new saturation current is less than the original.
29	A	When the potential difference is decreased, the energy of the most energetic x-ray photon decreases. Hence, minimum wavelength increases. The probability of the incoming electron knocking off the innermost electrons decreases, hence the intensity of the peaks also decreases.
30	D	λ is associated with the equation $A = \lambda N$

HCi H2 Physics 9749
2025 C2 Preliminary Examination
Paper 2 Suggested Solutions

Q1		
(a)	Pressure p at depth h in the fluid $= \dfrac{\text{force } F}{\text{area of base of container } A}$ $= \dfrac{\text{weight of fluid column } W}{\text{area } A}$ $= \dfrac{\text{mass of fluid column } m \times \text{acceleration of free fall } g}{A}$ $= \dfrac{(\text{density } \rho \times \text{volume } V)g}{A}$ $= \dfrac{\rho A h g}{A}$ $= \rho g h$	
(b)(i)	Let the volume of the object be V. Resultant force F = weight of object mg – upthrust U $F = mg - U$ $= (Vd)g - V\rho g$ $= Vdg\left(1 - \dfrac{\rho}{d}\right)$ $= mg\left(1 - \dfrac{\rho}{d}\right)$	
(b)(ii)	At equilibrium, taking moments about the pivot, Clockwise moment due to sample = anticlockwise moment due to standard mass (Resultant force on sample) x = (Resultant force on standard mass) x $mg\left(1 - \dfrac{\rho}{d}\right) = m_s g\left(1 - \dfrac{\rho}{d_s}\right)$ $m = m_s\left(1 - \dfrac{\rho}{d_s}\right) \Big/ \left(1 - \dfrac{\rho}{d}\right)$ $= (0.17851)\left(1 - \dfrac{1.29}{8493}\right) \Big/ \left(1 - \dfrac{1.29}{940.0}\right)$ $= 0.17873$ kg (5 d.p.)	

Q2		
(a)(i)	The mass passes through the equilibrium position P twice in a cycle, meaning that there are 100 complete cycles per minute. period, T = 1/f = 60/100 = 0.600 s	
(a)(ii)	At equilibrium position x = 0, the kinetic energy of the mass E_k is at its **maximum**. $\omega = \dfrac{2\pi}{T} = \dfrac{2\pi}{0.600} = 10.47$ rad s^{-1} $E_k = \dfrac{1}{2} m\omega^2 x_o^2 = \dfrac{1}{2}(0.42)(10.47)^2 x_o^2$ Amplitude $x_o = \sqrt{\dfrac{2(0.500)}{0.42(10.47)^2}} = 0.147$ m = 14.7 cm = 15 cm (2 s.f.)	
(a)(iii)	$E_k = \dfrac{1}{2} mv^2 \Rightarrow v = \sqrt{\dfrac{2E_k}{m}} = \sqrt{\dfrac{2(0.500)}{0.42}} = 1.54$ m s^{-1}	



	• Sinusoidal waveform • Maximum velocity of 1.54 m s^{-1} and time period of 0.60 s *No information is given whether mass starts oscillating from its equilibrium position or at its amplitude – sine or cosine graph*	
(b)(i)	No change	
(b)(ii)	Frequency multiplied by $\sqrt{2}$.	

Q3		
(a)	Gravitational potential at a point is **the work done per unit mass** in bringing a **small test mass from infinity to that point** (without a change in kinetic energy)	
(b)(i)	To just reach the neutral point from the Earth, gain in gravitational potential energy GPE = Loss in kinetic energy $\Delta U = m\Delta\phi = -\Delta KE$ $10.0\Delta\phi = 6.10\times10^{8}$ J $\Delta\phi = 6.10\times10^{7}$ J kg^{-1} $\phi_{\text{neutral point}} - \phi_{\text{earth surface}} = 6.10\times10^{7}$ $\phi_{\text{neutral point}} = 6.10\times10^{7} + \phi_{\text{earth surface}}$ $\phi_{\text{neutral point}} = 6.10\times10^{7} + (-62.3\times10^{6})$ $\phi_{\text{neutral point}} = -1.3\times10^{6}$ J kg^{-1} (2 s.f.) OR total energy at Earth surface = total energy at neutral point $KE_{\text{earth surface}} + U_{\text{earth surface}} = KE_{\text{neutral point}} + U_{\text{neutral point}}$ $6.10\times10^{8} + 10(-62.3\times10^{6}) = 0 - 10.0\times\phi_{\text{neutral point}}$ $\phi_{\text{neutral point}} = -1.30\times10^{6}$ J kg^{-1} (3 s.f.)	
(b)(ii)	The rock from the Moon must have enough energy to go past the neutral point, then resultant gravitational force of the Earth-mass system on the mass will accelerate it to the Earth. gravitational potential difference between the Moon's surface and the neutral point $\Delta\phi = \phi_{\text{neutral point}} - \phi_{\text{moon surface}}$ $= -1.30\times10^{6} - (-3.90\times10^{6})$ $= 2.60\times10^{6}$ J kg^{-1} Hence, the minimum kinetic energy needed to send a 1.4 kg rock from the Moon to the neutral point is $m\Delta\phi = (1.4)(2.60\times10^{6})$ = 3.64 × 10^{6} J or 3.6 × 10^{6} J (2 s.f.)	
(c)(i)	The gravitational force exerted on one star by the other star provides the centripetal force for each orbit. This pair of forces is an action-reaction pair (**Newton's 3rd law**), always equal in magnitude (and opposite in direction). OR The gravitational force between stars provides the centripetal force for each orbit. By **Newton's Law of Gravitation**, the gravitation force between the stars $= \frac{GM(2M)}{(3R)^2}$, thus the two stars experience the same magnitude of centripetal force.	

(c)(ii)	$\omega = \frac{2\pi}{T} = \frac{2\pi}{3.42\times10^{5}} = 1.837\times10^{-5}$ rad s^{-1} Consider the star of mass *M*, The gravitational force due to star of mass 2*M* provides the centripetal force for the orbit of *M*. $F_G = Ma_c$ $\frac{GM(2M)}{(3R)^2} = M(2R)\omega^2$ $R = \sqrt[3]{\frac{GM}{9\omega^2}}$ $= \sqrt[3]{\frac{6.67\times10^{-11}(3.14\times10^{30})}{9(1.837\times10^{-5})^2}}$ $= 4.10\times10^{9}$ m	

Q4

(a)

Let the distance from the source to the first area be r. Using geometry, the distance from the point source is 7.5 times more for the second area.

Method I

$I \propto \frac{1}{r^2} \propto A^2$. Hence, amplitude is inversely proportional to the distance away from a point source,

$A \propto \frac{1}{r}$ [M1]

Since the distance from the point source is 7.5 times more for the second area, the amplitude would be 7.5 times less. Hence, the new amplitude would be

$A_2 = \frac{A_0}{7.5} = 0.13A_0$ [A1]

Method II

Since the source is a point source, the intensity of the wave is inversely proportional to the square of the distance that the waves travel, $I \propto \frac{1}{r^2}$.

Hence the intensity at the second area, I_2

$\frac{I}{I_2} \propto \frac{r_2^2}{r^2} = \frac{(7.5r)^2}{(r)^2}$

$I_2 = \frac{I}{7.5^2}$ [M1]

Intensity is directly proportional to the square of the amplitude. Hence, the amplitude:

$\frac{I}{I_2} \propto \frac{A_0^{\,2}}{A_2^2} \rightarrow A_2^2 = \frac{I_2}{I} A_0^{\,2}$

$A_2 = \frac{A_0}{7.5} = 0.13A_0$ [A1]

Method III

Intensity = Power / Area

Intensity ∝ (1 / Area) ∝ (amplitude)^2

$\frac{I'}{I} = \frac{S}{S'} = \left(\frac{1.6}{12}\right)^2 \rightarrow I' = \left(\frac{1.6}{12}\right)^2 I$ [M1]

$A' = \frac{1.6}{12} A_0 = 0.13A_0$ [A1]

(b)(i) 1 & 2

Wavelength = 1.2 m. **Two** full wavelengths of **stationary waves** must be drawn with

- Nodes at 0.0 m, 0.6 m, 1.2 m, 1.8 m and 2.4 m.
- Antinode peaks at 0.3 m and 1.5 m or at 0.9 m and 2.1 m [B1]

Maximum amplitude for Y at 12.5 ms

$y = 5.0\sin(\omega t) = 5.0\sin\left(\frac{2\pi}{T}t\right)$

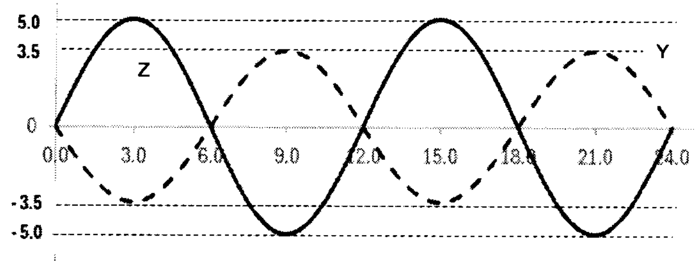
$y = 5.0\sin\left(\frac{2\pi}{20}12.5\right) = -3.5$ mm [B1]

Maximum amplitude for Z at 5.0 ms

$y_Z = 5.0\sin(\omega t) = 5.0\sin\left(\frac{2\pi}{20}5.0\right)$ [B1]

$y_Z = 5.0$ mm

The antinode peaks for Z should coincide with antinode troughs for Y and vice versa [B1]



(b)(ii) 180° or π rad

Q5

(a)(i) Direction of the electric field at x = 25.0 cm is towards the right.

Electric field is always directed towards lower potential.

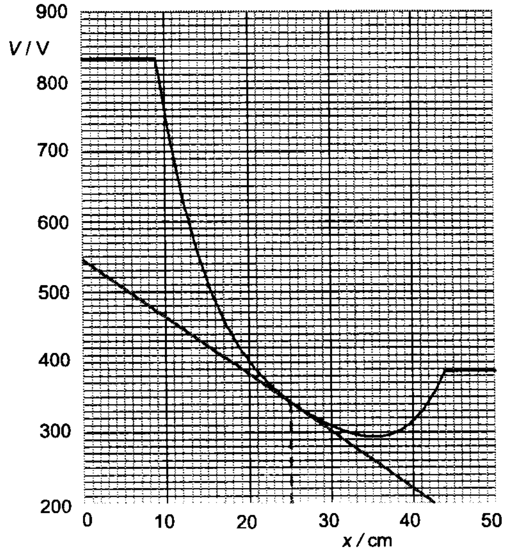
OR

Direction of the electric field at x = 25.0 cm is towards the right.

The potential gradient is negative at this value of x as can be observed by drawing a tangent to the curve at x = 25.0 cm.

Since E is (the negative) of the potential gradient, E takes on a positive value, which means the electric field is directed towards the right.

(a)(ii)



Draw a tangent to the curve at x = 25.0 cm

Potential gradient $\frac{dV}{dx} = \frac{545-200}{0.0-42.5} = -8.12$ (3 s.f.)

Electric field $E = -\frac{dV}{dx} = 8.12\ \text{V cm}^{-1}$ (acceptable range: 7.3 – 9.7)

(a)(iii) Mobile charge carriers within a conductor will always re-distribute until a certain equilibrium state where **the electric field within it is zero**.

Zero electric field means that there is **zero potential gradient**, and hence **constant potential**.

(b) The ion will accelerate to the right until ***x* = 35.0 cm**, then the ion will decelerate and momentarily come to rest at ***x* = 42.0 cm**,

and accelerate back to the left and momentarily stops at **x = 25.0 cm** before accelerating to the right again, **repeating** the motion.

OR

The ion will oscillate between the points ***x* = 25.0 cm and *x* = 42.0 cm**.

Q6		
(a)	The motion of electrons is random, so there is no net flow of electrons in any direction. OR On average, as much mobile electrons move in one direction as in the opposite direction, Thus there is no net transfer / movement of electric charge in a particular direction.	
(b)	Arrow to the right.	
(c)(i)	$v = \frac{I}{neA} = \frac{2.0}{8.5\times10^{28}(1.60\times10^{-19})\pi(0.40\times10^{-3})^2} = 2.9 \times 10^{-4}$ m s^{-1} $t = L/v = 0.50/(2.9 \times 10^{-4}) = 1700$ s (or 1710 s to 3 s.f.) *Accept answer up to 3 significant figures.*	
(c)(ii)	All mobile electrons in the circuit start drifting at the same time as the electric field is established in the wire almost instantaneously. The lamp lights up as soon as the mobile electrons already in the lamp filament begin to move which is much shorter than the time calculated in (c)(i).	
(c)(iii)	As $I = Anve$ and current (I), charge density (n) and charge (e) are the same in both wires, drift velocity v is inversely proportional to the cross-sectional area A of the wires. As the cross-sectional area for thicker wire is larger than that of the thinner wire, drift velocity of the electrons in the thicker wire is smaller than that in the thinner wire. (no marks for wrong explanations) **Alternatively,** Since the current in the circuit is the same, the thicker wire having a larger cross-sectional area (A), has greater number of electrons per unit length, since the charge density (n) is the same for the same metal. Thus the thicker wire should have a smaller drift velocity (v) to keep the number of electrons passing through a point per unit time (i.e. the current I) constant.	

Q7		
(a)(i)	When a graph showing the variation of count-rate from a radioactive sample over time is plotted, we observe ***fluctuations*** instead of a smooth curve.	
(a)(ii)	Variations in external factors such as ***temperature and pressure*** do not affect the curve variation in the count-rate over time	
(b)(i)	From the figure, at $t = 0$, $C_0 = 475$ s^{-1}. When the count rate is halved, $C_t = \frac{475}{2} = 237.5$ s^{-1}. To reach this value, reading from the graph, half-life is 15 days At $t = 10$ days, $C = 300$ s^{-1}. This is halved at $C = 150$ s^{-1}, which is at $t = 25$ days. This also gives a half-life of 15 days. The (averaged) half life is thus 15 days.	
(b)(ii)	Beta particles have a ***sufficiently long range*** that could cross the entire lab, so the student is exposed to it even when not conducting the experiment. OR Beta particles are ***ionising radiation*** that can cause health problems like cancer when exposed to a sufficiently high dose. Radiation dosage looks at the total amount accumulated over time and if this is high enough due to ***prolonged exposure***, it can be a health hazard.	
(b)(iii)	If the product is not stable, ***it can decay and that will contribute to the count rate*** measured which will not be just due to the decay of phosphorous-32 alone.	

Q8

(a)(i) The energy E of a photon is proportional to its frequency ($E = hf$).

The atom can only absorb a photon of energy equal to the ***difference*** in two energy levels.

From Fig 8.2, we see that the rubidium atom has ***discrete*** energy levels, and thus has discrete energy differences, thus only certain frequencies of photons can be absorbed.

(a)(ii) Energy of photon,

$$\Delta E = hf = \frac{hc}{\lambda} = \frac{(6.63\times10^{-34})(3.00\times10^{8})}{795\times10^{-9}} = 2.502\times10^{-19}\ \text{J}\ \ (=1.56\ \text{eV})$$

Energy difference,

$$E_A - E_{ground} = \Delta E$$

$$E_A - (-4.18)(1.60\times10^{-19}) = 2.502\times10^{-19}$$

$$E_A = -4.186\times10^{-19}\ \text{J}$$

$$\approx -2.62\ \text{eV}$$

(a)(iii) The photon is in the infrared part of the electromagnetic spectrum, outside the visible range, so it cannot be seen with the naked eye.

OR
The visible spectrum is from 400 nm to 700 nm / 750 nm, thus the photon's wavelength lies outside the visible range.

OR
The visible spectrum has wavelengths on the order of 10^{-7} m, and the photon's wavelength is near the edge of this range.

OR (not intended solution but accepted due to phrasing of the question)
A *single* photon reaching the eye has a very small intensity, thus it will be hard to see/detect with the naked eye.

(b)

$$E = \frac{3}{2}kT = \frac{1}{2}mv^2$$

$$v = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3(1.38\times10^{-23})(1000)}{86.9\times1.66\times10^{-27}}}$$

$$= 535.72 \approx 536\ \text{m s}^{-1}$$

OR

$$PV = NkT = \frac{1}{3}Nm\langle c^2\rangle$$

$$\sqrt{\langle c^2\rangle} = \sqrt{\frac{3kT}{m}} = \sqrt{\frac{3(1.38\times10^{-23})(1000)}{86.9\times1.66\times10^{-27}}}$$

$$= 535.72 \approx 536\ \text{m s}^{-1}$$

(c) It is the (average) time that the atom stays in that state before it de-excites to another state.

(d)(i) Using the de Broglie relation,

$$p_{photon} = \frac{h}{\lambda} = \frac{6.63\times10^{-34}}{795\times10^{-9}} = 8.34\times10^{-28}\ \text{kg m s}^{-1}$$

OR

$$E = hf = \frac{hc}{\lambda} = pc$$

From (a)(ii), $E = 2.502\times10^{-19}$ J

$$\therefore p_{photon} = \frac{E}{c} = \frac{2.502\times10^{-19}}{3.00\times10^{8}} = 8.34\times10^{-28}\ \text{kg m s}^{-1}$$

By the principle of conservation of momentum, taking right as positive

$$p_{atom} - p_{photon} = p'_{atom}$$

$$\Delta p_{atom} = p'_{atom} - p_{atom} = -p_{photon}$$

$$\text{Thus } |\Delta p_{atom}| = |-(8.34\times10^{-28})|$$

$$= 8.34\times10^{-28}\ \text{kg m s}^{-1}$$

(d)(ii) The photons are emitted in randomly in all directions. Since momentum is a vector quantity, the average change in momentum from this process is the vector sum

$$\Delta\bar{p} = \frac{\Delta\bar{p}_1 + \Delta\bar{p}_2 + \ldots + \Delta\bar{p}_N}{N} = \frac{0}{N} = 0$$

(d)(iii) From Table 8, the lifetime of the atom in state A is 27.6 ns.
Since from (d)(ii) we know that, on average, only absorbing a photon causes a change in momentum, therefore,

$$F = \frac{\Delta p}{\Delta t}$$

$$= \frac{8.34\times10^{-28}}{27.6\times10^{-9}}$$

$$= 3.02\times10^{-20}\ \text{N}$$

(d)(iv) The photons required to excite the atom to state B have shorter wavelength and hence greater momentum, thus each interaction causes a greater decrease in momentum of the atom.

OR
The lifetime of state B is shorter than state A, so it can absorb more photons per unit time

OR
the average force on the atom is greater.

(e) From Fig. 8.4, when the temperature decreases to T_C, the density of the cloud of atoms increases significantly, suggesting that the particles are overlapping.

OR

From Fig. 8.4, when the temperature is equal to or below T_C, <u>almost all the particles occupy a small space in the middle of the trap</u>, suggesting that the particles are overlapping.

(f) From the de Broglie relation,

$$\lambda = \frac{h}{p} = \frac{h}{\sqrt{3mkT}}$$

Since a BEC forms when $\lambda \geq d$, where $T \leq T_C$,

and $d \approx \frac{1}{\sqrt[3]{1.00\times10^{19}}} = 4.6416\times10^{-7}$ m,

$$\frac{h}{\sqrt{3mkT_C}} = \frac{1}{\sqrt[3]{n}}$$

$$T_C = \frac{h^2}{3mk}n^{\frac{2}{3}}$$

$$= \frac{\left(6.63\times10^{-34}\right)^2}{3\left(86.9\times1.66\times10^{-27}\right)\left(1.38\times10^{-23}\right)}\left(1.00\times10^{19}\right)^{\frac{2}{3}}$$

$$= 3.4164\times10^{-7} \approx 3.42\times10^{-7} \text{ K}$$

<u>Alternative solution without using de Broglie relation (max 3 marks only)</u>

From the Heisenberg uncertainty principle,

$$\Delta x \Delta p \gtrsim h$$

Taking $\Delta p \approx p = \sqrt{3mkT}$,

$$\Delta x \gtrsim \frac{h}{\sqrt{3mkT}}$$

Since a BEC forms when the particles "overlap", i.e. $\Delta x \geq d$, where $T \leq T_C$,

and $d \approx \frac{1}{\sqrt[3]{1.00\times10^{19}}} = 4.6416\times10^{-7}$ m,

$$\frac{1}{\sqrt[3]{n}} = \frac{h}{\sqrt{3mkT_C}}$$

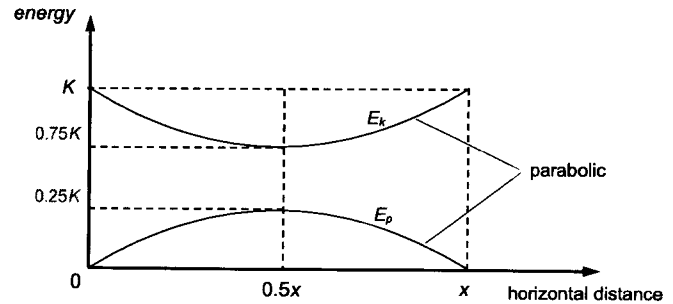
$$T_C = \frac{h^2}{3mk}n^{\frac{2}{3}}$$

$$= \frac{\left(6.63\times10^{-34}\right)^2}{3\left(86.9\times1.66\times10^{-27}\right)\left(1.38\times10^{-23}\right)}\left(1.00\times10^{19}\right)^{\frac{2}{3}}$$

$$= 3.4164\times10^{-7} \approx 3.42\times10^{-7} \text{ K}$$

HCI H2 Physics 9749
2025 C2 Preliminary Examination
Paper 3 Suggested Solutions

Q1			
(a)	(i)	Vertical component of the ball's initial velocity, $u_y = u \sin\theta$ $= 25 \sin 30°$ $= 12.5$ m s^{-1} $= 13$ m s^{-1}	
	(ii)	Considering the vertical component motion, At maximum height, the vertical component of the ball's velocity will decrease to zero. Using $v_y^2 = u_y^2 + 2a_ys_y$ and taking upwards direction as positive, $0 = (12.5)^2 + 2(-9.81)s_y$ Vertical displacement (i.e. max height reached), $s_y = 7.96 = 8.0$ m	
	(iii)	Initial total energy = $K = \frac{1}{2}mu^2$ At maximum height of 8.0 m, ball's vertical component velocity, $v_y = 0$. Its velocity will be its horizontal component velocity, $v_x = u \cos 30° = \frac{\sqrt{3}}{2}u$ kinetic energy at 8.0 m = $\frac{1}{2}m\left(\frac{\sqrt{3}}{2}u\right)^2 = \frac{3}{4}\left(\frac{1}{2}mu^2\right) = 0.75K$ Gain in potential energy of system = Loss in kinetic energy of ball Potential energy at 8.0 m = $K - \frac{3}{4}K = 0.25K$ OR: Initial total energy at 8.0 m, $K = \frac{1}{2}mu^2 \Rightarrow m = \frac{2K}{u^2}$ $PE = mgh = \frac{2K}{u^2}gh = \frac{2(9.81)(8.0)}{(25)^2}K = 0.25K\,(2\text{ s.f.})$ $KE = K - PE = K - 0.25K = 0.75K\,(2\text{ d.p.})$	

(b)	(i)	 Fig. 1.2	
		Correct graph E_p parabolic curve starts from zero, peaks at $K/4$ at the middle, ends at zero. E_k parabolic curve starts from K, decreases to $3K/4$ at the middle, ends at K. Correct labels, clear markings, symmetry	

Q2

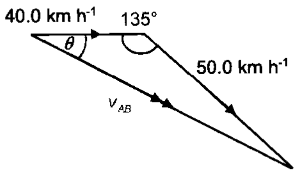
(a)

$$F_d = \frac{1}{2}\rho C_d A v^2$$
$$= \frac{1}{2}(1.20)(0.30)(2.50)\left(\frac{108\times1000}{60\times60}\right)^2$$
$$= 405 \text{ N}$$

$$\frac{\Delta F_d}{F_d} = \frac{\Delta\rho}{\rho} + \frac{\Delta C_d}{C_d} + \frac{\Delta A}{A} + \frac{2\Delta v}{v}$$
$$\frac{\Delta F_d}{405} = \frac{0.05}{1.20} + \frac{0.02}{0.30} + \frac{0.05}{2.50} + \frac{2(2)}{108}$$
$$\Delta F_d = 70 \text{ N (1s.f.)}$$

$F_d \pm \Delta F_d = 410 \pm 70$ N

(b) velocity of car A relative to car B, $v_{AB} = v_A - v_B$



By Cosine Rule, $v_{AB} = \sqrt{40.0^2 + 50.0^2 - 2(40.0)(50.0)\cos 135^\circ}$
$= 83.2 \text{ km h}^{-1}$

By Sine Rule, $\frac{\sin\theta}{50.0} = \frac{\sin 135^\circ}{83.2}$, hence $\theta = 25.1°$

direction: bearing = 90.0° + 25.1° = 115.1°

Q3

(a) Let mass of Planet Z be M, mass of argon molecules be m,
Consider an argon molecule escapes from the planet's surface to infinity.
By conservation of energy,

Loss in KE = Gain in GPE
$$KE_{surface} - KE_{\infty} = U_{\infty} - U_{surface}$$
$$\frac{1}{2}mv^2 - 0 = 0 - \left(-\frac{GMm}{r}\right)$$
$$v = \sqrt{\frac{2GM}{r}}$$
$$= \sqrt{\frac{2G\left(\frac{4}{3}\pi r^3\rho\right)}{r}}$$
$$= \sqrt{\frac{8}{3}G\pi r^2\rho} \quad \textit{(shown)}$$

(b)

$$v = \sqrt{\frac{8}{3}G\pi r^2\rho}$$
$$= \sqrt{\frac{8}{3}(6.67\times10^{-11})\pi(413\times10^3)^2(5500)}$$
$$= 724 \text{ ms}^{-1}$$

(c) Assume that escape velocity v is equal to the root-mean-square speed c_{rms} of the argon molecules.

By Kinetic Theory, average KE of one argon molecule = 3/2 kT
Average KE of one mole of monatomic gas is therefore 3/2 RT.

$$\frac{1}{2}M_r c_{rms}^2 = \frac{3}{2}RT_{max}$$ where is M_r the molar mass of argon.

$$T_{max} = \frac{M_r c_{rms}^2}{3R}$$
$$= \frac{(40\times10^{-3})(724)^2}{3\times8.31}$$
$$= 841\text{K}$$

(d) The root-mean-square speed of argon molecules will be less than escape velocity when temperature decreases.

However, due to the random distribution of speeds, some molecules will have speeds greater than the escape velocity and would be able to escape.

Q4

(a)

From Fig. 4.2, 5 mm corresponds to 3 fringe separations.

$3\Delta y = 5.0 \Rightarrow \Delta y = 5.0 \div 3 = 1.67$ mm

$$\Delta y = \frac{L\lambda}{d}$$

$$1.67\times10^{-3} = \frac{0.980(633\times10^{-9})}{d}$$

$$d = 3.7\times10^{-4}\text{ m}$$

(b)

Let θ be the angle made by 1st order minimum of the single slit diffraction envelope from the principle axis.

From Fig. 4.1 and Fig 4.2, $\tan\theta_{min} = \frac{10.0\times10^{-3}}{0.980} = 0.0102$

$$\sin\theta_{min} = \frac{\lambda}{b}$$

$$b = \frac{\lambda}{\sin\theta};\ \frac{\lambda}{\theta} \qquad \text{(Applying small angle approximation)}$$

$$= \frac{633\times10^{-9}}{0.0102}$$

$$= 6.2\times10^{-5}\text{ m}$$

<u>Alternative Method</u>

From Fig. 4.2, the first minimum for single slit diffraction envelope coincides with the 6th maximum for double slit interference (missing order).

Single slit diffraction: $b\sin\theta_1 = 1\lambda$

Double slit interference: $d\sin\theta_6 = 6\lambda$

Since $\theta_1 = \theta_6$,

$$\frac{b}{d} = \frac{1}{6}$$

$$b = \frac{d}{6} = \frac{3.7\times10^{-4}}{6}$$

$$= 6.2\times10^{-5}\text{ m}$$

(c)(i)

Increase slit separation d.

From $\Delta y = \frac{\lambda L}{d}$, a smaller d makes the fringe separation Δy wider, spreading the interference pattern.

(c)(ii)

Make the slits narrower.

Narrower slits produce a much wider single-slit diffraction envelope with lower overall intensity, so the bright fringes vary less in intensity.

Q5

(a)(i)

The component of velocity perpendicular to the magnetic field results in a magnetic force on the electron, which is always perpendicular to the motion. Hence, the electron rotates in a circular path.

The component of velocity parallel to the magnetic field remains constant. Hence, the electron travels at constant velocity along the direction of magnetic field.

The combination of both components of velocity of the electron results in a helical path.

(a)(ii)

$$F_B = Bqv_\perp = Bqv\sin 20°$$

$$v = \frac{F_B}{Bq\sin 20°} = \frac{4.3\times10^{-14}}{0.088(1.60\times10^{-19})\sin 20°}$$

$$v = 8.93\times10^{6}\text{ m s}^{-1}$$

(a)(iii)

Magnetic force provides centripetal force to the electron's component of velocity perpendicular to the magnetic field.

Find period T:

$$F_B = Bqv_\perp = \frac{mv_\perp^2}{r} \Rightarrow v_\perp = \frac{Bqr}{m}$$

$$v_\perp = \omega r = \frac{2\pi}{T}r$$

$$T = \frac{2\pi r}{v_\perp} = \frac{2\pi rm}{Bqr} = \frac{2\pi m}{Bq}$$

Pitch:`

$$p = v_P T$$

$$= v\cos 20°\left(\frac{2\pi m}{Bq}\right)$$

$$= \frac{(8.93\times10^{6})\cos 20°(2\pi)(9.11\times10^{-31})}{(0.088)(1.60\times10^{-19})}$$

$$= 3.4\times10^{-3}\text{ m}$$

(b)

The pair of forces generate a torque. The maximum output torque is $F \times d$

Torque $= \tau = Fd = (NBIl)d = NBIA$

$$B = \frac{\tau}{NIA} = \frac{395}{(1200)(96)(6.1\times10^{-3})}$$

$$B = 0.562\text{ T}$$

Q6		
(a)(i)	For any given metal, electrons are emitted only when the frequency of incident light is above some minimum value. This frequency is known as the threshold frequency.	
(a)(ii)	At threshold frequency, energy of photon matches the work function. Hence, $\Phi = \frac{hc}{\lambda_o}$ $E_{MAX} = hf - \Phi = \frac{hc}{\lambda} - \frac{hc}{\lambda_o} = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right)$	
(b)(i)	Extend line to the x-axis. The x-intercept is $\frac{1}{\lambda_o}$ $\frac{1}{\lambda_o} = 2.3\times10^{6}$ $\lambda_o = 4.35\times10^{-7}$ m	
(b)(ii)	Gradient of graph = hc $\frac{(3.1-1.0)\times10^{-19}}{(3.85-2.8)\times10^{6}} = h(3.00\times10^{8})$ $h = 6.7\times10^{-34}$ Js	
(c)	Same gradient Higher y-intercept, x-intercept more to the left.	
(d)	As electrons escape the surface, the sphere becomes more positively charged and the potential at the surface increases. It comes to a point when the electrons with maximum kinetic energy lose all the energy at almost infinite distance and they are attracted back to the surface due to the electric field. The system is finally in dynamic equilibrium. The rate of return is equal to the rate of emission, keeping the total charge constant at the surface. Thus, electric potential energy gained by an electron at infinity = E_{MAX} lost $U_{\infty} - U_{surface} = E_{MAX}$ $0 - \frac{Q(-e)}{4\pi\varepsilon_o r} = hc\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right)$ $Q = \frac{4hc\pi\varepsilon_o r}{e}\left(\frac{1}{\lambda} - \frac{1}{\lambda_o}\right)$	

Q7		
(a)	The binding energy E of a nucleus is the energy required to separate the nucleus into its constituent free neutrons and protons. It is related to the mass defect Δm by the formula, $E = \Delta mc^2$.	
(b)(i)	The energy equivalent of 1.00 u is given by, $= 1.00uc^2$ $= (1.66\times10^{-27})(3.00\times10^{8})^2$ J $= \frac{(1.66\times10^{-27})(3.00\times10^{8})^2}{(1.60\times10^{-19})(10^{6})}$ MeV $= 933.75$ MeV $= 934$ MeV	
(b)(ii)	For Nitrogen-14, Binding energy $E = (7(1.007276) + 7(1.008665) - 14.003074)uc^2$ $= 0.108513(934 \text{ MeV}) = 101.35$ MeV Binding energy per nucleon $= \frac{101.35}{14} = 7.24$ MeV per nucleon	
(c)(i)	The energy released in the reaction = final binding energy – initial binding energy $= 17(7.530) - [14(7.24) + 4(6.836)]$ $= 128.01 - 128.70$ $= -0.694$ MeV Hence there is actually a gain of mass in this reaction and 0.694 MeV of energy needs to be provided.	
(c)(ii)	We need at least 0.694 MeV of energy from the kinetic energy of the alpha particles as the oxygen nucleus and proton may also have kinetic energy after the reaction. Since the kinetic energy of the alpha particle is only 0.300 MeV, it is clearly insufficient and hence the reaction cannot proceed.	

Q8

(a) The net external force acting on a body is zero and the net moment on the body about any point is zero.

(b) (i) $T\sin\theta = kx$

$k = \dfrac{T\sin\theta}{x} = \dfrac{2.50\sin 36^\circ}{0.050}$

$= 29.389$

$= 29.4\ \text{N m}^{-1}$ or $29\ \text{N m}^{-1}$ (to 2 s.f.)

(ii) $T\cos\theta = mg$

$m = \dfrac{T\cos\theta}{g} = \dfrac{2.50\cos 36^\circ}{9.81}$

$= 0.206$ kg or 0.21 kg (to 2 s.f.)

(iii) $\text{EPE} = \dfrac{1}{2}kx^2 = \dfrac{1}{2}(29.4)(0.050)^2$

$= 0.0368$

$= 0.037$ J

(c) (i) Simple harmonic motion is a periodic motion in which the acceleration of the body is directly proportional to the displacement from its equilibrium point, and is always in the opposite direction to the displacement (or always directed to equilibrium position.)

(ii)1. By conservation of energy,
Loss in GPE = Gain in KE

$mgh = \dfrac{1}{2}mv_{max}^2$

$v_{max} = \sqrt{2gh} = \sqrt{2g(L - L\cos\theta)}$

$= \sqrt{2(9.81)(0.150 - 0.150\cos 10^\circ)}$

$= 0.21145$

$= 0.21\ \text{ms}^{-1}$

(ii)2. T will be greater than W because,

in addition to supporting the bob's weight, the string must provide the necessary centripetal force to keep the bob moving in its circular path.

OR

The vector sum of the weight and tension must provide the centripetal force for circular motion pointing upwards at the bottom.

(ii)3. T − W provides the centripetal force for the bob to move in its circular arc

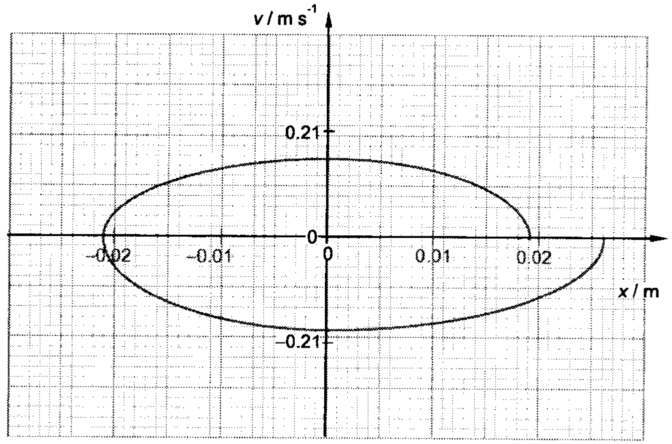
$T - W = \dfrac{mv^2}{r}$

$T = \dfrac{mv^2}{r} + mg = \dfrac{0.206(0.211^2)}{0.15} + 0.206(9.81)$

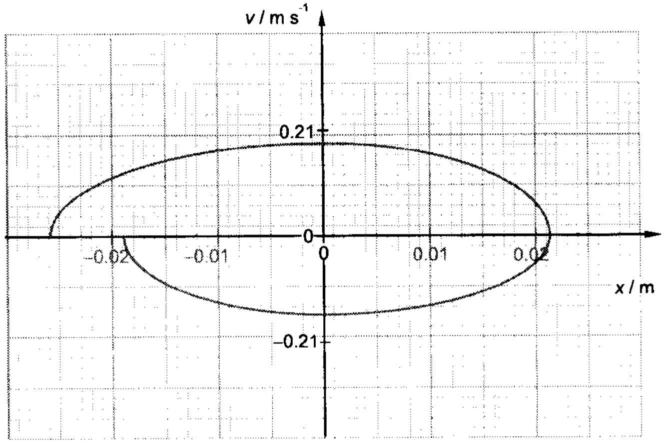
$= 2.082$ N

$= 2.1$ N

(d) (i) Correct shape starting at 0.026 m (reasonable smooth spiral)
Correct labelling of v_{max} and x_o
$x_o = L\sin\theta = 0.15 \sin 10^\circ = 0.02604 = 0.026$ m



OR

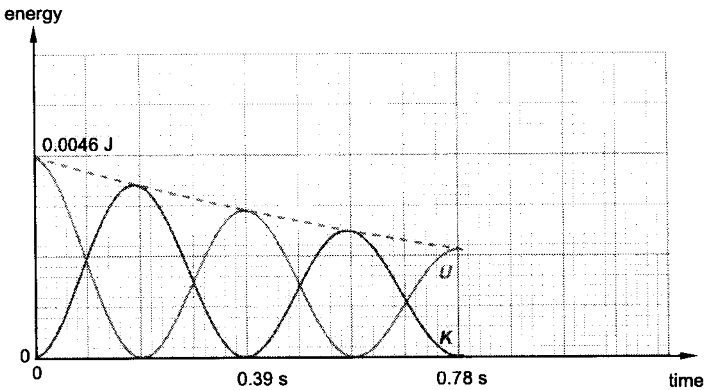


(ii)

$v = \omega x_0 = \left(\frac{2\pi}{T}\right) x_0$

$T = \frac{2\pi x_0}{v} = \frac{2\pi(0.026)}{0.21} = 0.78$ s

Total initial energy $= \frac{1}{2}mv^2 = \frac{1}{2}(0.21)(0.21)^2 = 0.0046$ J



Correct period labelled (2 cycles)
Correct shape of *U*
Correct shape of *K*

Q9			
(a)	(i)	As the coil rotates at constant angular speed ω, the component of magnetic flux density B perpendicular to the cross-sectional area A of the coil varies sinusoidally. Since the magnetic flux linkage Φ varies sinusoidally, the rate of change of flux linkage will be sinusoidal. For instance, if $\Phi = NBA\sin\omega t$, then $d\Phi/dt = NBA\omega\cos\omega t$. By Faraday's law, the magnitude of the induced emf is directly proportional to the rate of change of magnetic flux linkage. Thus emf induced in the coil will be sinusoidal.	
	(ii)	1. (6.8 cm × 0.050 V cm^{-1})/2 = 0.17 V 2. T = 5 cm × 8.0 ms = 40 ms f = 1/(40 × 10^{-3}) = 25 Hz	
	(iii)	The plane of the rectangular coil is perpendicular to the plane of the paper (i.e. minimum flux linkage), when maximum e.m.f. is induced in the coil. OR coil rotated 90°	
	(iv)	$E_0 = NBA\omega$ 0.17 = 120 × B × 0.0013 × 2π(25) $B = 6.94 \times 10^{-3}$ T	
(b)	(i)	The root-mean-square value of an alternating current is the equivalent constant direct current that will dissipate the same amount of heat per unit time in a given resistive load.	
	(ii)	$\omega = 2\pi f = 377$ $f = \frac{377}{2\pi} = 60.0$ Hz	
	(iii)	$V_{rms} = \frac{V_o}{\sqrt{2}} = \frac{240}{\sqrt{2}}$ Power dissipated in heater, $\langle P \rangle = \frac{(V_{rms})^2}{R}$ $= \left(\frac{240}{\sqrt{2}}\right)^2 \left(\frac{1}{38}\right)$ $= 758$ W	

(iv) The peak power, $P_o = (240)^2/38$

$= 1516$ W