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**.

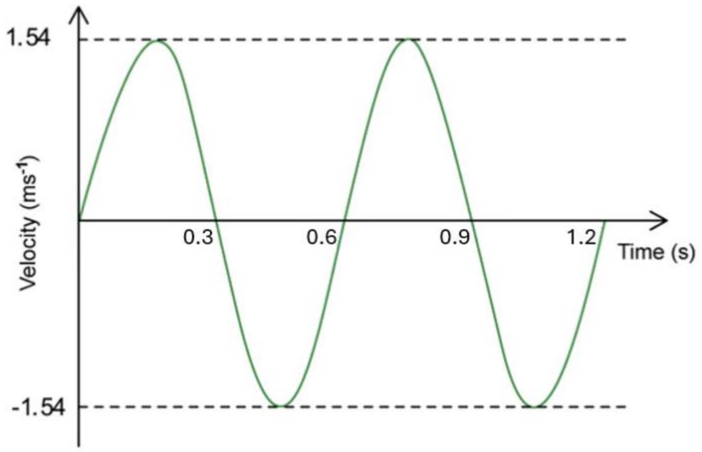
$$\omega = \frac{2\pi}{T} = \frac{2\pi}{0.600} = 10.47 \text{ rad s}^{-1}$$

$$E_k = \frac{1}{2}m\omega^2 x_o^2 = \frac{1}{2}(0.42)(10.47)^2 x_o^2$$

$$\text{Amplitude } x_o = \sqrt{\frac{2(0.500)}{0.42(10.47)^2}} = 0.147 \text{ m} = 14.7 \text{ cm} = 15 \text{ cm (2 s.f.)}$$

(a)(iii)

$$E_k = \frac{1}{2}mv^2 \Rightarrow v = \sqrt{\frac{2E_k}{m}} = \sqrt{\frac{2(0.500)}{0.42}} = 1.54 \text{ m s}^{-1}$$



- 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

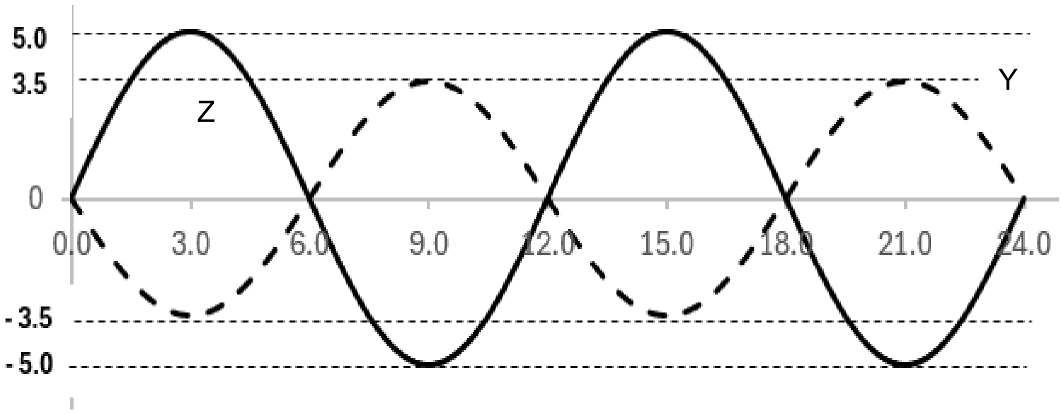
(b)(ii)

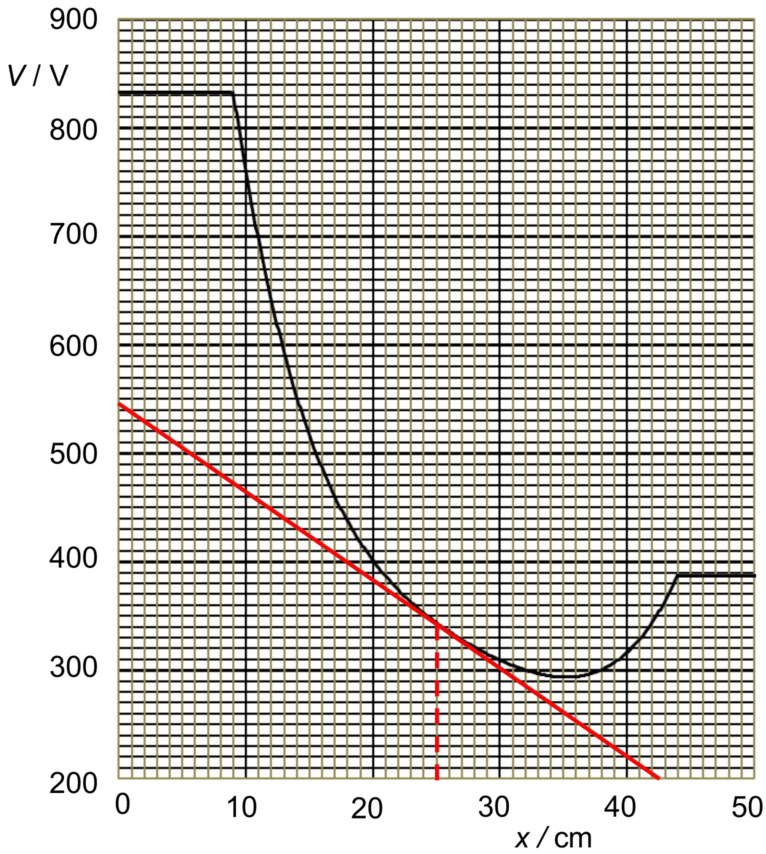
Frequency multiplied by $\sqrt{2}$.

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} $\phi_{\text{neutral point}} - \phi_{\text{earth surface}} = 6.10\times10^{7}$ $\phi_{\text{neutral point}} = 6.10\times10^{7} + \phi_{\text{earth surface}}$ $\phi_{\text{neutral point}} = 6.10\times10^{7} + \left(-62.3\times10^{6}\right)$ $\phi_{\text{neutral point}} = -1.3\times10^{6}$ J kg^{-1} (2 s.f.) OR total energy at Earth surface = total energy at neutral point $KE_{\text{earth surface}} + U_{\text{earth surface}} = KE_{\text{neutral point}} + U_{\text{neutral point}}$ $6.10\times10^{8} + 10\left(-62.3\times10^{6}\right) = 0 - 10.0\times\phi_{\text{neutral point}}$ $\phi_{\text{neutral point}} = -1.30\times10^{6}$ 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 $\Delta\phi = \phi_{\text{neutral point}} - \phi_{\text{moon surface}}$ $= -1.30\times10^{6} - \left(-3.90\times10^{6}\right)$ $= 2.60\times10^{6}$ J kg^{-1} Hence, the minimum kinetic energy needed to send a 1.4 kg rock from the Moon to the neutral point is $m\Delta\phi = (1.4)\left(2.60\times10^{6}\right)$ = 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 $= \dfrac{GM(2M)}{(3R)^2}$, 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*. $F_G = Ma_c$ $\frac{GM(2M)}{(3R)^2} = M(2R)\omega^2$ $R = \sqrt[3]{\frac{GM}{9\omega^2}}$ $= \sqrt[3]{\frac{6.67\times10^{-11}\left(3.14\times10^{30}\right)}{9\left(1.837\times10^{-5}\right)^2}}$ $= 4.10\times10^{9}$ 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** $y = 5.0\sin(\omega t) = 5.0\sin\left(\frac{2\pi}{T}t\right)$ [B1] $y = 5.0\sin\left(\frac{2\pi}{20}12.5\right) = -3.5$ mm **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)	$v = \frac{I}{neA} = \frac{2.0}{8.5 \times 10^{28}(1.60 \times 10^{-19})\pi(0.40 \times 10^{-3})^2} = 2.9 \times 10^{-4}$ 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 <u>already</u> 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, $E_A - E_{ground} = \Delta E$ $E_A - (-4.18)(1.60\times10^{-19}) = 2.502\times10^{-19}$ $E_A = -4.186\times10^{-19}\text{ J}$ $= -2.62\text{ eV}$	
(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, $p_{photon} = \frac{h}{\lambda} = \frac{6.63\times10^{-34}}{795\times10^{-9}} = 8.34\times10^{-28}$ kg m s^{-1} OR $E = hf = \frac{hc}{\lambda} = pc$ From (a)(ii), $E = 2.502\times10^{-19}$ J $\therefore p_{photon} = \frac{E}{c} = \frac{2.502\times10^{-19}}{3.00\times10^{8}} = 8.34\times10^{-28}$ kg m s^{-1} By the principle of conservation of momentum, taking right as positive $p_{atom} - p_{photon} = p'_{atom}$ $\Delta p_{atom} = p'_{atom} - p_{atom} = -p_{photon}$ Thus $\lvert\Delta p_{atom}\rvert = \lvert-(8.34\times10^{-28})\rvert$ $= 8.34\times10^{-28}$ 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 $\Delta\vec{p} = \frac{\Delta\vec{p}_1 + \Delta\vec{p}_2 + \ldots + \Delta\vec{p}_N}{N} = \frac{0}{N} = 0$	
(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, $F = \frac{\Delta p}{\Delta t}$ $= \frac{8.34\times10^{-28}}{27.6\times10^{-9}}$ $= 3.02\times10^{-20}$ 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 $d \approx \frac{1}{\sqrt[3]{1.00 \times 10^{19}}} = 4.6416 \times 10^{-7}$ m , $\frac{h}{\sqrt{3mkT_C}} = \frac{1}{\sqrt[3]{n}}$ $T_C = \frac{h^2}{3mk} n^{\frac{2}{3}}$ $= \frac{\left(6.63 \times 10^{-34}\right)^2}{3\left(86.9 \times 1.66 \times 10^{-27}\right)\left(1.38 \times 10^{-23}\right)} \left(1.00 \times 10^{19}\right)^{\frac{2}{3}}$ $= 3.4164 \times 10^{-7} \approx 3.42 \times 10^{-7}$ 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 $d \approx \frac{1}{\sqrt[3]{1.00 \times 10^{19}}} = 4.6416 \times 10^{-7}$ m , $\frac{1}{\sqrt[3]{n}} = \frac{h}{\sqrt{3mkT_C}}$ $T_C = \frac{h^2}{3mk} n^{\frac{2}{3}}$ $= \frac{\left(6.63 \times 10^{-34}\right)^2}{3\left(86.9 \times 1.66 \times 10^{-27}\right)\left(1.38 \times 10^{-23}\right)} \left(1.00 \times 10^{19}\right)^{\frac{2}{3}}$ $= 3.4164 \times 10^{-7} \approx 3.42 \times 10^{-7}$ K	