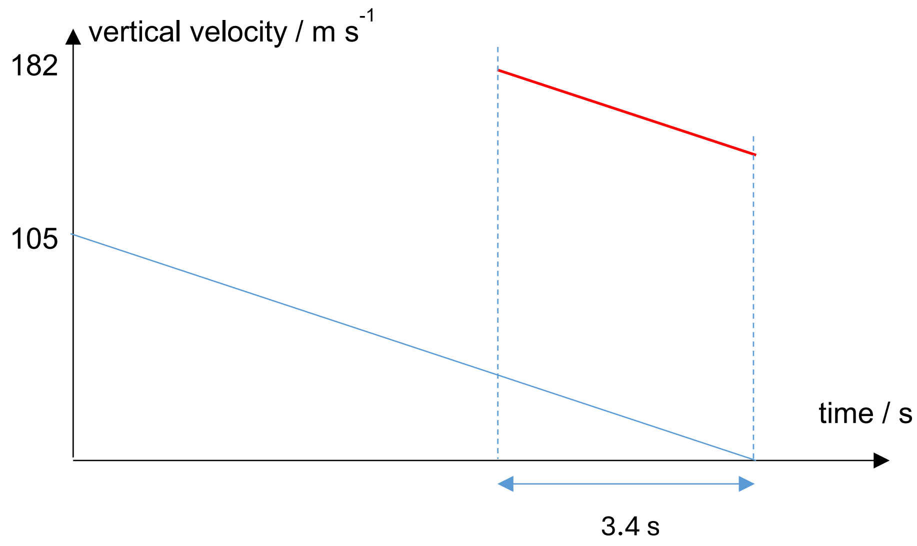
2024 HCI Preliminary Examination Paper 3 Suggested Solutions

Q1		
(a)	Random errors are deviations of the measured value from the mean value, with varying signs and magnitudes. Systematic errors are deviations of the mean value from the true value, with same sign and similar magnitude.	**B1** **B1**
(b)	The units of P are $\frac{(\text{kg m s}^{-2})(\text{m})}{\text{s}}$ = kg m^2 s^{-3} The units of $k\rho A^p v^q$ are (1) $(\frac{\text{kg}}{\text{m}^3})(\text{m}^2)^p(\text{m s}^{-1})^q = \text{kg m}^{-3+2p+q}\text{s}^{-q}$ For the equation to be homogeneous, the units of P must be equal to the units of $k\rho A^p v^q$. Comparing power: seconds: $-q = -3 \Rightarrow q = 3$ metres: $-3 + 2p + q = 2 \Rightarrow p = 1$	**M1** **M1** **A1**

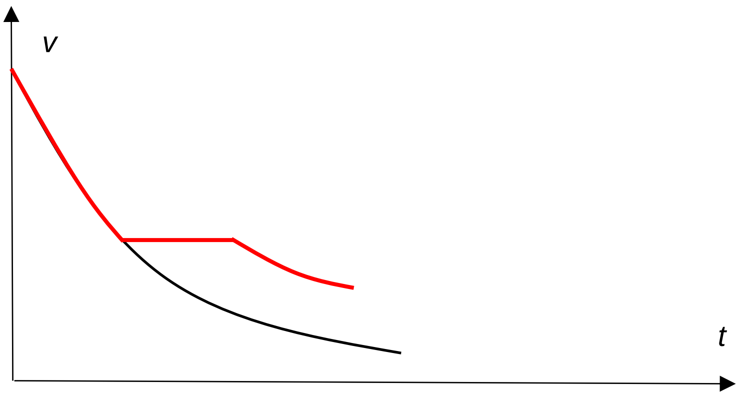
Q2		
(a)	The **acceleration** of an object is its **rate of change of velocity** with respect to time.	**A1**
(b)(i)	Taking upward to be positive and using $v_y^2 = u_y^2 + 2a_y s_y$, where v_y is the vertical component of the final velocity, u_y is the vertical component of the initial velocity, a_y is the vertical component of the acceleration and s_y is the vertical component of the displacement. At the highest point, the vertical component of the velocity is zero. Furthermore, ignoring air resistance, the vertical component of the acceleration is $a_y = -g = -9.81$ m s^{-2}. Hence, $0 = (210 \sin(30^o))^2 + 2(-9.81)\ h$ $h = 561.9$ m $= 560$ m (1, 2 or 3 s.f.)	**M1** **A1**
(b)(ii)	Taking upwards as positive and using $v_y = u_y + a_y t$ $0 = (210 \sin(30^o)) + (-9.81)\ t$ $t = 10.703$ s $= 11$ s (1, 2 or 3 s.f.)	**M1** **A1**
(b)(iii)	From (b)(i), we know that the highest point for P is 561.9 m. Using $s_y = u_y t + \frac{1}{2} a_y t^2$, $561.9 = (210 \sin(60^o))t_Q + (0.5)(-9.81)\ t_Q^2$ $t = 3.4$ s or $t = 33.7$ s Since t must be less than 10.7 [from part (b)(ii)], $t = 33.7$ s should be rejected. $t = 3.4$ s (shown)	**B1** **A0**
(b)(ii)	 B1 – **parallel to** and **above** original line. (P starts at $210 \sin 30° = 105$ m s^{-1} while Q starts at $210 \sin 60° = 182$ m s^{-1}. Values not needed in sketch) B1 – **starts after mid-point** of original line and **ends at the same time** (3.4 s not needed in sketch)	

Q3		
(a)(i)	Fluid **pressure increases with depth**. The **upward forces** due to the fluid pressure acting on the lower surface of the material are larger than the **downward forces** due to the fluid pressure acting on the upper surface of the material, resulting in a **net upward force** called the upthrust.	**B1** **B1**
(a)(ii)	Upthrust on cup = weight of water displaced $= V \rho_{water} g$ $= (6.8 \times 10^{-5}) \times (1000) \times (9.81) = 0.66708$ N Weight of cup $= V \rho_{cup} g$ $= (6.8 \times 10^{-5}) \times (2200) \times (9.81)$ $= 1.4676$ N Since the weight of the cup is larger than the upthrust acting on the cup, an *upwards* external force *F* is required to keep the cup stationary. Since the cup is held in equilibrium, the net force acting on the cup is zero. Hence, $F + U = W_{cup}$ $F = W_{cup} - U$ $= 1.4676 - 0.66708$ $= 0.800496$ $= 0.80$ N	**M1** **M1** **A0**
(a)(iii)	Since the cup was already fully submerged, there is **no difference in the volume** and hence weight **of fluid displaced**, the upthrust stays constant. or The **difference in pressure between the upper and lower surface remains the same** and therefore the upthrust stays constant.	**B1** **B1**
(b)	Pressure of compressed air = pressure at depth *d* = (atmospheric pressure) + (hydrostatic pressure) $= p_{atm} + \rho g d$ $= (1.0 \times 10^5) + (1000) \times (9.81) \times (0.30)$ $= 1.02943 \times 10^5$ Pa Applying $p V$ = constant, since temperature is unchanged, $(1.0 \times 10^5)(5.50 \times 10^{-4}) = (1.02943 \times 10^5) V$ $V = 5.3429 \times 10^{-4}$ m^3 $= 5.3 \times 10^{-4}$ m^3	**B1** **M1** **A1**

Q4		
(a)	An oscillatory motion where the acceleration is directly proportional to displacement from equilibrium, and where acceleration is always opposite to displacement / acceleration is always directed toward equilibrium.	**B1** **B1**
(b)	Since $a \propto -y$ By comparing with $a = -\omega^2 x$, $\omega^2 = \frac{\rho A g}{M}$ $T = \frac{2\pi}{\omega}$ $= 2\pi\sqrt{\frac{M}{\rho A g}}$ $= 2\pi\sqrt{\frac{0.012 + 0.025}{1000 \times 6.0 \times 10^{-4} \times 9.81}}$ $= 0.498$ s $= 0.50$ s	**B1** **B1**
(c)(i)	Energy of oscillation is the (maximum) kinetic energy the test-tube possesses, which decreases with time due to damping. Energy of oscillation = $\frac{1}{2} m v_0^{\ 2} = \frac{1}{2} m (\omega A)^2 = \frac{1}{2} m \omega^2 A^2$. A reduction of 75 % would mean that the energy of oscillation remaining is 25 % of its original. $\frac{E'}{E} = \frac{A'^2}{1.0^2}$ $\frac{1}{4} = \frac{A'^2}{1.0^2}$ $A' = 0.50$ cm From the graph, this happens at 1.0 s.	**M1** **A1**
(c)(ii)	Natural frequency of the system is 2.0 Hz (since period is 0.5 s). However, the driving frequency is only 1.0 Hz. Energy transfer from the (external forcing agent) water waves to the test-tube is not optimal / does not result in resonance.	**B1** **B1**

Q5		
(a)(i)	Q = mass x specific latent heat of vaporisation $= 0.37 \times 2.3 \times 10^6$ $= 8.5 \times 10^5$ J	**A1**
(a)(ii)	$pV = nRT$ $T = (100 + 273) = 373$ K Number of moles, $n = 0.37 \times 1000$ g / 18 g $V = \frac{(0.37 \times 1000) \times 8.31 \times 373}{18 \times (1.0 \times 10^5)}$ $= 0.63714$ $= 0.64$ m^3	**B1** **B1** **B1**
(a)(iii)	Work done *by* the water = (atmospheric pressure)(increase in volume) $= (1.0 \times 10^5)(0.64)$ $= 6.4 \times 10^4$ J	**A1**
(a)(iv)	Work done on water is negative. From the first law of thermodynamics, increase in internal energy = heat supplied + work done *on* water $= (8.5 - 0.64) \times 10^5$ $= 7.9 \times 10^5$ J	**M1** **A1**
(b)	Kinetic energy of the molecules remains unchanged because there is no temperature change. Potential energy of the molecules increases, because molecular bonds are broken and the molecules are further apart. Hence, the internal energy of the system increases.	**B1** **B1** **A0**

Q6		
(a)(i)	The resistance is infinite.	**B1**
(a)(ii)	The resistance decreases as *V* increases.	**B1**
(b)(i)	Method 1: When the galvanometer reads zero, $V_{XZ} = V_{LDR} = \frac{R_{LDR}}{R_{LDR} + R} E = \frac{1600}{1600 + 1200}(9.0) = 5.143\text{ V}$ For the wire, $\frac{V_{XZ}}{V_{XY}} = \frac{L_{XZ}}{L_{YZ}} \quad \Rightarrow L_{XZ} = \frac{V_{XZ}}{V_{XY}} L_{YZ} = \frac{5.143}{9.0}(1.2) = 0.6857$ $= 0.69\text{ m}$ Method 2: $\frac{V_{XZ}}{V_{ZY}} = \frac{V_R}{V_{LDR}} \Rightarrow \frac{kL_{XZ}}{kL_{ZY}} = \frac{I \times 1600}{I \times 1200} = \frac{4}{3}$ $L_{XZ} = \frac{4}{7} \times 1.2$ $= 0.69\text{ m}$	**M1** **A1** **M1** **A1**
(b)(ii)1	As intensity of light is increased, the resistance of the LDR decreases and there is a smaller potential difference across the LDR. The length of XZ decreases.	**M1** **A1**
(b)(ii)2	The total resistance of the circuit decreases and more current is drawn from the battery. Hence power produced by the battery increased. OR The total resistance of the circuit decreases. Since power produced by battery = V^2/R_{total}, power produced by battery increased.	**M1** **A1** **M1** **A1**

Q7		
(a)	The magnetic flux (linkage) is given by $\Phi = NBA = B(wx)$ where x is the distance AB has moved past P. Hence the induced emf is given using **Faraday's Law** by $E = \frac{d\Phi}{dt} = Bw\frac{dx}{dt}$ $Bw\frac{dx}{dt} = Bwv$	**B2**
(b)(i)	As AB moves from P towards Q, **magnetic flux linkage** over the area ABCD enclosed by the frame **increases** resulting in an **induced e.m.f.** generated in the frame **by Faraday's Law**. **By Lenz's Law**, an **induced current** will flow **such that it opposes the increase in magnetic flux linkage**. (current flows in anticlockwise direction) Consequently, a **magnetic force acts on AB towards the left**, causing it to slow. (Using Fleming's Left Hand Rule) <u>Alternative</u>: AB **cuts the magnetic flux** as it moves through PQ, resulting in an induced e.m.f. generated in the frame **by Faraday's Law**. There is **induced current** in the full circuit **in the anticlockwise direction**. (or electrons in the clockwise direction) Consequently, a **magnetic force acts on AB towards the left**, causing it to slow. B1 – why there is an induced emf B1 – how is the direction of induced current determined B1 – effect on AB/frame	**B1** **B1** **B1** **B1** **B1** **B1**
(b)(ii)	 B1 – same slope where the speed is the same as the original graph B1 – plateau B1 – shorter time to pass through the field, higher speed as it leaves the field	**B3**

Q8		
(a)(i)	α-particles are very strong ionising radiation and hence have very weak penetrating power and would be stopped by a few cm of air. **OR** Alpha particles could be deflected by air molecules (obscuring the results).	**B1**
(a)(ii)1	Majority of α-particles passed through with little or no angular deflection. (This suggests that the gold nucleus is made up mostly of empty space, hence the nucleus must be very tiny. Students who stated something to the effect of 'few of the alpha particles underwent deflection or large deflection' would not get the credit. The reason being that the reverse of the statement need not be 'most of the alpha particles were undeflected', it could be that 'most of the alpha particles were absorbed.' This could still imply that the gold nucleus is large in dimensions.)	**B1**
(a)(ii)2	<u>One of the following:</u> A few α-particles were scattered by large angles. **OR** A few α-particles backscattered. (The deflections suggest that the gold nucleus is charged (as the alpha-particle is charged, and the back scattering – deflections that are larger than 90° imply that the nucleus is massive)	**B1**
(b)(i)	$E = \Delta m\, c^2$ $= [(18.00696 - 18.00568) \times 1.66 \times 10^{-27}] \times (3.0 \times 10^{8})^2$ $= 1.91232 \times 10^{-13}$ J $= 1.9 \times 10^{-13}$ J	**B1**
(b)(ii)	The helium nuclei possessed kinetic energy that can be used for the reaction.	**B1**
(b)(iii)	The products must also have non-zero kinetic energy after the reaction since the reactants had non-zero total momentum to begin with.	**B1**

Q9		
(a)	When two or more waves overlap/meet at the point (at a particular instance), the **resultant displacement** at that point is the **vector sum of the displacements** which would be caused by each wave at the point (at that instance).	**B1** **B1**
(b)(i)	From graph, Period of waves = 40.0×10^{-9} s Frequency = $1/40.0 \times 10^{-9} = 25.0 \times 10^{6}$ Hz = 25.0 MHz	 **B1** **A0**
(b)(ii)	At M, the waves arrive in phase / path difference is zero, hence constructive interference occurs Resultant wave amplitude = 2A (where A is the amplitude due to an individual wave), A = 0.5 units When only one source is on, the amplitude is 0.5 units. Diagram of waveform with same period, phase and amplitude = 0.5 units drawn. B1 – explain why constructive interference B1 – either indicating that resultant wave amplitude is twice or that the amplitude of each wave (from A or B) is half that observed at M. B1 – correct graph drawn	**B1** **B1** **B1**
(b)(iii)	Distance from M to N = distance between an antinode to a node = ¼ λ = ¼ (c/f) = ¼ ($3.00 \times 10^{8} / 25.0 \times 10^{6}$) = 3.00 m M1 – relating MN to λ/4 M1 – for finding λ using c=f λ Alternative: Let the distance moved be *x* so that the path difference increased by half a wavelength. (AN – BN) = ½ λ (6.00 + *x*) – (6.00 – *x*) = (0.5) ($3.00 \times 10^{8} / 25.0 \times 10^{6}$) where *x* is distance from M to N. *x* = 3.00 m	 **M1** **M1** **A0**

(b)(iv)	Point M is 6.00 m from A and B respectively. Point N is 9.00 m from A and 3.00 m from B As A and B are point sources, intensity of wave from each source, $I = \frac{\text{Power from source}}{4\pi r^2}$ (As power from sources are equal and constant), Hence $I \propto \frac{1}{r^2}$ $\frac{I_A}{I} = (\frac{6.00}{9.00})^2$ $I_A = 0.4444I$ = 0.444 I (shown) $\frac{I_B}{I} = (\frac{6.00}{3.00})^2$ I_B = 4.00 I (shown)	**B1** **B1** **B1**
(b)(v)	Using $I \propto A^2$ At point N, A_A is amplitude of wave due to source A and A_B is amplitude of wave due to source B. At point M, I is the intensity of wave from a single source (either A or B) and the amplitude of a wave from either source is 0.5 units. $\frac{0.444I}{I} = (\frac{A_A}{0.5})^2$ A_A = 0.333 units $\frac{4I}{I} = (\frac{A_B}{0.5})^2$ A_B = 1.00 units At N, waves source A and B arrive in antiphase, resultant amplitude = 1.000 – 0.333 = 0.666 units.	**M1** **M1** **A1**
(c)(i)	1. *D* must be much larger than *a*. (so that the two paths are parallel, resulting in $a\sin\theta = n\lambda$, where θ is the angle of each order. Clearly from the equation, the orders are not equally spaced). 2. *a* must be much larger than *λ*. (so that the angle is small and small-angle approximations can be made and fringe separation is then constant).	**A1** **A1**
(c)(ii)	$x = \frac{\lambda D}{a}$ (students must use the symbols defined in the question)	**A1**
(c)(iii)	As the slits have a finite width, the 1st order minima (due to single-slit diffraction) coincides where the 5th order maxima (due to double-slit interference) occurs.	**A1**

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<td>(c)(iv)</td>
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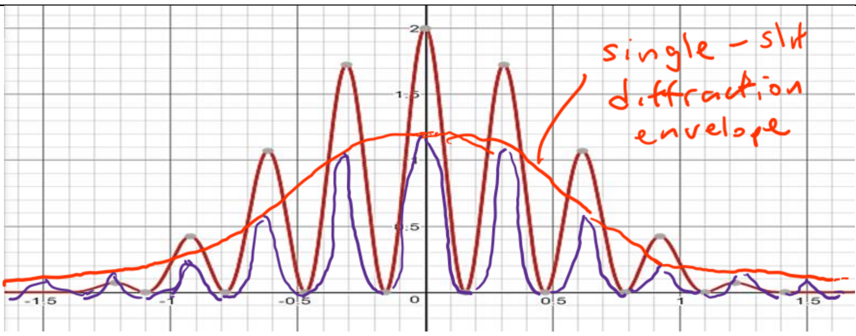

Marking points:

All fringes should be clearly shown to occur at the same position as original diagram. (As fringe separation x does not change.) (This mark must be awarded for the next mark to be awarded)
5th order maxima should be visible
(Using $\sin\theta = \frac{\lambda}{b}$ (single-slit diffraction), when b decreases, the angle of diffraction (of 1st or minima) gets wider thus the 5th order maxima of the double-slit interference pattern should be visible.

Additional points (not assessed)

The fringes should not exceed the single-slit diffraction envelope. (Also there should be symmetry of intensity about the zero order maximum.
As b decreases, amount of energy that passes through slits decreases, thus the intensity of light at the zero order maximum (for the double-slit interference pattern) should be reduced. For example, if the width is halved, the amplitude at the central maximum would be halved, resulting in intensity that is ¼ of the original.

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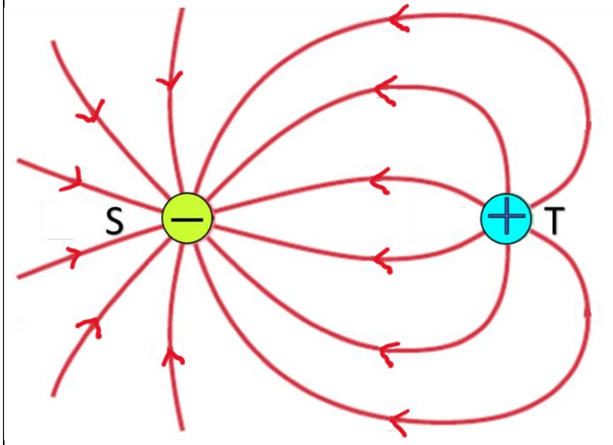
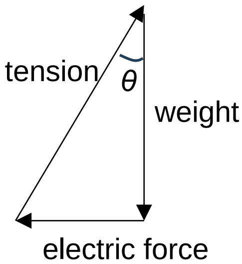
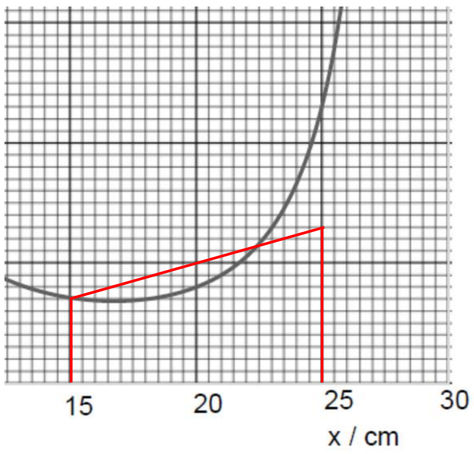
Q10		
(a)	Electric field strength at a point is the **electric force per unit positive charge** on a small test charge placed at the point.	**B1**
(b)(i)	 Correct direction. Correct ratio of lines (2:1). Correct asymmetry.	**B1** **B1** **B1**
(b)(ii)1	Consider the force-diagram of sphere T. The electric force must act horizontally to the left since S and T are align horizontally. The weight must act vertically down. Since T is in equilibrium under the effect of 3 forces, these three forces must force a closed right angle triangle as shown.  Electric force $= \frac{1}{4\pi\varepsilon_0}\frac{(2.4\times10^{-6})(1.2\times10^{-6})}{0.30^2}$ $= 0.287738$ N $\theta = \tan^{-1}\left(\frac{\text{electric force}}{\text{weight}}\right) = \tan^{-1}\left[\frac{0.287738}{0.036(9.81)}\right]$ $= 39°$	**M1** **M1** **A1**
(b)(ii)2	Once the string is cut, the net force on sphere T will be the vector sum of the weight and electric force. $\Sigma F = ma$ $\sqrt{[(0.036)(9.81)]^2 + 0.287738^2} = (0.036)a$ $a = 13$ m s^{-2}	**B1** **M1** **A1**

(b)(iii)	Area under the graph is **change** in potential. $\Delta V = \frac{1}{2}(0.10)\left[(0.14+0.26)\times10^{7}\right]$ $= 2.0\times10^{5}$ V (accept +/- 10%) From 25 cm to 15 cm, the positive helium nucleus loses potential energy and gains kinetic energy.  Gain in KE = $q\Delta V = 2\left(1.60\times10^{-19}\right)\left(2.0\times10^{5}\right) = 6.4\times10^{-14}$ J	**B1** **M1** **M1** **A1**
(c)(i)	Weight of lithium ion = $mg = 6.941\times1.66\times10^{-27}\times9.81 = 1.13\times10^{-25}$ N Electric force on ion = $qE = 1.60\times10^{-19}\times\left(\frac{150}{0.020}\right) = 1.2\times10^{-15}$ N The electric force is about 10^{10} times larger or 10 orders of magnitude larger than the gravitational force or weight.	**M1** **M1** **A1**
(c)(ii)	Time taken to travel through plates = $\frac{0.090}{3.0\times10^{5}} = 3.0\times10^{-7}$ s Applying $s = ut + \frac{1}{2}at^{2}$ in the vertical direction, $y = \frac{1}{2}\left(\frac{1.2\times10^{-15}}{6.941\times1.66\times10^{-27}}\right)\left(3.0\times10^{-7}\right)^{2}$ y = 4.7 mm	**M1** **M1** **A1**