Qn	Suggested Answer
1	
(a)(i)	The *linear momentum* of a body is defined as the product of its mass and its velocity and it is in the direction of the velocity.
(a)(ii)	The total final momentum of a system after a collision is equal to total initial momentum of the system before the collision
	provided no net external force acts on the system.
(b)(i)	Applying the principle of conservation of momentum, $m_A v_A + m_B v_B = 0$ $2.0 v_A = -1.0 v_B$ $v_B = -2.0 v_A \quad \cdots(1)$
	Applying law of conservation of energy, $\frac{1}{2} m_A {v_A}^2 + \frac{1}{2} m_B {v_B}^2 = 12 \quad \cdots(2)$
	Substitute equation (1) into equation (2), $\frac{1}{2}(2.0){v_A}^2 + \frac{1}{2}(1.0)(2.0v_A)^2 = 12$ ${v_A}^2 + 2.0{v_A}^2 = 12$ $\lvert v_A \rvert = 2.0 \text{ m s}^{-1}$
	$\lvert v_B \rvert = 4.0 \text{ m s}^{-1}$
(b)(ii)	A and B are moving towards each other. At any instant of time, the speed of B is twice that of A, distance covered by B is twice that of A when they collide.
	$x_A + x_B = 0.90$ $x_A + 2x_A = 0.90$
	$x_A = 0.30$ m
2	
(a)	An *ideal gas* obeys the equation *pV* = *nRT* where *p* is the gas pressure, *V* is the volume of the gas, *n* is the number of moles of gas, *R* is the universal gas constant, and *T* is the thermodynamic temperature of the gas.
	There are no intermolecular forces between the gas molecules, therefore an ideal gas has no potential energy.
(b)(i)	$PV = Nkt$ $N = \frac{PV}{kT}$ $= \frac{4.8 \times 10^5 \times 2.3 \times 10^4}{100^3 (65 + 273.15) \times 1.38 \times 10^{-23}}$
	$= 2.37 \times 10^{24}$ (3 s.f.)
(b)(ii)	$E = \frac{3}{2} NkT$ $= \frac{3}{2}(1.38 \times 10^{-23})(65 + 273.15)(2.37 \times 10^{24})$
	$= 1.66 \times 10^4$ J (3 s.f.)

(b)(iii)

$$\frac{1}{2}mc_{rms}{}^{2}=\frac{3}{2}kT$$

Since m and k are constant,

$$c_{rms}{}^{2}\propto T$$

$$\frac{c_{rms65}}{c_{rms75}}=\sqrt{\frac{(65+273.15)}{(75+273.15)}}$$

$$=0.986 \text{ (3 s.f.)}$$

(c)(i) The product of pressure and volume of the gas at B and C are the same.

(c)(ii)

process	work done on the gas / × 10^4 J	heat supplied to the gas / × 10^4 J	increase in internal energy / × 10^4 J
A → B	−1.92	4.80	2.88
B → C	3.05	−3.05	0
C → A	0	−2.88	−2.88

$$WD_{AB}=-p(\Delta V)$$

$$=-\frac{4.8\times10^{5}(6.3-2.3)\times10^{4}}{100^{3}}$$

$$=-1.92\times10^{4}\text{ J}$$

3

(a) As the tube is partially submerged, there is upthrust.

The weight and upthrust are equal in magnitude and acts in opposite directions. Hence, the resultant force is zero.

(b) At equilibrium,

weight of the tube and sand = upthrust

$$Mg=\rho Ahg$$

When further displaced and taking downwards as positive,

$$Mg-\rho A\left(h+x\right)g=Ma$$

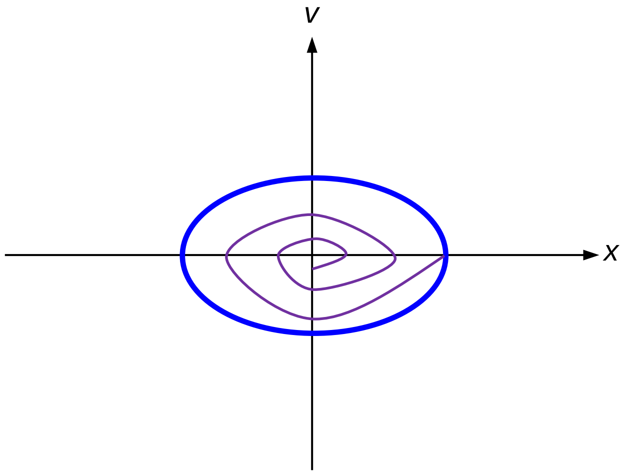
$$\rho Ahg-\rho Ahg-\rho Axg=Ma$$

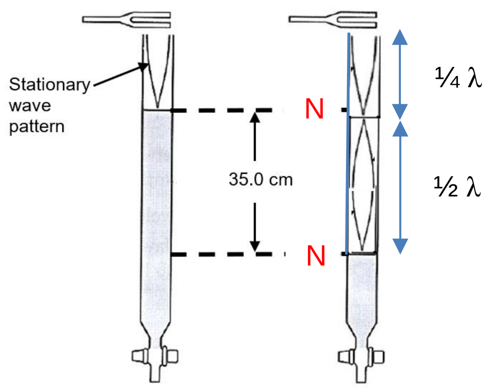
$$-\rho Axg=Ma$$

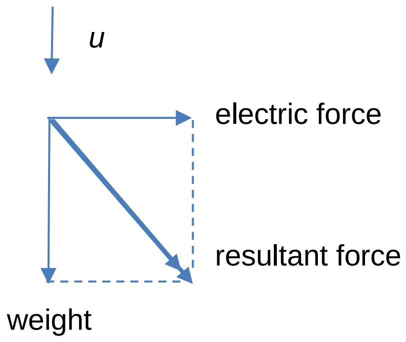
$$a=-\left(\frac{\rho Ag}{M}\right)x$$

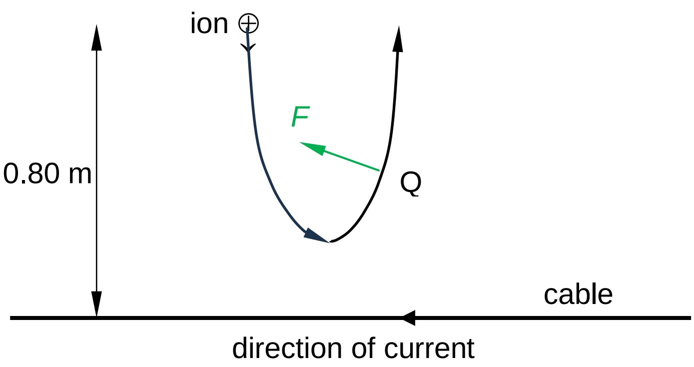
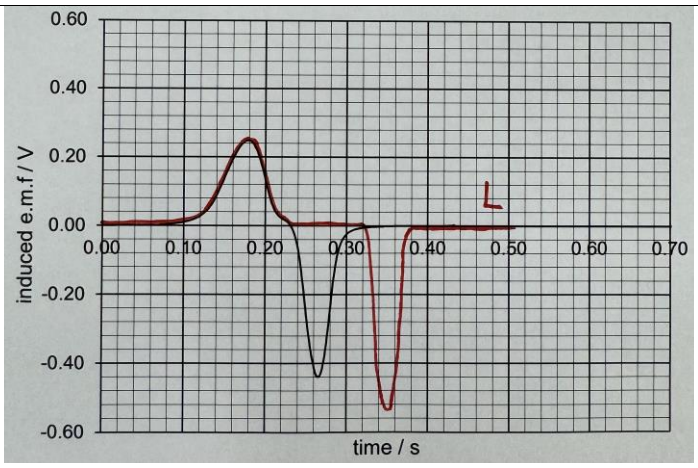
(c) Since ρ, A, g and M are constants, acceleration is directly proportional to displacement.

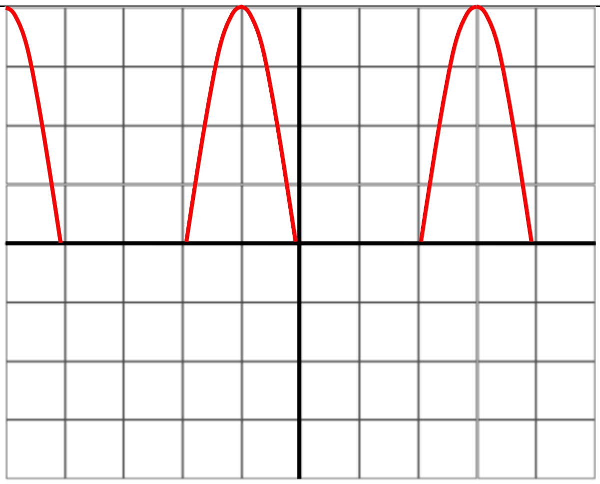
The negative sign shows that acceleration is in the opposite direction to displacement.

(d)	$\omega^2 = \dfrac{\rho A g}{M}$
	$\dfrac{2\pi}{T} = \sqrt{\dfrac{\rho A g}{M}}$ $f = \sqrt{\dfrac{\rho A g}{4\pi^2 M}}$ $f = \sqrt{\dfrac{(1.2\times10^{3})(5.5\times10^{-4})(9.81)}{4\pi^2(120\times10^{-3})}}$
	$= 1.2$ Hz (2 s.f.)
	
(e)(i)	Correct shape.
(e)(ii)	Spiral inwards clockwise starting from positive maximum displacement (downwards positive).
4	
(a)(i)	A *polarised wave* is a wave whose vibrations are restricted to one plane.
(a)(ii)	Apply Malus' Law, $I_1 = I_0(\cos 40°)^2$
	$I_2 = I_0(\cos 40°)^2(\cos 80°)^2$ $= 0.018I$ (2 s.f.)
(b)(i)1.	Displacement of wave laterally (left and right) from the central axis of the tube represents vibrations of air molecules vertically (up and down) along the axis of the tube.
	The vibrations are parallel to the direction of propagation of the incident wave down the tube.

	
(b)(i)2.	Correct stationary wave pattern.
(b)(i)3.	Correct number of nodes and location of nodes.
(b)(ii)	$\frac{1}{2}\lambda = 35.0 \text{ cm}$ $\lambda = 70.0 \text{ cm}$
	$f = \frac{340}{0.700}$ $= 486 \text{ Hz (3 s.f.)}$
(c)(i)	$d \sin\theta = n\lambda$ $\frac{1}{5.00\times10^{5}} \sin 90^\circ = n(540\times10^{-9})$
	$n = 3.70$ $= 3$ (round down to nearest whole number)
	Total number of maxima $= (3\times2)+1$ $= 7$
(c)(ii)	$d \sin\theta = n\lambda$ $\frac{1}{5.00\times10^{5}} \sin\theta = 2(542\times10^{-9})$ $\theta = 32.820^\circ$ $d \sin\theta = n\lambda$ $\frac{1}{5.00\times10^{5}} \sin\theta = 2(539\times10^{-9})$ $\theta = 32.616^\circ$
	Angular separation is 0.204° Since angular separation is less than 0.30°, the two wavelengths cannot be distinguished at the second order.
5	
(a)	Electric force $= q\frac{\Delta V}{d}$ $= 0.78\times10^{-6}\frac{2000}{5.0}$ $= 3.12\times10^{-4} \text{ N}$
	Direction of electric force is rightwards towards Q.

(b)(i)	 Forces must be labeled clearly.
(b)(ii)	The weight of particle X has the same order of magnitude as the electric force.
(c)	Horizontally, $s_x = 5.0, u_x = 0, a_x = \frac{3.12\times10^{-4}}{\frac{4.9\times10^{-4}}{9.81}} = 6.25 \text{ m s}^{-2}$
	Using $v_x^2 = u_x^2 + 2a_x s_x$, $v_x = 7.91 \text{ m s}^{-1}$
	Using $s_x = \frac{1}{2}a_x t^2$, $t = 1.26$ s Vertically, Using $v_Y = u + a_y t$ $v_Y = 23 + (9.81)(1.26)$ $= 35.4 \text{ m s}^{-1}$
	Magnitude of resultant velocity $= \sqrt{7.91^2 + 35.4^2}$ $= 36.3 \text{ m s}^{-1}$ (3 s.f.)
(d)	Since electric force and weight are of constant magnitudes and directions, the resultant force would also be of constant magnitude and direction.
	As the velocity has a component along the resultant force and a component perpendicular to it, the path taken by the particle would be parabolic.
(e)	$\Delta V = 2000$ V
	Change in EPE $= q\Delta V$ $= (-0.78\times10^{-6})(1000-(-1000))$ $= -1.56\times10^{-3}$ J
6	
(a)	Force per unit length acting on a straight, current-carrying conductor,
	carrying unit current and placed at right angles to an external magnetic field.

(b)(i)	$B=\left(\dfrac{4\pi\times10^{-7}\times80}{2\pi\times0.80}\right)$
	$F=Bqv\sin90°$ $=\left(\dfrac{4\pi\times10^{-7}\times80}{2\pi\times0.80}\right)(1.6\times10^{-19})(1.0\times10^{3})$
	$=3.2\times10^{-21}$ N
(b)(ii)	
	Force drawn perpendicularly to the tangent of the path at Q.
(b)(iii)	At P, the ion will experience a magnetic force to the right by FLHR. This will make the ion move in a circle.
	As ion moves nearer the cable, magnetic flux density due to the cable increases (*B* α 1/*r*), increasing the magnetic force (*F* = *Bqv*).
	Thus, the radius of circular path becomes smaller. Eventually there will be a point where the ion is moving parallel to the cable. The magnetic force will then cause the ion to turn back, with the radius of the circular path becoming larger as the ion moves further away from the cable.
(c)(i)1.	The magnetic field of the magnet is not uniform and the magnet's velocity is changing.
	The rate of change of magnetic flux linkage will not be constant.
(c)(i)2.	The magnetic flux linkage increases when the magnet enters the coil and decreases when the magnet leaves the coil.
(c)(i)3.	The magnet's velocity increases as it falls through the coil.
	The magnitude of the change in the magnetic flux linkage (area under the graph) is the same.
(c)(ii)	

	The positive e.m.f. region will be the same (as the magnet is released from the same height and would have the same velocity entering the coil (same rate of change of magnetic flux linkage)). There will be a region where e.m.f. is zero. (This is when the magnet is moving fully inside the coil as there is no rate of change magnetic flux linkage).
	The negative e.m.f. region will have a larger value of maximum e.m.f. with a shorter duration (as the magnet would have a higher velocity leaving the coil due to greater distance moved (greater rate of change of magnetic flux linkage)). (The positive area should be roughly equal to negative area.)
(d)(i)	For a half-rectified wave, $I_{rms} = \frac{I_0}{2}$
	$V_0 = I_0 R$ $= (2 \times 5.0 \times 10^{-3})(2.0 \times 10^{3})$ $= 20$ V
(d)(ii)	
	Timebase: f = 50 Hz, T = 20 ms (4 squares) Voltage gain: V_o = 20 V (4 squares)
	Correct shape: half-rectified wave of at least 2 cycles
7	
(a)	A photon is a quantum (i.e. a discrete amount) of energy of electromagnetic radiation.
	and its energy E, is given by $E = hf$ where h is the Planck's constant and f the frequency of the radiation.
(b)(i)	Discrete bright coloured lines on a dark background.
(b)(ii)	Each line in the emission spectrum corresponds to a specific frequency f, of the photons emitted.
	The photons are emitted when electrons transit from a higher to a lower electron energy level. Hence each energy level must be discrete.
(c)(i)	An atom is said to be in its ground state when the electrons in the atom occupies all the lowest energy states available.

(c)(ii)	Ionisation energy $E=-\frac{13.6}{\infty^2}-\left(-\frac{13.6}{1^2}\right)$ $=13.6\text{ eV}$ $=13.6\left(1.60\times10^{-19}\right)$
	$=2.176\times10^{-18}$ $=2.18\times10^{-18}$ J (3 s.f.)
(d)(i)	$\Delta E=\left(-\frac{2.176\times10^{-18}}{m^2}\right)-\left(-\frac{2.176\times10^{-18}}{2^2}\right)$ $\frac{hc}{\lambda}=2.176\times10^{-18}\left(\frac{1}{2^2}-\frac{1}{m^2}\right)$
	$\frac{1}{\lambda}=\frac{2.176\times10^{-18}}{hc}\left(\frac{1}{2^2}-\frac{1}{m^2}\right)$ $R=\frac{2.176\times10^{-18}}{\left(6.63\times10^{-34}\right)\left(3.00\times10^{8}\right)}$
	$=1.094\times10^{7}$ $=1.09\times10^{7}$ m^{-1} (3 s.f.)
(d)(ii)	Longest wavelength corresponds to m = 3 $\frac{1}{\lambda}=1.09\times10^{7}\left(\frac{1}{2^2}-\frac{1}{3^2}\right)$ $=1.514\times10^{6}$
	$\lambda=\frac{1}{1.514\times10^{6}}$ $=6.61\times10^{-7}$ m (3 s.f.)
(d)(iii)	Visible (red) light
(e)(i)	Electron diffraction / (Compton scattering).
(e)(ii)	$2\pi r=3\lambda_e$
	$\lambda_e=\frac{h}{m_e v}$
	$2\pi r=3\left(\frac{h}{m_e v}\right)$ $v=\frac{3h}{2\pi r m_e}$ $=\frac{3\left(6.63\times10^{-34}\right)}{2\pi\left(4.78\times10^{-10}\right)\left(9.11\times10^{-31}\right)}$ $=7.27\times10^{5}$ m s^{-1} (3 s.f.)

(e)(iii)	$\Delta x\,\Delta p \geq h$ $\Delta v \geq \dfrac{h}{m_e \Delta x}$ $\geq \dfrac{6.63 \times 10^{-34}}{\left(9.11 \times 10^{-31}\right)\left(0.0100 \times 10^{-9}\right)}$
	$\geq 7.278 \times 10^{7}\ \text{m s}^{-1}$ $\geq 7.28 \times 10^{7}\ \text{m s}^{-1}$ (round up to 3 s.f.)