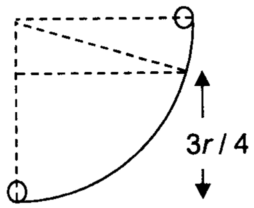
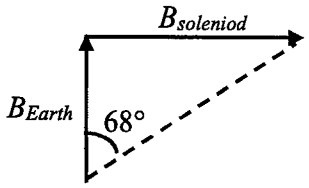
Qn	Ans	Discussion
1	B	mass of car $\approx$ 2000 kg speed $\approx 100\text{ km h}^{-1} \approx 28\text{ m s}^{-1}$ $\text{KE} = \frac{1}{2}mv^2 = 0.784\text{ MJ}$
2	C	$\frac{\text{KE}_{\text{top}}}{\text{KE}_{\text{initial}}} = \frac{\frac{1}{2}m(u\cos\theta)^2}{\frac{1}{2}mu^2} = \cos^2\theta$
3	A	At steady speed of 1.4 m s^{-1}, air resistance = weight component along slope 1.4 k = (80.0)(9.81)sin5° k = 48.857 At steady speed of 5.5 m s^{-1}, air resistance = (5.5)(48.857) = 268.71 N Additional force required = 268.71 – (80.0)(9.81)sin5°= 200 N (2 s.f.)
4	B	$x_1 = 10.0 - 7.5 = 2.5\text{ cm}$ At constant speed: $mg = kx_1$ $mg = kx_1 - (1)$ When slowing down: $mg - kx_2 = ma - (2)$ Sub(1) into (2) $kx_1 - kx_2 = ma - (3)$ $\frac{(3)}{(1)} \to \frac{a}{g} = \frac{x_1 - x_2}{x_1}$ $x_2 = 1.99 \approx 2.0\text{ cm}$ new length $= 10.0 - 2.0 = 8.0$ cm
5	B	Applying cosine rule, $(\Delta v)^2 = (20)^2 + (15)^2 - 2(20)(15)\cos 45°$ $\Delta v = 14.2\text{ m s}^{-1}$ $\Delta p = m\Delta v$ $= 0.140(14.2)$ $= 2.0\text{ N s (2 s.f.)}$
6	C	Considering X, Y and Z as a system, $F = 6\,ma$ Considering X as a system, $F - F_{YX} = ma$ $F_{YX} = 5\,ma = 5/6\,F$
7	A	Taking moments about the contact of the beam with the wall, Sum of clockwise moments = sum of anti-clockwise moments (Tcos30°)(Lsin60°) = (Tsin30°)(Lcos60°) + (1/2W)(Lsin60°) T = 85 N (2 s.f.)

8	B	$E_p = E_T$ $mgr = \frac{1}{2} m (4^2)$ $gr = 8$ If the mass possesses 75% of E, it means E has decreased by 25%. Let x be the point where GPE has decreased by $E/4$, $E_p = E_x$ $mgr = mg(3r/4) + \frac{1}{2} m v^2$ $v^2 = \frac{1}{2} gr$ $v = 2.0 \text{ m s}^{-1}$ 
9	C	As $v = r\omega$, Since ω is constant and r is decreasing at a steady rate with time, $v \propto r \propto t$ Graph is a straight line, negative gradient but with a non-zero speed (as $r \neq 0$)
10	D	All geostationary satellites must have the same radius, and angular velocity $\omega = \frac{2\pi}{T}$, and hence they will have the same linear speed.
		Why C is incorrect $m r \omega^2 = \frac{GMm}{r^2}$ where r - radius of orbit $T^2 = \frac{4\pi^2}{GM} r^3$ $(24 \times 60 \times 60)^2 = \frac{4\pi^2}{(6.67 \times 10^{-11})(6.0 \times 10^{24})} r^3$ $r = 4.231 \times 10^7 \text{ m}$ height from surface, $h = 4.231 \times 10^7 - R$
11	A	$M d \omega^2 = \frac{GM(3M)}{(d+D)^2}$ ……(1) $3MD\omega^2 = \frac{GM(3M)}{(d+D)^2}$ ……(2) Compare (1) & (2), $d = 3D$ ……(3) From (2) $\omega^2 = \frac{GM(3M)}{(3D+D)^2}\left(\frac{1}{3MD}\right)$ $\omega^2 = \frac{GM}{16D^3}$ ……(4)

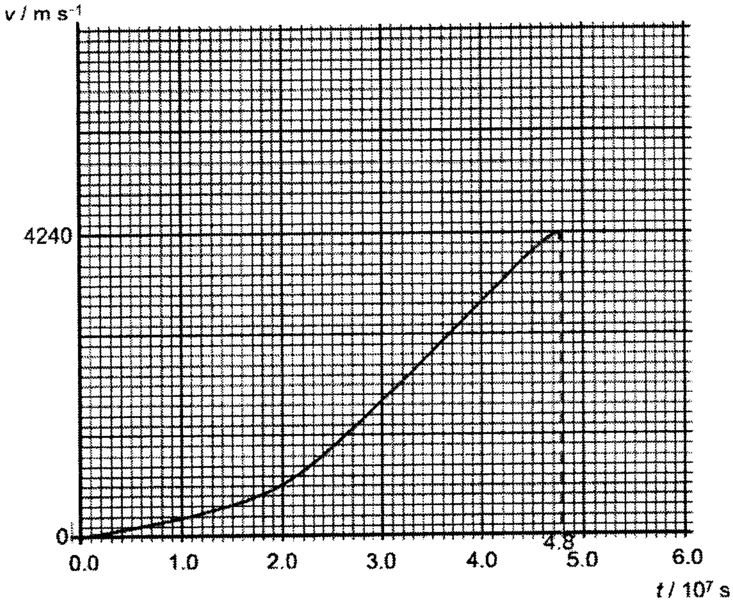
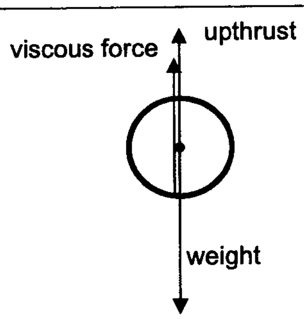
		KE of 2 stars $= \frac{1}{2}M(d\,\omega)^2 + \frac{1}{2}3M(D\,\omega)^2$ $= \frac{1}{2}M(3D)^2\omega^2 + \frac{1}{2}3M(D\,\omega)^2$ $= \frac{9}{2}M\,D^2\omega^2 + \frac{3}{2}M\,D^2\omega^2$ $= 6\,M\,D^2\omega^2$ $= 6\,M\,D^2\left(\frac{GM}{16D^3}\right)$ $= \frac{3GM^2}{8D}$
		Wrong answers: (B) Total $KE = \frac{GM(3M)}{2(3D)} = \frac{G\,M^2}{2\,D}$ (C) Total $KE = \frac{GM(3M)}{2D} = \frac{3G\,M^2}{2\,D}$ (D) Total $KE = \frac{GM(3M)}{2(3D)} + \frac{GM(3M)}{2D} = \frac{2GM^2}{D}$
12	**D**	Same temperature implies thermal equilibrium. Hence all 3 objects are in thermal equilibrium and have the same temperature. However the heat capacity of each material is different, so the amount of internal energy is different. Objects in thermal equilibrium can exchange thermal energy, but there will be no net exchange of thermal energy.
13	**B**	As n and T are constant, $pV = nRT$ $p_1V_1 = p_2V_2$ $30V_1 = 10V_2$ $V_2 = 3V_1$
14	**C**	$\sqrt{\frac{250^2+300^2+400^2+100^2+500^2}{5}} = 340\text{ m s}^{-1}$ (2 s.f.)
15	**C**	$ma = mg - N$ $ma = mg \quad \text{if } N = 0$ $m\omega^2 x_0 = mg$ $x_0 = \frac{g}{\omega^2} = \frac{9.81}{(2\pi f)^2} = \frac{9.81}{4\pi^2(2.0)^2} = 6.2\text{cm}$ (2 s.f.)
16	**A**	Graph shows U vs r of object undergoing simple harmonic motion. Hence $F = -kr$. Alternatively, $F = -\frac{dU}{dr}$, magnitude and direction of F can be obtained from negative gradient of the graph.

17	D	$A = A_0 \sin\theta$ where A_0 – amplitude of wave at transmitter $A^2 = A_0^2 \sin^2\theta$ $P_R \propto I_R \propto A^2 = A_0^2 \sin^2\theta$ $P_T \propto I_T \propto A_0^2 = \dfrac{A^2}{\sin^2\theta}$
18	B	$\dfrac{\lambda}{2} = 0.49 - 0.15$ $\lambda = 0.68\, m$ $v = f\lambda$ $330 = f(0.68)$ $f = 490\text{ Hz (2 s.f.)}$
19	D	The glass block has higher refractive index and the speed of wave and hence the wavelength is smaller. The number of wavelengths within the thickness of the glass block is more than the same thickness in air. Hence, central maximum position where the 2 waves have no path difference is above the original position.
20	B	$\dfrac{Q}{4\pi\varepsilon_0 y^2} = \dfrac{4Q}{4\pi\varepsilon_0 (x+y)^2}$ $\left(\dfrac{x+y}{y}\right)^2 = 4$ $x + y = 2y$ $y = x$
21	A	The particle can be either positively or negatively charged. The particle will be deflected at the point of entry. Electric field lines (and the equipotential lines) are closer together, hence has a stronger electric field strength.
22	C	$d = \dfrac{m}{AL} \rightarrow A = \dfrac{m}{dL}$ $R = \dfrac{\rho L}{A} = \dfrac{\rho L}{\frac{m}{dL}} = \dfrac{\rho L^2 d}{m} \rightarrow m = \dfrac{\rho L^2 d}{R}$ Since L and R are the same, $\dfrac{m_a}{m_c} = \dfrac{\rho_a}{\rho_c} \times \dfrac{d_a}{d_c} = \dfrac{2}{1} \times \dfrac{1}{3} = 0.67$ (2 s.f.)

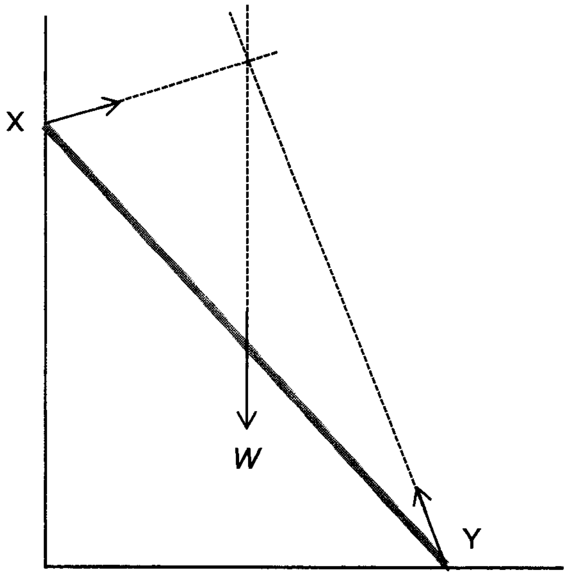
23	**A**	Option A is correct since resistance of A is 15 Ω while resistance of B is 10 Ω. Option B is incorrect since power of A = 0.40 W while power of B = 0.60 W. So power dissipated in B is only 1.5 times of that in A. Option C is incorrect since total current = 0.30 + 0.20 = 0.50 A Option D is incorrect since at 0.20 A, A will have 2.0 V across it while B will have 3.0 V across it.
24	**C**	Assuming $B_{solenoid}$ is to the right,  $\tan\theta = \frac{B_{solenoid}}{B_{Earth}}$ $B_{solenoid} = B_{Earth}\tan\theta$ $= 2.0\times10^{-5}\tan 68° \quad = 4.95\times10^{-5}$ $B_{solenoid} = \mu n I$ $4.95\times10^{-5} = (4\pi\times10^{-7})(\frac{20}{15\times10^{-2}})I$ $I = 0.30$ A (2 s.f.)
25	**B**	Sliding the rod right or left will induce an e.m.f. across the rod. Since the rod is in the centre of the metal frame, it will produce currents in opposite directions in the left and right sections of the frame. When the magnitude of the magnetic flux density increases, the frame experiences an increase in magnetic flux linkage out of the plane of the paper. By Lenz's law, an induced current will flow in the frame to create a magnetic field into the plane of the paper to oppose this change. Hence, this leads to a clockwise current flowing through the frame.
26	**C**	$T = \frac{1}{f} = \frac{1}{50} = 0.02 \text{ s} = 2 \text{ div}$ $\text{time-base} = \frac{0.02}{2} = 10 \text{ ms div}^{-1}$ $V = 2.8 \text{ V} = 1.4 \text{ div}$ $\text{Y-gain} = \frac{2.8}{1.4} = 2.0 \text{ V div}^{-1}$
27	**A**	The cut-off wavelength corresponds to the most energetic photon released.
28	**D**	The uncertainty principle is independent of the experiment equipment. These uncertainties would remain because they originate in the wave like nature of matter.
29	**C**	$\Delta m = [(235.04393 + 1.00866) - (140.91440 + 91.92617 + 3\times1.00866)]u$ $\Delta m = 3.088\times10^{-28} kg$ $E = (\Delta m)c^2$ $= 2.78\times10^{-11}$ J (3 s.f.)

30	**B**	$\ln C = mt + c$ $\text{grad} = \frac{0-5.20}{26.0-0} = -0.2 = \lambda$ $t_{1/2} = \frac{\ln 2}{\lambda}$ $= \frac{\ln 2}{0.2}$ $= 3.5$ s (2 s.f.)

Qn	Suggested Answer
Q1	
(a)(i)	The absolute uncertainty of both measurements is the same. OR Fractional/percentage uncertainty is reduced by measuring *N* coins.
	By measuring *N* coins, the absolute uncertainty of the thickness of 1 coin is divided by *N*. OR By measuring *N* coins, fractional uncertainty is $\Delta x / T$. By measuring 1 coin, fractional uncertainty is $\Delta x / T/N$.
(a)(ii)	Use a micrometer screw gauge/vernier caliper as the instrument has smaller absolute uncertainty compared to the half metre rule.
(b)	$pV = nRT$ $p = \dfrac{0.00200 \times 8.31 \times (273.15 + 36.7)}{\frac{4}{3}\pi(0.0250)^3}$ $= 78682$ Pa
	$\pm\dfrac{\Delta p}{p} = \pm(3\dfrac{\Delta d}{d} + \dfrac{\Delta T}{T})$ $= \pm[3(\dfrac{0.1}{50.0}) + \dfrac{0.1}{(273.15 + 36.7)}]$
	$\pm\Delta p = \pm 497$ Pa $p \pm \Delta p = (78700 \pm 500)$ Pa
Q2	
(a)(i)	Constant velocity in the horizontal direction and a constant acceleration in the vertical direction
(a)(ii)	$v^2 = u^2 + 2as$
	$0 = (20.0 \sin\theta)^2 + 2(-9.81)(15.8)$
	$\theta = 61.7°$
	$\theta = 62°$ (0 d.p.) (shown)
(a)(iii)	$v_y = u_y + a_y t$ $0 = 20.0 \sin 61.7° - 9.81t$
	$t = 1.80$ s (3 s.f.)
(b)(i)	Since force exerted on the spaceship *F* is constant but mass of the spaceship decreases with time, given that $F = ma$, *a* increases with time.
(b)(ii)	$F_{\text{on fuel}} = v_{rel}\dfrac{dm}{dt}$ $= (3.0 \times 10^4)(1.7 \times 10^{-6})$
	= 0.051 N $\lvert F_{\text{on spaceship}} \rvert = \lvert F_{\text{on fuel}} \rvert$
(b)(iii)	Change in velocity = area under graph $= \frac{1}{2}(9.450 + 8.200) \times 10^{-5} \times 4.80 \times 10^7$
	$= 4240$ m s^{-1}
	Final velocity = 4240 – 0 = 4240 m s^{-1}

(b)(iv)	
	Increasing gradient from $t = 0$ to $t = 4.8 \times 10^7$ s, starting from $v = 0$ to final v at 4240 m s^{-1}.
	Between $t = 4.8 \times 10^7$ to $t = 6.0 \times 10^7$ s, there is no more force. Therefore, constant v at 4240 m s^{-1}.
Q3	
(a)	 Correct labelling of forces
	As speed of metal ball increases, viscous force increases. As viscous force increases, net acceleration decreases.
	When the total upward force (viscous force and upthrust) becomes equal in magnitude to the weight of the ball, there is no net force, and the metal ball reaches terminal velocity.
(b)(i)	Taking moments about B, $P \times 6.0\cos 30° = 150 \times 3.0 \sin 30°$ $P = 43.301$ N
	= 43 N (2 s.f.) shown
(b)(ii)	The horizontal component of Q which is pointing to the left will balance force P which is pointing to the right.
	The vertical component of Q which is acting upwards will balance W which is acting downwards vertically. This will allow the ladder to be in equilibrium.
(b)(iii)	Horizontal component = 43 N Vertical component = 150 N Magnitude of Q $= \sqrt{43^2 + 150^2} = 156$ N (3 s.f.)

(b)(iv)



Three forces intersect at same point and force at X is facing upwards diagonally.

4

(a)

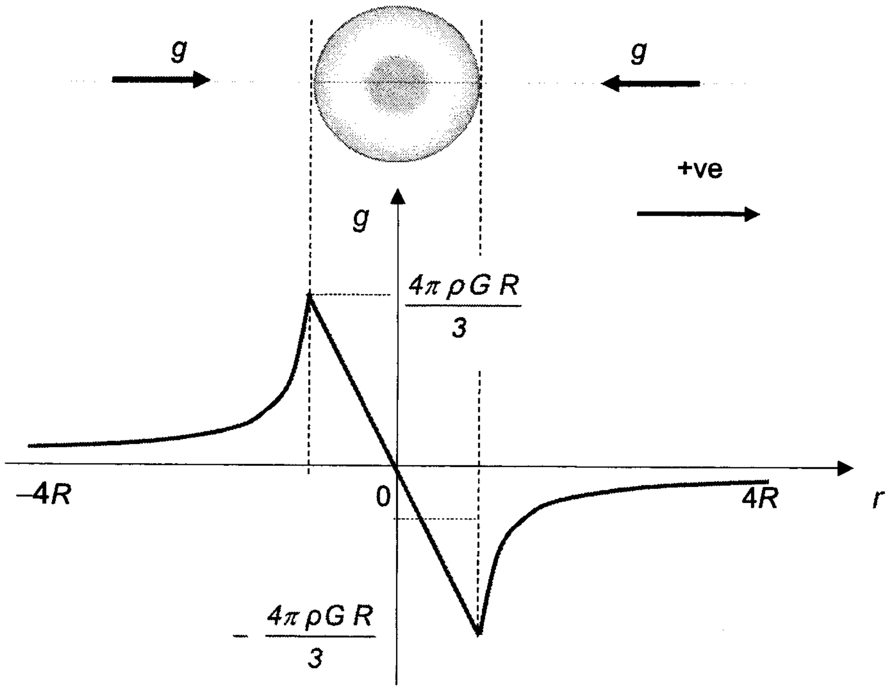
$$g = \frac{F}{m} \qquad \text{where } F = \frac{GMm}{r^2}$$

$$= \frac{GM}{r^2}$$

as $\rho = \dfrac{M}{\frac{4}{3}\pi R^3}$

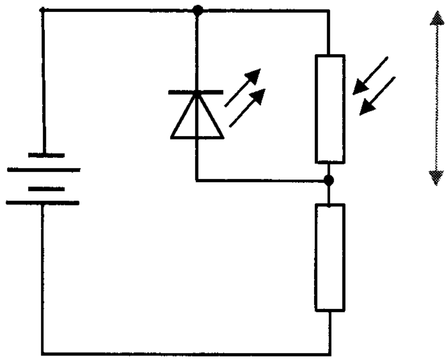
$$g = \frac{4\pi\rho G R^3}{3 r^2}$$

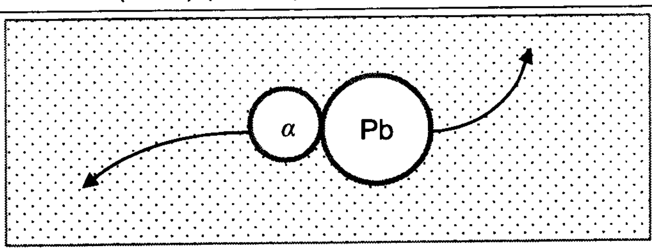
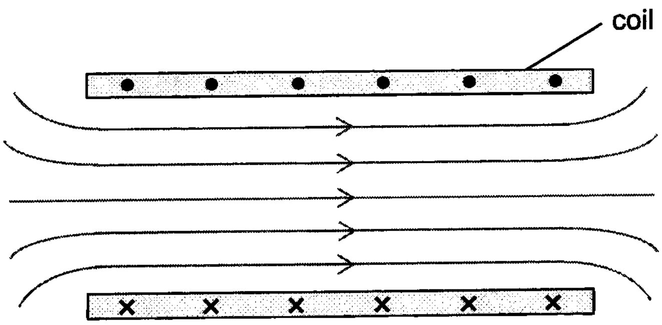
(b)



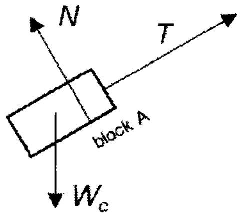
$-R < r < R$: straight line passing through the origin

	$r < -R$ and $r > R$: inverse square graph
	+ve and -ve direction of g (according to stated sign convention)
	$r = R: \quad g = \dfrac{4\pi \rho G R}{3}$
(c)(i)	By N2L, $ma = mg$ $a = \dfrac{4\pi \rho G}{3} r \quad \cdots\cdots(1)$ For SHM, $a = \omega^2 x \quad \cdots\cdots(2)$ Comparing $\omega^2 = \dfrac{4\pi \rho G}{3}$
	$\left(\dfrac{2\pi}{T}\right)^2 = \dfrac{4\pi \rho G}{3}$ $T = \sqrt{\dfrac{3\pi}{\rho G}}$
(c)(ii)	Maximum time taken (as assuming released from rest in Singapore) = half a period
	$\dfrac{T}{2} = \dfrac{1}{2}\sqrt{\dfrac{3\pi}{\rho G}}$ $= \dfrac{1}{2}\sqrt{\dfrac{3\pi}{(5.51\times10^{3})6.67\times10^{-11}}}$ $= 2530$ s (3 s.f.)
5	
(a)(i)	As the light intensity increases, the resistance of the LDR decreases.
	In Fig. 5.1(a), since the components are in parallel, as the resistance of the LDR varies, the voltmeter reading will remain constant.
	In Fig. 5.1(b), the voltmeter is placed across the fixed resistor so as the light intensity increases by potential divider principle $V = \dfrac{500}{500 + R_{LDR}} \times 6.0$, the voltmeter reading increases.
(a)(ii)	By the potential divider principle, $V = \dfrac{500}{500 + R_{LDR}} \times 6.0 = 3.75$
	$R_{LDR} = 300\ \Omega$
(b)(i)	When dark, resistance of LDR increases, p.d. across LDR and LED increase. So the LED turns on. Resistance of LDR decreases. OR When bright, resistance of LDR decreases, p.d. across LDR and LED decrease. So the LED turns off. Resistance of LDR increases.
	The p.d. across LED and LDR decrease, forcing the LED to switch off. OR The p.d. across LED and LDR increase, forcing the LED to switch on.
	When the LED is off, the p.d. across LED and LDR will increase, forcing the LED to switch on. OR

	When the LED is on, the p.d. across LED and LDR will decrease, forcing the LED to switch off.
	 Consider the potential difference across the LED in parallel to LDR
(b)(ii)	A sensible suggestion, e.g. point the LED away from the LDR / increase distance (between LED and LDR) / insert a card between (LED and LDR)
(c)(i)	Horizontal line at 6.0 V.
(c)(ii)	When R = 5.0 Ω, V = 4.0 V. $V = E - Ir$ $r = \frac{E-V}{I} = \frac{6.0-4.0}{(4.0/5.0)}$
	r = 2.5 Ω
6	
(a)	The half-life of a radioactive nuclide is the mean time taken for a quantity x to reduce to half its initial value where x represents either the number, activity or count rate of radioactive nuclei.
(b)	Spontaneous: Not affected by chemical reactions and physical conditions such as temperature and pressure.
	Random: No way to predict which particular nucleus in a radioactive sample will decay next. Each nucleus in a sample has the same chance of decaying per unit time.
(c)(i)	${}^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e +$ energy
(c)(ii)	$\lambda = \frac{\ln 2}{5730 \times 365 \times 24 \times 60 \times 60}$
	$= 3.84 \times 10^{-12}$ s^{-1} (3 s.f.)
(c)(iii)	$A = A_0 e^{-\lambda t}$ $5.4 = (0.23 \times 10000) e^{-3.84\times10^{-12} t}$
	$t = 1.577 \times 10^{12}$ s
	$t = \frac{1.577 \times 10^{12}}{365 \times 24 \times 60 \times 60}$ = 50000 years (3 s.f.)
(d)(i)	$m_{Pb}u_{Pb} + m_{\alpha}u_{\alpha} = m_{Pb}v_{Pb} + m_{\alpha}v_{\alpha}$ $0 = 206v_{Pb} + 4v_{\alpha}$

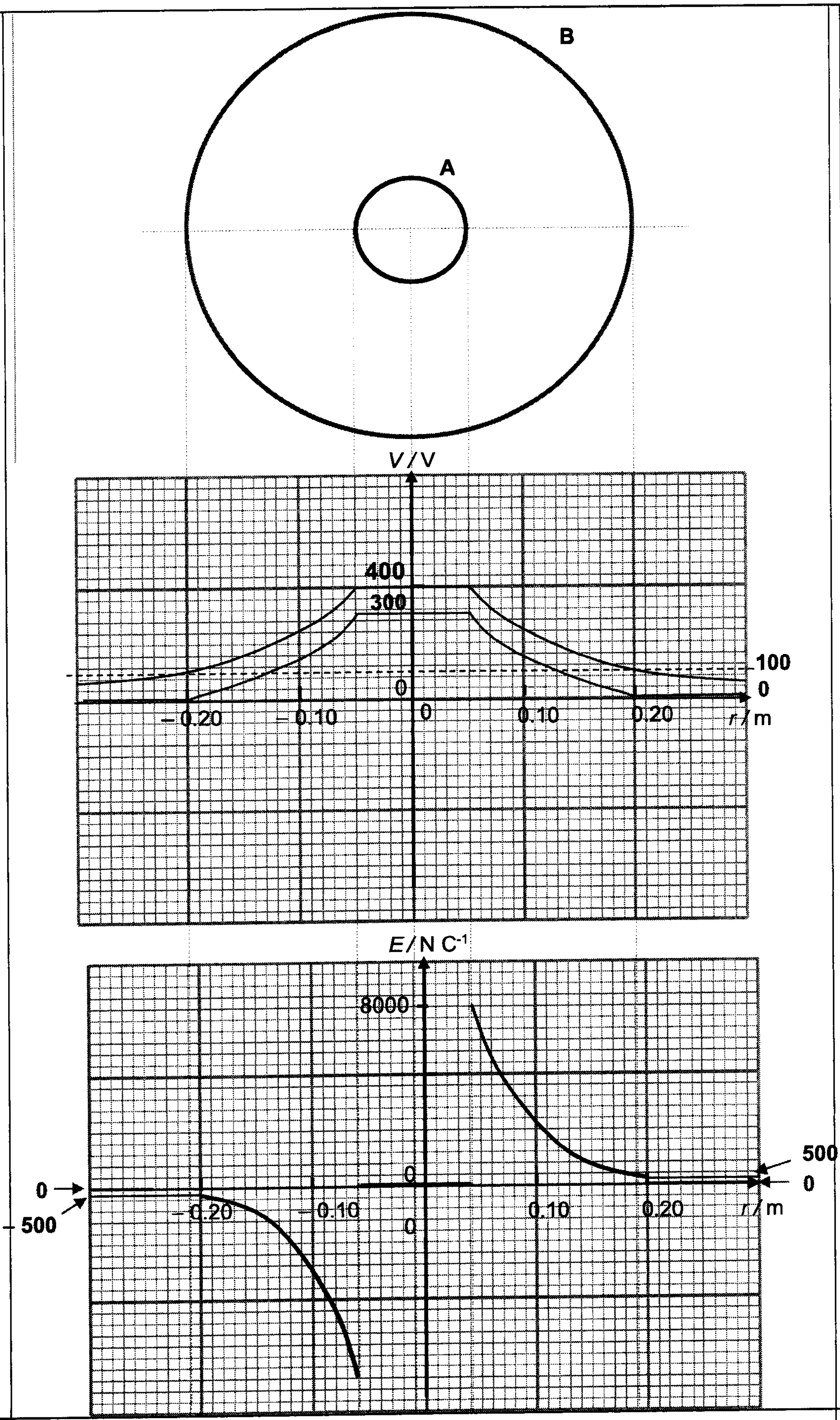
	$KE = \dfrac{p^2}{2m}$ $\dfrac{\text{KE of Pb}}{\text{KE of } \alpha} = \dfrac{\dfrac{p_{Pb}{}^2}{2m_{Pb}}}{\dfrac{p_\alpha{}^2}{2m_\alpha}} = \dfrac{m_\alpha}{m_{Pb}} = \dfrac{4}{206}$
	= 0.019417
	= 0.0194 (3 s.f.) (shown)
(d)(ii)	 Magnetic force provides centripetal force $Bqv = \dfrac{mv^2}{r}$ $r = \dfrac{mv}{Bq}$ • both nuclei have the same momentum • Pb nucleus has much larger charge than α-particle • Pb nucleus has smaller radius than α-particle • apply Fleming's left hand rule to determine direction of motion
	Opposite direction for Pb nucleus (right) and α-particle (left)
	Correct path for Pb nucleus and α-particle with smaller radius for Pb nucleus
7	
(a)(i)	
	Correct direction of magnetic field with at least 5 lines
	Correct shape with equal distance between lines inside the coil Lines must be straight inside the coil Lines must curve outside the coil
(a)(ii)	To reduce resistance of the coil to allow for higher current to be used in coil OR With high current, resistance of the coil increases, cooling will prevent overheating.

(b)	Scanner generates a very strong magnetic field causes a strong magnetic force to attract metallic implants. This may harm patients with these implants by dislodging the metallic parts.
(c)(i)	The hydrogen nuclei has one unpaired proton.
	Hence its net spin is 1/2.
(c)(ii)	The carbon nuclei has 3 pairs of protons and 3 pairs of neutrons. Hence, it has no net spin.
	It is unable to absorb photons of a particular frequency.
(d)	Energy of photon $= hf$ $= h\nu$ $= h\gamma B$ $= (6.63\times10^{-34})(42.58\times10^{6})(1.5)$ $= 4.235\times10^{-26}$ J
	$= \dfrac{4.235\times10^{-26}}{1.60\times10^{-19}}$ eV
	$= 2.65\times10^{-7}$ eV (3 s.f.)
(e)(i)	Damage or destroy living cells OR Break bonds that hold water molecules together, forming toxic substances OR Creating free radicals
(e)(ii)	Energy of X-ray photon $= \dfrac{hc}{\lambda}$ $= \dfrac{(6.63\times10^{-34})(3.00\times10^{8})}{10^{-10}}$
	$= 1.99\times10^{-15}$ J (3 s.f.) Since energy of X-ray photon > 6.0×10^{-19} J, X-rays are ionizing.
(f)(i)	Phosphorus does not have an isotope.
(f)(ii)	The hydrogen $^{1}_{1}H$ nuclei has a higher natural abundance of 0.99985 and is the most common hydrogen isotope.
	It is also has the highest biological abundance of 0.63, which makes it the most common element in the human body.
(f)(iii)	Soft tissues are mostly made up of water and hydrogen nuclei are naturally found in water.
	When an external magnetic field is applied, the hydrogen nuclei can absorb photons of a particular frequency.
	As the nuclei return to their resting alignment, energy is emitted and converted to images of the soft tissues.

Q1	Suggested Answer
(a)(i)	 Legend: N – normal contact force T – tension of string W_C – weight of block A
	Forces correctly labelled (ruler should be used) Correct direction indicated (T longer in length than component of W_c along slope)
(a)(ii)	**Taking mass B as the system** $m_B g - T = m_B a$ $(8.3 \times 9.81) - 54 = 8.3a$ $a = 3.30 \text{ m s}^{-2}$
	Taking mass A as the system $T - m_A g \sin 50° = m_A a$ $54 - (m_A \times 9.81 \sin 50°) = m_A \times 3.30$
	$m_A = 4.99 \text{ kg}$
	$= 5.0 \text{ kg}$ (2 s.f.) (shown)
(b)(i)	Force on block A = gradient $= \dfrac{-2.00 - (-10.00)}{3.00 \times 10^{-3}}$ $= 2670 \text{ N}$ (3 s.f.)
	Force on block A = – Force on block C $= -2670 \text{ N}$
(b)(ii)	$v_A = \dfrac{p_A}{m_A}$ $= \dfrac{-2.00}{5.0}$
	$= -0.40 \text{ m s}^{-1}$
(b)(iii)	Total momentum conserved: $p_i = p_f$ $p_i = p_{fA} + p_{fC}$ $p_{fC} = p_i - p_{fA} = -10.00 - (-2.00) = -8.00 \text{ N s}$
	$v_C = -\dfrac{8.00}{10} = -0.80 \text{ m s}^{-1}$

	Total KE before collision $= \frac{1}{2} m_A u^2$ $= \frac{1}{2}(5.0)(\frac{-10.00}{5.0})^2$ $= 10$ J Total KE after collision $= \frac{1}{2}[m_A v_A{}^2 + m_C v_C{}^2]$ $= \frac{1}{2}[(5.0)(-0.40)^2 + (10)(-0.80)^2]$ $= 3.6$ J **OR** relative speed of approach $= u_A - u_C$ $= 2.0$ m s^{-1} relative speed of separation $= v_C - v_A$ $= 0.80 - 0.40$ $= 0.40$ m s^{-1}
	Since total KE is not conserved, the collision is not elastic. OR Since relative speed of approach is not equal to the relative speed of separation, the collision is not elastic.
Q2	
(a)	Electric potential at a point in an electric field is defined as the work done per unit positive charge by an external agent in bringing a small test charge from infinity to that point, without producing any acceleration.
(b)	$V \propto \frac{1}{r}$ $\frac{V_2}{400} = \frac{0.050}{0.200}$ $V_2 = 100$ V
	$E \propto \frac{1}{r^2}$ $\frac{E_2}{8000} = \left(\frac{0.050}{0.200}\right)^2$ $E_2 = 500$ N C^{-1}
(c)(i)1	Refer to sketches
	$-R < r < R$: Horizontal line $V_{inside} = +400$ V
	• $(r < -R)$ *and* $(r > R)$: Curve $V = +$ ○ $V_{0.050m} = +400$ V $V_{0.200m} = +100$ V

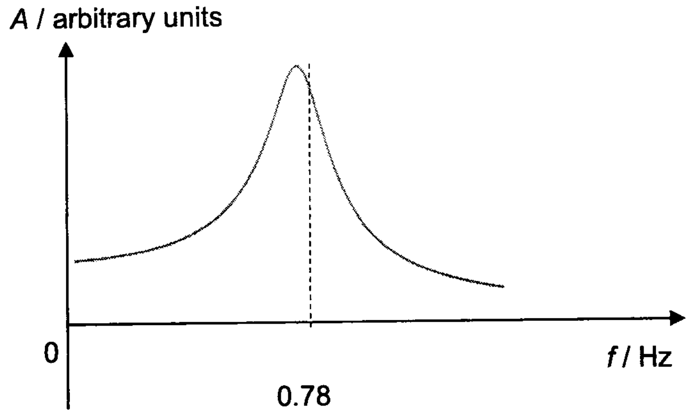
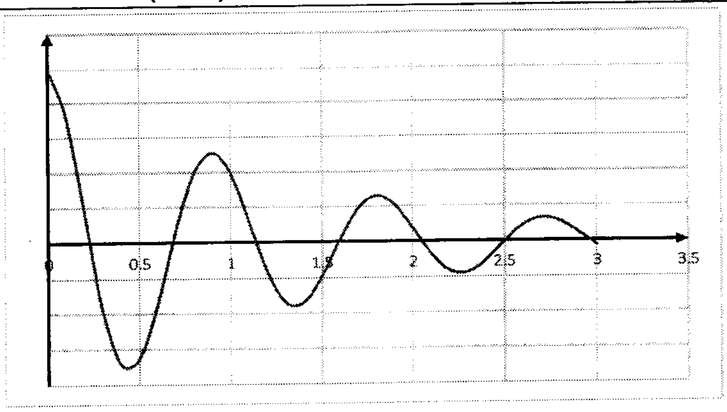
(c)(i)2	$0 < r < R$: Horizontal line $E_{inside} = 0$ • ($-R < r < 0$) and ($R > r > 0$) : Curve & direction ○ (When $r = +$, $E = +$) (When $r = -$, $E = -$) ○ $E_{0.050m} = \pm$ 8000 N C^{-1} $E_{0.200m} = \pm$ 500 N C^{-1}
(c)(ii)1	• $-R < r < R$: $V_{inside} = +$ 300 V (horizontal line) • ($r < -R$) and ($r > R$) : Curve $V = +$ ($r < -R$) and ($r > R$) : horizontal line at $V_{0.200m} = 0$
(c)(ii)2	• Between $E_{0.050m}$ and $E_{0.200m}$: Curve & direction ○ ($r = +$, $E = +$) ($r = -$, $E = -$) ○ $E_{0.050m} = \pm$ 8000 N C^{-1} ○ $E_{0.200m} = \pm$ 500 N C^{-1} ($r = +$, $E = +$) ($r = -$, $E = -$) • $E_{inside} = 0$ $E_{beyond\ 0.200m} = 0$

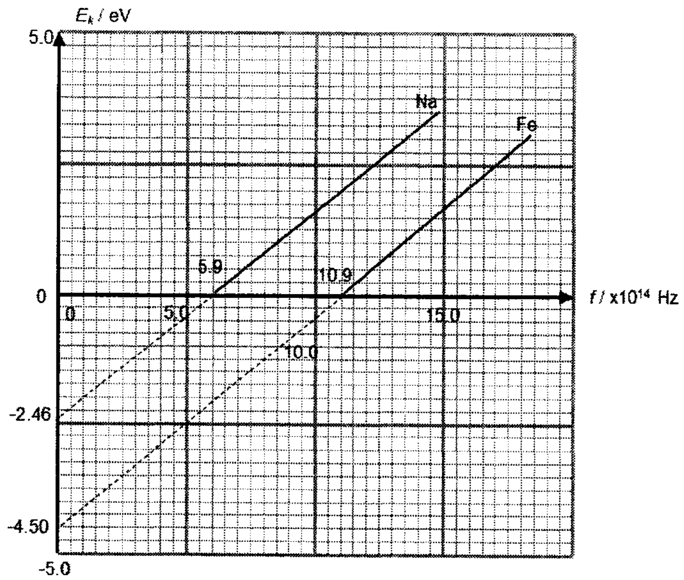

B
A
V / V
400
300
100
0
0
−0.20
−0.10
0
0.10
0.20
r / m
E / N C⁻¹
8000
500
0
0
−500
−0.20
−0.10
0
0.10
0.20
r / m

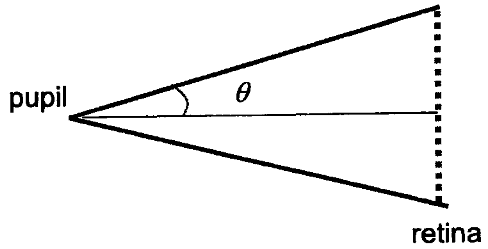
3	
(a)	First Law of Thermodynamics states that the increase in internal energy of a system
	is the sum of the heat supplied to the system and the work done on the system.
(b)	$q_{to} = (2.26\times10^6)(5.0)$
	$\Delta V = (\frac{5.0}{0.598} - \frac{5.0}{1000})$
	$w_{on} = -(1.01\times10^5)(\frac{5.00}{0.598} - \frac{5.00}{1000})$
	$\Delta U = q_{to} + w_{on}$ $= 1.05\times10^7$ J (3 s.f.)
(c)(i)	As the product of p and V at state C is greater than the product of p and V at state D, **OR** $\Delta U = q_{to} + w_{on}$ Since q_{to} is 0 and w_{on} is negative due to expansion,
	State C is at a higher temperature.
(c)(ii)	(see table below)
Q4	
(a)(i)	Taking the direction of displacement as positive, $F_R = mg - T$ $ma = mg - k(d + x)$
	Since $kd = mg$ $ma = -kx$ $a = -\frac{k}{m}x$
(a)(ii)	Negative sign of expression shows that acceleration acts in the opposite direction of the displacement.
	Since k and m are constants, acceleration is directly proportional to displacement.

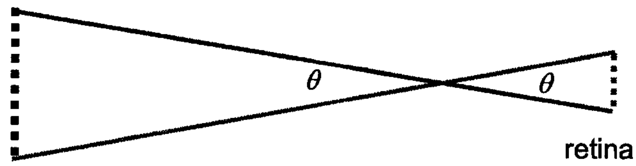
(c)(ii)

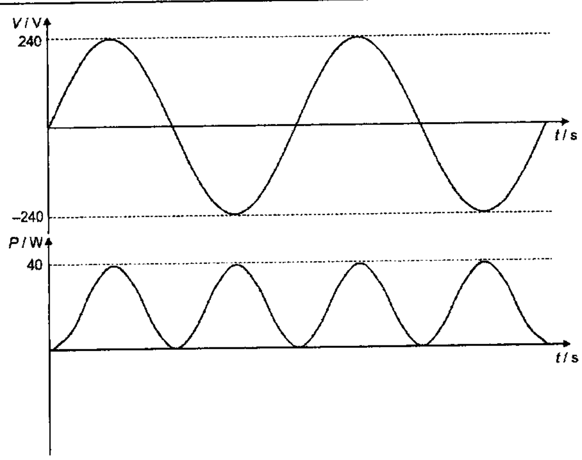
section of cycle	heat supplied to gas / J	work done on gas / J	increase in internal energy of gas / J
A to B	**0**	**300**	300
B to C	**2580**	- 740	1840
C to D	**0**	**- 440**	**- 440**
D to A	**-1700**	**0**	**- 1700**

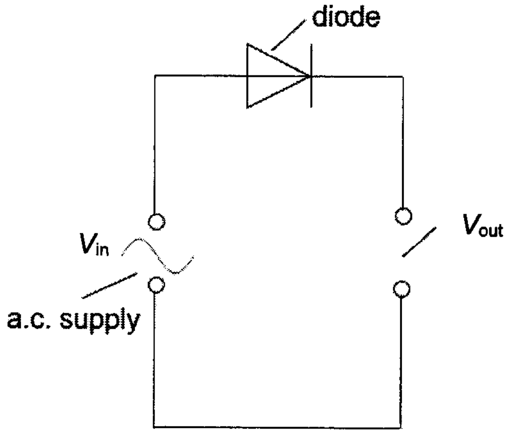
(a)(iii)	$a = -\frac{k}{m}x$ $\omega^2 = \frac{k}{m}$ $(2\pi f)^2 = \frac{1.2}{50 \times 10^{-3}}$
	$f = 0.780$ Hz (3 s.f.)
(a)(iv)	 Correct shape, left side must be higher than right side, not symmetrical, cannot start from origin Peak slightly to the left of 0.78 Hz
(b)(i)	$k_2 = 2k$ $\omega^2 = \frac{2k}{m}$ $(2\pi f)^2 = \frac{2.4}{50 \times 10^{-3}}$
	$f = 1.10$ Hz (3 s.f.)
(b)(ii)	 Oscillating graph with period of about 0.91 s or slightly longer, must start from x_o at $t = 0$ Amplitude is decreasing exponentially with time
Q5	
(a)(i)	It is a quantum of electromagnetic radiation energy.
	The energy of a photon E is hf, where h is the Planck's constant and f is the frequency of the electromagnetic radiation.

(a)(ii)	$E = h\dfrac{c}{\lambda}$ $= 6.63\times10^{-34}\times\dfrac{3.00\times10^{8}}{390\times10^{-9}}$ $= 5.10\times10^{-19}\text{ J}$ $= \dfrac{5.10\times10^{-19}}{1.60\times10^{-19}}$
	$= 3.188$ eV
	$= 3.19$ eV (3 s.f.) (shown)
(a)(iii)1	
	Parallel lines drawn
	Correct labeling on *x*-axis (5.9,10.9)
	Correct labeling on *y*-axis (-2.46,-4.50)
(a)(iii)2	Gradient – no change because the gradient is the Planck's constant and not dependent on the intensity of light
	Vertical intercept – no change because the vertical intercept is work function is dependent on the metal and not dependent on the intensity of light
(b)(i)	13.6 eV Electron energy level difference between lowest energy state to 0 eV.
(b)(ii)	The highest energy level is 0 eV. **OR** The electrostatic force between the electron and nucleus is attractive. **OR** Positive work done by external force to ionise the hyrogen atom.
(b)(iii)	Only photons with energy equal to the energy difference between the energy levels will be absorbed.
	The electrons in the lower energy state will absorb the photons and get excited to a higher energy level. Photons not absorbed will continue to travel to screen.
	Excited electrons will return to lower energy level by emitting photons in all directions, resulting in dark lines at these wavelengths as the photons is much smaller in numbers compared to the other unabsorbed photons.

Q6	
(a)(i)	A stationary wave is formed when two progressive waves of the same type of equal amplitude, equal frequency (or wavelength) and same speed, meet when they travel in opposite directions.
(a)(ii)1	For fundamental frequency, length of string $L = \frac{\lambda}{2}$
	Consider length of string L, and speed of each progressive wave, $v = f\lambda$ $405 = (622)\,2L$ $L = 0.326\text{ m (3 s.f.)}$
(a)(ii)2	$v = \omega\sqrt{x_0^2 - x^2}$ $v_{max} = \omega x_0$ $= 2\pi(622)\,3.3\times10^{-3}$ $= 12.9\text{ m s}^{-1}\text{ (3 s.f.)}$
	$= 12.9\text{ m s}^{-1}\text{ (3 s.f.)}$
(a)(iii)1	$I = \frac{P}{2\pi r^2}$ $= \frac{200}{2\pi(10.0)^2}$
	$= 0.318\text{ W m}^{-2}\text{ (3 s.f.)}$
(a)(ii)	**Possible reasons (any 2)**
	• If the 2 identical loudspeakers are far apart, the path difference between the 2 waves is significant and their amplitudes are significantly different at all points (except the mid point/middle section). • Waves reflections from surfaces will superpose with the 2 waves from the loudspeakers. • There is an obstacle between the 2 loudspeakers, and the 2 waves are unable to meet. • Air in the medium is not stationary (e.g. if wind is blowing from one speaker to another, one wave has a smaller, and one has a larger frequency than the original frequency).
(b)(i)	
	For single slit diffraction, at the 1st minima $m = 1$, $\sin\theta = \frac{m\lambda}{b}$ ……… (1)

	For small angle approximation, $\sin\theta \approx \tan\theta$ .... (2)
	$\tan\theta = \sin\theta$ $\tan\theta = \frac{\lambda}{b}$ $\frac{w/2}{L} = \frac{\lambda}{b}$ $\frac{4.80\times10^{-6}/2}{17.0\times10^{-3}} = \frac{\lambda}{3.0\times10^{-3}}$
	$\lambda = 4.24\times10^{-7}$m $= 424$ nm (3 s.f.)
	OR Pythagoras Theorem can be used to derive equation for θ.
(b)(ii)1	Two images are just resolved
	when the central maximum of one image falls on the first minimum of the other image.
(b)(ii)2	
	Applying Rayleigh Criterion, for minimum wavelength $\theta_R = \frac{\lambda_{min}}{b}$ .... (1) $= \frac{380\times10^{-9}}{3.00\times10^{-3}}$ $= 1.27\times10^{-4}$ rad (3 s.f.)
(b)(ii)3	By geometry and small angle approximation, for minimum distance between 2 adjacent pixels, $\theta_{min} = \frac{d_{min}}{D}$ .... (2)
	$d_{min} = \frac{72\times10^{-2}\text{ m}}{710}$
	$\theta_{min} = \frac{d_{min}}{D}$ $= \frac{\left(\frac{72\times10^{-2}}{710}\right)}{1.5}$ $= 6.761\times10^{-4}$ rad
	Since $\theta_{min} > 2.91\times10^{-4}$ rad, the observer can distinguish between any two adjacent blue pixels of the smaller distance and smallest wavelength of blue.

(b)(ii)4	Slit width increases, angular resolution decreases, hence minimum distance increases.
Q7	
(a)(i)	$B_C = 7.5 \times 10^{-3}$ T
(a)(ii)	$B = \dfrac{\mu_0 NI}{2r}$ $7.5 \times 10^{-3} = \dfrac{\mu_0 (300)(2.0)}{2(0.050)}$
	$\mu_0 = 1.25 \times 10^{-6}$ H m^{-1}
(b)(i)	The <u>magnitude of the induced e.m.f.</u> in a conductor is <u>directly proportional</u> to the <u>rate of change of magnetic flux linkage</u> experienced by the conductor.
(b)(ii)	0.024 – 0.036 m
(b)(iii)	The gradient of the graph is the maximum.
	As coil Q is moved at a steady speed, the rate of change of magnetic flux linkage is the greatest. Hence induced e.m.f. is maximum.
(b)(iv)	When coil Q is moved to the right, the magnetic flux will decrease.
	By Lenz's law, an induced current caused by an induced e.m.f. in coil Q will flow in the same direction as the current in coil P to create a magnetic field to the left.
(b)(v)1	B at 0.040 m = 3.6×10^{-3} T $\Delta B = 3.6 \times 10^{-3} - 7.5 \times 10^{-3}$ $= -3.9 \times 10^{-3}$ T
(b)(v)2	$\varepsilon_{ave} = -\dfrac{d\phi}{dt}$ $= -\dfrac{dNBA\cos\theta}{dt}$ $= -NA\dfrac{dB}{dt}$
	$= -\dfrac{(5000)(1.5 \times 10^{-4})(-3.9 \times 10^{-3})}{0.25}$
	$= 1.17 \times 10^{-2}$ V
(c)(i)	Value of an alternating current that is equal to the <u>steady direct current</u> that would <u>dissipate heat at the same average rate in a given resistor</u>.
(c)(ii)1	

	$P_0 = 2P_{ave}$ $= 2(20)$ $= 40\ \text{W}$
	Correct shape for 2 complete cycles
(c)(ii)2	$\frac{V_{0\,S}}{V_{0\,P}} = \frac{N_S}{N_P}$ $\frac{V_{0\,S}}{240} = \frac{1}{50}$ $V_{0\,S} = 4.8\ \text{V}$
	$V_{\text{r.m.s. S}} = \frac{4.8}{\sqrt{2}}$ $= 3.39\ \text{V (3 s.f.)}$
(c)(iii)	
	Labelled circuit diagram with correct symbols showing V_{in}, V_{out}, a.c. supply and diode.
(c)(iv)	$V_{\text{r.m.s. half-wave}} = \frac{4.8}{2}$ $= 2.4\ \text{V}$

Q1		
(a)(i)	Value of V to 2 d.p. in V	1
(a)(ii)	Potential difference across the voltmeter is non-zero since the $\frac{\text{resistance of } P}{\text{resistance of } Q}$ is not equal to $\frac{\text{resistance of AB}}{\text{resistance of CD}}$	1
(a)(iii)	Value of N to the nearest mm in the range of 50.0–70.0 cm	1
(a)(iv)	• Value of M to the nearest mm in the range of 55.0–65.0 cm • Value of N to the nearest mm in the range of 40.0–60.0 cm • Value of N in **(a)(iii)** > Value of N in **(a)(iv)**	1
(b)(i)	Show correct calculation of a and b by using simultaneous equations to solve for a and b	1
	Correct units for a (cm^{-1}) and b (cm^{-1})	1
(b)(ii)	Correct substitution and solve for M $\frac{1}{N} = a + b$ $M = N$ Correct units for M (cm)	1
(c)(i)	• Checking for zero error on micrometer screw gauge • Repeated measurements	1
	Value of d_1 and d_2 to the nearest 0.01 mm	1
(c)(ii)	Correct working and calculation of $\frac{\rho_1}{\rho_2}$ Value of $\frac{\rho_1}{\rho_2}$ given to 2 or 3 s.f. No units for $\frac{\rho_1}{\rho_2}$	1

[Total: 10 marks]

Q2		
(a)	• Value of α to the nearest degree • Value of α in the range 46-52° • Evidence of repeated measurements	1
(b)	• Value of β to the nearest degree • Value of $\beta > \frac{\alpha}{2}$ • Evidence of repeated measurements	1
(c)	Six sets of readings of x and β and range of x at least 6.0 cm	2

	• Correct column headings • Each column heading must contain a quantity, a unit and a separating mark where appropriate • Evidence of repeated measurements x / cm | β / ° | $\tan\left(\beta - \frac{\alpha}{2}\right)$	1
	• Correct decimal place of raw values for x and β • (x: 1 d.p. in cm, β: 0 d.p.) • Check for x in (b)	1
	• Correct calculation of $\tan\left(\beta - \frac{\alpha}{2}\right)$ • Value of $\tan\left(\beta - \frac{\alpha}{2}\right)$ given to 2 or 3 s.f.	1
(d)	**Graph** • Sensible scales must be used. Awkward scales (e.g. 3:10) are not allowed. • Scales must be chosen so that plotted points occupy at least half the graph grid in both the x and y directions. • Axes must be labelled with the quantity which is being plotted.	1
	Graph All observations to be plotted to an accuracy of at least half a small square.	1
	Graph • Line of best fit – even distribution of points on both sides of the line. • Anomalous point should be circled and labelled on the graph.	1
	• Points used to calculate the gradient must be greater than half the length of the drawn line. • Read-offs must be accurate to half a small square and indicated on graph. • Calculation of gradient must be accurate. • Associate P with the gradient with units cm^{-1}. • Value of gradient given to 3 or 4 s.f.	1
	• y-intercept read off accurately with correct precision, OR, calculated accurately from $y = mx + c$ using one point on the line. • Check for s.f. if calculated (ECF for wrong gradient) • Check for d.p. if read off graph. • Associate Q with the y-intercept witn no units.	1

[Total: 12 marks]

Q3		
(a)(i)	Value for C recorded to the nearest mm.	1
(a)(ii)	• Percentage uncertainty based on absolute uncertainty of at least 0.2 cm to 0.5 cm. • Show correct method of calculation to obtain percentage uncertainty. • Answer must be given to 1 or 2 s.f.	1

(a)(iii)	• Repeated readings for N oscillations. • Time taken for N oscillations, $t \geq 20.0$ s • $T = \frac{t}{N}$ • Value of T in the range 0.50 s to 1.50 s to correct significant figures.	**1**
(a)(iv)	• Absolute uncertainty of t at least 0.4 to 0.8 s. • Show calculation for absolute uncertainty of T to 1 or 2 sf. • $\Delta T = \frac{\Delta t}{N}$ • Percentage uncertainty based on absolute uncertainty of T. • Show correct method of calculation to obtain percentage uncertainty. • Answer must be given to 1 or 2 s.f.	**1**
(b)	second C > first C	**1**
	second T > first T	**1**
(c)(i)	• It is difficult to judge where is the lowest point of the chain since it is based on human visual judgement. • Results in measurement of C being inaccurate. **<u>OR</u>** • It is difficult to determine the starting and ending of each oscillation since the paperclip has a certain width. • This results in an inaccurate reading of the total time for the oscillations affecting T.	**1**
(c)(ii)	• Clamp the metre rule vertically between the 15^{th} and 16^{th} paperclip from either end. Place vertical end of the set square against the vertical rule and slide up till the horizontal end of the set square meets the chain to obtain a scale reading from the metre rule for the lowest point. • Hence achieving a more accurate measurement of C. **<u>OR</u>** • Use a marker to mark the point on the paperclip to take reference to when starting and stopping the stopwatch when it passes the equilibrium position (indicated by another marker). • This ensure the measurement of T is more accurate.	**1**
(d)(i)	• Both values of k correctly calculated. • Units for k • Given to 2 or 3 s.f. (depending on s.f. of C and T)	**1**
(d)(ii)	Follows the least s.f. between C and T Which quantity to follow – C or T (or both have the same s.f.)	**1**

(d)(iii)	(1) Find percentage difference in $k = (k_{larger} - k_{smaller}) / k_{smaller} \times 100$ %. (2) Find percentage uncertainty in k. Since $\frac{\Delta C}{C}$ was calculated in (a)(ii) and $\frac{\Delta T}{T}$ was calculated in (a)(iv), it is assumed that $\frac{\Delta C}{C} + 2\frac{\Delta T}{T}$ is a good approximation for the percentage uncertainty of k. (3) If percentage difference in k > percentage uncertainty in k, experiment results do not support the relationship. If percentage difference in k < percentage uncertainty in k, experiment results support the relationship.	1
(e)	**Basic Procedure (1 m)**	1
	• Set up the experiment as shown in Fig. 3.1. • Vary the mass of the paper clips used in the chain and determine period.	
	Measurement (1 m)	1
	• Measure the mass of the paper clip chain using a mass balance. • Measure and record the time taken for 30 oscillations using a stopwatch. • Determine the period by taking the total time taken divided by the number of oscillations.	
	Controlled Variables (1 m)	1
	• Keep the length of the chain constant by using the same number of paper clips. • Keep the distance between the retort stands constant.	
	Analysis (1 m)	1
	• Obtain 3 or more readings. • If the period remains the same for all 3 sets of data, the period of the oscillations is independent of mass. **<u>OR</u>** • Plot a graph of period against mass. • If the graph is a horizontal line, the period of the oscillations is independent of mass.	
(f)(i)	• Three sets of readings of y and T. • t should be ≥ to 20.0 s. • Range of number of clips: 10 to 20. (y should correspond to this)	1
	• Correct column headings • Each column heading must contain a quantity, a unit and a separating mark where appropriate	1
	Correct trend. As y decreases, T decreases.	1
(f)(ii)	• Extract data to verify ➢ For hanging chain: C (21.0 to 30.8 cm), T (0.811 to 0.957s) ➢ For vertical chain: y (25.5 cm), T (0.877s) • Since y falls within the range of C for the hanging chain and the T also lies within the range of T for the hanging chain. It is possible for the hanging chain and vertical chain to have the same period if $C = y$.	1

(f)(iii)

Method 1 — 1

experiment data of vertical chain		theoretical calculation for a simple pendulum	fractional difference of T_T and T_E	fractional uncertainty of T_E
y / cm	T_E /s	T_T /s	$\frac{\Delta T}{T} = \frac{T_E - T_T}{T_E}$	$\left(\frac{\Delta T}{T}\right)_T = \frac{\Delta t}{t}$

- Calculate and tabulate periods T_T of a simple pendulum for the y values
- Tabulate periods T_E of a vertical chain
- Compare the **minimum** fractional difference between T_T and T_E,

$$\left(\frac{\Delta T}{T}\right)_E = \frac{T_E - T_T}{T_E}$$

- with the fractional uncertainty of T_T.

$$\left(\frac{\Delta T}{T}\right)_T = \frac{\Delta t}{t} = \frac{0.2+0.2}{N\,T_T}$$

As $\left(\frac{\Delta T}{T}\right)_E > \left(\frac{\Delta T}{T}\right)_T$, the period of vertical chain cannot be calculated is using the period of a simple pendulum. — 1

Method 2 — 1

experiment data of vertical chain		theoretical calculation for a simple pendulum
y / cm	T_E /s	g / m s^{-2}

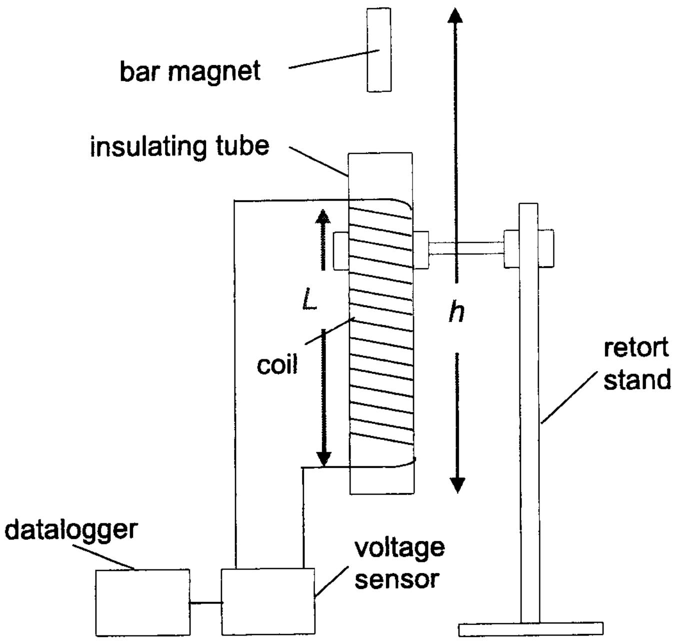
- Calculate the fractional difference of g for 3 sets of y and T experimental values using the equation of period for simple pendulum,

$$\left(\frac{\Delta g}{g}\right) = \frac{|g_{small} - 9.81|}{9.81}$$

- Compare the fractional difference of g with 10%

As $\left(\frac{\Delta g}{g}\right) > 0.10$, the period of vertical chain cannot be calculated is using the period of a simple pendulum. — 1

[Total: 21 marks]

Q4		
	Diagram (1 m)	
		
	Labelled diagram showing • coil wound around a cardboard/plastic tube • supported by a retort stand with bosses and clamps, • bar magnet above the coil and • voltage sensor connected to datalogger OR voltmeter OR CRO.	**D1**
	Basic procedure (2 m)	
	• Vary n by using coils of different number of turns N per unit length L for the same solenoid (and the same length of wire) • Keep v constant by having the same release height h	**B1**
	• Vary v by changing release heights of magnet h. • Keep n constant using the same coil (hence the same number N and L)	**B1**
	Measurement (3 m)	
	Measure $n = \frac{N}{L}$ by counting number of turns N and measuring the length of solenoid L with a metre rule / vernier calipers	**M1**
	• Measure the release height of magnet to the bottom of the coil h with a metre rule • Measure time taken t to fall this distance with a stopwatch **OR** using 2 pairs of light gates a small distance apart placed at the slightly below the tube **OR** speedometer placed slightly below the tube.	**M1**

	• Calculate the maximum velocity v (at the bottom of the solenoid) using $v = \frac{2h}{t}$ **OR** $v = \sqrt{2gh}$ **OR** $v = gt$	
	Measure maximum emf E by taking direct reading of the peak of graph from datalogger attached to a voltage sensor **OR** C.R.O. **OR** maximum voltmeter reading	**M1**
	Control of Variables (max 1 m)	
	Same magnet or magnets of the same magnetic flux density	**C1**
	Same diameter of coil	**C1**
	Analysis (2 m)	
	$E = k\,n^a\,v^b$ $\ln E = a\ln(n) + \ln(k\,v^b)$ - when varying n Plot a straight line graph of $\ln E$ against $\ln n$ where a is the gradient and $\ln(k\,v^b)$ is the vertical intercept Or $E = k\,n^a\,v^b$ $\ln E = b\ln(v) + \ln(k\,n^a)$ - when varying v Plot a straight line graph of $\ln E$ against $\ln v$ where b is the gradient and $\ln(k\,n^a)$ is the vertical intercept	**A1**
	Substitute a set of values of E, n and v into $E = k\,n^a\,v^b$ to find k. (**OR** in the expression $\lg k = \lg E - a\lg n - b\lg v$)	**A1**
	Further Details (max 2 m)	
	Repeat measurement of E and find the average to reduce random errors.	**F1**
	Use a coil with large number of turns per unit length / release magnet from large heights (to have a larger E) / use a strong bar magnet to obtain a measurable value of E. **OR** Preliminary experiment to ensure parameters e.g. height, time gives a measurable value of E.	**F1**
	Use a non-metallic material like cardboard or plastic for the tube that the coil is wound around so that e.m.f. is not induced within the tube. **OR** Use a non-magnetic retort stand / turn away the base of a metallic retort stand **OR** Ensure other magnetic materials e.g. other magnets are kept far away from the magnet.	**F1**
	Use a bar magnet of a much shorter length so that v at the bottom of the coil is nearly constant.	**F1**
	Maximum e.m.f. induced occurs when the magnet exits from the bottom of the coil. **OR** Read off the (higher) peak value from the datalogger.	**F1**

	Diameter of coil sufficiently larger so that the magnet will not hit the sides of the coil.	**F1**
	Use a cushion at the bottom of the coil to absorb the impact of the magnet to miminise the breakage of the magnet	**F1**
	Safety (max 1 m)	
	Use a cushion / tray to absorb the impact of the magnet to prevent it from rebound to hit person. Using a G-Clamp to clamp the base of the retort stand to prevent the experiment setup from toppling.	**S1**

[Total: 12 marks]