Paper 1 – Multiple Choice Questions

Question	Key
1	A
2	D
3	C
4	D
5	C
6	A
7	A
8	C
9	B
10	C

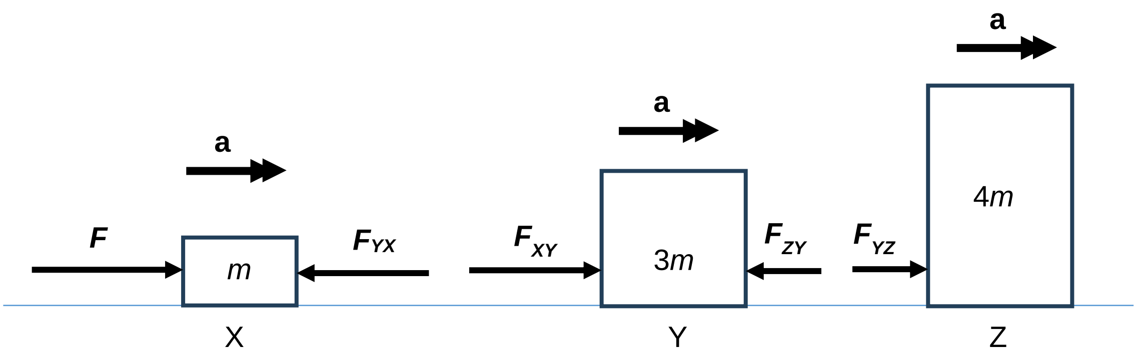
Question	Key
11	A
12	D
13	C
14	D
15	C
16	D
17	B
18	D
19	A
20	D

Question	Key
21	C
22	A
23	A
24	C
25	B
26	B
27	C
28	A
29	C
30	C

1	**Answer: A**
	Notice that the options are all given in electrical units, hence we express *power* in terms of *potential difference* and *current*. $\text{unit for } k = \dfrac{\text{unit for } (IV)}{\text{unit for } (I)^2}\left(\dfrac{\cancel{\text{unit for } \lambda}}{\cancel{\text{unit for } L}}\right)^2$ $= \dfrac{\text{unit for } (V)}{\text{unit for } (I)} = \text{unit for } (R) = \Omega$

2	**Answer: D**
	Velocity is a vector, thus the direction sign of the velocity when the ball is going up is the negative of the direction sign of the velocity when the ball is coming back down. Thus, reject option A and option B. Given the asymmetry of the height-time graph where the time taken for upward journey of ball is shorter than downward journey, air resistance must be present. Since work is continually done against air resistance, the final kinetic energy of the ball (just before hitting ground) would be less than the initial kinetic energy of the ball (when it was first thrown up from the ground). Also, the area under graph for the first part of graph should be same as that in the second part since the distance travelled up and down are the same. So, reject option C.

3	**Answer: C**
	$+\downarrow: \; s_y = \cancel{u_y t} + \frac{1}{2}gt^2$ $+\rightarrow: s_x = u_x t$ Combining the 2 equations gives $s_y = \frac{1}{2}g\left(\frac{s_x}{u_x}\right)^2$ or $s_x \propto u_x\sqrt{s_y}$ Thus, $\frac{x_A}{x_B} = \frac{u_A}{u_B}\sqrt{\frac{s_A}{s_B}}$ $= \frac{2}{1}\sqrt{\frac{1}{2}} = \sqrt{2} = 1.41$

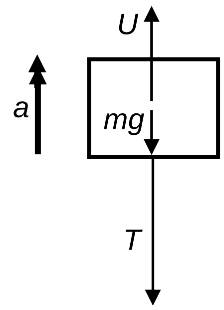
4	**Answer: D**
	 For Z, $F_{YZ} = 4ma$ ……(1) For Y, $F_{XY} - F_{ZY} = 3ma$ ……(2) From Newton's 3rd Law: $\lvert F_{YZ}\rvert = \lvert F_{ZY}\rvert = 4ma$ ……(3) From (2) & (3), $F_{XY} - 4ma = 3ma$ $F_{XY} = 7ma = F_{YX}$ Thus, $\frac{F_{YX}}{F_{ZY}} = \frac{7ma}{4ma} = \frac{7}{4}$

5 **Answer: C**

Newton's 2nd Law gives

$F_{net} = m_{wood}a$

$U - m_{wood}g - T = m_{wood}a$



When string breaks, tension $T = 0$

$(\rho_{water}V_{wood})g - (\rho_{wood}V_{wood})g - 0 = m_{wood}a$

$1000(1.0)(9.81) - (800)(1.0)9.81 = (800)(1.0)a$

$a = 2.45 \text{ m s}^{-1}$

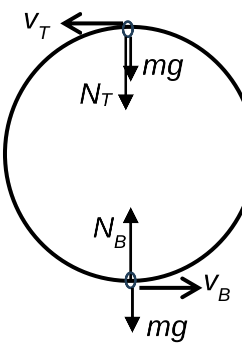
6 **Answer: A**

Apply Newton's 2nd Law:

At bottom, $N_B - mg = \dfrac{mv_B^{\,2}}{r}$ .....(1)

At top, assume N_T points downwards

$$N_T + mg = \frac{mv_T^{\,2}}{r} \qquad .....(2)$$



From bottom to top, conservation of energy gives

$$mg(2r) = \frac{1}{2}m\left(v_B^{\,2} - v_T^{\,2}\right) \qquad .....(3)$$

(1)-(2), then substituting (3) gives

$N_B - N_T = 6mg$

$5.5 - N_T = 6mg$

$N_T = -0.5mg$

Negative sign indicates N_T should point upwards, opposite to assumption.

7	**Answer: A**
	The work done by the net force provides the change in kinetic energy, which is equal to the kinetic energy if the initial kinetic energy is 0. KE at displacement s = work done by the net force $= \int F ds =$ area under the F-s graph Hence, gradient of KE-s graph = F. (It's easier to work with gradient.) From s_1 to s_2, F increases from 0, so the gradient of KE-s increases from 0. From s_2 to s_3, F decreases from a positive value to 0, so the gradient of KE-s decreases. Only **A** fits the above description. KE is always positive, so reject options C and D. Area under F-s graph = work done by F = Gain in KE. From s_1 to s_3, area always increasing, also F always positive, so KE always increasing, thus reject option B.

8	**Answer: C**
	$\phi = -\frac{GM}{r} = -\frac{GM}{(6.371\times10^6)+80000}$ .... (1) $g = -\frac{GM}{r^2} \Rightarrow 9.81 = -\frac{GM}{(6.371\times10^6)^2} \Rightarrow GM = 3.98\times10^{14}$ .... (2) Sub (2) into (1): $\phi = -\frac{GM}{r} = -\frac{3.98\times10^{14}}{(6.371\times10^6)+80000} = 62\times10^6 = 62$ MJ

9	**Answer: B**
	Using $T^2 \propto r^3$ (Can use in MCQ direct, but must prove starting from F_g provides F_c if in P2 or P3) Note to find "radius of orbit" given the satellite's height above Earth. Height r $\Rightarrow$ radius of orbit = $2r$ Height $3r$ $\Rightarrow$ radius of orbit = $4r$ $\left(\frac{T'}{T}\right)^2 = \left(\frac{4r}{2r}\right)^3$ $T'^2 = 2^3 T^2$ $T' = 2\sqrt{2}T$

10	**Answer: C**
	$a_0 = \omega^2 x_0 = (2\pi f)^2 x_0 = 4\pi^2 (10000)^2 \left(0.32 \times 10^{-3}\right) = 1.26 \times 10^6$ Hz

11	**Answer: A**
	From displacement-time graphs of P and Q in question, the amplitude of oscillation by Q decreases faster than that of P $\Rightarrow$ Q undergoes more damping than P. Hence answer is A. For heavier damping, • Peak has lower amplitude. • Peak shifts to a lower frequency.

12	**Answer: D**

Question asked for "rate of heat loss". [J s^{-1}]

- Eliminate A and C by unit analysis.

  Note that m is defined as rate of loss of mass. [kg s^{-1}]

  $$\left[\frac{P}{m}\right] = \left[\frac{E/t}{m}\right] = \frac{\text{J s}^{-1}}{\text{kg s}^{-1}} = \frac{\text{J}}{\text{kg}}$$

- Option B: P$_1$ **–** P$_2$ removes the rate of heat loss term. Eliminate.

- Mathematical proof for D:

$$P_1 m_2 - P_2 m_{11} = \frac{\cancel{m_2 m_1 l_v} + m_2 h - \cancel{m_1 m_2 l_v} - m_1 h}{m_2 - m_1} = \frac{\cancel{(m_2 - m_1)}h}{\cancel{m_2 - m_1}}$$

13	**Answer: C**

For full cycle processes, the net change in internal energy is zero.

$$\Delta U = Q + W$$

$$0 = Q + [(-4.2) + (1.0 \times 10^5 \times (20.0 - 5.0) \times 10^{-6})]$$

$$Q = 2.7 \text{ J}$$

14	**Answer: D**

Note that θ is measured with respect from the polarising axis of P$_1$.

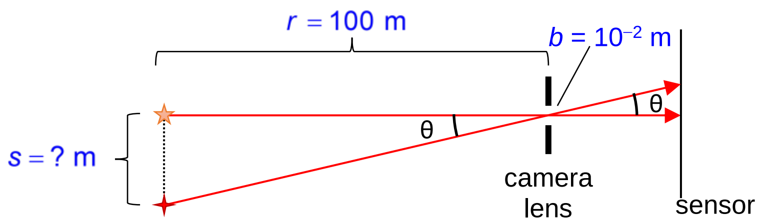
Let the light emerging from P$_1$, P$_2$ and P$_3$ have intensity I_1, I_2, I_3 respectively.

$$I_3 = I_2 \cos^2(\theta - 30)° = I_1 \cos^2 30° \cos^2(\theta - 30)°$$

$$14 = 30 \cos^2 30° \cos^2(\theta - 30)°$$

$$\theta = 68°$$

15	**Answer: C**



From circular measure

$s \approx r\theta$

Rayleigh's Criterion

$\theta \approx \dfrac{\lambda}{b}$

For small angle,

$$\frac{s}{r} \approx \theta \approx \frac{\lambda}{b}$$

$$s \approx \frac{r\lambda}{b}$$

$$= \frac{(100)(550\times10^{-9})}{10\times10^{-2}}$$

$$= 5.5\times10^{-4}\ \text{m} = 0.55\ \text{mm}$$

16	**Answer: D**

$$d\sin\theta = n_1\lambda_1 = n_2\lambda_2 \Rightarrow n_1\left(480\times10^{-9}\right) = n_2\left(640\times10^{-9}\right) \Rightarrow \frac{n_2}{n_1} = \frac{480}{640} = \frac{3}{4}$$

min $n_1 = 4$ and min $n_2 = 3$

Using $d\sin\theta = n_1\lambda_1$,

$$\frac{0.01}{5000}\sin\theta = 4\left(480\times10^{-9}\right)$$

$$\theta = 74°$$

17	**Answer: B**

Applying potential divider principle, the potential difference <u>across</u> the variable resistor, V_R varies between:

$$V_R = \left(\frac{100}{100+500}\right)30 = 5\text{V} \quad \text{to} \quad V_R = \left(\frac{500}{500+500}\right)30 = 15\text{V}$$

18	**Answer: D**
	A and B are wrong because the diode is connected in reverse-bias. When temperature of the thermistor is low, resistance is high and hence p.d. across the thermistor is high. The heater should be connected across the thermistor.

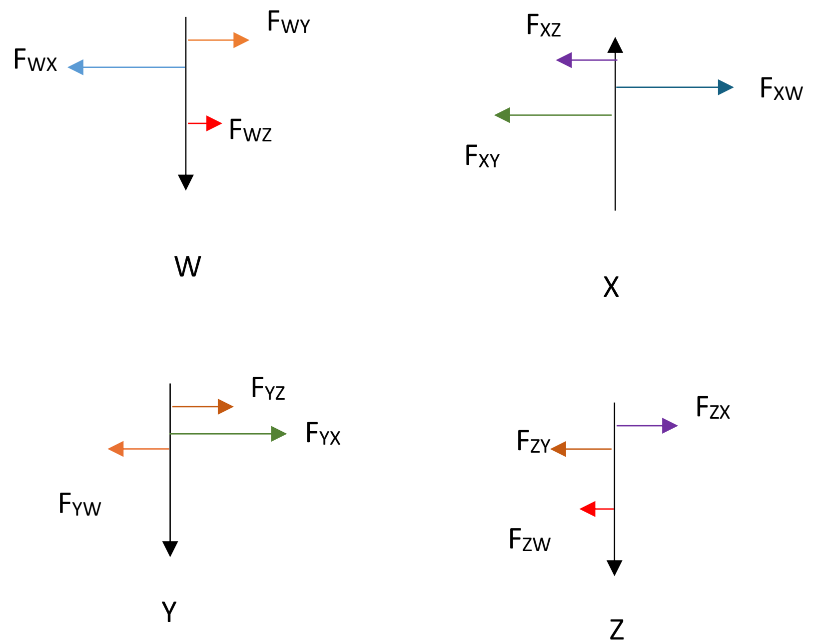
19	**Answer: A**
	change in potential energy = final potential energy – initial potential energy $= \left[\frac{qQ_1}{4\pi\varepsilon_0}\left(\frac{1}{x_1+x_2}\right) + \frac{q(-Q_2)}{4\pi\varepsilon_0}\left(\frac{1}{x_3}\right)\right] - \left[\frac{qQ_1}{4\pi\varepsilon_0}\left(\frac{1}{x_1}\right) + \frac{q(-Q_2)}{4\pi\varepsilon_0}\left(\frac{1}{x_2+x_3}\right)\right]$ $= \frac{qQ_1}{4\pi\varepsilon_0}\left(\frac{1}{x_1+x_2} - \frac{1}{x_1}\right) + \frac{qQ_2}{4\pi\varepsilon_0}\left(\frac{1}{x_2+x_3} - \frac{1}{x_3}\right)$ work done by electric field = –(change in potential energy) $= \frac{qQ_1}{4\pi\varepsilon_0}\left(\frac{1}{x_1} - \frac{1}{x_1+x_2}\right) + \frac{qQ_2}{4\pi\varepsilon_0}\left(\frac{1}{x_3} - \frac{1}{x_2+x_3}\right)$ **Note**: The change in potential energy is the work done by the external force. The electric force is equal and opposite to the external force (in defining the electric potential), hence there is an overall negative sign between the work done by the two forces.

20	**Answer: D**
	The electric field is uniform between the plates, so $F_A = F_B$. Point A is closer to the negative plate, hence is at a lower potential, i.e. $V_A < V_B$. Since $U = qV$, and electron is negatively charged ($q < 0$), $U_A > U_B$.

21	**Answer: C**

Draw the magnetic forces acting on each wire due to the rest of the wires.

Wire Y has a large magnetic force acting to the right due to wire X and its larger current. Wire Y is also attracted to the right by wire Z.



OR

Force on wire X due to wire Y = F_{XY}

$$F_{XY} = B_Y I_X L$$

$$B_Y = \frac{\mu_o I_Y}{2\pi a}$$

$$F_{XY} = \frac{\mu_o I_Y}{2\pi a} I_X L$$

$$F_{XY} = \frac{\mu_o I_Y I_X L}{2\pi a}$$

$$= k\frac{I_Y I_X}{a} \text{ where } k = \frac{\mu_o L}{2\pi}$$

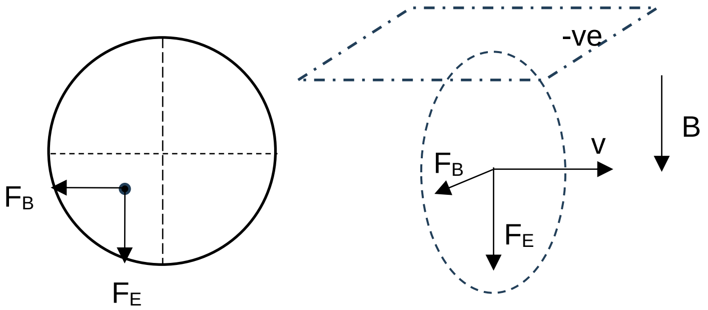
Taking to the right as positive:

$$F_W = -F_{WX} + F_{WY} + F_{WZ}$$

$$= -k\frac{2I^2}{a} + k\frac{I^2}{2a} + k\frac{I^2}{3a}$$

$$= -k\frac{7I^2}{6a}$$

	$F_X = -F_{XY} - F_{XZ} + F_{XW}$ $= -k\dfrac{2I^2}{a} - k\dfrac{2I^2}{2a} + k\dfrac{2I^2}{a}$ $= -k\dfrac{I^2}{a}$ $F_Y = -F_{YW} + F_{YX} + F_{YZ}$ $= -k\dfrac{I^2}{2a} + k\dfrac{2I^2}{a} + k\dfrac{I^2}{a}$ $= k\dfrac{5I^2}{2a}$ $F_Z = -F_{ZW} - F_{ZY} + F_{ZX}$ $= -k\dfrac{I^2}{3a} - k\dfrac{I^2}{a} + k\dfrac{2I^2}{2a}$ $= -k\dfrac{I^2}{3a}$

22	**Answer: A**
	

23	**Answer: A**
	$I = \dfrac{\varepsilon}{R} = \dfrac{\Delta BA}{\Delta t}\left(\dfrac{1}{R}\right) = \dfrac{(4.0\times10^{-5})\sin 50(\pi(\frac{0.50}{2})^2)}{2.0}\left(\dfrac{1}{3.0}\right) = 1.0\times10^{-6}\,\text{A}$ The current remains constant as the rate of change of flux is constant.

24	**Answer: C**
	To find I_{rms}, first square the graph, find total area over 1 period, find the average area over 1 period, then square root. $I_{rms} = \sqrt{\frac{4.0^2 x1 + 2.0^2 x2}{4}}$ $= 2.45$ A $P_{ave} = I_{rms}^2 R$ $= 2.45^2 \times 11$ $= 66$ W

25	**Answer: B**
	$\text{Intensity} = \frac{\text{Power}}{\text{Area}} = \left(\frac{n_{photon}}{t}\right)\frac{hf}{A}$ $E_{photon} = hf = \phi + eV_s$ • From graph, saturated current constant $\Rightarrow$ number of electrons constant $\Rightarrow$ no. of photons per unit time constant • stopping potential is smaller $\Rightarrow$ KE_{max} smaller $\Rightarrow$ *f* smaller Hence, intensity must be lower.

26	**Answer: B**
	If the accelerating potential changes, the kinetic energies of the electrons change. The intensities across the spectrum, as well as λ_{min}, will change. The wavelengths of the spikes are determined by the type of metal (the energy differences between the inner shells of the metal atoms). They are <u>not</u> affected by the energy of the electrons (so long as they are fast enough to knock out the inner shell electrons).

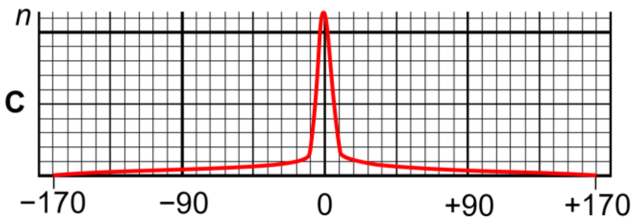
27	**Answer: C**
	According to the uncertainty principle, if a measurement of position is made with uncertainty Δx and a simultaneous measurement of momentum is made with uncertainty Δp, the product of the two uncertainties can never be smaller than the Planck constant. The uncertainty principle is hence about the minimum (lower bound) of the uncertainties.

28 **Answer: A**

From notes,

- Majority of α-particles went straight through or were deviated by small angles of less than 10°.
- A small proportion (about 1 in 8000) of the α-particles were deflected through large angles of more than 90° or came straight back.

A typical graph of N against θ should look like this, indicating a significant drop from the straight-through position to deviation of 10°:



It is hence useful to make sense of the numbers at key points of the given graphs

	N		
	0° (Straight-through)	**10°**	**Remarks**
Option A	10^8	10^5	Decrease to 1/1000 of straight through
Option B	0.7×10^9	0.35×10^9	Decrease by 50%
Option C	0.7×10^9	0.68×10^9	Decrease by less than 10 times
Option D	10^8	$10^{7.8}$	Decrease by less than 10 times

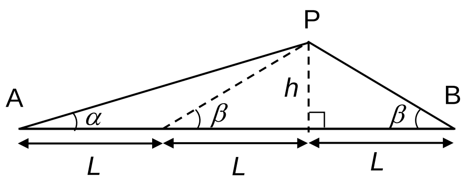
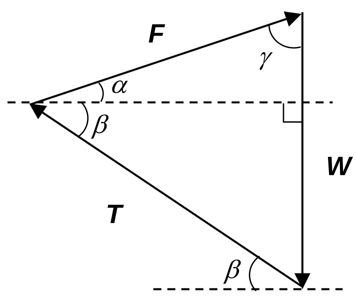
Option A shows the drastic drop in N from the straight through to 10° deviation position. This also implies that beyond 10° deviation, there is only a small fraction of particles with those angular deflection.

29	**Answer: C**
	Paper stops alpha particles, so $\alpha + \beta + background = 352$min^{-1} $\beta + background = 256$min^{-1} Initial count of beta particle source = 256-16=240min^{-1} Initial count of alpha particle source = 352-256=96min^{-1} After 12 days, alpha particle source undergoes 3 half-lives and beta particle source undergoes 4 half-lives Final count of alpha particle source=$\frac{96}{2^3} = 12min^{-1}$ Final count of beta particle source=$\frac{240}{2^4} = 15min^{-1}$ Total count = 12+15+16=43min^{-1}

30	**Answer: C**
	Number of reactions = 0.0010 / 1.008u = 5.976×10^{23} Energy released in one reaction = [7.018u + 1.008u – 2(4.004u)]c^2 = 2.689×10^{-12} J Total energy released = $2.689 \times 10^{-12} \times 5.976 \times 10^{23}$ = 1.61×10^{12} J

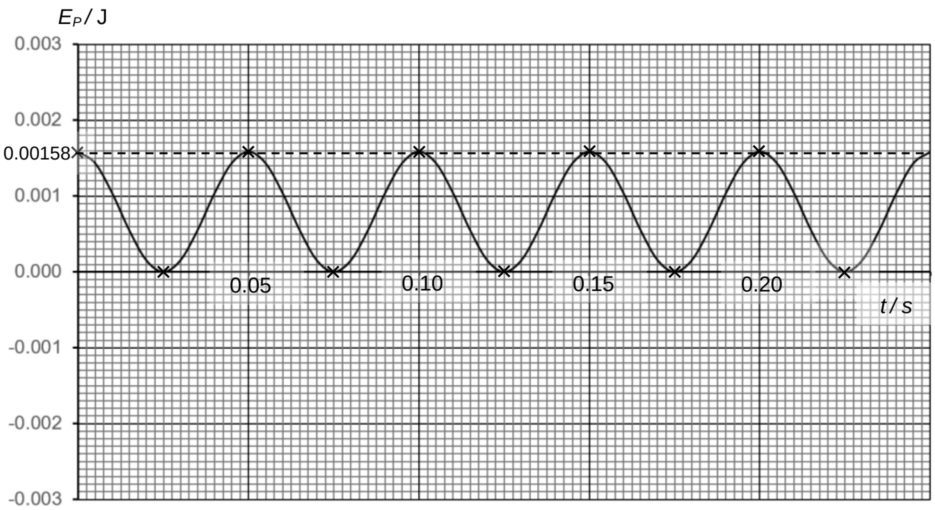
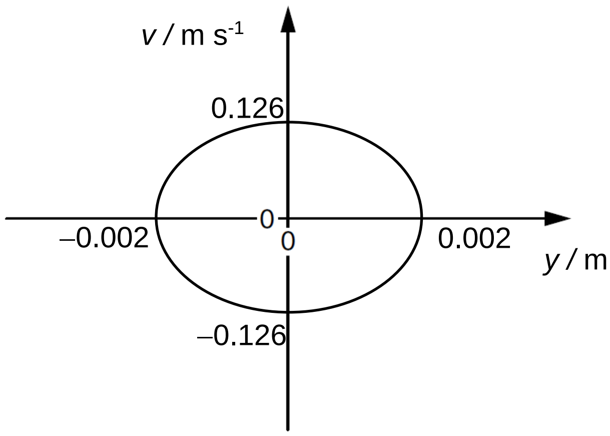
Paper 2 – Structured Questions

Qns	Answer	Marks
1(a)	**Resultant** force acting on the body is zero. **Resultant moment OR Torque <u>about any point</u>** is zero.	**B1** **B1**
1(b)	**<u>Point</u>** at which **<u>whole weight of body</u> <u>may be considered / seems to act</u>**.	**B1**
1(c)(i)	Since T and W have zero moment about P (because their line of actions passes through P), so F must have zero moment, i.e. line of action of F must pass through P OR When all forces have lines of actions that pass through P, (perpendicular) distance from P is zero for all forces (M1), so sum of moments about P is zero	**B1** **B1**

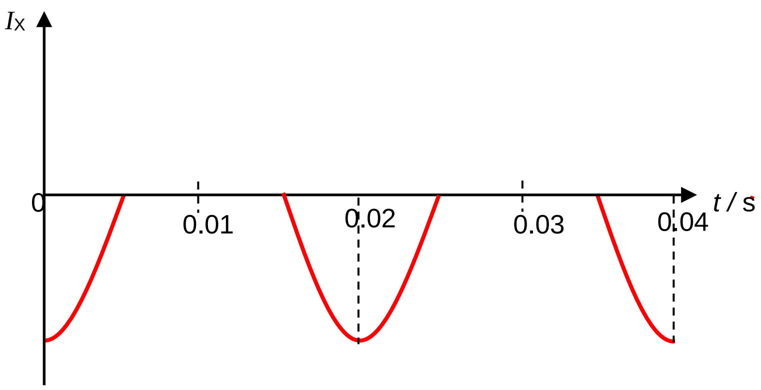
1(c)(ii)1.	**By principle of moment** and **taking moments about A,** $2W = 3T\sin\beta$ $2(10) = 3T\sin 30°$ $T = 13.3\ \text{N}$	**B1** **A1**
1(c)(ii)2.	Sum of forces in the vertical direction and horizontal direction are both zero. Considering horizonal forces: $F\cos\alpha = T\cos\beta \qquad (1)$ Considering vertical forces: $W = F\sin\alpha + T\sin\beta \Rightarrow F\sin\alpha = W - T\sin\beta \qquad (2)$ $\frac{\text{Eq(2)}}{\text{Eq(1)}}: \tan\alpha = \frac{W - T\sin\beta}{T\cos\beta} = \frac{10 - 13.3\sin 30}{13.3\cos 30}$ $\alpha = 16.2°$ (Physics statements to be present to score full credit) <u>Alternative method (for both parts):</u>  $\tan\alpha = \frac{h}{2L}$ $\tan\beta = \frac{h}{L}$ $\tan\alpha = 0.5\tan\beta$ $= 0.5\tan 30^0$ $\alpha = 16^0$  $\gamma = 90^0 - \alpha = 90^0 - 16^0 = 74^0$ Using sine rule, $\frac{T}{\sin\gamma} = \frac{W}{\sin(\alpha+\beta)}$ $T = \frac{10}{\sin(30^o + 16^o)} \times \sin 74^o$ $= 13.4\ \text{N}$	**B1** Horizontal **B1** Vertical **A1**

Qns	Answer	Marks
2(a)(i)	An arrow originating from the object, pointing towards point O, and labelled Z.	**B1**
2(a)(ii)	The frictional force provides the centripetal force, and hence must point towards the centre of the disc.	**B1**
2(b)(i)	Using points (6.00, 5.90) and (9.00, 8.90) on the line $\text{Gradient} = \frac{8.90 - 5.90}{9.00 - 6.00} = 1.00$	**B1** **B1**
2(b)(ii)	$\text{gradient} = \frac{\omega_{\text{max}}^2}{\frac{1}{r}} = r\omega_{\text{max}}^2 = a_{c(\text{max})}$ Hence, the gradient is numerically equal to the **maximum** centripetal acceleration.	**B1** **A1***

2(c)	$f = \text{gradient} \times m$ $= 1.00 \times 0.80$ $= 0.80\ \text{N}$	**C1** **A1**
(d)	As angular speed increases, **required** centripetal force increases. (friction provides required centripetal force) When required centripetal force exceeds maximum frictional force possible, object slides.	**B1** **B1**

Qns	Answer	Marks
3(a)(i)	**Free oscillations** are oscillations with constant amplitude and <u>without</u> energy loss or gain as there is no driving or resistive forces acting on it.	B1
3(a)(ii)	**Natural frequency** is the frequency at which a body will vibrate when there is <u>no driving</u> or <u>no resistive forces</u> acting on it.	B1
3(b)(i)	 $E_{p(max)} = \frac{1}{2}my^2\omega^2 = \frac{1}{2}(0.200)(0.002)^2\left(\frac{2\pi}{0.1}\right)^2$ $= 0.00158$ J •	**B1** correct sine-square shape, all above x-axis **B1** correct period & phase **B1** correct max E_p indicated
3(b)(ii)	 $v_0 = \omega y_o = \frac{2\pi}{T}y_o = \frac{2\pi}{0.1}(0.002) = 0.126$ m s^{-1}	**B1** Correct & smooth shape **B1** correct max v caln at y=0 **B1** correct max y at v=0
3(b)(iii)	Period decrease. Equilibrium point is raised once the mass is removed. Hence amplitude increases.	B1 B1

Qns	Answer	Marks
4 (a)(i)	The Principle of Conservation of Linear Momentum states that the **total linear momentum** of an **isolated system of interacting bodies** before and after collision remains constant if **no net external force acts on the system**. OR The Principle of Conservation of Linear Momentum states that the total linear momentum of a system remains constant provided that no resultant external force acts on the system.	B1
(a)(ii)	The **resultant force acting on a body** is **proportional to the rate of change of momentum** of that body.	B1
(b)(i)	After collision, the bodies will move along the same line that joins the 2 bodies' centre of mass rightwards.	B1
(b)(ii)	By principle of conservation of momentum: $mu + 14m(0) = 15mV$ $V = \frac{1}{15}u$ Ratio of kinetic energy $= \frac{KE_{nitrogen}}{KE_{neutron}} = \frac{\frac{1}{2}MV^2}{\frac{1}{2}mv^2} = \frac{15\cancel{m}\left(\frac{\cancel{v}}{15}\right)^2}{\cancel{m}\cancel{v^2}} = \frac{1}{15} = 0.067$	C1 M1 A1
(b)(iii)	From (bii), since initial total KE before collision not equals to final total KE after collision, the collision is not elastic (inelastic). OR Since there is no relative separation between the neutron and nitrogen atom after collision, the relative speed of approach is not equals to relative speed of separation, the collision is not elastic (inelastic).	M1 A1

Qns	Answer	Marks
5 (a)	When S is opened, current in coil Y stops flowing and the magnetic flux produced by the current in coil Y decreases. Hence magnetic flux density through **coil X** decreases. By Faraday's Law, an electromotive force is induced in coil X. By Lenz's Law, the induced emf in coil X would be in a direction so as to produce effects to **oppose the decrease** in the magnetic flux density. The induced emf would have produce current, in coil X in the clockwise direction when viewed from Q. But since this current would be in reversed biased direction, LED remain unlit. (For last B1, Student to either describe direction of current to be CW (from Q) leading to LED unlit OR describe current being in reversed biased direction leading to LED unlit.)	**B1** **B1** **B1** **B1**
5b		**B1** Negative cosine graph **B1** Rectified in the correct regions

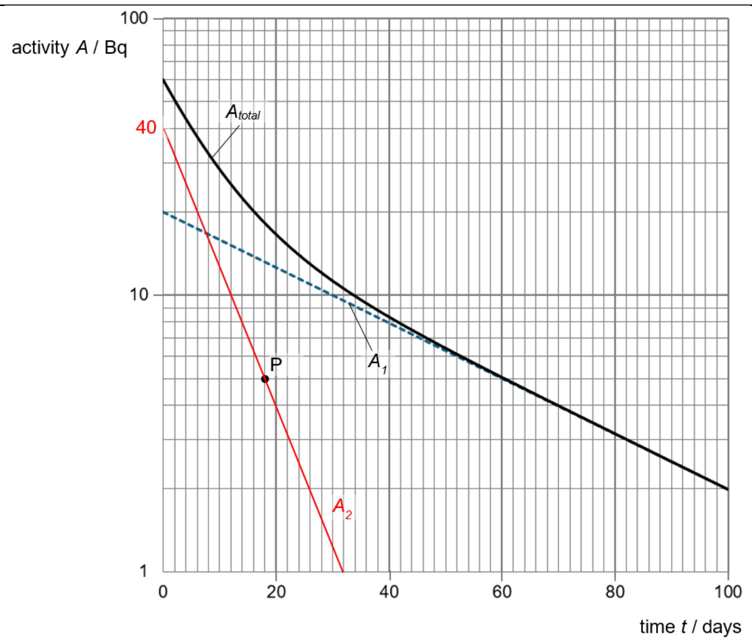
Qns	Answer	Marks
6(ai)	Lamination increases resistance, thus reduces induced (eddy) current in the iron core, which would reduce heat loss.	**M1**
6(aii)	Alternating current in primary coil (I_{pri}) give rise to changing magnetic flux (ϕ) in the primary coil and the iron core. Thus primary coil current is in phase with the magnetic flux.	**B1**
	This changing magnetic flux (ϕ) links the secondary coil through the iron core.	**B1**
	E.m.f. induced in secondary coil (E_{sec}) is proportional to rate of change of flux (ϕ). Secondary coil e.m.f. (E_{sec}) is not in phase with the flux (ϕ). (Hence e.m.f induced in secondary coil not in phase with alternating current in primary coil.	**B1**

6(b)	$\left(\frac{V_{sec}}{V_{pri}}\right)_{rms} = \frac{N_{sec}}{N_{pri}}$ $(V_{sec})_{rms} = \frac{8100}{300} \times 9.0 = 243 \text{ V}$	**C1**
	Peak voltage across load = $(V_{sec})_{rms} \times \sqrt{2} = 243 \times \sqrt{2}$ $= 3.4 \times 10^2$ V	**A1**

Qns	Answer	Marks
7(a)(i)	The force on the electron is (always) **perpendicular** to the <u>velocity</u>/ **perpendicular** to the <u>direction of travel/motion</u> of the electron. Thus no work is done by the force on the particle. (The speed remains unchanged and the force changes its direction.)	**B1**
7(a)(ii)	$F = Bqv$ $= (0.0050)(1.60\times10^{-19})(5.0\times10^{6})$ $= 4.0\times10^{-15}\text{N}$	**C1** **A1**
7(a)(iii)	Magnetic force provides the centripetal force. $F = ma$ $= m\left(\dfrac{v^2}{r}\right)$ $r = \dfrac{mv^2}{F}$ $= \dfrac{(9.11\times10^{-31})(5.0\times10^{6})^2}{4.0\times10^{-15}}$ $= 5.69\times10^{-3}$ $= 5.7\text{mm}$ $F = ma$ $(Bqv) = m\left(\dfrac{v^2}{r}\right)$ $r = \dfrac{mv}{Bq}$ $= \dfrac{(9.11\times10^{-31})(5.0\times10^{6})}{(0.0050)(1.60\times10^{-19})}$ $= 5.69\times10^{-3}$ $= 5.7\text{mm}$	**B1** **B1** c
7(a)(iv)	Radius of path is proportional to its mass. Mass of proton is <u>many order of magnitude larger</u> than the electron implies the radius of the proton would be many orders of magnitude larger (and is too large as compared to a typical laboratory).	**B1** **B1**
7(b)	$F = ma \Rightarrow eE = ma \Rightarrow e\dfrac{V}{d} = ma \Rightarrow a = \dfrac{eV}{md}$ ...... (1) $t = \dfrac{x}{v}$ ...... (2) Substituting (1) & (2): $y = \cancel{ut} + \dfrac{1}{2}at^2$ $= \dfrac{1}{2}\left(\dfrac{eV}{md}\right)\left(\dfrac{x}{v}\right)^2$ $= \left(\dfrac{eV}{2mdv^2}\right)x^2$	**M1** **M1** Correct substitution into the correct kinematics formula **A1**

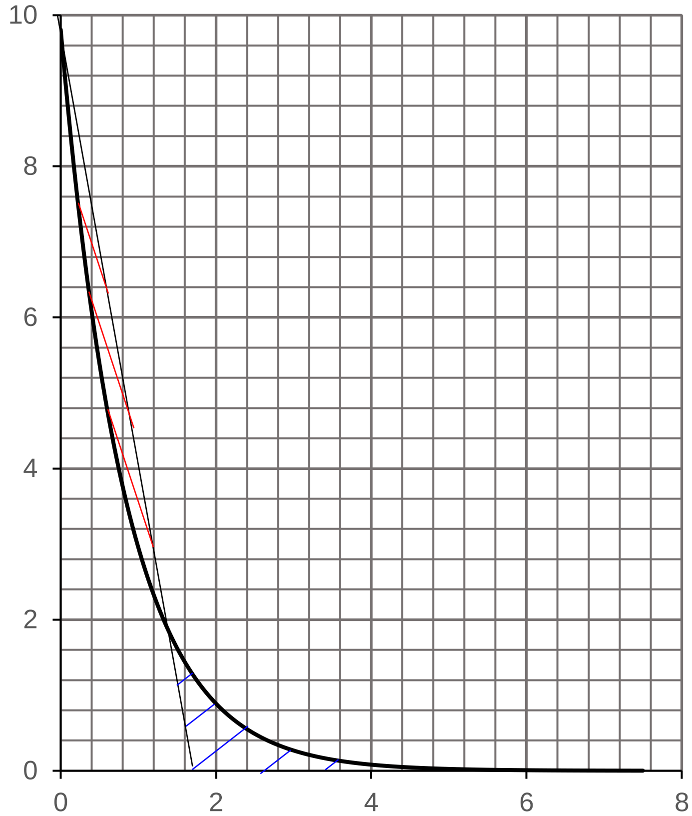
Qns	Answer	Marks
8(a)(i)1	α particles have greater ionisation power than X-rays, γ rays and energetic β rays. Hence, there is greater damage (biological effect stated in the last sentence in the 2nd last para on pg 18) produced by α particles.	**B1** **B1**
8(a)(i)2	Neutrons can be absorbed by the nucleus of an atom to form a radioactive isotope, which is unstable and produces secondary ionising radiations.	**B1**
8(a)(ii)	**Shield** from source using suitable materials. **Increase the distance** from a source.	**B2**
8(a)(iii)	Absorbed dose $= \dfrac{\text{energy deposited per year}}{\text{mass of tissue}}$ $= \dfrac{(\text{no. of decay})(\text{energy released per decay})}{\text{mass of tissue}}$ $= \dfrac{\left[(3.70\times10^{4})(365\times24\times3600)\right]\left[(5.23\times10^{6})(1.60\times10^{-19})\right]}{2.00}$ $= 0.489$ Gy Dose equivalent $= (\text{absorbed dose})\times\text{RBE}$ $= 0.489\times20$ $= 9.8$ Sv year^{-1}	**C1** **C1** **A1**

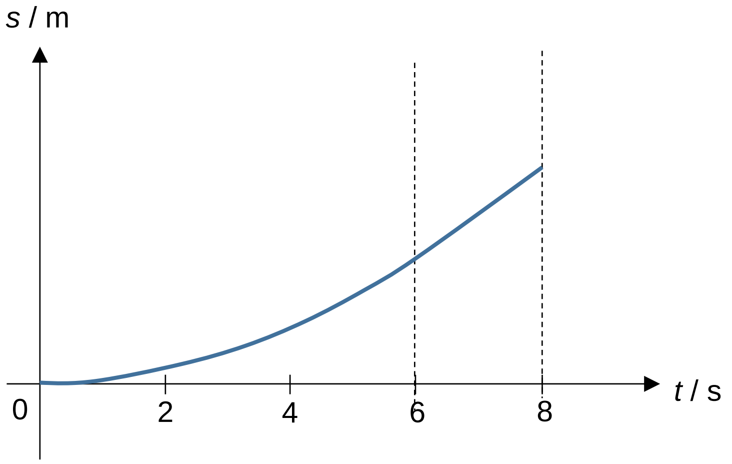
8(b)(i)	Gamma rays can pass through the tissue of the body to be captured by the **camera outside** while beta particles will be stopped by the body tissue.	**A1**
8(b)(ii)	$\lambda_E = \lambda_B + \lambda_T$ $\frac{\ln 2}{t_E} = \frac{\ln 2}{t_B} + \frac{\ln 2}{t_T}$ $t_E = \frac{t_T t_B}{t_T + t_B}$	**B1**
8(b)(iii)1	$A_o = \lambda N_o$ $= \left(\frac{\ln 2}{t_T}\right)\left(\frac{M}{\text{molar mass}} \times N_A\right)$ $= \left(\frac{\ln 2}{6.02 \times 3600}\right)\left(\frac{1.0 \times 10^{-12}}{99} \times 6.02 \times 10^{23}\right)$ $= 1.94 \times 10^5$ $= 1.9 \times 10^5$ Bq	**B1** **B1**
8(b)(iii)2	$t_E = \frac{t_T t_B}{t_T + t_B}$ $= \frac{6.02 \times 24}{6.02 + 24}$ $= 4.8$ h	**A1**
8(b)(iii)3	$A = \left(\frac{1}{2}\right)^{t/t_E} A_o$ $= \left(\frac{1}{2}\right)^{\frac{3.0 \times 24}{4.8}} (1.9 \times 10^5)$ $= 5.8$ Bq	**C1** **A1**

8(c)(i)	After a long enough time, the activity of the nucleus having the shorter half-life would have decreased to a **negligible** value compared to the activity of the nucleus having the longer half-life. Hence the total activity would be the same as the activity of the nucleus having the longer half-life.	**A1**
8(c)(ii)	From graph, time taken for activity of nucleus 1 to decrease from an initial value of 20 Bq to 10 Bq is 30 days, 10 Bq to 5 Bq is 30 days. Hence average half-life = 30 days	**A1**
8(c)(iii)	At t = 0 day, $A_{total} = A_1 + A_2$ $60 = 20 + A_2$ $A_2 = 40$ Bq	**A1**
8(c)(iv)	 	**B1** • line passes through point P and y-intercept at 40 Bq • line must be labelled
8(c)(v)	From graph, time taken for activity of nucleus 2 to decrease from an initial value of 40 Bq to 20 Bq is 6 days, 20 Bq to 10 Bq is 6 days, 10 Bq to 5 Bq is 6 days. Hence average half-life is 6 days.	**B1**

Paper 3 – Longer Structured Questions

Qns	Answer	Marks
1(a)	$T = \sqrt{4\pi^2 \dfrac{0.500}{9.8}}$ $= 1.41923\text{ s}$ $\dfrac{\Delta T}{T} = \dfrac{1}{2}\dfrac{\Delta L}{L} + \dfrac{1}{2}\dfrac{\Delta g}{g}$ $= \dfrac{1}{2}\left(\dfrac{0.2}{50.0}\right) + \dfrac{1}{2}\left(\dfrac{0.1}{9.81}\right)$ $= 0.00710$ $\Delta T = 0.01008\text{ s}$ T = 1.42 ± 0.01 s	M1 M1 M1 A1
(b)(i)	Assume that the uncertainty of each timing taken by each student is 0.2 s (typical timing for human error). Then the uncertainty for each of these reading is: $\Delta T_{\text{first}} = 0.2\text{ s}$ $\Delta T_{\text{second}} = \dfrac{0.2}{20} = 0.01\text{ s}$ Since the <u>uncertainty of second set of data is estimated to be smaller</u>, it will have smaller scatter, hence <u>will be a more precise set of data</u>.	M1 A1
(b)(ii)	The human error committed is a <u>systematic error</u> which <u>cannot be reduced by finding the average time</u> from multiple oscillations.	B1

Qns	Answer	Marks
2(a)	Acceleration is the rate of change of velocity.	**B1**
(b)(i)	As the object accelerates downwards, its velocity increases with time. Since the drag force (due to viscous fluid) on the object increases with speed, net force (weight – resistive/drag force) acting on the object decreases, hence the acceleration decreases with time.	**B1** **B1**
(b)(ii)	Initially the velocity of the object is zero, hence the drag force is also zero. The acceleration of the object is only due to its weight / gravitational force , hence acceleration 9.8 m s^{-2}. (Assume upthrust is negligible since given that acceleration is 9.8 m s^{-2})	**B1**
(b)(iii)	Change in velocity = area under *a-t* graph $v - 0 \approx$ (50 small squares)(0.4 x 0.4) = 8.0 m s^{-1} (range: 7.5-9.0 m s^{-1}) One way to estimate the area under the curve is to draw a line as shown in the diagram below. The line chosen is such that the area shaded in red is roughly equal to the area shaded in blue. The area under the original curve is then roughly equal to the area of the triangle, with base 1.7 and height 9.8. Thus, $\text{velocity} = \text{area under curve} \approx \frac{1}{2} \times 9.8 \times 1.7 = 8.3 \text{ m s}^{-1}$. Better estimation of the area can be achieved by using more triangles/trapeziums to approximate it.  Some students used kinematics equations without understanding that the acceleration graph already shows that the acceleration is not constant.	**C1** **A1**

(b)(iv)	 **Gradient = 0 at *t* = 0 s**, then gradually increasing till $t \approx 5.2$ s . After $t \approx 6$ s, gradient is constant (terminal velocity reached) at the value that was reached at 6 s - no kink allowed.	**B1** **B1**

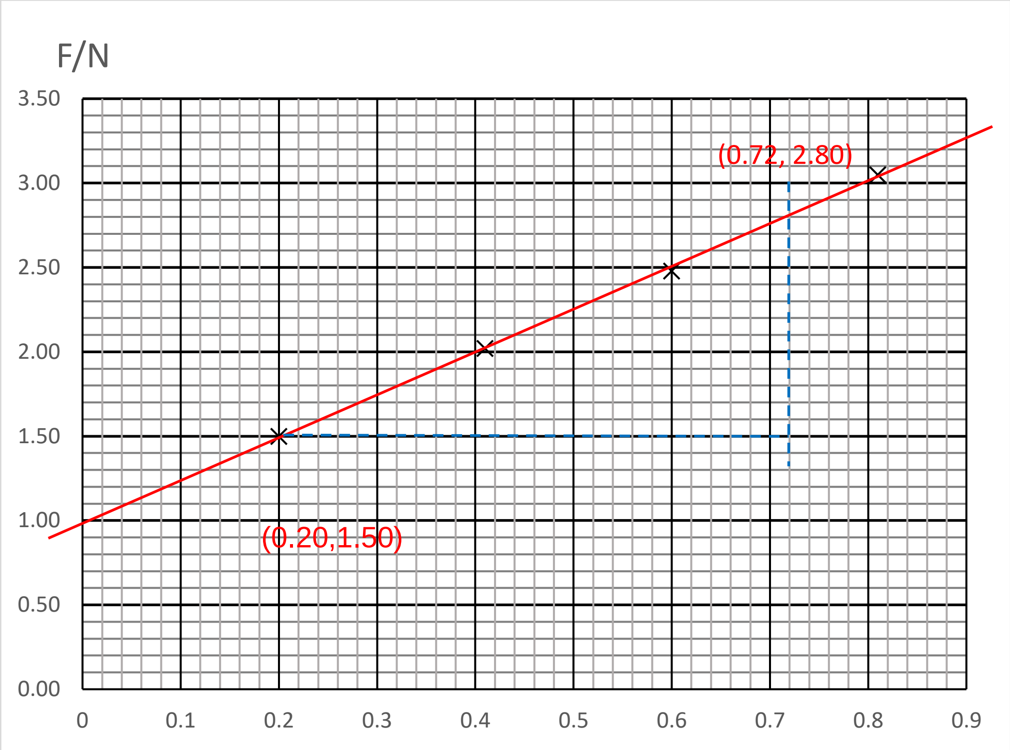
Qns	Answer	Marks

3(a)(i)	$R_{total} = R_{//} + r$
	$= (\frac{1}{600} + \frac{1}{3000})^{-1} + 30 = 530\ \Omega$
	$V_{LDR} = V_{terminal} = \varepsilon - Ir$
	$= 12 - (\frac{12}{530})(30) = 11.3$ V
	$I_{LDR} = \frac{V_{LDR}}{R_{LDR}}$
	$= \frac{11.3}{3000} = 3.77$ mA $= 3.8$ mA (2sf) (shown)
	
	OR
	
	$R_{//} = (\frac{1}{600} + \frac{1}{3000})^{-1} = 500\ \Omega$
	$V_{LDR} = V_{//} = \frac{R_{//}}{R_{//} + r} \times \varepsilon$
	$= \frac{500}{500 + 30} \times 12 = 11.3$ V
	$I_{LDR} = \frac{V_{LDR}}{R_{LDR}}$
	$= \frac{11.3}{3000} = 3.77$ mA $= 3.8$ mA (2sf) (shown)
	
	OR
	
	$R_{total} = R_{//} + r$
	$= (\frac{1}{600} + \frac{1}{3000})^{-1} + 30 = 530\ \Omega$
		M1
		
		M1
		
		M1

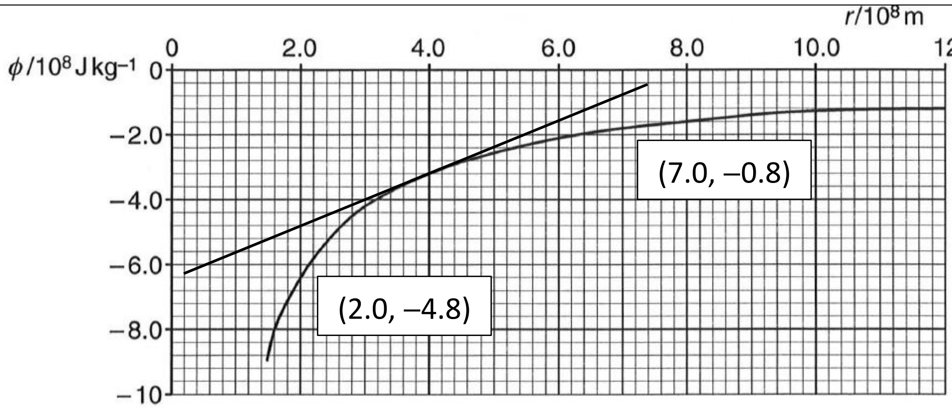
	$I_{Tot} = \dfrac{\varepsilon}{R_{Tot}} = \dfrac{12}{530} = 0.0226\text{ A}$ $I_{\text{LDR}} = \dfrac{600}{600+3000} \times I_{Tot}$ $= \dfrac{600}{600+3000} \times 0.0226 = 3.77\text{ mA} = 3.8\text{ mA (2sf) (shown)}$	

(a)(ii)	$P_{\text{LDR}} = I_{\text{LDR}}{}^2 R_{\text{LDR}}$ $= (3.8\times10^{-3})^2(3000)$ $= 0.043$ W (2sf)	**A1**
(b)	**<u>Explanation 1 (preferred):</u>** Resistance of LDR decreases in bright light, thus effective total resistance of entire circuit decreases. Total current I_{Tot} in circuit increases, resulting in larger potential drop V_r across the internal resistance *r* Since $V_{\text{terminal}} = \varepsilon - V_r = \varepsilon - I_{Tot}r$, where V_{terminal} is the terminal p.d. , ε is the e.m.f. if the cell; thus the terminal p.d. decreases. OR **<u>Explanation 2:</u>** Resistance of LDR decreases in bright light, thus resistance of the combination of parallel resistors decreases. By potential divider rule, potential difference (p.d.) across parallel resistors decreases. Since terminal p.d. is the same as p.d. across parallel resistor, terminal p.d. decreases.	**B1** **B1** **B1**

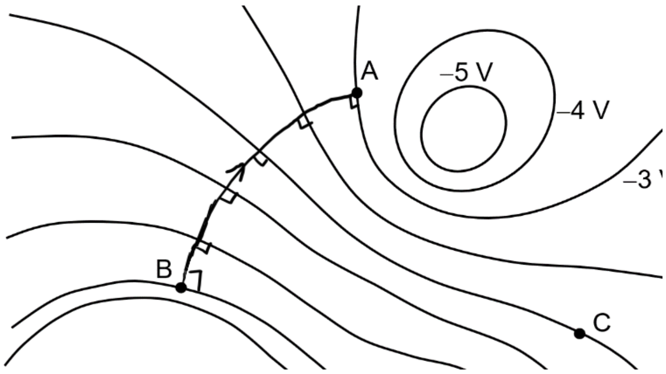
Qns	Answer	Marks
4(a)	Magnetic flux density *B* is the force acting per unit current per unit length on a wire carrying a current that is normal to the magnetic field.	**B1**
b(i)	Both arrows point vertically downwards (in diagram). The <u>current</u> flows <u>perpendicular to the magnetic flux density</u> at all parts of the coil. Hence the current carrying conductor will experience a magnetic force. The direction of the magnetic force can be deduced by <u>Fleming's Left Hand Rule</u>.	**B1** **B1** **B1**

(b)(ii)	 $\text{Gradient} = \dfrac{2.80-1.50}{0.72-0.20}$ $= \dfrac{1.30}{0.52}$ $= 2.5$ Force per unit current = F/L = 2.5 N A^{-1} From the graph, zero error of the balance =1.00 N OR Use point (0.20,1.50) and gradient =2.50 to find the y-intercept: 1.50 = (0.20)(2.80) + C C = 0.94 Zero error = C = 0.94 N	**B1** correct plots **B1** Best fit line **B1** use of gradient rather than plots, within range **B1**
(iii)	$F = BIL \Rightarrow \dfrac{F}{I} = BL$ From (b)(i), $\dfrac{F}{I} = 2.5 \text{ N A}^{-1}$, $2.5 = B\left(50 \times 2\pi\left(0.025\right)\right)$ $B = 0.637 \text{ T}$	**M1** **A1**

Qns	Answer	Marks
5(a)	The gravitational field strength at a point is the **gravitational force** (of attraction) **<u>per</u> unit mass** (acting on a small test mass) placed at that point in the field.	B1
(b)	**Gravitational force provides the centripetal force**. $G\dfrac{Mm}{r^2}=m\dfrac{v^2}{r}$ $G\dfrac{Mm}{r}=mv^2$ $\dfrac{1}{2}mv^2=\dfrac{1}{2}\times G\dfrac{Mm}{r}$ Since $E_P=-G\dfrac{Mm}{r}$, $E_K=-\dfrac{E_P}{2}$	M1 M1 clear algebra showing proof A0
(c)(i)	From graph, $\phi=-3.2\times10^8$ J kg^{-1} at $r=4.0\times10^8$ m. $E_{tot}=E_K+E_P=-\dfrac{E_P}{2}+E_P=\dfrac{E_P}{2}=\dfrac{m\phi}{2}$ $=\dfrac{8.93\times10^{22}\times(-3.2\times10^8)}{2}$ $=-1.43\times10^{31}$ J	M1 M1 A1

(c)(ii)	1. From **(b)**, $E_K = G\dfrac{Mm}{2r}$. Hence, when r decrease, kinetic energy **increases** 2. From **(c)(i)**, $E_{tot} = \dfrac{E_P}{2} = -G\dfrac{Mm}{2r}$. Hence, when r decrease, total energy **decreases**.	**B1** Show eqn or state relations **B1**
(c)(iii)	 **Method 1** (preferred as it is valid in all cases) Using (2.0, –4.8) and (7.0, –0.8), $g = -\dfrac{d\phi}{dr}$ $= \dfrac{[-4.8-(-0.8)]\times10^8}{(2.0-7.0)\times10^8}$ (minimum 2 s.f.) $= 0.80 \text{ m s}^{-2}$ **Method 2** (discouraged; valid only in the case when Jupiter is the only planet contributing to the potential being graphed i.e. the ϕ - r graph is an inverse r graph, else the relationship between potential and distance does not hold) $g = \dfrac{\phi}{r}$ $= \dfrac{-3.2\times10^8}{4.0\times10^8}$ $= -0.80 \text{ m s}^{-2}$	 **M1** **A1**

Qns	Answer	Marks
6a	The *increase* in internal energy of a system is equal to the sum of the *heat supplied to* the system and the *work done* *on* the system.	B2
6b	Since the temperature increases by the same amount for the same amount of gas, the increase in internal energy (ΔU) is the same. (First process) When heated at constant volume, no work is done on the gas (W=0). By first law of thermodynamics, heat transferred to the system is solely to increase its internal energy (Q=ΔU). (Second process) When heated at constant pressure, the gas expands, and work is done by the gas (W<0). By first law of thermodynamics, heat is required for the increase of internal energy AND the work done by the gas ($\Delta U = Q + W \Rightarrow Q = \Delta U - W > \Delta U$, since W<0). Hence, to increase the temperature by the same amount, the heat required at constant pressure is greater than heat required at constant volume.	B1 B1 B1
6ci	Using equation of state for ideal gas: $pV = NkT$ $(2.62\times10^{5})(0.0360) = N(1.38\times10^{-23})(273.15+25)$ $N = 2.29\times10^{24} = 2.3\times10^{24}$	M1 A1
6cii	mass per molecule $m = \dfrac{6.5\times10^{-3}}{6.02\times10^{23}}$ By kinetic theory, $pV = \dfrac{1}{3}Nm < c^2 >$ $(2.62\times10^{5})(0.0360) = \dfrac{1}{3}\times2.29\times10^{24}\times\dfrac{6.5\times10^{-3}}{6.02\times10^{23}} < c^2 >$ $c_{rms} = 1070\ m\ s^{-1}$	M1 (or finding n) M1 A1

<table>
<tr><th>Qns</th><th>Answer</th><th>Marks</th></tr>
<tr><td>7a</td><td>Electric potential at a point is <u>the work done</u> (by an external agent) <u>per unit positive charge to move a small test charge from infinity to that point</u>.</td><td>B1</td></tr>
<tr><td>7bi</td><td>

The field line must be perpendicular to all the field lines from A to B.

The direction (as indicated by the arrow) is from B to A.

The field line must be reasonably smooth.

–1 for each mistake (to a minimum of 0).</td><td></td></tr>
<tr><td>7bii</td><td>By Principle of Conservation of Energy,

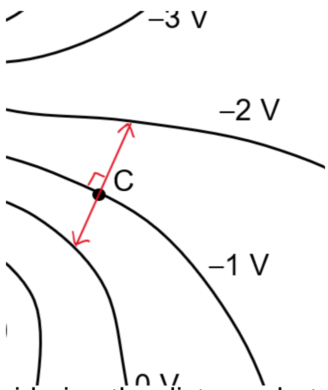
Gain in Kinetic energy = Loss in Electric Potential Energy

$\frac{1}{2} mv^2 - \frac{1}{2} mu^2 = e\,(V_i - V_f)$

$\frac{1}{2}(9.11 \times 10^{-31})v^2 - \frac{1}{2}(9.11 \times 10^{-31})(2.6 \times 10^{6})^2 = -1.6 \times 10^{-19}(-3-2)$

$v = 2.9 \times 10^{6}$ m s^{-1} (2.92×10^{6})</td><td>C1
Statement

C1
decrease in EPE

A1</td></tr>
<tr><td>7biii</td><td>

Considering the distance between the nearest two equipotential lines around point C (0V and –2V)

d = 1.8 cm (accept 1.7 to 1.9cm)

$E = \Delta V/d = (2-0)/(1.8\times10^{-2})$

$F = eE = 1.6 \times 10^{-19} \times (2-0)/(1.8\times10^{-2})$

$= 1.8 \times 10^{-17}$ N</td><td>C1</td></tr>
</table>

		A1
Qns	**Answer**	**Marks**
8(a)(i)	In a polarised wave, the oscillations are along one direction only, in a single plane that is normal to the direction of energy transfer of the wave	**B1** **B1**
8(a)(ii)	Light waves that have a constant phase difference.	**B1**
8(b)(i)	$sin\,\theta = \frac{\lambda}{x}$ For small angles, $sin\,\theta \approx tan\,\theta$ $\frac{\lambda}{x} = \frac{\frac{1}{2}w}{D}$ $\frac{590\times10^{-9}}{x} = \frac{\frac{1}{2}\left(30.7\times10^{-3}\right)}{2.6}$ $x = 1.0\times10^{-4}$ m	 **C1** **A1**
8(b)(ii)	$\theta > \frac{\lambda}{x} = \frac{590\times10^{-9}}{1.0\times10^{-4}}$ ≈ 0.0059 rad	**C1** **A1**
8(b)(iii)	The continuous central maximum is replaced by an interference pattern of equally spaced bright and dark fringes within the single slit envelope.	**B1** **B1**
8(b)(iv)	$\frac{I_{\text{single}}}{I_{\text{double}}} = \frac{kA^2}{k(2A)^2} = \frac{1}{4} = 0.25$	**B1**
8(b)(v)	1. Waves from both sources of light might be polarized in perpendicular planes. 2. Waves from both sources of light do not have constant phase difference OR are not coherent OR have different wavelength/frequencies. 3. Waves might have different amplitudes. (The resulting interference pattern will have less contrast due to incomplete cancellation at the minima.) Any two above.	**B1** **B1**
8(c)(i)	Negative energy levels indicate that the atom is a bound system - electron cannot escape from the atom. **OR** Energy must be supplied to the system to bring the electron to infinity. **OR** The potential energy is taken to be 0 at infinity, and negative work needs to be done to move the electron from infinity to a point. Hence, the electric potential energy is negative.	**B1**
8(c)(ii)	10.38 eV	**B1**
8(c)(iii)(1)	Downward arrows All three arrows	**B1** **B1**

8(c)(iii)(2)	Longest wavelength corresponds to the lowest transition energy: –1.57–(–5.74) = 4.17 eV $\Delta E = \dfrac{hc}{\lambda}$ $4.17 \times 1.6 \times 10^{-19} = \dfrac{6.63 \times 10^{-34} \times 3 \times 10^{8}}{\lambda}$ $\lambda = 2.98 \times 10^{-7}\ \text{m} = 298\ \text{nm}$	 **B1** **B1**
8(c)(iv)	Since <u>the energy of the photon (8.9 eV) does not match the energy difference between any two of energy levels</u>, the electrons will not be excited. Hence, there is <u>no spectral lines</u>.	**B1** **B1**

Qns	Answer	Marks
9(a)(i)	Diffraction is the spreading of a wave into the geometric shadow when it passes through a slit or past an edge of an obstacle.	B1
9(a)(ii)	Wavelength of blue light is less than wavelength of red light Hence more orders seen OR each order is at a smaller angle than for the equivalent red	B1 B1 either statement
9(b)(i)	$d = \frac{\lambda}{2} = \frac{0.30}{2} = 0.15$ m	A1
9(b)(ii)	**N** labelled at A and B, and nowhere else	B1
9(c)(i)	As M moves, path difference of between S_1M and S_2M changes continuously. When path difference between S_1M and S_2M is integer number of wavelength, constructive interference occurs, a loud sound is received by M When path difference between S_1M and S_2M off integer number of half wavelength, destructive interference occurs, a soft/no sound is received by M. **<u>OR</u>** The waves from S_1 and S_2 are of the same type, wavelength, frequency and amplitude. They travel opposite to each other, overlap and form a stationary wave, with displacement nodes and antinodes at regular intervals. M detects a large sound at displacement nodes, and soft (or no) sound at displacement antinodes.	B0 B1 B1 **<u>OR</u>** B1 B1
9(c)(ii)	$v = f\lambda$ $330 = 1100\lambda$ $\lambda = 0.30$ m distance between consecutive max (displacement nodes or pressure antinodes) $= 0.30 / 2 = 0.15$ m No. of max M passes through in 1 s $= \frac{20}{0.15} = 133 = 130$ (2 sf) Hence frequency of the fluctuation of the sound is 130 Hz.	C1 wavelength C1 distance between max A1

9(d)(i)	This can be explained if the EM radiation is quantized, with each **photon** having **energy** equal to ***hf***, *h* being the plank's constant and *f* being the frequency of the EM radiation. Each electron absorbs energy from a **single** photon (hf). If the energy of photon is less than the work function of the metal ($hf<\Phi$), the electron will not be emitted, no matter how many photons there are or how long the electron is exposed to the EM radiation.	**B1** **B1** **B1**
9(d)(ii)(1)	Method 1 When $E_{max} = 0$, $\frac{hc}{\lambda_0} = \Phi$. Hence, $\Phi = \frac{hc}{\lambda_0} = \frac{6.63 \times 10^{-34} \times 3 \times 10^8}{300 \times 10^{-9}} = 6.63 \times 10^{-19}\,\text{J} = 4.14\text{ eV}$. Method 2 Using $E_{max} = \frac{hc}{\lambda} - \Phi$: As λ approaches infinity, E_{max} approaches Φ asymptotically. From Fig. 9.4, the (dotted) curve approaches –4 eV asymptotically. Hence, $\Phi \approx 4$ eV.	**M1** **A1**
9(b)(ii)(2)	$f_0 = \frac{c}{\lambda_0} = \frac{3 \times 10^8}{300 \times 10^{-9}} = 1.0 \times 10^{15}\,\text{Hz}$	**B1**
9(b)(ii)(3)	According to Fig. 9.4, E_{max} = 20 eV when λ = 220 nm. Using $E_{max} = eV_s$, or $V_s = \frac{E_{max}}{e} = \frac{20\text{eV}}{e} = 20\text{ V}$	**M1** **A1**
9(c)	The same curve shifted downward (smaller *x*-intercept). Part of curve below the axis has to be dotted, same as the original curve. Curve must be reasonably smooth, and must not intersect with the original curve and the y-axis. The part of the curve below the horizontal axis must be dashed.	**M1** **A1** –1 for each mistake