TOPIC D

Paper 2 Exam Questions

1.

(a) State *Newton's law of gravitation*. [2]

(b) Show that a moon orbiting a planet of mass M in a circular orbit of radius r and period T

$\frac{4\pi^2 r^3}{T^2} = GM$. [2]

(c) Io is a moon of Jupiter with orbit radius 4.2×10^5 m and period 1.8 days. Titan is a moon of Saturn with orbit radius 1.2×10^6 m and period 16 days.

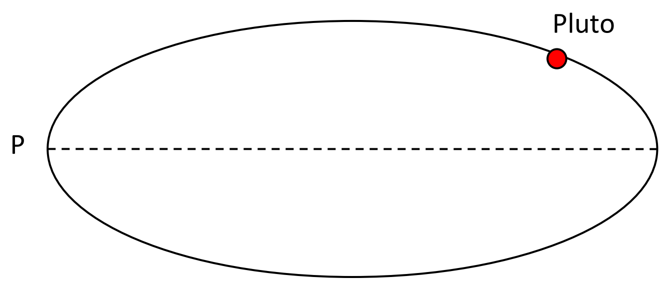
Calculate the ratio of Jupiter mass to Saturn mass $\frac{M_J}{M_S}$. [3]

Question 1		Answers	Marks
a		There is an attractive force between two point masses acting along the line joining them✓ Which is proportional to the product of the masses and inversely proportional to the square of their separation✓	2
b		$v=\sqrt{\frac{GM}{r}} \Rightarrow \left(\frac{2\pi r}{T}\right)=\sqrt{\frac{GM}{r}}$ ✓ $\frac{4\pi^2 r^2}{T^2}=\frac{GM}{r}$ ✓ Rearranging to get answer.	2
c		$\frac{M_J}{M_S}=\frac{\frac{r_{Io}^3}{T_{Io}^2}}{\frac{r_{Titan}^3}{T_{Titan}^2}}$ ✓ $\frac{M_J}{M_S}=\frac{r_{Io}^3}{r_{Titan}^3}\frac{T_{Titan}^2}{T_{Io}^2}$ ✓ $\frac{M_J}{M_S}=\left(\frac{4.2\times10^5}{1.2\times10^6}\right)^3\times\left(\frac{16}{1.8}\right)^2=3.39\approx3.4$ ✓	3

2.

(a) State what is meant by *gravitational field strength*. [2]

(b) The dwarf planet Pluto orbits the Sun in an elliptical orbit. The minimum distance between Pluto and the Sun is 30 AU and the maximum distance is 50 AU. One AU is the distance between the Earth and the Sun and equals 1.5×10^{11} m.



Pluto has its maximum speed at P.

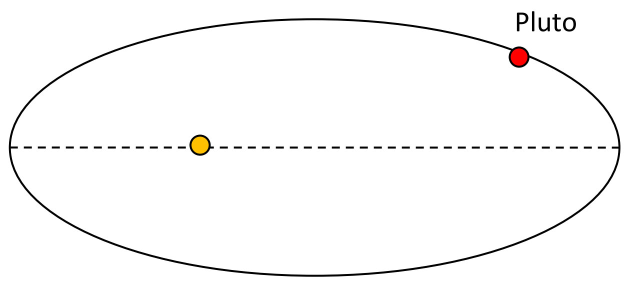
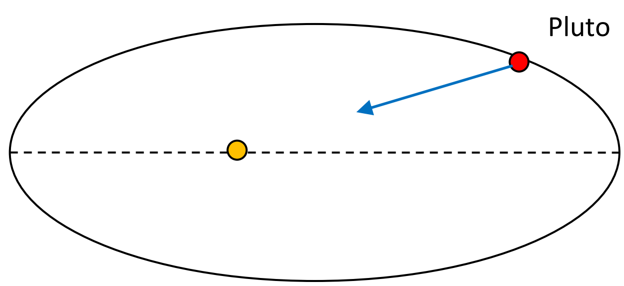
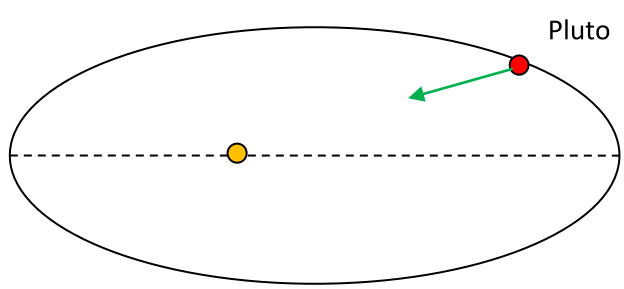
On the diagram draw

(i) the approximate position of the Sun. [1]

(ii) an arrow to indicate the gravitational force on Pluto from the Sun. [1]

(iii) an arrow to indicate the acceleration of Pluto. [1]

(c) The maximum speed of Pluto in its orbit is 5.4×10^{3} m s^{-1}. Calculate Pluto's minimum speed in its orbit. [2]

Question 2		Answers	Marks
a		The gravitational force per unit mass✓ Experienced by a test mass (a small, point mass)✓	**2**
b	**i**	 Approximately correct position on major axis ✓ (Do not accept center of ellipse)	**1**
b	**ii**	 Arrow towards Sun (consistent with (i))✓	**1**
b	**iii**	 Arrow towards Sun (consistent with (i))✓	**1**
c		$v_A \times 50 = 5.4 \times 10^3 \times 30$ ✓ $v_A = \frac{30}{50} \times 5.4 \times 10^3 = 3.2 \times 10^3 \text{ m s}^{-1}$ ✓	**2**

3.

(a) A satellite is in a circular orbit of radius r around the Earth. Show that the time T to complete one revolution is given by $T^2 = \frac{4\pi^2}{GM}r^3$ where M is the mass of the Earth. [2]

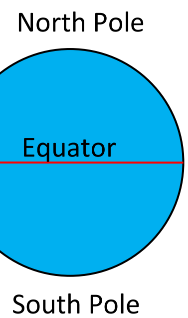
(b) A geostationary orbit is an orbit in which T = 24 hours. The mass of the Earth is 6.0×10^{24} kg and the radius of the Earth is 6.4×10^6 m.

(i) Show that the height of a satellite in a geostationary orbit is about 3.6×10^7 m above the Earth's surface. [3]

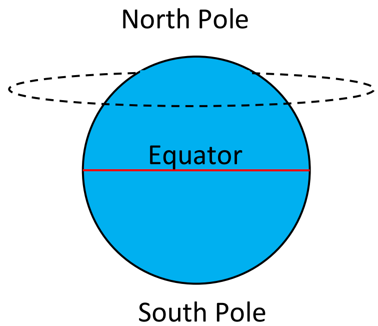
(ii) Hence show that the speed of this satellite is 3.1×10^3 m s^{-1}. [2]

(iii) Suggest an advantage of a satellite in a geostationary orbit. [2]

(iv) On the diagram draw a possible geostationary orbit. [1]

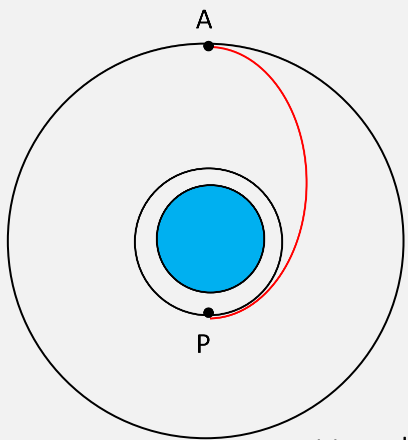


(v) Explain why the orbit shown is not a possible orbit in which gravity is the only force acting. [2]



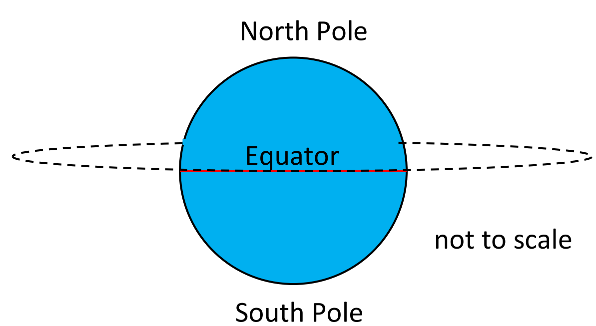
(c) Another satellite is in a low Earth orbit at a height of 320 km above the Earth's surface. Calculate the period of revolution in the low Earth orbit. [2]

(d) The diagram shows how the satellite in the low Earth orbit of (c) can be moved to the higher orbit of (b). Engines are fired at P and the satellite enters the red elliptical orbit. At A the engines are fired again, and the satellite enters the high orbit. When in the elliptical orbit, the speed at A is 1.6×10^3 m s^{-1}.



(i) Calculate the work done when the rocket engines are fired at A. The mass of the satellite is 350 kg. [4]

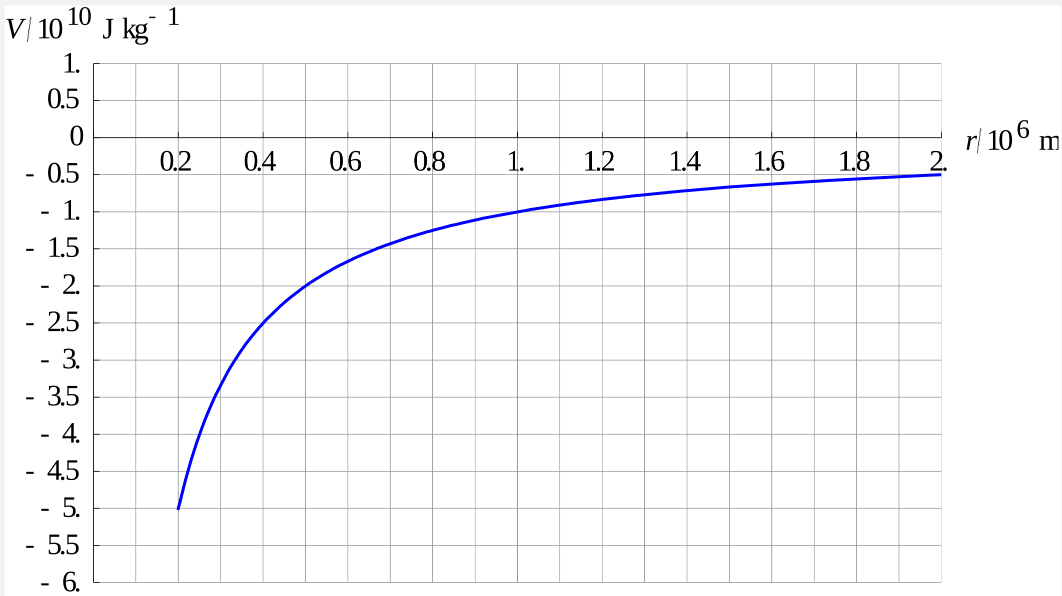
(ii) The force exerted by the rocket engines is 80 kN. Estimate the time interval for which the rocket engines must fire. [2]

Question 3		Answers	Marks
a		$v=\sqrt{\dfrac{GM}{r}}\Rightarrow\left(\dfrac{2\pi r}{T}\right)=\sqrt{\dfrac{GM}{r}}$ ✓ $\dfrac{4\pi^2 r^2}{T^2}=\dfrac{GM}{r}$ ✓ Rearranging to get answer.	**2**
b	**i**	$r^3=\dfrac{GM}{4\pi^2}T^2$ ✓ $r^3=\dfrac{6.67\times10^{-11}\times6.0\times10^{24}}{4\pi^2}\times(24\times3600)^2\Rightarrow r=4.23\times10^7\text{ m}$ ✓ $h=4.23\times10^7-6.4\times10^6=3.59\times10^7\approx3.6\times10^7\text{ m}$ ✓	**3**
b	**ii**	$v=\dfrac{2\pi r}{T}$ ✓ $v=\dfrac{2\pi\times4.23\times10^7}{24\times60\times60}=3.07\times10^3\approx3.1\times10^3\text{ m s}^{-1}$ ✓	**2**
b	**iii**	They look down at the same point on Earth✓ And so are useful for communications, surveillance etc.✓	**2**
b	**iv**	A circular orbit above the equator✓  	**1**
b	**v**	The resultant force on the satellite points towards the center of the circular orbit ✓ But the gravitational force is pointing towards the earth's center ✓	**2**
c		$\left(\dfrac{4.23\times10^7}{6.72\times10^6}\right)^3=\dfrac{24^2}{T^2}$ ✓ $T=1.520\text{ hours}=91.2\approx91\text{ min}$ ✓	**2**
d	**i**	Speed in the elliptical orbit is 1.6×10^3 m s^{-1} which must be increased to the circular orbit speed 3.1×10^3 m s^{-1}✓ The change in kinetic energy is	**4**

		$\frac{1}{2}\times 350\times\left((3.1\times 10^3)^2-(1.6\times 10^3)^2\right)=1.2\times 10^9$ J ✓ There is no change in gravitational potential energy so the change in the total energy is 1.2×10^9 J ✓ So, the work done by the engines is 1.2×10^9 J ✓	
d	**ii**	The impulse needed is $J=350\times\left(3.1\times 10^3-1.6\times 10^3\right)=5.25\times 10^5$ N s ✓ $\Delta t=\frac{J}{F}=\frac{5.25\times 10^5}{80\times 10^3}=6.6$ s ✓	**2**

4.

The graph shows the variation with distance r of the gravitational potential, V_g, due to a planet of radius 2.0×10^5 m.



(a) Calculate the mass of the planet. [2]

(b) Show that the escape speed from the surface of the planet may be written as $v_{esc} = \sqrt{-2V}$, where V is the gravitational potential on the planet's surface. [1]

(c) Determine the escape speed from this planet. [2]

(d)

(i) Calculate how much energy is required to move a rocket of mass 1500 kg from the surface of the planet to a point 1.0×10^6 m from the centre. [2]

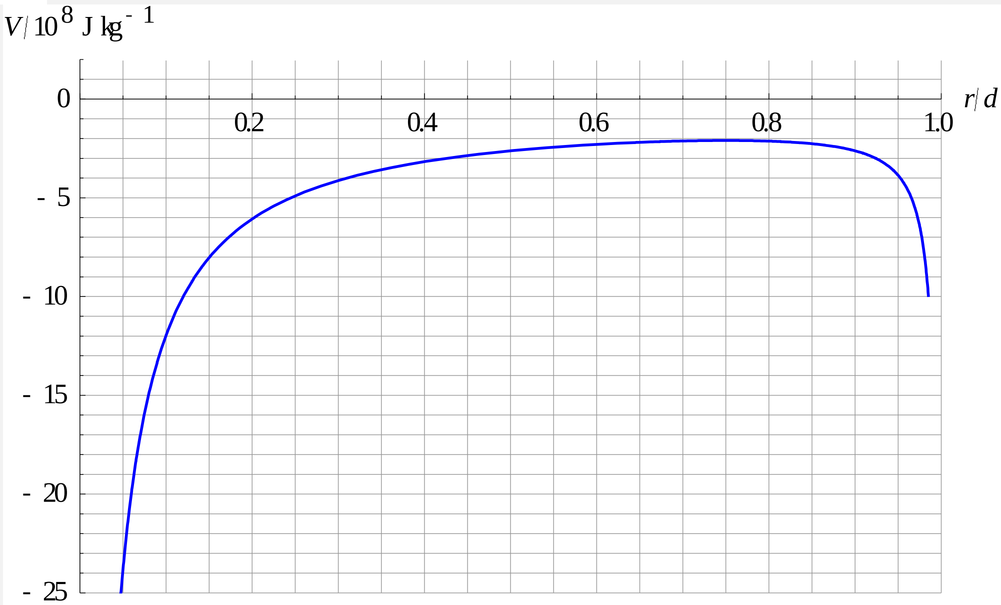
(ii) Determine the **additional** energy required to put the rocket in orbit at the distance in part (i). [2]

(e) A probe is released from rest at a distance from the planet's canter of 0.50×10^6 m and crashes onto the planet's surface. Determine the speed with which the probe hits the surface. [3]

Question 4		Answers	Marks
a		At surface $V=-\dfrac{GM}{R}=-5.0\times10^{10}\text{ J kg}^{-1}$ ✓ $M=\dfrac{5.0\times10^{10}\times2.0\times10^{5}}{6.67\times10^{-11}}=1.499\times10^{26}\approx1.5\times10^{26}\text{ kg}$ ✓	2
b		$v_{\text{esc}}=\sqrt{\dfrac{2GM}{R}}=\sqrt{-2\left(-\dfrac{GM}{R}\right)}$ ✓ $v_{\text{esc}}=\sqrt{-2V}$	1
c		$v_{\text{esc}}=\sqrt{-2V}=\sqrt{-2\times(-5.0\times10^{10})}$ ✓ $v_{\text{esc}}=3.2\times10^{5}\text{ m s}^{-1}$ ✓	2
d	i	$W=m\Delta V$ and $\Delta V=(-1.0\times10^{10}-(-5.0\times10^{10})=4.0\times10^{10}\text{ J kg}^{-1}$ ✓ $\Delta V=1500\times4.0\times10^{10}=6.0\times10^{13}\text{ J}$ ✓	2
d	ii	We must provide the kinetic energy in orbit: $\dfrac{mv^2}{r}=\dfrac{GMm}{r^2}\Rightarrow mv^2=\dfrac{GMm}{r}\Rightarrow E_K=\dfrac{1}{2}\dfrac{GMm}{r}=-\dfrac{1}{2}mV$ ✓ $E_K=-\dfrac{1}{2}\times1500\times(-1.0\times10^{10})=7.5\times10^{12}\text{ J}$ ✓ ***OR*** Total energy in orbit is $-\dfrac{GMm}{2r}=\dfrac{mV}{2}=-\dfrac{1500\times1.0\times10^{10}}{2}=-7.5\times10^{12}\text{ J}$ ✓ Energy in initial position is $-\dfrac{GMm}{R}=mV=-1500\times5.0\times10^{10}=-7.5\times10^{13}\text{ J}$ so difference is $-7.5\times10^{12}-(-7.5\times10^{13})=6.75\times10^{13}\text{ J}$. We have already provided $6.0\times10^{13}\text{ J}$ so the additional energy is $6.75\times10^{13}-6.0\times10^{13}=7.5\times10^{12}\text{ J}$ ✓	2
e		$E_T=mV$ at $r=0.50\times10^{6}\text{ m}$ ✓ $\dfrac{1}{2}mv^2+mV_{\text{surface}}=mV\Rightarrow v=\sqrt{2(V-V_{\text{surface}})}$ ✓ $v=\sqrt{2(-2.0\times10^{10}-(-5.0\times10^{10}))}=2.4\times10^{5}\text{ m s}^{-1}$ ✓	3

5.

The graph shows the variation with distance r from the centre of a planet of the combined gravitational potential V_g due to the planet (of mass M) and its moon (of mass m) along the line joining the planet and the moon. The horizontal axis is labelled $\frac{r}{d}$, where d is the centre-to-centre separation of the planet and the moon. The graph starts on the surface of the planet and ends on the surface of the moon.



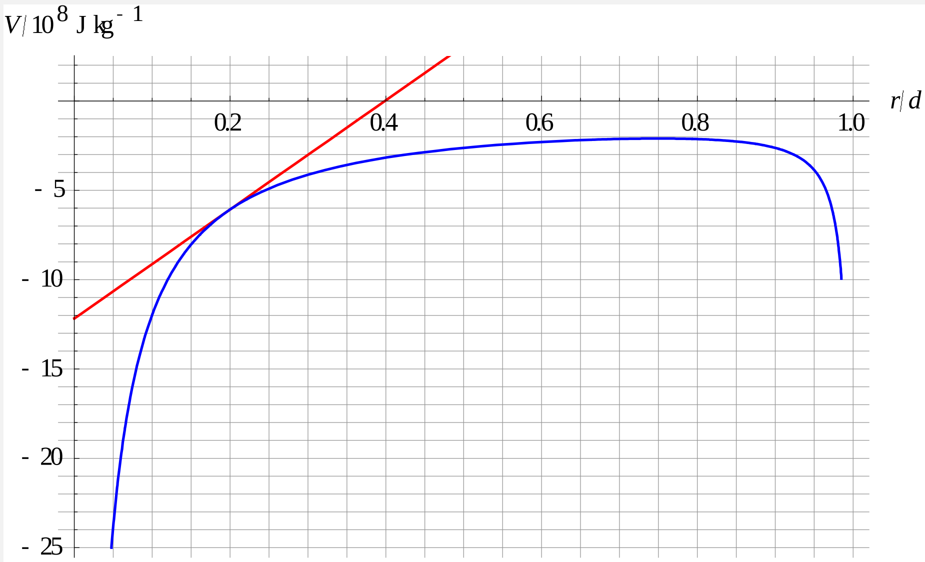
(a) (i) The distance d is equal to 4.8×10^8 m. Use the graph to calculate the magnitude of the gravitational field strength at the point where $\frac{r}{d}=0.20$ to one s.f. [3]

(ii) Suggest why it is not worth giving the answer to more than 1 s.f. [2]

(b) Explain the physical significance of the point where $\frac{r}{d}=0.75$. [2]

(c) Calculate the ratio M/m. [2]

(d) A probe of mass 2500 kg is to leave the surface of the moon and return to the surface of the planet.
Determine the minimum kinetic energy that must be given to the probe on the surface of the moon. [2]

<table>
<tr><th colspan="2">Question 5</th><th>Answers</th><th>Marks</th></tr>
<tr><td>a</td><td>i</td><td>The gravitational field strength is the gradient of the tangent to the potential curve ✓


Tangent drawn ✓
Gradient: $g=\dfrac{0-(-12\times10^8)}{(0.40-0)\times4.8\times10^8}=6.25\approx 6\ \mathrm{N\,kg^{-1}}$ ✓</td><td>3</td></tr>
<tr><td>a</td><td>ii</td><td>Drawing the tangent by hand is very inaccurate ✓
The gradient is very sensitive to the line drawn ✓</td><td>2</td></tr>
<tr><td>b</td><td></td><td>The gradient of the potential curve is zero ✓
So g is zero ✓</td><td>2</td></tr>
<tr><td>c</td><td></td><td>$\dfrac{GM}{0.75^2}=\dfrac{Gm}{0.25^2}$ ✓
$\dfrac{M}{m}=\dfrac{0.75^2}{0.25^2}=9$ ✓</td><td>2</td></tr>
<tr><td>d</td><td></td><td>Probe must make it to the top of the potential energy curve ✓
$W=m\Delta V=2500\times(-2.0\times10^8-(-10\times10^8))=2.0\times10^{12}\ \mathrm{J}$ ✓</td><td>2</td></tr>
</table>

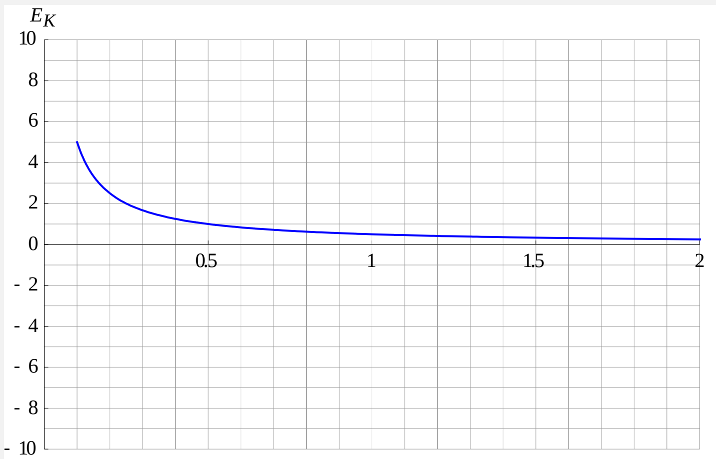
6.

(a)

(i) State what is meant by *gravitational potential energy* of a system of two masses. [1]

(ii) A probe is at rest on the surface of a planet. Suggest why the gravitational potential energy of the planet and the probe is negative. [1]

(b) A satellite is in a circular orbit around a planet. The graph shows the variation of the kinetic energy of the satellite with orbit radius. Units are for reference and are arbitrary.



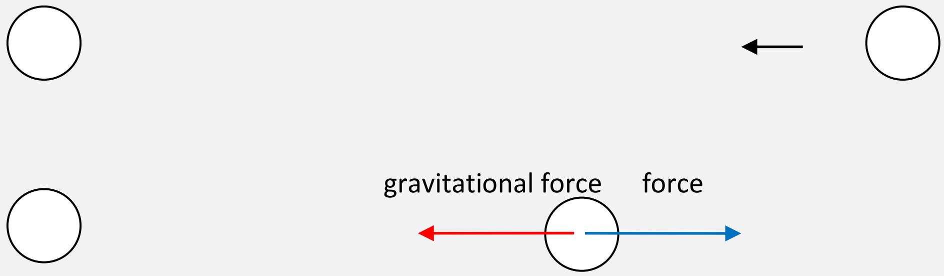
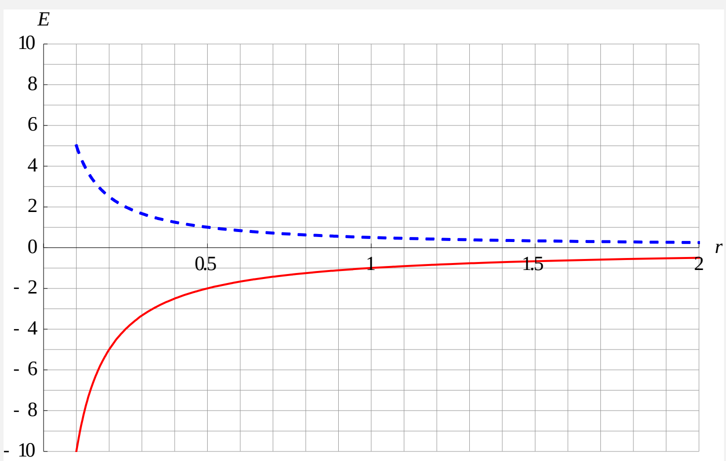
Draw, on the axes, the variation of the potential energy of the satellite, with orbit radius. [2]

(c) Engines are fired to bring the satellite closer to the planet surface. State and explain

(i) the change in the satellite's kinetic energy, [2]

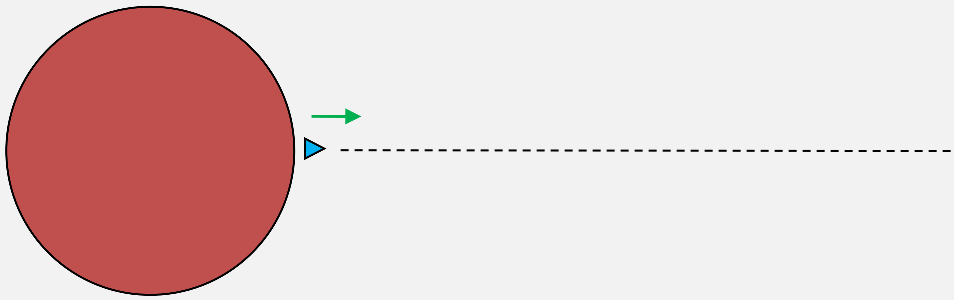
(ii) the change in the satellite's total energy, [2]

(iii) whether the work done by the engines is positive or negative. [2]

Question 6		Answers	Marks
a	i	The work done by an external agent in bringing the masses from an infinite separation to their present positions✓	1
a	ii	 The diagram shows the force (in blue) that the external agent must exert to bring the two masses close to each other at a small, constant speed✓ The work done by the external agent is negative✓	2
b		 Red curve Negative✓ Double in magnitude✓	2
c	i	$E_K = \frac{GMm}{2r}$ ✓ So since r decreases KE increases✓	2
c	ii	$E_T = -\frac{GMm}{2r}$ ✓ So, since r decreases total energy becomes more negative i.e. decreases ✓	2
c	iii	Work done is the change in the total energy✓ So, work done is negative✓	2

7.

A probe of mass $m = 3.8\times10^{4}$ kg is launched from the surface of a planet of mass $M = 5.0\times10^{23}$ kg and radius R with kinetic energy $\frac{9}{10}\frac{GMm}{R}$.



(a) State what is meant by *escape speed*. [1]

(b) Explain, by reference to escape speed, why the probe will eventually crash on the surface of the planet. [2]

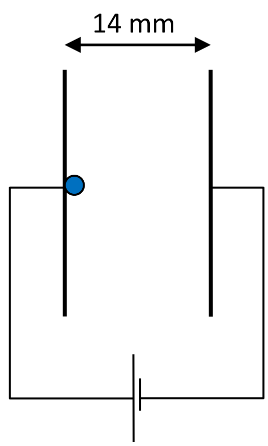
(c) The kinetic energy of the probe as it passes a point a distance $2R$ from the centre of the planet is 9.0×10^{10} J. Calculate R. [3]

(d) Determine the largest distance from the centre of the planet the probe will get to. [2]

Question 7		Answers	Marks
a		The minimum speed at launch so that an object gets to infinity✓	1
b		$E_K = \frac{1}{2}mv^2 = \frac{9GMm}{10R} \Rightarrow v = \sqrt{\frac{9GM}{5R}}$ ✓ $\sqrt{\frac{9GM}{5R}} < \sqrt{\frac{2GM}{R}}$ $(= v_{esc})$ ✓ ***OR*** $E_K = \frac{1}{2}mv^2 = \frac{9GMm}{10R} \Rightarrow E_T = \frac{9GMm}{10R} - \frac{GMm}{R}$ ✓ $E_T = -\frac{GMm}{10R} < 0$ ✓	2
c		$\frac{9GMm}{10R} - \frac{GMm}{R} = 9.0\times10^{10} - \frac{GMm}{2R}$ ✓ $\frac{2GMm}{5R} = 9.0\times10^{10} \Rightarrow \frac{2\times6.67\times10^{-11}\times5.0\times10^{23}\times3.8\times10^{4}}{5R} = 9.0\times10^{10}$ ✓ $R = 5.6\times10^{6}$ m ✓	3
d		$-\frac{GMm}{r} = \frac{9GMm}{10R} - \frac{GMm}{R} = -\frac{GMm}{10R}$ ✓ $r = 10R = 5.6\times10^{7}$ m ✓	2

8.

A potential difference of 280 V is established between two parallel plates a distance 14 mm apart. A proton is placed on the positive plate and then released.



(a) (i) Draw the electric field lines for this arrangement. [2]

(ii) Estimate the electric field strength in between the plates. [1]

(b) Calculate, in J, the work done by the electric force in moving the proton from one plate to the other. [1]

(c) (i) The proton impacts the negative plate with speed v_p. An alpha particle placed at the positive plate and released impacts the negative plate with speed v_α. Determine the ratio $\frac{v_p}{v_\alpha}$, [3]

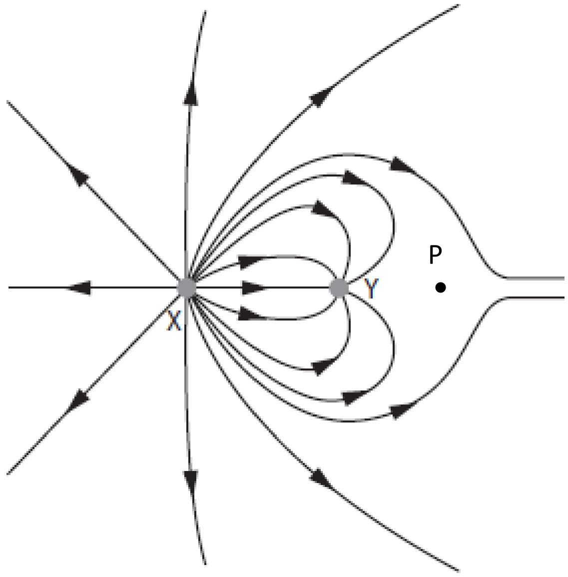
(ii) Determine the ratio $\frac{t_p}{t_\alpha}$ of the times taken for the proton and the alpha [article to reach the negative plate, [3]

(iii) The separation of the plates is doubled. Suggest how the answer to (c) (i) changes, if at all. [1]

Question 8		Answers	Marks
a	i	Uniformly spaced lines in between plates directed from the positive to negative plate✓ Curved edge effects✓	2
a	ii	$E = \frac{V}{d} = \frac{280}{14 \times 10^{-3}} = 2.0 \times 10^{4}\ \text{N C}^{-1}$ ✓	1
b	i	$W = q\Delta V = 1.6 \times 10^{-19} \times 280 = 4.48 \times 10^{-17} \approx 4.5 \times 10^{-17}\ \text{J}$ ✓	1
c	i	$\frac{1}{2} m_{\text{p}} v_{\text{p}}^2 = q\Delta V$ and $\frac{1}{2} m_{\alpha} v_{\alpha}^2 = 2q\Delta V$ ✓ Hence: $2 \times \frac{1}{2} m_{\text{p}} v_{\text{p}}^2 = \frac{1}{2} m_{\alpha} v_{\alpha}^2$ ✓ $\frac{v_{\text{p}}^2}{v_{\alpha}^2} = \frac{m_{\alpha}}{2m_{\text{p}}} \approx 2 \Rightarrow \frac{v_{\text{p}}}{v_{\alpha}} \approx \sqrt{2}$ ✓	3
c	ii	$d = \frac{1}{2} a t^2 \Rightarrow t = \sqrt{\frac{2d}{a}} = \sqrt{\frac{2d}{\frac{qE}{m}}} = \sqrt{\frac{2md}{qE}}$ ✓ Hence, $\frac{t_{\text{p}}}{t_{\alpha}} = \sqrt{\frac{m_{\text{p}}}{m_{\alpha}} \frac{q_{\alpha}}{q_{\text{p}}}}$ ✓ $\frac{t_{\text{p}}}{t_{\alpha}} = \sqrt{\frac{1}{4} \times \frac{2}{1}} = \frac{1}{\sqrt{2}}$ ✓	3
c	iii	The work done for each particle is the same, so the ratio does not change✓	1

9.

The diagram shows electric field lines for two point charges X and Y. At point P the net electric field strength is zero.



(a) State what is meant by

(i) *electric field strength*, [2]

(ii) *electric field lines*. [2]

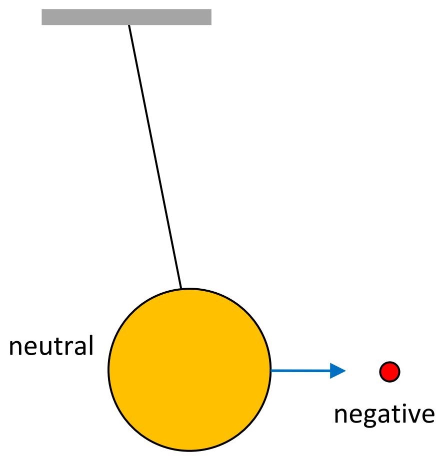
(b) State three properties of electric field lines. [3]

(c) State the signs of X and Y. [1]

(d) (i) Explain how it is known that the magnitude of the charge of X is greater than that of Y.

(ii) By making appropriate measurements on the diagram with your ruler estimate the ratio of charge X to charge Y. [2]

(e) A negatively charged point particle is held close to a neutral, conducting sphere that hangs from an insulated thread.



The sphere experiences an attractive force.

(i) Explain how this force arises. [3]

(ii) The negatively charged point particle is replaced by a positively charged particle. State and explain what will happen now. [2]

Question 9		Answers	Marks
a	i	The electric force per unit charge✓ Exerted on a test charge (small, positive, point charge) ✓	2
a	ii	Field lines are mathematical lines originating and ending in electric charges (or infinity)✓ Tangents to these lines give the direction of the electric field at a point✓	2
b		The leave from positive charges (or infinity) and end in negative charges (or infinity)✓ They cannot cross✓ Their density is proportional to the electric field strength✓	3
c		X is positive and Y is negative✓	1
d	i	The electric field is zero at P which is closer to Y✓ ***OR*** The field lines of X are not as different from that of a single point charge as that of Y✓	1
d	ii	Ratio of distances approximately: $\frac{\text{XP}}{\text{YP}} \approx 2.5$ ✓ $\frac{kQ_\text{X}}{2.5^2} = \frac{kQ_\text{Y}}{1.0^2} \Rightarrow \frac{Q_\text{X}}{Q_\text{Y}} = 2.5^2 = 6.25 \approx 6$ ✓	2
e	i	The point charge pushes electrons to the left side of the sphere✓ Leaving an excess positive charge on the right side of the sphere✓ The positive charge on the sphere is closer to the point charge than the negative charge on the sphere, resulting in an attractive force✓	3
e	ii	The positively charged particle will attract electrons to the right side of the sphere✓ The force will again be attractive✓	2

10.

The diagram shows two parallel wires, X and Y, a distance 24 mm apart, each carrying current 3.0 A into the page.

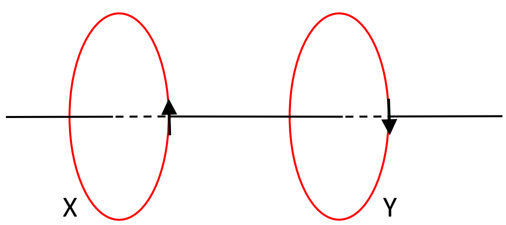
(a) On the diagram, draw arrows to indicate

(i) the magnetic field at the position of each wire. [2]

(ii) the magnetic force on each wire. [2]

(b) The current in wire X is doubled. Calculate the force per unit length on wire X and wire Y. [4]

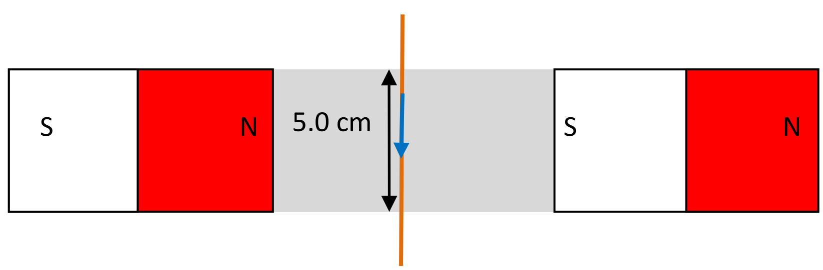
(c) The diagram shows two current carrying rings X and Y with their planes parallel.



Looked at from the left, the current in X is counter-clockwise and that in Y clockwise.

Determine the direction of the magnetic force on each ring. [2]

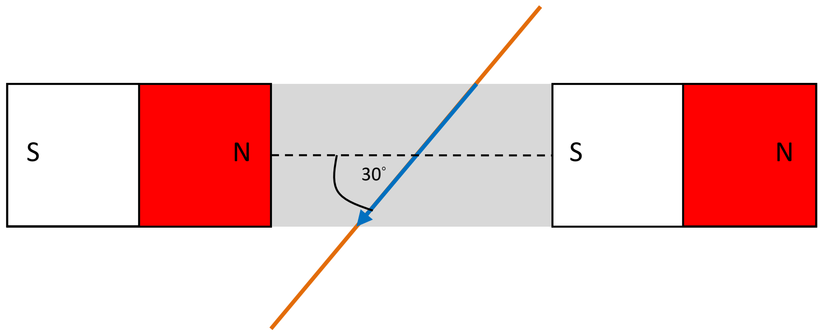
(d) A wire on a vertical plane carrying a current of 12 A is normal to the magnetic field of two bar magnets. The magnetic field may be assumed to be negligible outside the shaded region and constant at 0.50 T in the shaded region. A length L = 5.0 cm of the wire is in the region of the magnetic field.



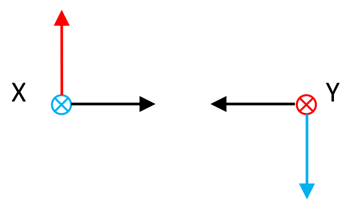
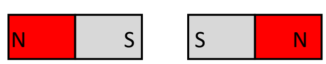
(i) Determine the direction of the force on the wire [1]

(ii) Estimate the magnetic force on the wire. [1]

(e) A second wire carrying the same current is placed in the region between the poles of the magnets in (d) making an angle 30° with the magnetic field. The wire is still on a vertical plane.

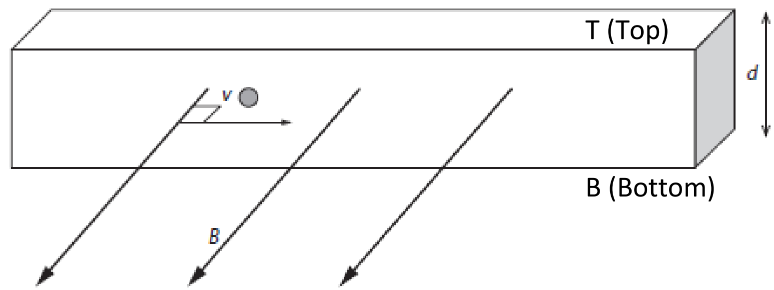


Estimate the magnetic force on the wire. [2]

Question 10		Answers	Marks
a	i	 Equal arrows✓ In directions shown✓	2
a	ii	 Equal magnitude and opposite forces✓ Attractive✓	2
b		Both wires will experience the same magnitude force✓ $\frac{F}{L}=\mu_0\frac{I_1I_2}{2\pi r}=4\pi\times10^{-7}\times\frac{6.0\times3.0}{2\pi\times24\times10^{-3}}$ ✓ $\frac{F}{L}=1.5\times10^{-4}\text{ N m}^{-1}$ ✓	3
c		 The rings behave as the bar magnets shown✓ Hence equal and opposite repulsive forces on rings✓	2
d	i	By the right-hand force rule the force is directed out of the page✓	1
d	ii	$F=BIL=0.50\times12\times0.050=0.30\text{ N}$ ✓	1
e		$F=BIL\sin30^\circ$ and $L\sin30^\circ=0.050\text{ m}$ ✓ So $F=0.30\text{ N}$ out of the page ✓	2

11.

A current I is established in the conductor. The diagram shows one of the electrons making up the current moving with drift speed v. The conductor is exposed to a magnetic field B at right angles to the direction of motion of the electron.



(a) Draw an arrow to indicate the direction:

(i) of the conventional current in the conductor [1]

(ii) the magnetic force on the electron. [1]

(b) Explain why an electric field will be established between the top (T) and bottom (B) faces of the conductor. [3]

(c) The drift speed of the electrons is 2.4×10^{-4} m s^{-1} and the magnetic field is 0.20 T. The distance d is 5.0 mm. Calculate the potential difference between T and B. [3]

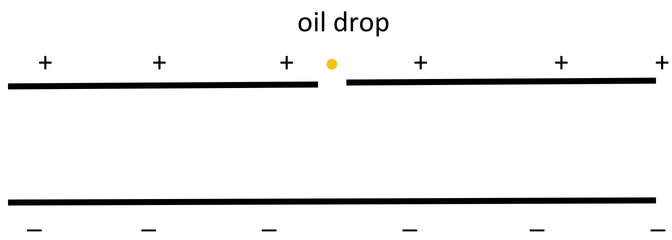
(d) Outline how the existence of this potential difference can be used to verify the sign of the charge carriers in the conductor. [2]

Question 11		Answers	Marks
a	i	Arrow to the left✓	1
a	ii	Vertically upward✓	1
b		Electrons will accumulate on the T surface✓ Leaving an equal excess positive charge at the B surface✓ Hence there will be an electric field directed from B to T✓	3
c		$qE = qvB$ ✓ $\frac{V}{d} = vB \Rightarrow V = vBd$ ✓ $V = 2.4\times10^{-4}\times0.20\times5.0\times10^{-3} = 2.4\times10^{-7}\ \text{V} = 0.24\ \mu\text{V}$ ✓	3
d		With negative charge carriers✓ The polarity of the voltage is such that the top side of the conductor will be negative✓	2

12.

(a) Electric charge is said to be *quantized*. Explain what is meant by this statement. [2]

In an experiment, electrically charged oil drops are introduced in the space between two oppositely charged parallel plates though a small hole in the upper plate.



(b) The potential difference between the plates is 648 V and the distance between them is 7.62 mm. Calculate the electric field strength E in between the plates. [1]

(c) A particular oil drop is observed to be stationary in the space between the plates. The buoyant force on the oil drop is negligible.

(i) Identify the forces on this oil drop by drawing and labelling arrows on the diagram. [2]

(ii) State the sign of the charge on this oil drop. [1]

(iii) Show that the electric charge on this oil drop is given by

$$q = \frac{4\pi r^3 \rho_o g}{3E}$$

where ρ_o is the density of oil and r is the radius of the oil drop. [2]

(d) The electric field is turned off. The oil drop in (c) is now observed to fall vertically with constant terminal speed *v*. State the magnitude of the net force on the oil drop. [1]

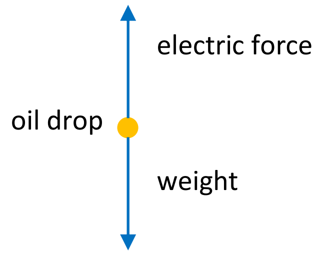
(e) The following data are available:

Viscosity of air	1.60×10^{-5} Pa s
Terminal speed of oil drop	1.20×10^{-4} m s^{-1}
Density of oil	703 kg m^{-3}

(i) Determine the radius of the oil drop. [3]

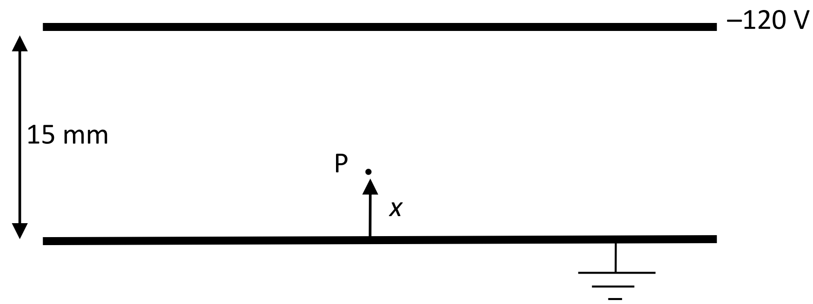
(ii) Hence, show that the magnitude of the charge on the oil drop is about 3*e*. [1]

(iii) The oil drop splits into two equal smaller oil drops. Both are charged. State and explain the magnitude of the charge on each of the two oil drops. [2]

Question 12		Answers	Marks
a		Every measured value of electric charge✓ is an integral multiple of a certain fundamental quantity of charge✓	2
b		$E=\dfrac{V}{d}=\dfrac{648}{7.62\times10^{-3}}=8.5039\times10^{4}\approx8.50\times10^{4}\ \text{N C}^{-1}$ ✓	1
c	i	 Correct labels✓ Equal lengths✓	2
c	ii	Negative✓	1
c	iii	$mg=\rho_{\text{oil}}Vg=qE$ ✓ and $V=\dfrac{4\pi r^{3}}{3}$ $q=\dfrac{4\pi r^{3}\rho_{\text{oil}}g}{3E}$ ✓	2
d		Zero✓	1
e	i	$mg=\rho_{\text{oil}}\dfrac{4\pi r^{3}}{3}g=6\pi\eta rv$ ✓ $r=\sqrt{\dfrac{9v\eta}{2\rho_{\text{oil}}g}}$ ✓ $r=\sqrt{\dfrac{9\times1.20\times10^{-4}\times1.60\times10^{-5}}{2\times703\times9.8}}=1.1199\times10^{-6}\approx1.12\times10^{-6}\ \text{m}$ ✓	3
e	ii	$q=\dfrac{4\pi\times(1.1199\times10^{-6})^{3}\times9.8\times703}{3\times8.5093\times10^{4}}=4.76\times10^{-19}\ \text{C}\approx4.8\times10^{-19}\ \text{C}=3e$ ✓	1
e	iii	Charge is quantized in units of *e*✓ So, the oil drops must have charges of *e* and 2*e*✓	2

13.

Two parallel plates are 15 mm apart. The lower plate is earthed and the top is kept at potential of – 120 V. Point P is at a distance *x* from the lower plate.



(a) (i) Calculate the magnitude of the electric field strength at P. [1]

(ii) Determine, in terms of *x*, the electric potential at P. [2]

(b) A proton is placed at the lower plate and is then released. Calculate

(i) the time it would take the proton to reach the top plate, [2]

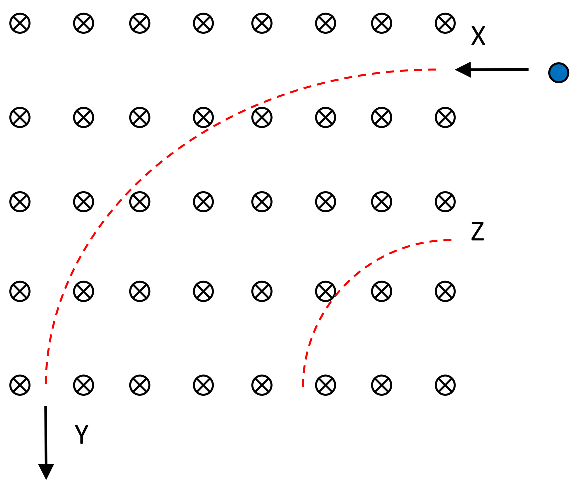
(ii) the speed with which the proton arrives at the top plate. [1]

(c) The distance between the plates is doubled. Suggest how the answers to (b) (i) and (ii) change, if at all. [3]

Question 13		Answers	Marks
a	i	$E=\frac{V}{d}=\frac{120}{15\times10^{-3}}=8.0\times10^{3}\text{ N C}^{-1}$ ✓	1
a	ii	$E=-\frac{\Delta V}{\Delta x}\Rightarrow\Delta V=-8.0\times10^{3}\Delta x$ ✓ $V-0=-8.0\times10^{3}(x-0)\Rightarrow V=-8.0\times10^{3}x$ ✓ (where *V* is in volts and *x* in m)	2
b	i	$a=\frac{F}{m}=\frac{1.6\times10^{-19}\times8.0\times10^{3}}{1.67\times10^{-27}}=7.66\times10^{11}\text{ m s}^{-2}$ ✓ $s=\frac{1}{2}at^{2}\Rightarrow t=\sqrt{\frac{2s}{a}}=\sqrt{\frac{2\times15\times10^{-3}}{7.66\times10^{11}}}=1.979\times10^{-7}\approx2.0\times10^{-7}\text{ s}$ ✓	2
b	ii	$v=at=7.66\times10^{11}\times1.979\times10^{-7}=1.5\times10^{5}\text{ m s}^{-1}$ ✓	1
c		$t'=\sqrt{\frac{2s'}{a'}}=\sqrt{\frac{2\times2s}{\frac{a}{2}}}=\sqrt{4\times\frac{2s}{a}}$ ✓ So, time doubles✓ $v'=a't'$ acceleration halves and time doubles so no change✓ ***OR*** $\frac{1}{2}mv^{2}=q\Delta V$ so no change to speed since ΔV does not change ✓	3

14.

A proton of mass m_p enters a region of magnetic field at point X and exits at point Y. The speed of the proton at X is v. The path followed by the proton is a quarter of a circle.



(a) State and explain whether the speed of the proton at Y is the same as the speed at X. [2]

(b) Suggest why the path of the proton is circular. [1]

(c) (i) Show that the radius of the circular path is given by $R = \frac{m_p v}{qB}$, where B is the magnetic flux density. [1]

(ii) The speed of the proton is 3.6×10^{6} m s^{-1} at X and the magnetic flux density is 0.25 T. Show that the radius of the path is 15 cm. [1]

(iii) Calculate the time the proton is in the region of the magnetic field. [2]

(d) Another proton enters the region of magnetic field at Z with half the speed of the proton in (c). The path in the region of the magnetic field is also a quarter circle. Determine how the answer to (c) (iii) changes, if at all. [2]

(e) (i) A beam of singly ionised atoms of neon enters the region of magnetic field at X. The ions have the same speed. The beam splits into two beams: B_1 of radius 38.0 cm and B_2 of radius 41.8 cm. The ions in beam B_1 have mass 3.32×10^{-26} kg. Predict the mass of the ions in beam B_2. [2]

(ii) Suggest the implication of (e) (i) for nuclear structure. [2]

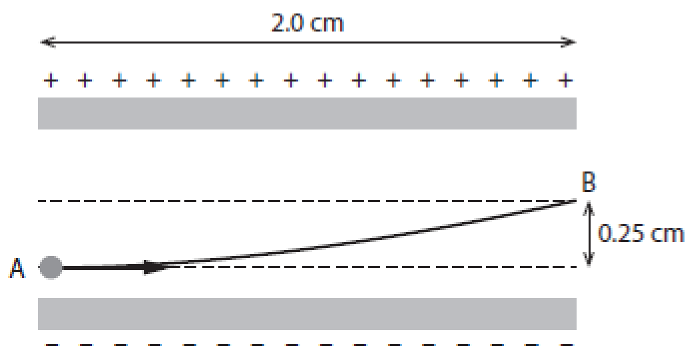
Question 14		Answers	Marks
a		The work done by the magnetic force is zero because the force is at right angles to the velocity✓ Thus, there is no change in the kinetic energy and speed✓	2
b		Because the magnetic force is at right angles to the velocity providing the centripetal force✓	1
c	i	$qvB = \frac{mv^2}{R}$ ✓ Re-arranging to get answer.	1
c	ii	$R = \frac{m_p v}{qB} = \frac{1.67\times10^{-27}\times3.6\times10^{6}}{1.6\times10^{-19}\times0.25} = 0.150\ \text{m} = 15\ \text{cm}$ ✓	1
c	iii	$T = \frac{1}{4}\frac{2\pi R}{v}$ ✓ $T = \frac{1}{4}\times\frac{2\pi\times0.15}{3.6\times10^{6}} = 6.5\times10^{-8}\ \text{s}$ ✓	2
d		From $R = \frac{m_p v}{qB}$, the radius will halve ✓ $T' = \frac{1}{4}\times\frac{2\pi\times\frac{R}{2}}{\frac{v}{2}} = T$ so time does not change ✓	2
e	i	$\frac{R_1}{R_2} = \frac{m_1}{m_2}$ ✓ $\frac{38.0}{41.8} = \frac{3.32\times10^{-26}}{m_2} \Rightarrow m_2 = 3.65\times10^{-26}\ \text{kg}$ ✓	2
e	ii	We have two types of atoms of the same chemical element✓ Which differ in mass due to extra neutrons in the nucleus, evidence for isotopes✓	2

15.

An electron is accelerated from rest by a potential difference of 29 V.

(a) Show that the electron acquires a speed of 3.2×10^{6} m s^{-1}. [2]

The accelerated electron enters the region between two parallel oppositely charged plates at point A. The electron exits the plates at point B after having moved a vertical distance of 0.25 cm. The length of the plates is 2.0 cm.



(b) Calculate the time the electron spends within the plates. [1]

(c) Determine the magnitude of the electric field within the plates. [4]

(d) Calculate the angle that the velocity of the electron makes with the horizontal at point B. [2]

(e) Calculate the work done on the electron from A to B. [2]

(f) Using your answer to (e), state the potential difference between points A and B. [1]

Question 15		Answers	Marks
a		$\frac{1}{2}mv^2 = q\Delta V \Rightarrow v = \sqrt{\frac{2q\Delta V}{m}}$ ✓ $v = \sqrt{\frac{2\times 1.6\times 10^{-19}\times 29.1}{9.1\times 10^{-31}}} = 3.193\times 10^{6} \approx 3.2\times 10^{6}\text{ m s}^{-1}$ ✓	2
b		$t = \frac{d}{v} = \frac{2.0\times 10^{-2}}{3.193\times 10^{6}} = 6.26\times 10^{-9} \approx 6.3\times 10^{-9}\text{ s}$ ✓	1
c		$y = \frac{1}{2}at^2 \Rightarrow a = \frac{2y}{t^2}$ ✓ $a = \frac{2\times 0.25\times 10^{-2}}{(6.26\times 10^{-9})^2} = 1.276\times 10^{14}\text{ m s}^{-2}$ ✓ $a = \frac{qE}{m} \Rightarrow E = \frac{ma}{q}$ ✓ $E = \frac{9.1\times 10^{-31}\times 1.276\times 10^{14}}{1.6\times 10^{-19}} = 725.7 \approx 730\text{ N C}^{-1}$ ✓	4
d		$v_y = at = 1.276\times 10^{14}\times 6.26\times 10^{-9} = 7.988\times 10^{5}\text{ m s}^{-1}$ ✓ $\theta = \tan^{-1}\frac{v_y}{v_x} = \tan^{-1}\frac{7.988\times 10^{5}}{3.193\times 10^{6}} = 14^{\circ}$ ✓	2
e		$W = Fy = qEy$ ✓ $W = 1.6\times 10^{-19}\times 725.7\times 0.25\times 10^{-2} = 2.9\times 10^{-19}\text{ J}$ ✓	2
f		$\Delta V = \frac{W}{q} = \frac{2.9\times 10^{-19}}{1.6\times 10^{-19}} = 1.8\text{ V}$ ✓	1

16.

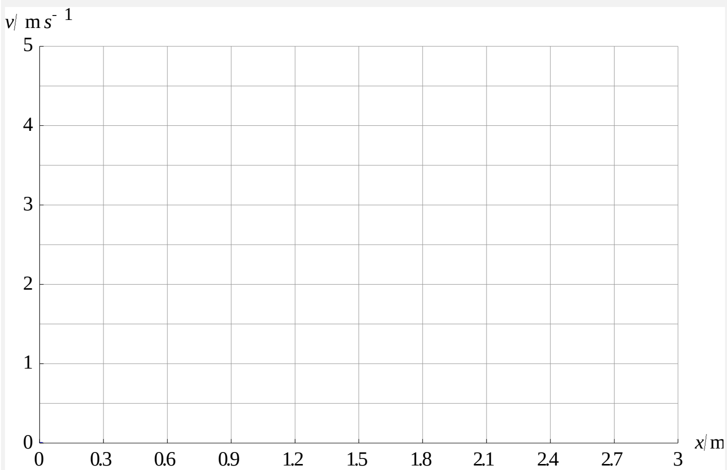
A sphere of radius 0.25 m has positive charge + 8.8 μC uniformly distributed on its surface. A small pellet of mass 0.075 kg and charge + 2.4 μC is directed radially at the sphere. When the pellet is at a distance of 0.75 m from the centre of the sphere, its speed is 3.2 m s^{-1}.

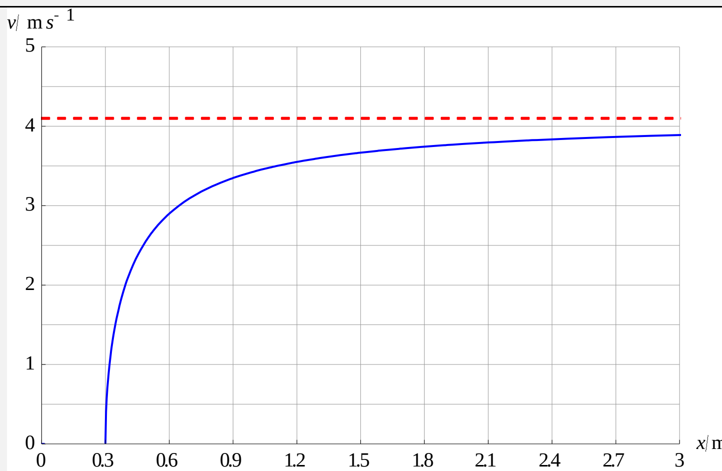
(a) Determine the distance from the centre of the sphere at which the pellet will stop. [3]

(b) Describe qualitatively the subsequent motion of the pellet. [3]

(c) (i) Determine the speed of the pellet after it moves very far from the sphere. [2]

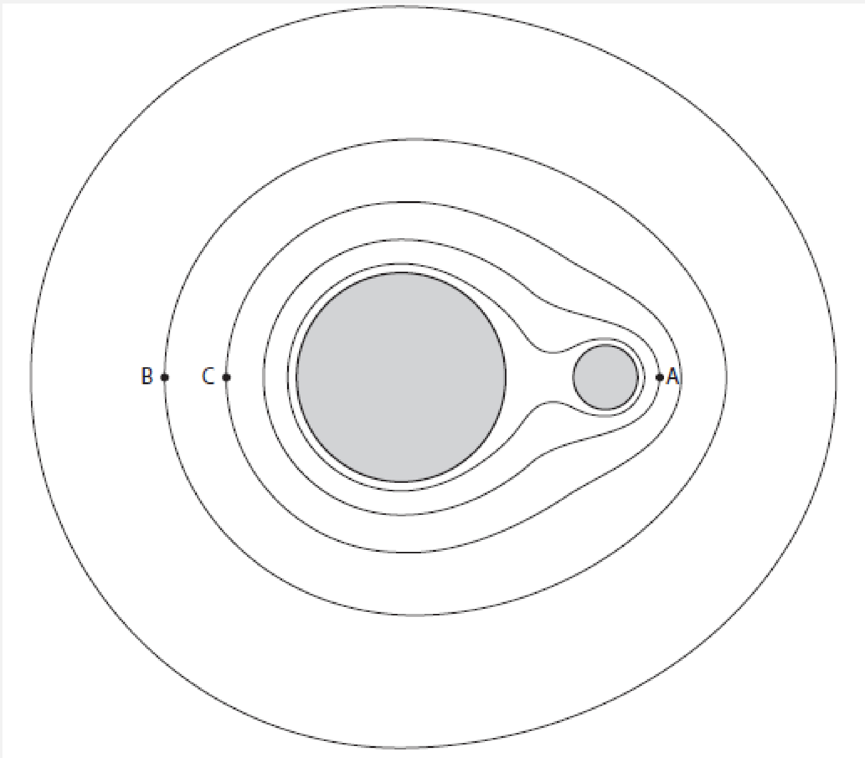
(ii) On the axes draw a sketch graph to show the variation of the speed of the pellet with distance from the centre of the sphere. [2]



Question 16		Answers	Marks
a		Total energy: $\frac{1}{2}mv^2+\frac{kQq}{r}=\frac{1}{2}\times 0.075\times 3.2^2+\frac{8.99\times 10^9\times 8.8\times 10^{-6}\times 2.4\times 10^{-6}}{0.75}=0.6372\text{ J}$ ✓ $\frac{8.99\times 10^9\times 8.8\times 10^{-6}\times 2.4\times 10^{-6}}{r}=0.6372\text{ J}$ ✓ $r=0.298\approx 0.30\text{ m}$ ✓	3
b		Moves radially away from sphere✓ With increasing (but bounded) speed✓ And decreasing acceleration✓	3
c	i	$\frac{1}{2}\times 0.075\times v^2=0.6372\text{ J}$ ✓ $v=4.1\text{ m s}^{-1}$ ✓	2
c	ii	 Zero speed at 0.30 m✓ Curve showing speed approaching constant value 4.1 m s^{-1} as distance increases✓	2

17. (a) State what is meant by an *equipotential surface*. [1]

(b) The diagram shows five equipotential surfaces around two charged spheres.



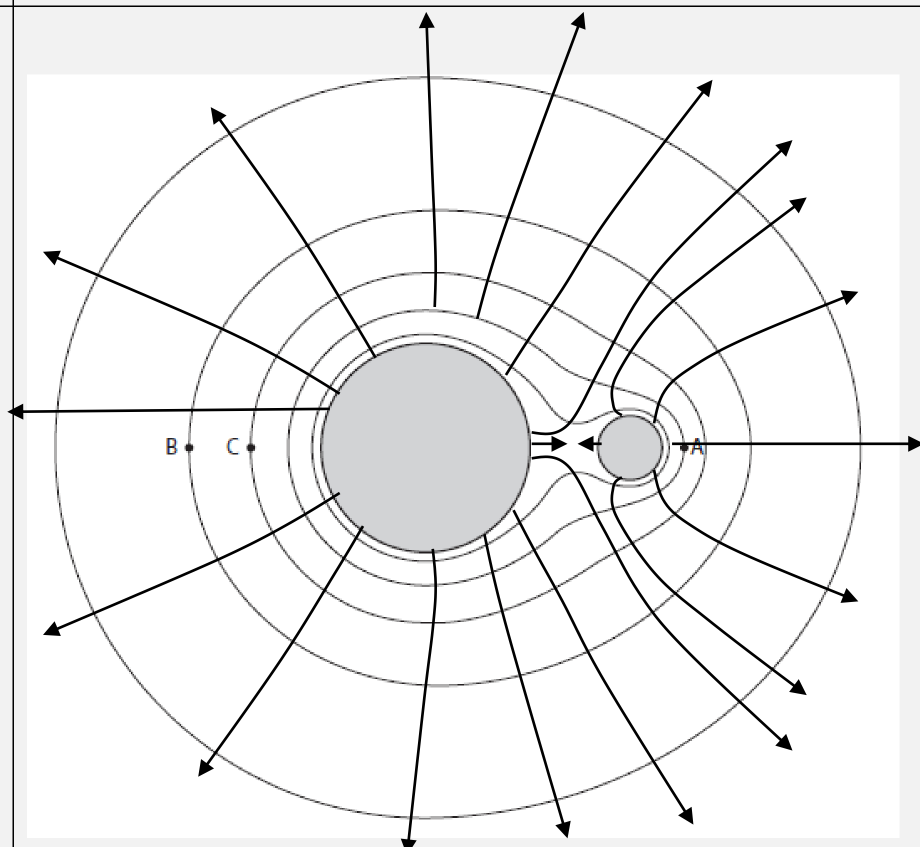
(i) State and explain what can be deduced about the sign of the charges on the two spheres just from this diagram. [2]

(ii) Draw lines to represent field lines for this arrangement of charges. You must draw **six** field lines. [2]

(iii) Two consecutive lines are separated by a potential difference of 25 V and the innermost line has potential 250 V. Calculate the work done to move a charge of 3.0 μC from point A to point B. [2]

(iv) The distance between points B and C is 4.0 cm. Estimate the average electric field strength between B and C. [1]

(c) The equipotential surfaces tend to become spherical as the distance from the sources increases. Explain this observation. [2]

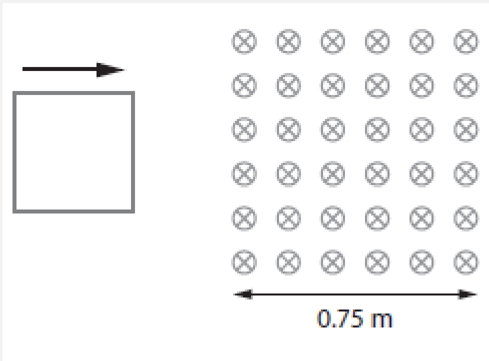
Question 17		Answers	Marks
a		A surface all points of which are at the same potential✓	1
b	i	They have the same sign✓ Because there is a point on the line joining the charges where the electric field is zero✓	2
b	ii	 All arrows either inward or outward✓ Two arrows with gap in between charges✓ All field lines normal to equipotentials✓	3
b	iii	Potential difference is 50 V✓ $W = q\Delta V = 3.0\times10^{-6}\times50 = 150\ \mu\text{J}$ ✓	2
b	iv	$E = \dfrac{\Delta V}{\Delta x} = \dfrac{25}{0.040} = 625\ \text{N C}^{-1}$ ✓	1

c		From a large distance the two charges appear as one✓ The equipotential surfaces of a single charge are spherical✓	**2**

18.

A square loop of side 0.25 m is made to move at constant speed 5.0 cm s^{-1}. The loop enters a region of uniform magnetic field of strength 0.40 T directed into the plane of the page. There are 50 turns of conducting wire around the loop.

The loop begins to enter the region of magnetic field at t = 0.

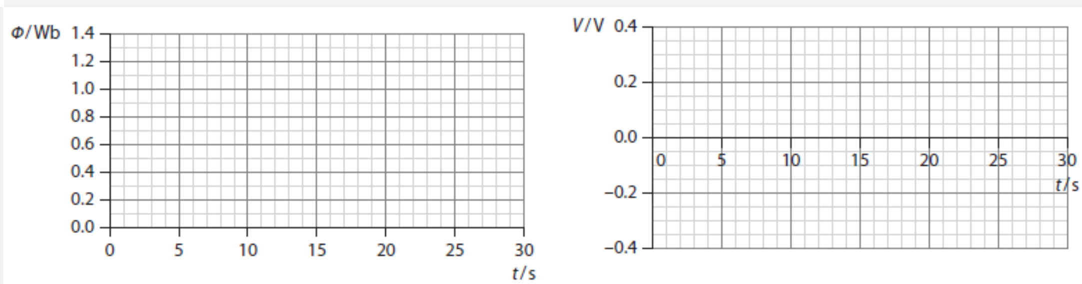


(a) On a copy of the axes below, draw a graph to show the variation with time t of:

(i) the magnetic flux linkage Φ through the loop. [3]

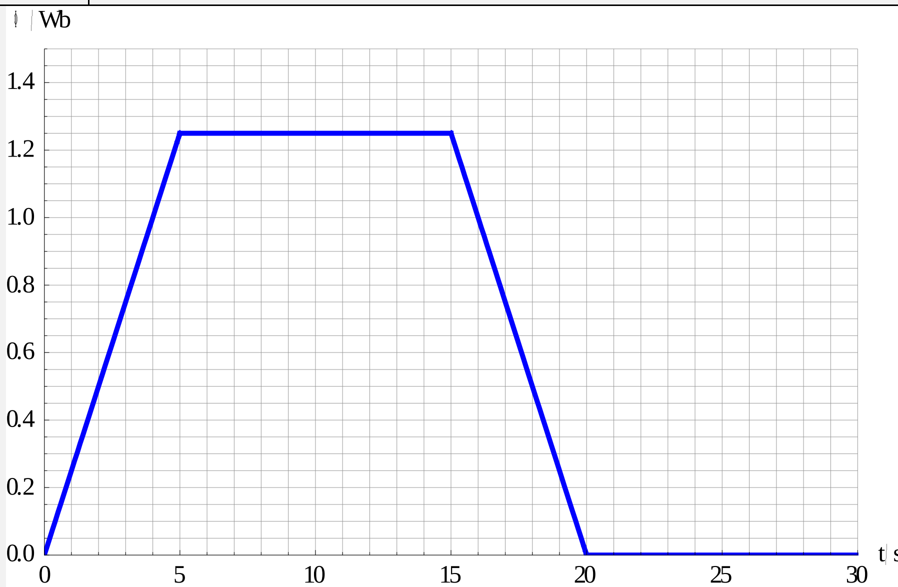
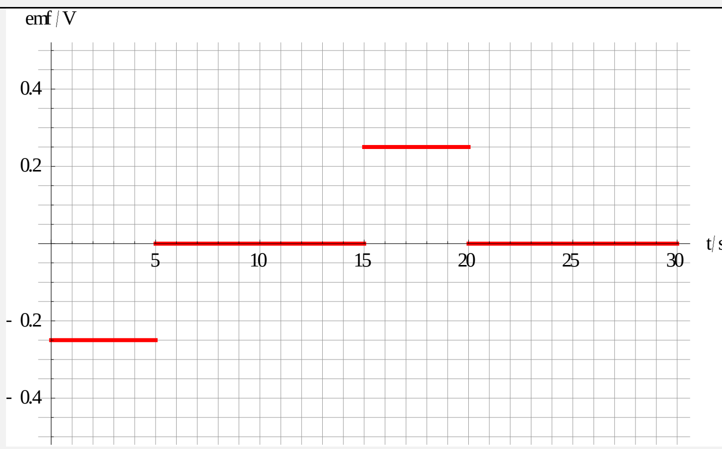
(ii) the induced emf in the loop. [3]

(b) The total resistance of the wire around the loop is 0.75 Ω.



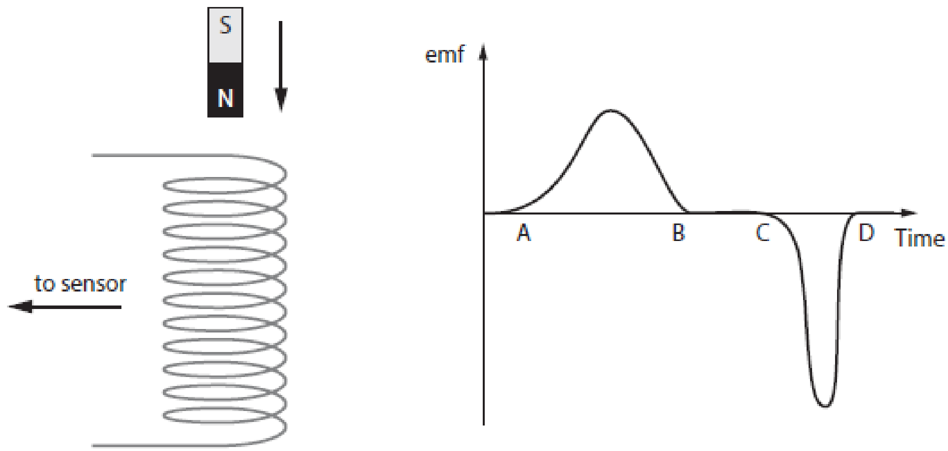
(i) Calculate the power exerted by the agent pushing the loop. [3]

(ii) Explain what has become of this power. [2]

Question 18		Answers	Marks
a	i	 Correct time to fully enter✓ Correct time to fully exit✓ Correct peak flux: $\Phi = 50 \times 0.25^2 \times 0.40 = 1.25$ Wb ✓	3
a	ii	 (Accept reverse of this.) Correct voltage✓ Times consistent with (i) ✓ Zero emf while loop is totally within magnetic field✓	3
b	i	The induced current is $\frac{0.25}{0.75} = 0.333$ A ✓ The magnetic force acting on the loop while entering or leaving the region of magnetic field is $F = NBIL = 50 \times 0.40 \times 0.333 \times 0.25 = 1.665$ N ✓ Hence the power in pushing the loop when entering or leaving is $P = Fv = 1.665 \times 0.050 = 83$ mW ✓	3
b	ii	This is power that is dissipated as thermal energy✓ In the cables of the coil ($P = VI = 1.25 \times 0.333 = 83$ mW)✓	2

19.

The diagram shows a small magnet that has been dropped from above a solenoid. As the magnet falls through the solenoid, a sensor shows how the induced emf in the solenoid varies with time.



(a) Explain why an emf is induced in the solenoid from A to B. [3]

(b) Explain why the induced emf from C to D, when compared to that from A to B, has:

(i) a greater peak value [2]

(ii) a shorter duration. [1]

(c) Suggest:

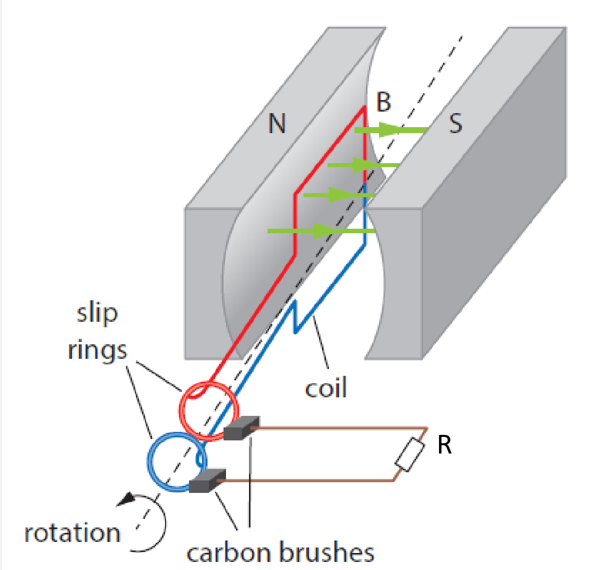
(i) what the areas between the graph and the time axis from A to B and from C to D represent [2]

(ii) whether these areas are equal. [2]

Question 19		Answers	Marks
a		As the magnet gets closer to the top of the coil the magnetic field at the coil increases✓ Hence the magnetic flux though the coil increases✓ By Faraday's law, a changing flux induces an emf✓	3
b	i	From C to D the magnet is moving faster than from A to B✓ Hence the rate of change of flux, and therefore emf, is higher✓	2
b	ii	Since the magnet moves faster it takes less time to move past the magnet✓	1
c	i	The graph is a graph of emf versus time i.e. $\frac{\Delta\Phi}{\Delta t}$ versus time✓ So, the area is the change in flux✓	2
c	ii	The area from A to B is the change in flux from when the magnetic is very far away until it is essentially in the middle of the coil✓ The area from C to D is the exact opposite and so the areas are the same (in magnitude) ✓	2

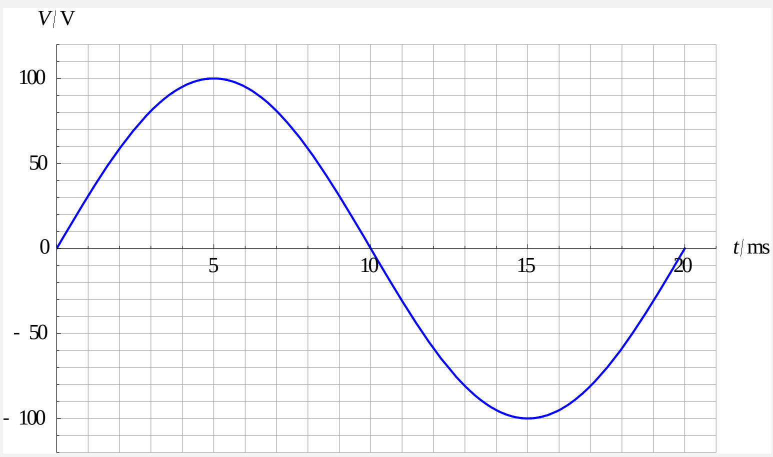
20.

The diagram shows an AC generator. The generator is connected to an external resistor R.



(a) Suggest why an emf will be induced in the coil when the coil is rotating. [3]

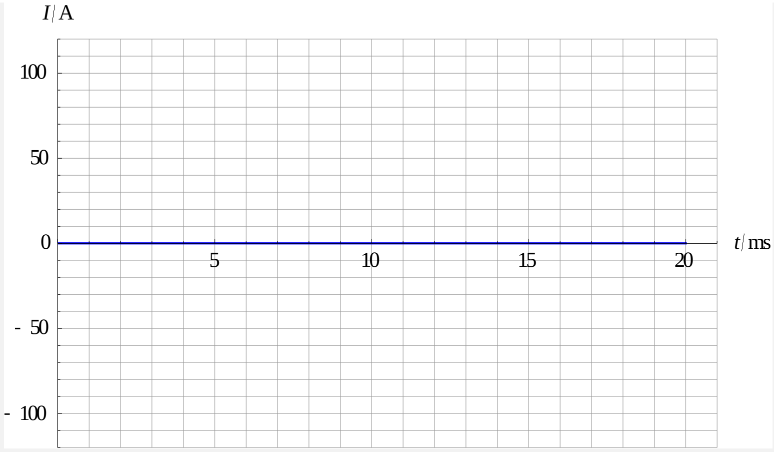
(b) The graph shows the variation of the voltage V at the ends of the resistor R with time t.



(i) Calculate the frequency of rotation of the coil. [1]

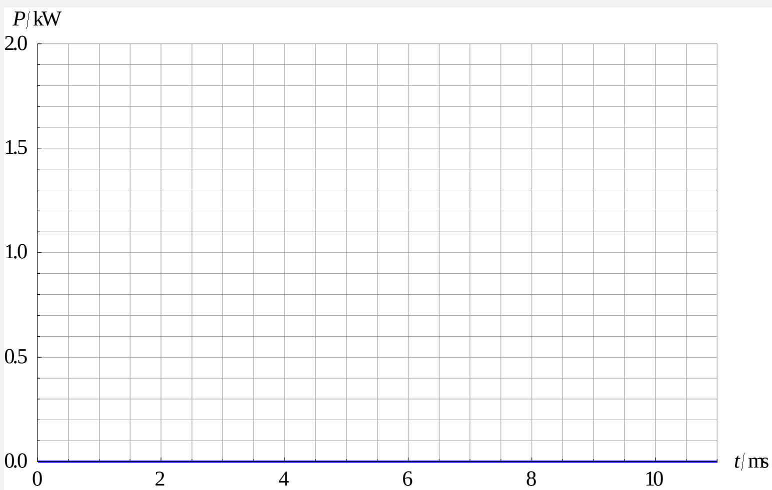
(ii) Mark with the letter M a point on the graph where the flux through the coil is zero. [1]

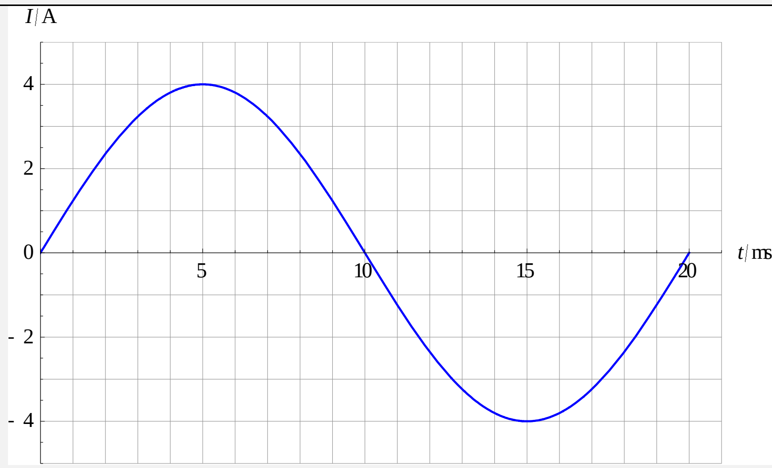
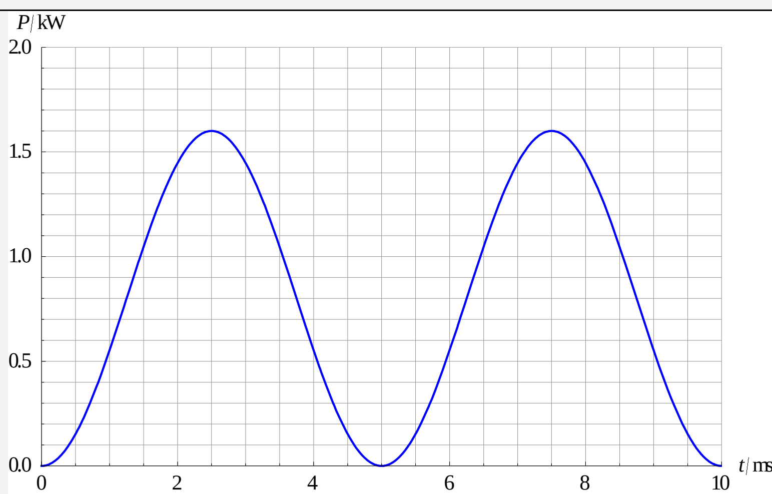
(iii) The resistance of R is 25 Ω. On the axes draw a graph to show the variation with time of the current in R. [2]



(iv) Determine the maximum power dissipated in R. [2]

(c) The frequency of rotation of the coil is doubled. On the axes draw a graph to show the variation with time of the power dissipated in the resistor. [2]



Question 20		Answers	Marks
a		The flux in the coil is $BA\cos\theta$ where θ is the angle between the magnetic field and the normal to the coil✓ The angle θ keeps changing with time as the coil rotates✓ By Faraday's law, a changing flux induces an emf✓	3
b	i	$f = \dfrac{1}{20\times10^{-3}} = 50\text{ Hz}$ ✓	1
b	ii	At 5 or 15 ms✓	1
b	iii	 Sine function✓ Of correct amplitude and frequency✓	2
b	iv	400 W✓	1
c		 Correct amplitude 1.6 kW ✓ Two loops as shown within new period of 10 ms ✓	2