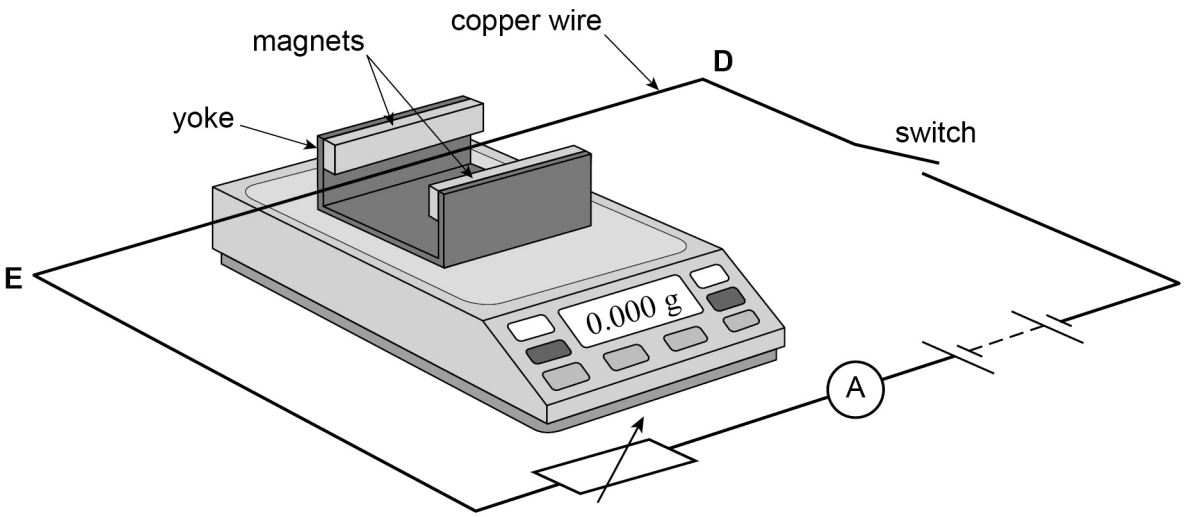
0 2 **Figure 2** shows two magnets, supported on a yoke, placed on an electronic balance.

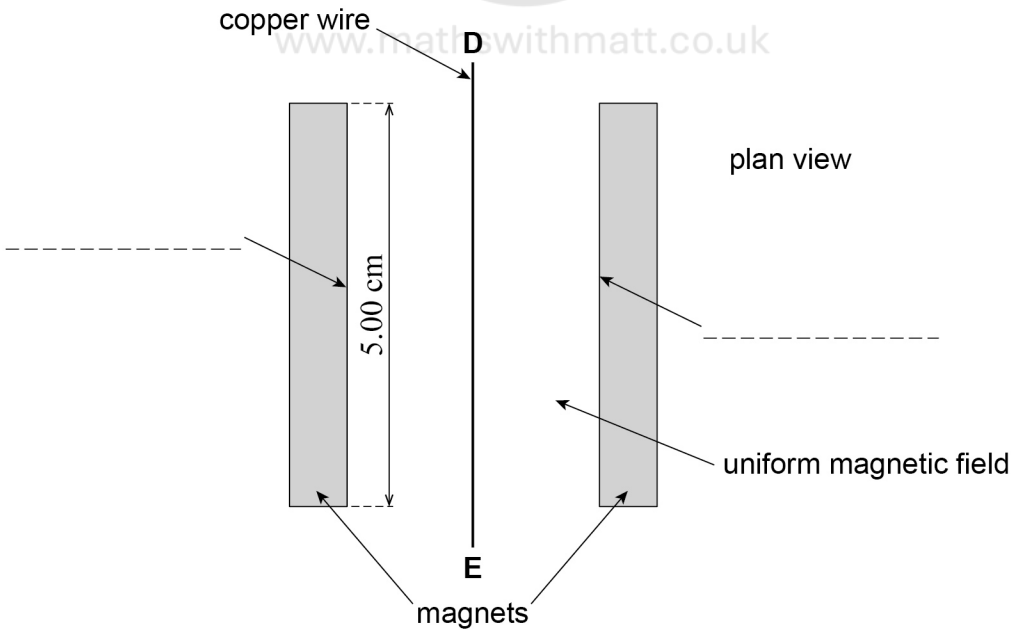
Figure 2



The magnets produce a uniform horizontal magnetic field in the region between them. A copper wire **DE** is connected in the circuit shown in **Figure 2** and is clamped horizontally at right angles to the magnetic field.

Figure 3 shows a simplified plan view of the copper wire and magnets.

Figure 3



When the apparatus is assembled with the switch open, the reading on the electronic balance is set to 0.000 g. This reading changes to a positive value when the switch is closed.

0 2 . 1 Which of the following correctly describes the direction of the force acting on the wire **DE** due to the magnetic field when the switch is closed?

Tick (✓) the correct box.

[1 mark]

towards the left magnet in **Figure 3** ☐

towards the right magnet in **Figure 3** ☐

vertically up ☐

vertically down ☐

0 2 . 2 Label the poles of the magnets by putting **N** or **S** on each of the two dashed lines in **Figure 3**.

[1 mark]

0 2 . 3 Define the tesla.

[1 mark]

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0 2 . 4 The magnets are $5.00\ \text{cm}$ long. When the current in the wire is $3.43\ \text{A}$ the reading on the electronic balance is $0.620\ \text{g}$.

Assume the field is uniform and is zero beyond the length of the magnets.

Calculate the magnetic flux density between the magnets.

[2 marks]

magnetic flux density = _____ T

5

Question	Answers	Additional Comments/Guidelines	Mark
02.1	Vertically up (third row of table) ✓		1
02.2	(Using Flemings LHR) the configuration of the letters is S N ✓	Answer must be near/on the dashed lines.	1
02.3	The tesla is the (strength) of the magnetic field/flux density that produces a force of 1 newton in a wire of length 1m with 1 ampere (flowing perpendicular to the field). ✓ (owtte but must contain 1N, 1A and 1m)	For mark a reference to 1N, 1A and 1m must be seen. However the word 'unit' is equivalent to '1'. E.g. unit force = 1N. Do not allow definitions based on $F = Bqv$.	1
02.4	Use of ($B = F / I l$) = $m g / I l$ ✓ (mark may come from substitution as in next line) $B = 0.620 \times 10^{-3} \times 9.81 / (3.43 \times 0.0500) = 0.035$ or 0.036 (T) ✓	Treat power of 10 error as an AE so lose one mark only. Lack of use of 'g' is a PE and scores zero.	2
Total			**5**

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0 3 A cyclotron has two D-shaped regions where the magnetic flux density is constant. The D-shaped regions are separated by a small gap.
An alternating electric field between the D-shaped regions accelerates charged particles. The magnetic field causes the charged particles to follow a circular path.

Figure 4 shows the path followed by a proton that starts from **O**.

Figure 4

0 3 . 1 Explain why it is **not** possible for the magnetic field to alter the speed of a proton while it is in one of the D-shaped regions.

[1 mark]

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0 3 . 2 Derive an expression to show that the time taken by a proton to travel round one semi-circular path is independent of the radius of the path.

[3 marks]

0 3 . 3 The maximum radius of the path followed by the proton is 0.55 m and the magnetic flux density of the uniform field is 0.44 T.

Ignore any relativistic effects.

Calculate the maximum speed of a proton when it leaves the cyclotron.

[2 marks]

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maximum speed = _____ m s^{-1}

6

Turn over for the next question

Question	Answers	Additional Comments/Guidelines	Mark
03.1	It is not possible as the force (due to the magnetic field) is perpendicular to the motion/direction of travel/velocity ✓ (it can only change the charged particle's direction or alternatively no work is done on the proton) Or No component of force in the direction of motion.	The main part being examined is the reference to the force being perpendicular to the motion.	1
03.2	$B\,Q\,v = m\,v^2 / r$ ✓ $t_{\text{semi-circle}}$ (= distance / speed) = $\pi\,r\,/v$ Or use of t_{circle} (= distance / speed) = $2\,\pi\,r\,/v$ ✓(this mark can only be awarded if it follows an attempt to answer the first mark) combining gives ($t_{\text{circle}} = 2\pi\,m\,/\,B\,Q$ so) $t_{\text{semi-circle}} = \pi\,m\,/\,B\,Q$ (which does not contain r / is independent of r) ✓	Accept 'e' if used instead of 'Q' Alternatives can be given for the first two marks. 1st needs a centripetal force term. 2nd is a circular motion expression to enable r to be removed.	3
03.3	(rearranging first equation in 03. 2 or from data booklet $v = B\,Q\,r\,/\,m$) $v = 0.44 \times 1.6 \times 10^{-19} \times 0.55 / 1.67 \times 10^{-27}$ ✓ $v = 2.3 \times 10^{7}$ (m s^{-1}) ✓	Correct answer scores both marks.	2
Total			**6**

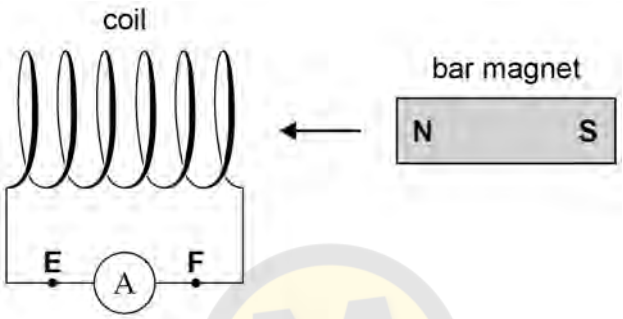
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0 4 . 1 State Lenz's law.

[1 mark]

0 4 . 2 Lenz's law can be demonstrated using a bar magnet and a coil of wire connected to a sensitive ammeter as shown in **Figure 6**.

Figure 6



The bar magnet is moved towards the coil and is then brought to a halt.

State how the reading on the ammeter changes during this process.

[1 mark]

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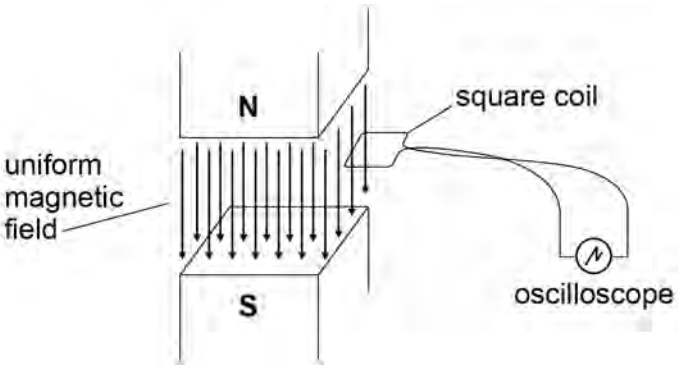
0 4 . 3 During the demonstration an induced current is detected by the ammeter. The induced current is in the direction **E** to **F**.

Explain how this demonstrates Lenz's law.

[2 marks]

0 4 . 4 **Figure 7** shows an arrangement for investigating induced emf.

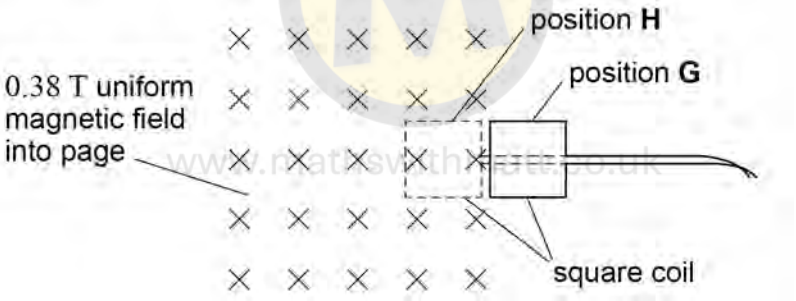
Figure 7



As shown, the uniform vertical magnetic field is confined to the gap between the poles of the magnet. The plane of the square coil is horizontal and is made of conducting wire. The coil consists of a single turn and is attached by flexible wire to an oscilloscope.

The oscilloscope gives a reading of 2.9×10^{-4} V when the coil is moved at uniform speed from position **G** outside the field to position **H** inside the field, as shown in **Figure 8**.

Figure 8



Length of side of square coil = 32 mm

Magnetic flux density of uniform magnetic field = 0.38 T

Calculate the time taken to move the coil from position **G** to position **H**.

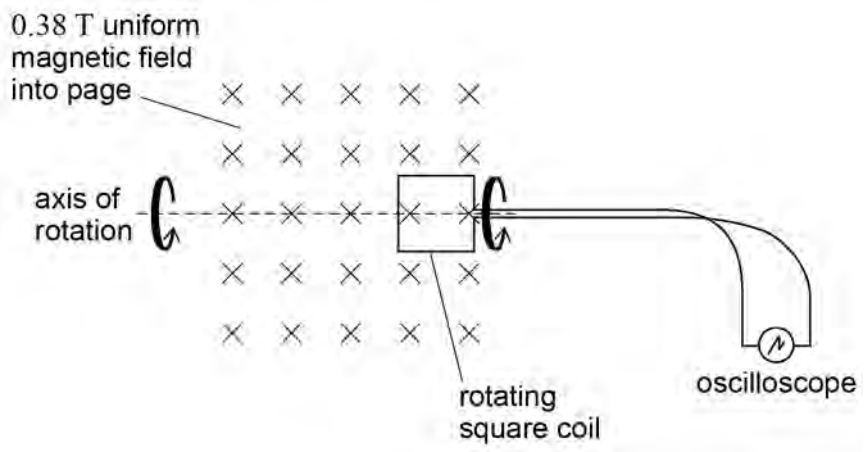
[2 marks]

time = _____ s

Question 4 continues on the next page

0 4 . 5 The square coil is rotated through $360°$ at a constant angular speed about the horizontal axis shown in **Figure 9**.

Figure 9



Calculate the angular speed of the coil when the maximum reading on the oscilloscope is 5.1 mV

[2 marks]

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angular speed = _____ rad s^{-1}

8

Question	Answers	Additional Comments/Guidance	Mark	ID details
04.1	The direction of the induced emf (when there is a change of flux linkage) is such that it will (try) to oppose the change (of flux) that is producing it ✓ owtte	A reference to emf is needed rather than induced current as this is dependent on a circuit. Ignore reference to current if emf is given.	1	AO1

04.2	(The reading shows a dc) current flow which then becomes zero (when the magnet stops moving) ✓	The reading does not have to be steady. So reading increasing or pulsing up before falling to zero is okay. There should be no hint that the reading changes direction.	1	AO2
04.3	(The induced current produces) a north pole on the right hand side of the coil. ✓ which opposes the motion of the bar magnet **OR** and the two north poles repel each other **OR** to try to maintain the (small) magnetic field as the magnet approaches the coil (without this the magnet would increase the magnetic field beside the coil) ✓	The polarity of the coil may be shown on the diagram. The two marks are independent but the second mark does not stand completely alone as it has to be said in context. EG 'Two North poles repel' on its own will not gain a mark.	2	AO1 AO2
04.4	(Use of $\varepsilon = BlV$ as the straight leading edge of the coil is the only conductor that cuts the magnetic flux lines. Also using $v = s / t$) $t = Bls/\varepsilon$ ✓ (There must be some evidence of use for the mark but the mark can come from substituting numbers, eg $t = 0.38 \times 0.032 \times 0.032 / 2.9 \times 10^{-4}$) $t = 1.3(4)$ (s)✓ **OR** (Using $\varepsilon = (-)N\,\Delta\phi/\Delta t$ then $\Delta t = \Delta(BA)/\varepsilon$) $t = BA/\varepsilon$ ✓ (There must be some evidence of use for the mark but the	Useful numbers $BA = 3.89 \times 10^{-4}$ Although the first mark can come from substituting numbers the equation mark may be lost if it is obvious that the equation is not understood by the way substitutions are made (this does not include a simple AE slip). This loss of a mark is directed at the candidate who quotes several equations and happens to hit on the correct equation but fails to use it properly. Failure to square the side length is a PE. Answer only gains 2 marks.	2	AO2

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	mark can come from substituting numbers, eg.$t = 0.38 \times .032^2 / 2.9 \times 10^{-4}$) $t = 1.3(4)$ (s) ✓			

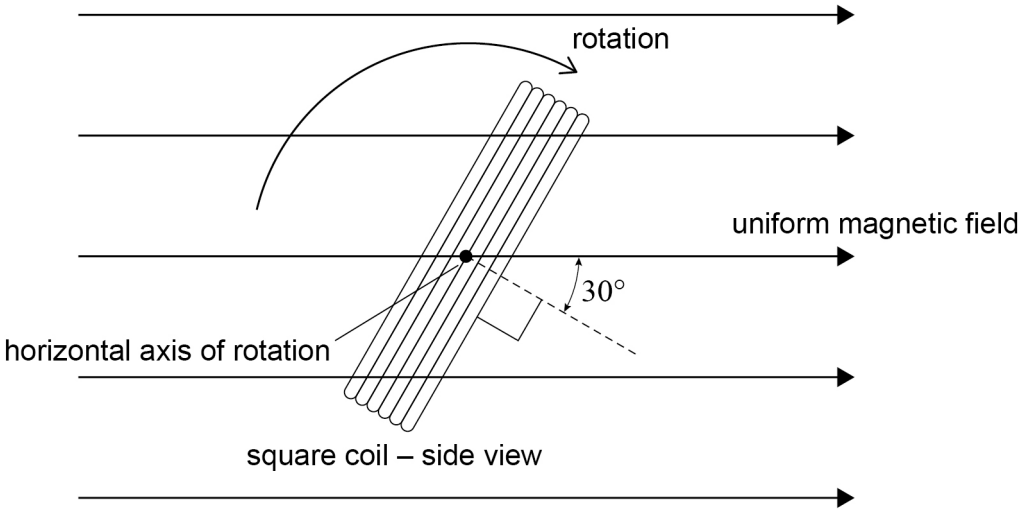
04.5	(using $\varepsilon = BAN\omega \sin \omega t$ which give a maximum value of $\varepsilon_{max} = BAN\omega$) ω (= ε_{max} / BAN) = $5.1 \times 10^{-3} / (0.38 \times (0.032)^2$ ✓ $\omega = 13(.1)$ (rad s^{-1}) ✓	Candidates who cannot maximise/remove sin ωt gain no marks. {may see $\omega = 5.1 \times 10^{-3} / 3.9 \times 10^{-4}$}	2	AO2

Total			**8**

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0 5 A square coil of wire is rotating at a constant angular speed about a horizontal axis. **Figure 4** shows the coil at one instant when the normal to the plane of the coil is at $30°$ to a magnetic field.

Figure 4



The area of the coil is 5.0×10^{-4} m^2 and the flux density of the uniform magnetic field is 2.5×10^{-2} T.

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0 5 . 1 The maximum flux linkage of the coil during its rotation is 1.5×10^{-3} Wb turns.

Calculate the number of turns in the coil.

[2 marks]

number of turns = _____

0 5 . 2 Calculate the flux linkage of the coil at the instant shown in **Figure 4**.

[1 mark]

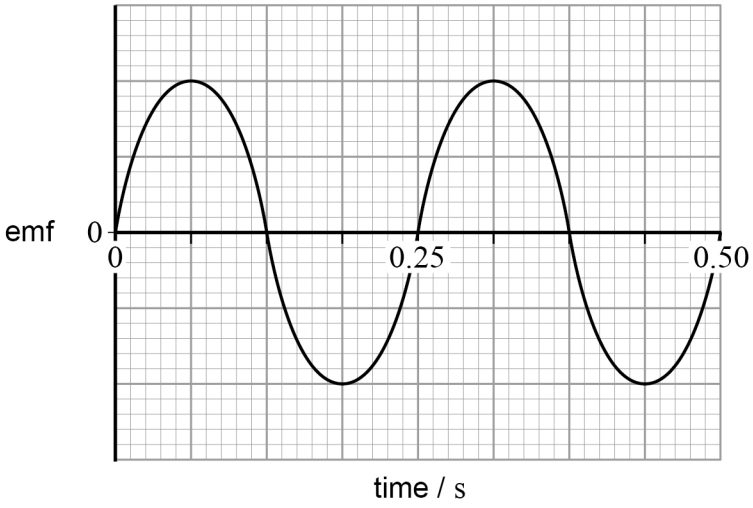
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flux linkage = _____ Wb turns

Question 5 continues on the next page

0 5 . 3 The coil forms part of an electrical generator. **Figure 5** shows the emf generated by the coil.

Figure 5



Calculate the peak value of the emf generated.

[2 marks]

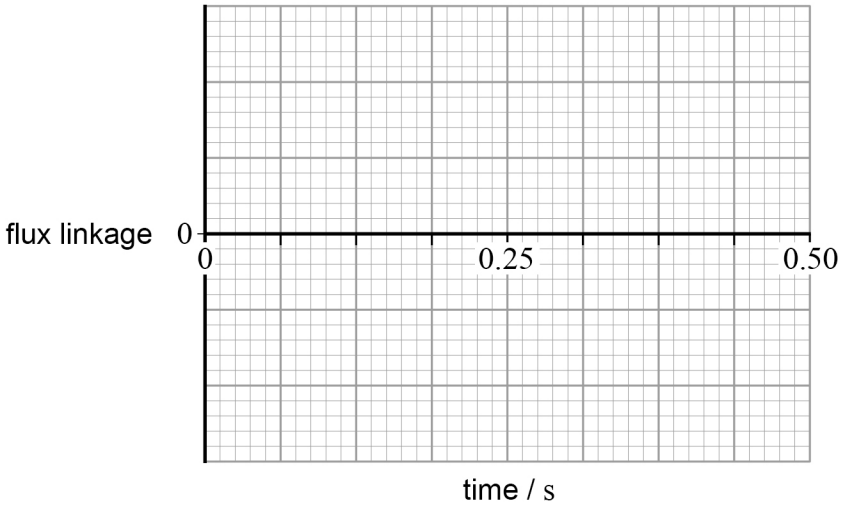
emf = _____ V

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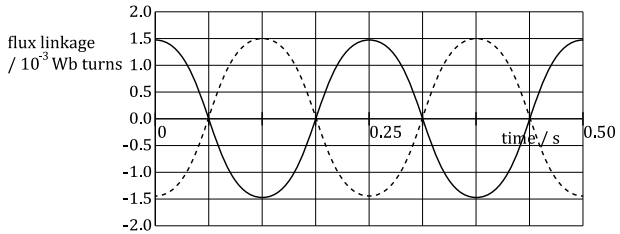
0 5 . 4 Sketch on **Figure 6** the variation with time of flux linkage for the same time interval as **Figure 5**.

[1 mark]

Figure 6



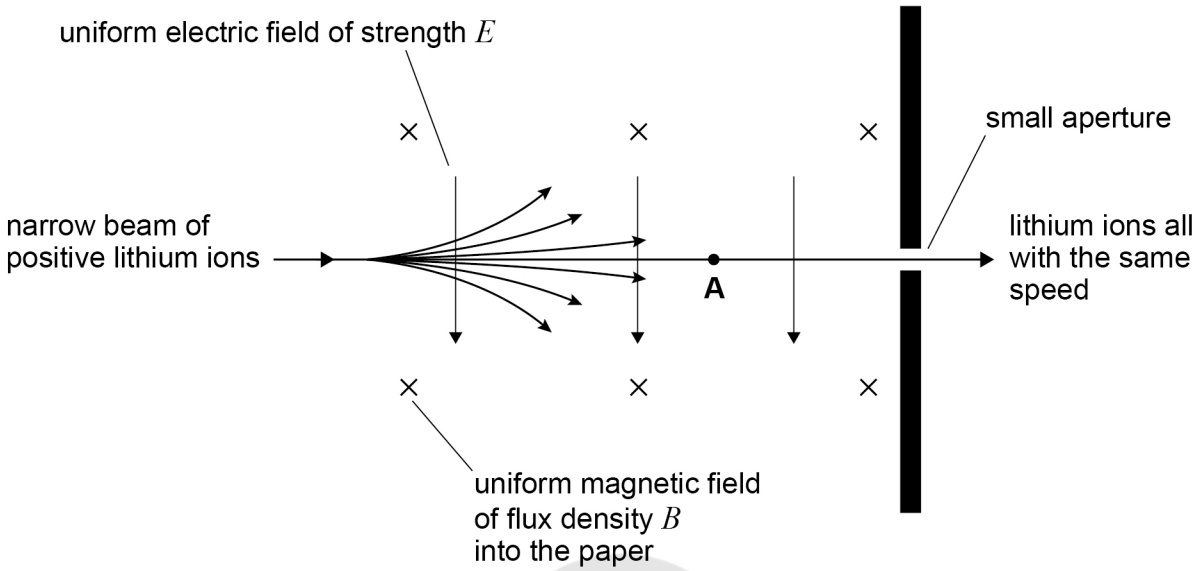
6

Question	Answers	Additional Comments/Guidance	Mark	ID details
05.1	$N = \frac{\Phi}{AB}$ Or $N = \frac{1.5 \times 10^{-3}}{2.5 \times 10^{-2} \times 5.0 \times 10^{-4}}$ ✓1 N = 120 (turns) ✓2	✓1 N must be the subject of the equation for the mark. ✓2 A correct answer gains both marks. If no mark is awarded a single mark can be given for $\Phi = BAN\cos 30^{o}$ being used to find N =139.	2	AO1-1a-1 AO2-1f-1 Math2-1
05.2	$\Phi\left(= \text{NAB}\cos\theta = 1.5 \times 10^{-3}\cos 30^{o}\right)$ Flux linkage = 1.3×10^{-3} (Wb turns) ✓		1	AO2-1f-1 Math2-1
05.3	$f = \frac{1}{T} = \frac{1}{0.25}$ = 4.0 (Hz) or ω = 25.1 or 8π (rad s^{-1}) ✓1 Peak emf (= $BAN\frac{2\pi}{T}$= $1.5 \times 10^{-3} \times \frac{2\pi}{0.25}$) = 0.038 (volt) ✓2 (0.0377 volt)	✓1 Condone using 1 sig fig for *f* but not ω or *T*. The mark can be gained from seeing *f* or ω or *T* given explicitly or from a substitution in the peak emf equation in the second mark. ✓2 A correct answer gains both marks.	2	AO1-1a-1 AO2-1h-1 Math2-2
05.4	 Either solid or dashed line gains mark ✓	The mark is dependent on the exact crossing of the time axis which has a tolerance of ± 1 small square. The vertical axis figures is not expected. Also ignore errors in height and the exact positions of the peaks. Only a rough sinusoidal shape is expected. A	1	AO3-1a-1 Math2-1

0 3 Mass spectrometers are used to measure the masses of ions.

Figure 3 shows one part of a mass spectrometer.

Figure 3



A narrow beam consists of positive lithium ions travelling at different speeds.
The beam enters a region where there is an electric field and a magnetic field.
The directions of the uniform electric field of strength E and the uniform magnetic field of flux density B are shown on **Figure 3**.

Most ions are deflected from their original path.
Lithium ions that travel at one particular speed are not deflected, and pass through the small aperture.

0 3 . 1 The positive lithium ion **A** in **Figure 3** moves at a speed v.

Draw **two** labelled arrows on **Figure 3** to show the directions of the electric force F_E and the magnetic force F_M acting on **A**.

[1 mark]

0 3 . 2 Lithium ions travelling at 1.5×10^5 m s^{-1} pass through the small aperture.

Calculate E.

$B = 0.12$ T

[2 marks]

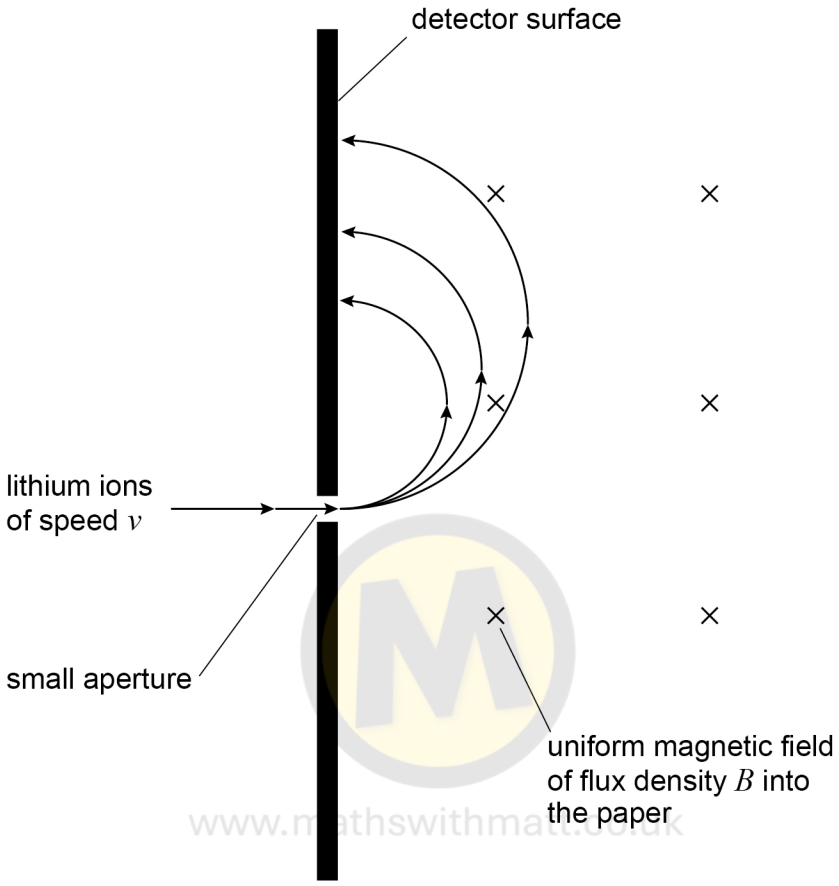
$E =$ _____ V m^{-1}

Question 3 continues on the next page

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0 3 . 3 Ions that pass through the small aperture enter a second uniform magnetic field of flux density B.
Ions of different mass are separated because they follow different paths as shown in **Figure 4**.

Figure 4



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Ions of mass m and charge q travelling at speed v follow a circular path in the uniform magnetic field.

Show that the radius r of the circular path is given by

$$r = \frac{mv}{Bq}$$

[1 mark]

0 3 . 4 The ions of different mass are deflected and strike the detector surface at different distances from the small aperture as shown in **Figure 4**.

A singly-charged lithium ion ($^{6}_{3}\mathrm{Li}^{+}$) passes through the small aperture.

Calculate the distance between the small aperture and the point where this ion strikes the detector surface.

$v = 1.5 \times 10^{5}\ \mathrm{m\ s^{-1}}$

$B = 0.12\ \mathrm{T}$

mass of $^{6}_{3}\mathrm{Li}^{+}$ ion $= 1.0 \times 10^{-26}\ \mathrm{kg}$

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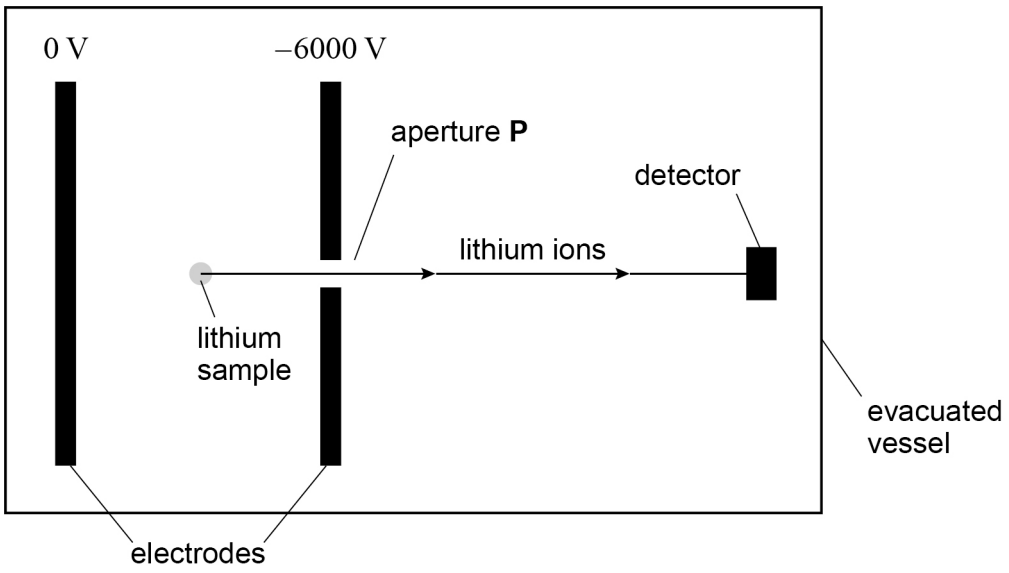
[2 marks]

distance = _____ m

Question 3 continues on the next page

0 3 . 5 **Figure 5** shows a different type of mass spectrometer working with lithium ions.

Figure 5



A stationary $^{7}_{3}\mathrm{Li}^{+}$ ion in the lithium sample is at the mid-point between the parallel electrodes. The $^{7}_{3}\mathrm{Li}^{+}$ ion accelerates towards aperture **P**.

Determine the speed of the ion when it emerges through aperture **P**.

mass of $^{7}_{3}\mathrm{Li}^{+}$ ion = 1.2×10^{-26} kg

[3 marks]

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speed = _____ $\mathrm{m\ s^{-1}}$

0 3 . 6 $^{6}_{3}Li^{+}$ and $^{7}_{3}Li^{+}$ ions are produced in the sample simultaneously and travel a distance L from aperture **P** to the detector.
For each type of ion, the time interval between production and detection is measured.

Discuss how the masses of the ions can be deduced from the measurement of these time intervals.

[2 marks]

11

Turn over for the next question

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Question	Answers	Additional comments/Guidelines	Mark	AO
03.1	Arrow pointing up labelled magnetic force or F_M and arrow pointing down labelled electric force or F_E ✓	As location A is given in the question the base of the arrows do not need to sit exactly on A but arrows, if extended, should pass through A. Care – in some cases A can look like an arrow head.	1	AO1.1b
03.2	Statement that electric and magnetic forces balance OR $qE = Bqv$ OR $E = vB$ OR $1.5 \times 10^5 \times 0.12$ ✓ electric field strength = $E = 1.8 \times 10^4$ (V m^{-1}) ✓	A correct final answer gains both marks	2	AO1.1b AO2.1b M2
03.3	(centripetal force or $F_c = \frac{mv^2}{r}$, equals force due to the magnetic field or $F_m = Bqv$) $F = \frac{mv^2}{r} = Bqv$ and hence $r = \frac{mv}{Bq}$ ✓	Condone use of F to represent both F_c and F_m Allow an interchange between use of q and Q. Note F = is required	1	AO2.1c
03.4	$r\left(= \frac{mv}{Bq} = \frac{1.0\times10^{-26}\times1.5\times10^{5}}{0.12\times1.6\times10^{-19}}\right) = 0.078(1)$ ✓ distance (= $2r$) = 0.16 (m) ✓ (0.156 m)	ecf on second mark. second mark given only if mv/Bq used.in an calculation.	2	AO1.1b ×2 M2

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Question	Answers	Additional comments/Guidelines	Mark	AO
03.5	(using an energy approach) work done by field equals gain in KE $qV = \frac{1}{2}mv^2$ ✓1a (so $v = \sqrt{\frac{2qV}{m}} = \left(\frac{2\times1.6\times10^{-19}\times\frac{6000}{2}}{1.2\times10^{-26}}\right)^{1/2}$) mark for using the $V/2$ either in an equation or via a substitution ✓2a $= 2.8(3) \times 10^5$ (m s^{-1}) ✓3a OR (using a force approach) Force on ion = $ma = qE$ ✓1b ($E = V/d$ $a = \frac{6000 \times 1.6 \times 10^{-19}}{1.2 \times 10^{-26} \times d} = 8.0 \times 10^{10}/d$ Using $v^2 = u^2 + 2as$) Mark for using equation for *E* and equation of motion either in symbols or via a substitution ✓2b $v = 2.8 \times 10^5$ (m s^{-1}) ✓3b	1a in words or equation which can be awarded even if the ion is not singly charged (candidates can wrongly think it has a charge of 3e) 2a for making use of half the pd ie 3000 V 3a Only allow ecf using 6000V giving $v = 4.0 \times 10^5$ m s^{-1}	3	AO1.1b AO2.1f ×2 M2 ×2

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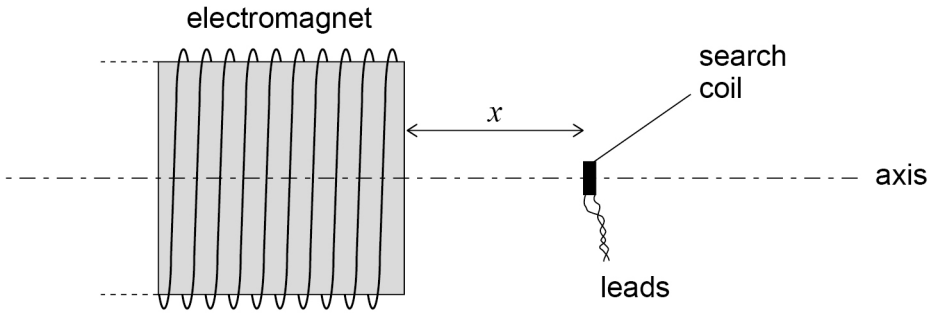
03.6	A smaller mass gives a smaller time interval ✓1 (The explanation can come from a Force or a Work done approach) The ions are given the same force ✓2a (so) smaller mass has higher acceleration and smaller time interval ✓3a OR Work done on ions or kinetic energy gained is the same ✓2b (so) smaller mass is given greater speed and smaller time interval ✓3b Award any two of the three marks	condone use of 'lighter' for 'smaller mass'	3 max 2	AO3.1b ×2

Total			**11**

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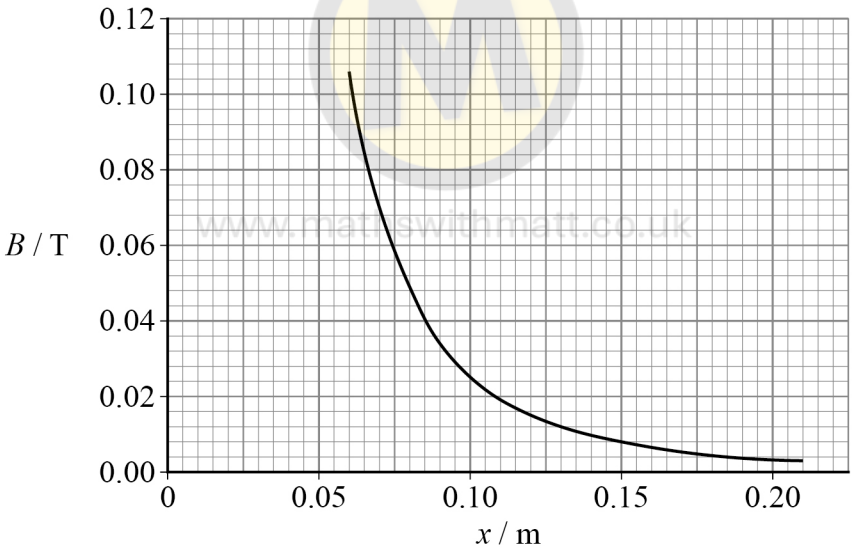
0 4 **Figure 7** shows a search coil positioned on the axis of an electromagnet, with the plane of the search coil perpendicular to the axis. A magnetic field is produced by a constant current in the electromagnet.
Assume that the magnetic flux density inside the search coil is uniform.

Figure 7



The distance between the search coil and the end of the electromagnet is x.
Figure 8 shows how the magnetic flux density B of the field varies with x.

Figure 8



The search coil has 200 turns and a cross-sectional area of $3.5 \times 10^{-5}\ \text{m}^2$.

0 4 . 1 The search coil is placed at $x = 0.070\ \text{m}$.

Show that the magnetic flux linkage through the search coil is about $5 \times 10^{-4}\ \text{Wb}$.

[2 marks]

The search coil is now moved at a constant speed of $0.80\ \text{m s}^{-1}$ along the axis so that x is increasing. An emf is induced across the terminals of the search coil.

0 4 . 2 Explain what happens to the value of the emf as the search coil moves.

[2 marks]

0 4 . 3 The search coil passes through the position where $x = 0.10\ \text{m}$.

Deduce whether the emf can exceed $5\ \text{mV}$ for values of x greater than $0.10\ \text{m}$.

[4 marks]

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Question	Answers	Additional comments/Guidelines	Mark	AO
04.1	Magnetic flux density at $0.070\ \text{m} = 0.07 \pm 0.005\ \text{T}$ ✓ (use of flux linkage $N\Phi = BAN$ $= 0.07 \times 3.5 \times 10^{-5} \times 200$) Flux linkage $= 4.9 \pm 0.2 \times 10^{-4}$ (Wb-turns) ✓	shown calculated to at least 2 sig figs	2	3.7.5.3 AO2 1d ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
04.2	(As the coil moves) there is a rate of change of flux through the coil ✓$_1$ (owtte) The induced emf is proportional to the rate of change of flux (linkage) so the (magnitude) of the emf decreases ✓$_2$ (owtte)	✓$_1$ The first part ie the induced emf is proportional to the rate of change of flux linkage may be given in a number of ways eg emf $= N\frac{\Delta\Phi}{\Delta t}$ or $N\frac{\Delta(BA)}{\Delta t}$ or simply saying 'because of Faraday's law'. Ignore the sign of the emf ✓$_2$ It's not enough to say the emf decreases Connection between rate of change of flux and change of flux with distance must be made	2	3.7.5.4 AO1 1b AO2 1c

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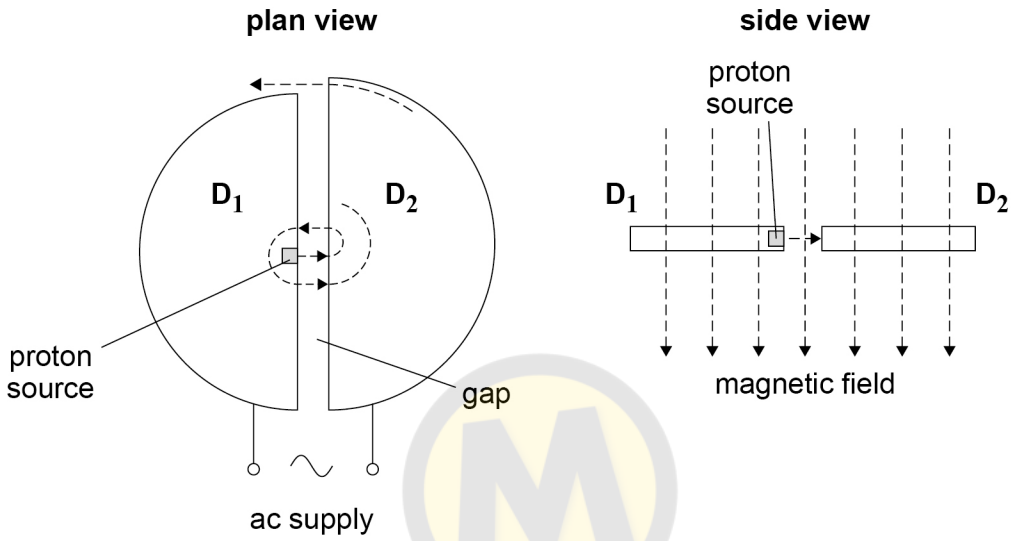
Question	Answers	Additional comments/Guidelines	Mark	AO
04.3	Finding a gradient from a tangent ✓1 Attempting to use Faraday's law emf $= N\frac{\Delta(BA)}{\Delta t}$ OR incorporating velocity into Faraday's law $NA\left(\frac{\Delta B}{\Delta x}\right)v$ ✓2 emf $= \left(200 \times 3.5 \times 10^{-5}(0.693) \times 0.80\right)$ emf $= 3.6$ to 4.2×10^{-3} (V) ✓3 The maximum emf (in the range considered) is the greatest at $x = 0.10$ m (as the gradient is the greatest) So No ✓4 owtte	✓1 This can be calculated at any x eg at $x = 0.10$ m gives $\frac{\Delta B}{\Delta x} = \left(\frac{0.095}{0.137}\right) = 0.69(3)$ (T m^{-1}) ✓2 The mark is given for an attempt to use Faraday's law. Allow errors provided the form of the equation remains correct. ✓3 The expected value is $3.8(8) \times 10^{-3}$ V {range to be decided at standardisation} ✓4 No and an indication that the emf at $x = 0.10$ m is the maximum available. This could come earlier in the answer and can be inferred by a reference to the maximum gradient in the range considered. No ecf. If no marks are awarded allow 1 mark if candidate states that the largest emf is expected at $x = 0.10$ m If only the second mark is awarded allow a mark for finding $\frac{\Delta B}{\Delta t}$ or $N\frac{\Delta \emptyset}{\Delta t}$ between x = 0.07 and 0.10 m (e.g. $\frac{200 \times 3.5 \times 10^{-5}(0.07-0.024)}{0.0375}$)	4	3.7.5.4 AO2 1d ×2 AO3 1a ×2
Total			**8**	

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0 5 **Figure 9** shows a cyclotron. A proton is released from rest and is accelerated each time it reaches the gap between two horizontal 'dees' $\mathbf{D_1}$ and $\mathbf{D_2}$. Between these accelerations the proton moves at constant speed. A vertical magnetic field of flux density B acts over the dees so that the proton follows a semicircular path in each dee.

The dees are connected to an alternating potential difference (pd).
This pd is adjusted so that the proton is always accelerated by the peak electric field as it crosses the gap between the dees.

Figure 9



0 5 . 1 Explain why the proton travels in a semicircular path in a dee.

[2 marks]

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Question 5 continues on the next page

0 5 . 2 The peak pd of the alternating supply is $10.0\ \text{kV}$. The proton leaves the cyclotron with kinetic energy of $14\ \text{MeV}$.

Determine the number of times the proton moves across the gap before it leaves the cyclotron.

[1 mark]

number of times = _____

The radius of the outermost semicircular path of the proton is R and the proton leaves with a maximum kinetic energy E_k.

0 5 . 3 Show that E_k is given by

$$E_\text{k} = \frac{e^2 B^2 R^2}{2m_\text{p}}$$

[3 marks]

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0 5 . 4 A hospital decides to purchase a cyclotron in order to manufacture its own radioactive isotopes using high-speed protons.
The required minimum kinetic energy of the emerging protons is $11\ \text{MeV}$.
The cost of a cyclotron is approximately proportional to $E_k^{1.5}$.
The cost of a $10\ \text{MeV}$ cyclotron is about £2.3 million.
Table 1 gives information for three cyclotrons **X**, **Y** and **Z**.

Table 1

Cyclotron	B / T	R / m
X	1.3	0.38
Y	1.1	0.50
Z	0.5	0.60

Deduce which cyclotron **X**, **Y** or **Z** will satisfy the energy requirement for the lowest cost.
Go on to determine the approximate cost of this cyclotron.

[4 marks]

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cyclotron = _____

cost = _____

10

Question	Answers	Additional comments/Guidelines	Mark	AO
05.1	Force due to uniform magnetic field (is constant and always) at 90° to direction of travel ✓ Identifies this force as the centripetal force for circular/semicircular motion ✓	Reference to velocity will be taken as the velocity of the proton	2	AO1 1a ×2

Question	Answers	Additional comments/Guidelines	Mark	AO
05.2	(1 electron through 10 kV = 10000 eV 14 MeV by 10000 eV) = 1400 (times) ✓		1	AO2 1f × 1

Question	Answers	Additional comments/Guidelines	Mark	AO
05.3	$F = Bev$ AND $F = m_p v^2/R$ ✓ Equates forces giving $v = eBR/m_p$ ✓ $E_k = ½m_p v^2 = ½m_p(eBR/m_p)^2$ ✓ $E_k = e^2B^2R^2 / 2m_p$	1st mark for either or both 2nd mark for expression for v 3rd mark for substituting in $½m_p v^2$ Condone use of *Q or q* for *e*	3	AO2 1d ×3

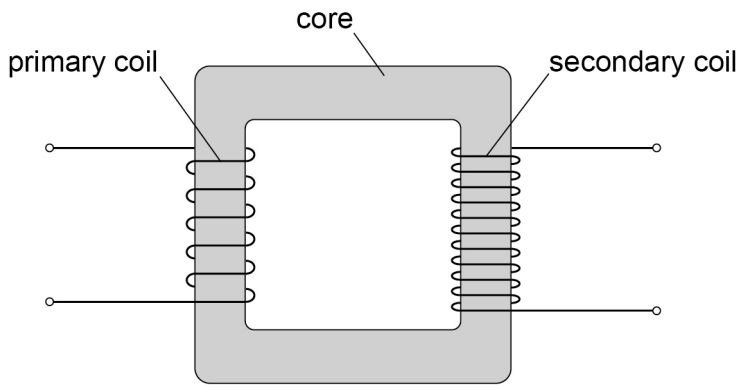
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Question	Answers	Additional comments/Guidelines	Mark	AO
05.4	Uses $= \frac{e^2B^2R^2}{2m_p}$ to calculate E_k for any one cyclotron in J or eV ✓ Calculates E_k for 3 cyclotrons or argues that as **X** is just OK, **Y** will be greater and **Z** will be less than 11 MeV ✓ So reasoned choice of **X** ✓ cost/$11.7^{1.5}$ = £2.3 million/$10^{1.5}$ cost = £2.9 million ✓	For **X** $E_k = \frac{(1.6 \times 10^{-19})^2 \times 1.3^2 \times 0.38^2}{2 \times 1.67 \times 10^{-27}}$ $= 1.87 \times 10^{-12}$ J or 11.7 MeV For **Y** $E_k = 2.32 \times 10^{-12}$ J or 14.5 MeV **or Y** must have higher energy because BR and hence B^2R^2 must be greater For **Z** $E_k = 6.89 \times 10^{-13}$ J 4.3 MeV **or** by inspection B^2R^2 will be too low to give 11 MeV Or other appropriate method	4	AO2 1h ×1 AO3 1a ×3
Total			**10**	

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0 5 **Figure 7** shows a transformer.

Figure 7



0 5 . 1 Explain the functions of the core and the secondary coil.

[3 marks]

core _____

_____

_____

_____

secondary coil _____

_____

_____

_____

_____

_____

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0 5 . 2 **Figure 8** shows a cross-section through the transformer core. Thin iron sheets are separated by material **M**.

Explain how the efficiency of the transformer is increased by constructing the core in this way.

[3 marks]

Figure 8

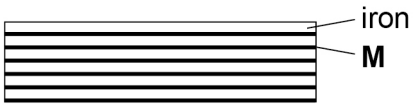
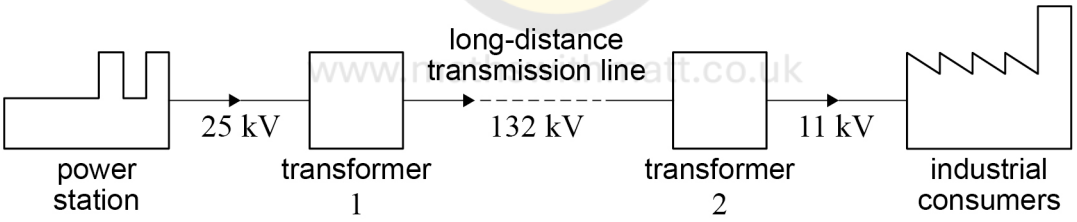


Figure 9 shows a schematic diagram of a power transmission system.

Figure 9



0 5 . 3 Voltages between 33 kV and 400 kV are used for long-distance transmission.

Suggest why engineers have chosen 132 kV for this system.

[2 marks]

Question 5 continues on the next page

0 5 . 4 The industrial consumers use $72\ \text{MW}$ of power.
Transformers 1 and 2 each have an efficiency of 98% and the transmission line has an efficiency of 94%.

Calculate the current in the $25\ \text{kV}$ line from the power station.

[3 marks]

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current = _____ A

11

Question	Answers	Additional comments/Guidelines	Mark	AO
05.1	Core – idea that it provides greater linkage/increases linkage of magnetic flux/field (from the primary coil to the secondary coil compared to an air core)✓1 OWTTE Secondary coil – (a conductor) has a varying/alternating/changing magnetic flux/field passing through/linking with it ✓2 OWTTE Producing an induced emf / induces an emf that is determined by the number of turns in (the primary and) the secondary coils ✓3 OWTTE	✓1 This can be expressed using terms such as “channels/directs/concentrates/focuses/funnels”. In MP1 the reference to an air core can be inferred. Condone “ links all/most flux”. ✓2 ‘varying’ is important for this mark. ✓3 errors may cancel this mark eg ‘this increases the power output’, will not gain this mark. Do not allow reference to “induced voltage” or "induced current" in MP3. When no other mark awarded, MAX 1 for “this is a step-up transformer/the voltage is less on the primary than on the secondary because there are more secondary turns than primary turns”	3	3 x AO1 3.7.5.6

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Question	Answers	Additional comments/Guidelines	Mark	AO
05.2	MAX 3 Design feature 1✓$_{1a}$ Link to efficiency ✓$_{1b}$ Design feature 2✓$_{2a}$ Link to efficiency ✓$_{2b}$ Award ✓$_a$ only once for "thin sheets/ laminations of iron are used".	For each example ✓$_b$ is contingent on ✓$_a$ Example A ✓$_a$ The (sheets) of material **M /** laminations are made from insulator/high resistivity material ✓$_b$ reduces/limits (eddy) currents or charge flowing in the core. Example B: ✓$_a$ thin sheets/ laminations of iron are used ✓$_b$ so smaller emf's are induced in the core Example C ✓$_a$ thin sheets/ laminations of iron are used ✓$_b$ so resistance is high causing lower (eddy) currents If no other marks awarded, give 1 MAX for ✓ Iron is used which magnetises and demagnetises easily OR ✓ Eddy currents produce a magnetic field that opposes the magnetic field supplied to the core	3 max	1 x AO1 2 x AO3 3.7.5.6

Question	Answers	Additional comments/Guidelines	Mark	AO
05.3	If the voltage is lower/$33\ \mathrm{kV}$ then power is transmitted at high current. So energy/power is wasted/lost in the cable by (I^2R) heating. ✓1 OWTTE If the voltage is made too high this will create major insulation/isolation difficulties. ✓2 OWTTE	These two points can be expressed the other way round. They could state why the voltage needs to be high and then why it should not be low. Do not accept 'changes affect the resistance (of the cable)'. In ✓2 accept "taller pylons", "transformers that have better insulation against spark/flash over", "more expensive equipment"	2	1 x AO1 1 x AO3 3.7.5.6

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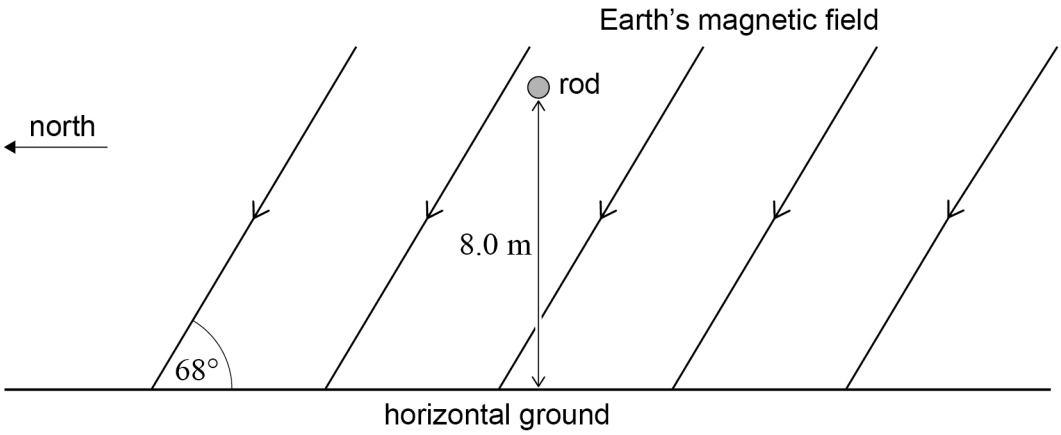
Question	Answers	Additional comments/Guidelines	Mark	AO
05.4	Correct use of efficiency $\eta = \frac{\text{power}_{\text{out}}}{\text{power}_{\text{in}}}$ once ✓1 Correct use of $I = P/V$ with their values once at any point ✓2 I = 3200 (A) (correct answer only, no ecf) ✓3	✓1 examples could be: power at 132 kV = 72 / 0.98 = 73.5 MW OR at transmission line start = 73.5 / 0.94 = 78.2 MW OR at 25 kV = 78.2 / 0.98 = 79.8 MW OR in single stage Power at 25 kV = 72 / (0.94 × 0.98^2) = 79.8 MW) ✓2 eg at consumers I = 72 × 10^6 / 11 × 10^3 = 6545 A (Calculator value: 3190.16 A)	3	3 x AO2 3.7.5.6
Total			**11**	

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0 3 A conducting rod is held horizontally in an east–west direction.
The magnetic flux density of the Earth's magnetic field is 4.9×10^{-5} T and is directed at an angle of $68°$ to the ground.

0 3 . 1 **Figure 5** shows the arrangement. The rod has a length of 2.0 m.

Figure 5



The rod is released and falls 8.0 m to the ground. It remains in a horizontal east–west direction as it falls.

Determine the average emf across the rod during its fall to the ground.
Assume that air resistance is negligible.

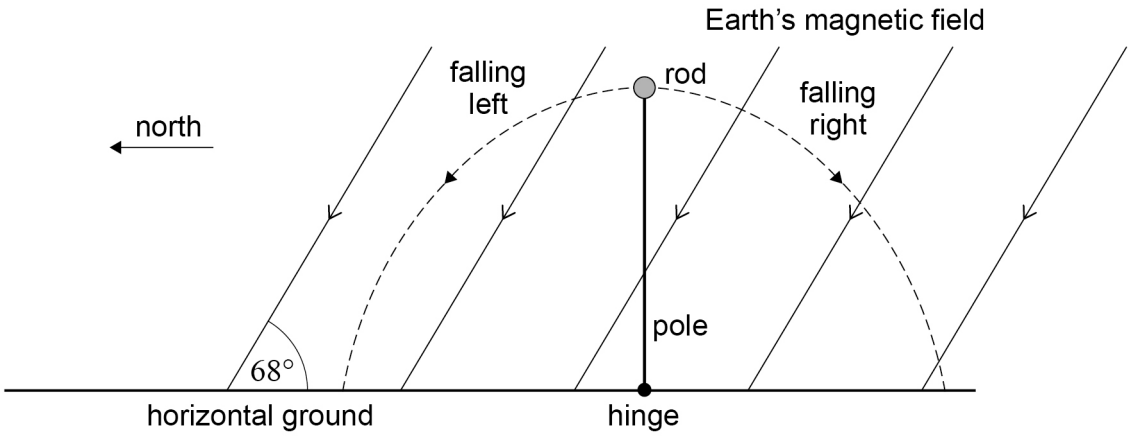
[3 marks]

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average emf = _____ V

0 3 . 2 The rod is returned to its original position. It is now supported by a non-conducting pole that is hinged on the ground as shown in **Figure 6**.
The pole is initially vertical and is then released.
The rod and pole can fall to the ground to the left or to the right.

Figure 6



During each fall there are changes in the magnitude and direction of the induced emf.
These changes differ depending on whether the rod falls to the left or to the right.

Explain any changes in the magnitude and direction of the induced emf as the rod falls:
- to the left
- to the right.

[4 marks]

left _____

_____

_____

_____

right _____

_____

_____

_____

7

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Question	Answers	Additional comments/Guidelines	Mark	AO
03.1	Max 2 from one route ✓✓ **Alternative 1** • $\Phi = BA\cos\theta = 4.9 \times 10^{-5} \times (2 \times 8.0) \times \cos 68° = 2.9(4) \times 10^{-4}$ (Wb) OR $\Phi = BA = 4.9 \times 10^{-5} \times (2 \times 8.0) = 7.84 \times 10^{-4}$ (Wb) • Time to fall to the ground = 1.3 (1.28) (s) • $\varepsilon = \frac{\Delta\Phi}{\Delta t}$ with their $\Delta\Phi$ and t **Alternative 2** • $\varepsilon = Blv$ or $\varepsilon = Blv\cos\theta$ seen • $v = \sqrt{2g\Delta h}$ OR $\sqrt{2as} = 12.5$ (m s^{-1}) OR Time to fall to the ground = 1.3 (1.28) (s) • $v_{avg} = \frac{v}{2}$ with their v OR $v_{avg} = \frac{s}{t}$ for their t $\varepsilon = 2.3 \times 10^{-4}$ ✓ (V)	Marks can only be awarded from one route. mp1 and 2 the mark can be awarded from seeing a substitution. For mp1 condone $\sin 68°$ in both routes $t = \left(\frac{2s}{a}\right)^{\frac{1}{2}} = \left(\frac{2\times 8.0}{9.81}\right)^{\frac{1}{2}} = 1.28$ In 3rd bullet do **not** allow $\varepsilon = \frac{\Delta B}{\Delta t}$ or $\varepsilon = \frac{\Delta B\cos\theta}{\Delta t}$ but condone any value for A.	3	1 × AO1a 1 × AO2a 1 × AO3-1a

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<table>
<tr><th>Question</th><th>Answers</th><th>Additional comments/Guidelines</th><th>Mark</th><th>AO</th></tr>
<tr><td>03.2</td><td>Max 4✓✓✓✓
Fall to the left
<table>
<tr><td>Statement</td><td>Explanation</td></tr>
<tr><td>the direction of the emf changes</td><td>the rod cuts across the magnetic field in both directions / passes parallel point</td></tr>
<tr><td>the emf goes through a zero (when $68°$ to the vertical)</td><td>momentarily the rod travels parallel to the field or does not cut lines of flux / 0 change in flux</td></tr>
<tr><td>emf reduces (and then increases)</td><td>as (direction of) velocity or motion gets closer to being parallel to field / same direction as field / cuts less flux per unit time</td></tr>
</table>
Fall to the right
<table>
<tr><td>Statement</td><td>Explanation</td></tr>
<tr><td>the direction of the emf stays the same</td><td>the rod cuts across the magnetic field always in the same direction</td></tr>
<tr><td>Idea that the emf goes through a maximum (when $22°$ to the vertical)</td><td>the rod cuts across the magnetic field at right angles or the cutting of field line is a maximum</td></tr>
<tr><td>emf increases (and then decreases)</td><td>as (direction of) velocity or motion gets closer to perpendicular to field / cuts more flux per unit time</td></tr>
</table></td><td>All marking points are to be OWTTE.
Ignore comments about different direction falling left and right.
Statement and explanation are separate marking points.
Explanation must not contradict statement to be awarded.
Condone emf increases as speed of fall increases (Blv) or smaller time $\left(N\frac{\Delta\Phi}{\Delta t}\right)$✓ ✓ for either direction but not both.
Allow the following statement and explanation as an alternative to either a fall to the left or to the right but not both:
Statement – when falling left the average emf is less than falling to the right.
Explanation – as the total change in flux / number of flux lines cut is less than when falling to the right.</td><td>4</td><td>2 × AO2g
2 × AO3-1a</td></tr>
<tr><td>Total</td><td></td><td></td><td>7</td><td></td></tr>
</table>