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# HL Paper 2

This question is in **two** parts. **Part 1** is about energy resources. **Part 2** is about transformers.

## Part 2 Transformers

Modern televisions (TVs) can be left in “standby” mode so that they are available for immediate use. The internal circuits are powered at low voltage using a step-down transformer connected to the mains power supply. To prevent the TV from using any energy, the transformer must be disconnected from the mains supply.

When in “standby” mode, a TV transformer supplies a current of 0.45 A at 9.0 V to the internal circuits.

- f. Outline the features of an ideal step-down transformer. [2]
- g. Real transformers are subject to energy loss. State and explain how **two** causes of these energy losses may be reduced by suitable features in these transformers. [4]

1.

2.

- h.i. Calculate the power consumed by the internal circuits when the TV is in “standby” mode. [1]
- h.ii. The efficiency of the transformer is 0.95. Determine the current supplied by the 230 V mains supply. [2]
- h.iii. The TV is on “standby” for 75% of the time. Calculate the energy wasted in one year by not switching off the TV. [1]

$$1 \text{ year} = 3.2 \times 10^7 \text{ s}$$

## Markscheme

- f. number of secondary coils < primary coils;  
coils wound around an iron core;  
ideally no flux leakage/zero resistive heating;
- g. solution;  
with linked explanation;  
another solution;  
with linked explanation;

eg:

laminations in core;

prevents eddy currents in core;

thick/low resistance wires for primary and secondary turns;

reduces heating losses in wires;

h.i.4.1 W;

h.ii.power required at primary =  $\frac{4.1}{0.95} = 4.3 \text{ W}$ ; (allow ECF from (h)(i))

current  $\frac{4.3}{230} = 1.9 \times 10^{-2} \text{ A}$ ;

h.iiiapproximately  $1.0 \times 10^8 \text{ J}$ ;

Allow use of either power value.

## Examiners report

f. Many candidates described the purpose of a step-down transformer. The question asked for features, such as an iron core or more primary than secondary turns.

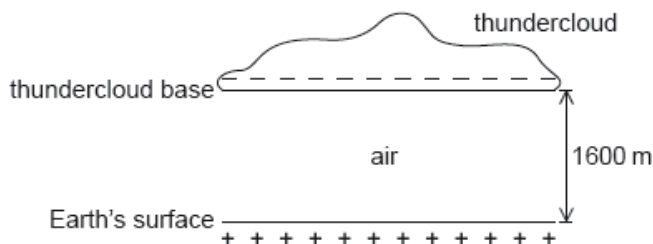
g. Further features such as a laminated core or low resistance coils were not often given, with explanations, as ways of increasing the efficiency of a transformer.

h.i.A very easy mark, 4.1W.

h.ii.To determine the primary current the efficiency needed to be applied correctly to the power in the two circuits. There were many correct answers, with a minority placing the efficiency on the wrong side of the equation.

h.iiiTV power consumption in standby mode was an easy calculation for 1 mark.

A negatively charged thundercloud above the Earth's surface may be modelled by a parallel plate capacitor.



The lower plate of the capacitor is the Earth's surface and the upper plate is the base of the thundercloud.

The following data are available.

Area of thundercloud base	$= 1.2 \times 10^8 \text{ m}^2$
Charge on thundercloud base	$= -25 \text{ C}$
Distance of thundercloud base from Earth's surface	$= 1600 \text{ m}$
Permittivity of air	$= 8.8 \times 10^{-12} \text{ F m}^{-1}$

Lightning takes place when the capacitor discharges through the air between the thundercloud and the Earth's surface. The time constant of the system is 32 ms. A lightning strike lasts for 18 ms.

a. Show that the capacitance of this arrangement is  $C = 6.6 \times 10^{-7}$  F. [1]

b.i. Calculate in V, the potential difference between the thundercloud and the Earth's surface. [2]

b.ii. Calculate in J, the energy stored in the system. [2]

c.i. Show that about -11 C of charge is delivered to the Earth's surface. [3]

c.ii. Calculate, in A, the average current during the discharge. [1]

d. State **one** assumption that needs to be made so that the Earth-thundercloud system may be modelled by a parallel plate capacitor. [1]

## Markscheme

a.  $C = \epsilon \frac{A}{d} \Rightarrow 8.8 \times 10^{-12} \times \frac{1.2 \times 10^8}{1600}$

« $C = 6.60 \times 10^{-7}$  F»

[1 mark]

b.i.  $V = \frac{Q}{C} \Rightarrow \frac{25}{6.6 \times 10^{-7}}$

$V = 3.8 \times 10^7$  «V»

Award [2] for a bald correct answer

[2 marks]

b.ii. **ALTERNATIVE 1**

$E = \frac{1}{2} QV \Rightarrow \frac{1}{2} \times 25 \times 3.8 \times 10^7$

$E = 4.7 \times 10^8$  «J»

**ALTERNATIVE 2**

$E = \frac{1}{2} CV^2 \Rightarrow \frac{1}{2} \times 6.60 \times 10^{-7} \times (3.8 \times 10^7)^2$

$E = 4.7 \times 10^8$  «J» /  $4.8 \times 10^8$  «J» if rounded value of V used

Award [2] for a bald correct answer

Allow ECF from (b)(i)

[2 marks]

c.i.  $Q = Q_0 e^{-\frac{t}{\tau}} \Rightarrow 25 \times e^{-\frac{18}{32}}$

$Q = 14.2$  «C»

charge delivered =  $Q = 25 - 14.2 = 10.8$  «C»

« $\approx -11$  C»

Final answer must be given to at least 3 significant figures

[3 marks]

c.ii.  $I = \frac{\Delta Q}{\Delta t} = \frac{11}{18 \times 10^{-3}} \approx 610 \text{ «A»}$

Accept an answer in the range 597 – 611 «A»

[1 mark]

d. the base of the thundercloud must be parallel to the Earth surface

OR

the base of the thundercloud must be flat

OR

the base of the cloud must be very long «compared with the distance from the surface»

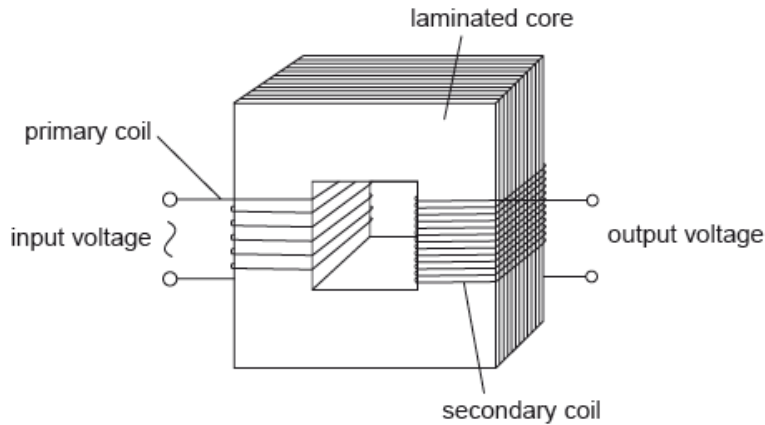
[1 mark]

## Examiners report

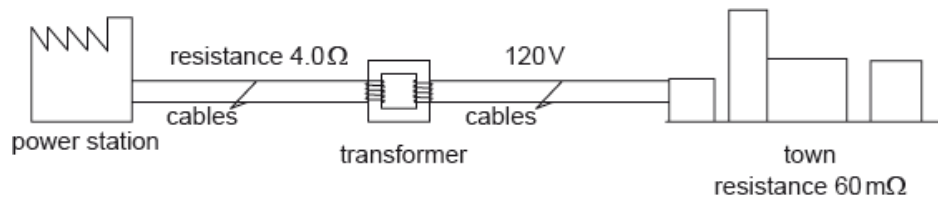
- a. [N/A]
- b.i. [N/A]
- b.ii. [N/A]
- c.i. [N/A]
- c.ii. [N/A]
- d. [N/A]

### Part 2 Power transmissions

The diagram shows the main features of an ideal transformer whose primary coil is connected to a source of alternating current (ac) voltage.



A different transformer is used to transmit power to a small town.



The transmission cables from the power station to the transformer have a total resistance of  $4.0 \Omega$ . The transformer is 90% efficient and steps down the voltage to 120 V. At the time of maximum power demand the effective resistance of the town and of the cables from the transformer to the town is  $60 \text{ m}\Omega$ .

- d. Outline, with reference to electromagnetic induction, how a voltage is induced across the secondary coil. [3]
- e. The primary coil has 25 turns and is connected to an alternating supply with an input voltage of root mean squared (rms) value 12 V. The secondary coil has 80 turns and is not connected to an external circuit. Determine the peak voltage induced across the secondary coil. [2]
- f.i. Calculate the current in the cables connected to the town [1]
- f.ii. Calculate the power supplied to the transformer. [2]
- f.iii. Determine the input voltage to the transformer if the power loss in the cables from the power station is 2.0 kW. [2]
- g. Outline why laminating the core improves the efficiency of a transformer. [2]

## Markscheme

- d. (alternating) pd/voltage across primary coil leads to (alternating) current (in primary coil);  
 hence there is a changing/alternating magnetic field in primary;  
 leading to a changing magnetic flux linked to/appearing in secondary;  
 according to Faraday's law, an alternating emf is induced in the secondary coil;
- e. rms secondary voltage =  $38.4 \text{ (V)}$ ;  
 peak voltage =  $(38\sqrt{2} =) 54 \text{ (V)}$ ; (allow ECF from MP1)  
 Award [2] for a bald correct answer.
- f.i.  $(I_s = \frac{120}{60 \times 10^{-3}}) = 2.0 \text{ k(A)}$ ; (30 A is a common and incorrect answer)
- f.ii. power (supplied to town) =  $2.0 \times 10^3 \times 120$  or  $2.4 \times 10^5$ ; (allow ECF from (f)(i))  
 power (supplied to transformer) =  $(\frac{2.4 \times 10^5}{0.9} =) 2.67 \times 10^5 \text{ (W)}$ ; } (30 A in (f)(i) leads to 4 kW)  
 Award [2] for a bald correct answer.
- f.iii.  $I_p = \sqrt{\frac{2 \times 10^3}{4.0}} = 22.4 \text{ (A)}$ ;  
 $V = \frac{P}{I} = \frac{2.67 \times 10^5}{22.4} = 12 \text{ k(V)}$ ;  
 Allow ECF from (f)(i) and (f)(ii).  
 30 A and 4 kW earlier leads to 179 V.  
 Award [2] for a bald correct answer.
- g. laminations increase resistance / reduce current in core material/metal / reduce eddy currents;  
 thus reducing  $I^2 R$ /power/(thermal) energy/heat losses in the core;

## Examiners report

- d. In the second part of this question, candidates showed themselves to be much less confident with ideas of electromagnetic induction. Discussion of induction of the secondary emf in the transformer ought to be well rehearsed and confident from a candidate at this level. Instead, examiners were treated to incomplete and often non-physical descriptions. Standard and expected terminology was rare. Terms such as magnetic flux, linking, emf and induction were either omitted or misused. This is clearly an area where there is much misunderstanding.
- e. On the other hand, candidates were well able to cope with the (straightforward) calculation of the induced emf across the secondary coil. However, a frequent omission was the final conversion to a peak value.
- f.i. This whole sequence of calculations was poorly done. Candidates appear never to have considered the problem of energy loss in the cabling between energy generator and consumer. This ought to be straightforward work for the candidates, but it proved not to be. Solutions as a whole were confused with little clear explanation of what was going on. Candidates were evaluating the wrong quantities without realising it and then misapplying them later in the question. As an example, simply labelling a quantity as “Power =...” is unhelpful. What power is being referred to by the candidate? The argument *must* be clear in order that an examiner can award error carried forward.
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- g. Many had rote learnt the first point about laminations in a transformer core: that the eddy currents are reduced. However, a good candidate will realise that the nature of the core must mean that they are never entirely eliminated – complete elimination of the currents was a common and incorrect answer.

This question is about electromagnetic induction.

- a. In order to measure the rms value of an alternating current in a cable, a small coil of wire is placed close to the cable.

[3]

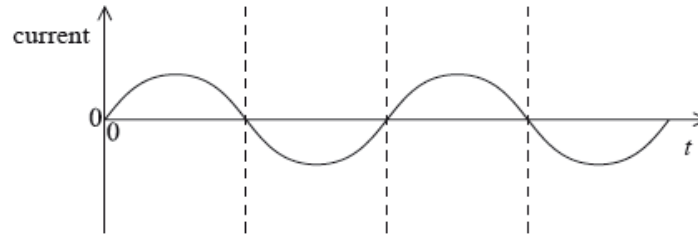


The plane of the small coil is parallel to the direction of the cable. The ends of the small coil are connected to a high resistance ac voltmeter.

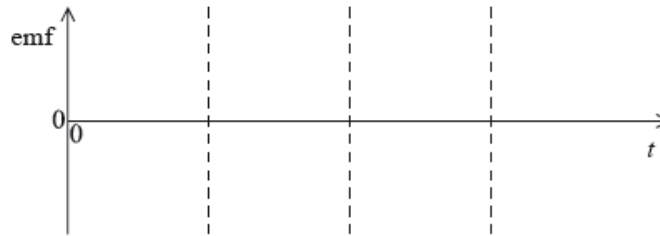
Use Faraday's law to explain why an emf is induced in the small coil.

- b. The graph below shows the variation with time  $t$  of the current in the cable.

[2]



On the axes below, draw a sketch graph to show the variation with time of the emf induced in the small coil.



- c. Explain how readings on the high resistance ac voltmeter can be used to compare the rms values of alternating currents in different cables.

[3]

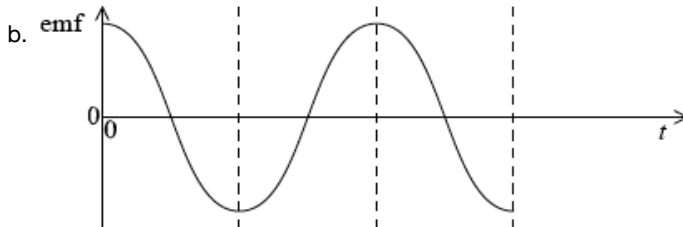
## Markscheme

- a. induced emf is (directly) proportional/equal to rate of change/cutting of flux (linkage);

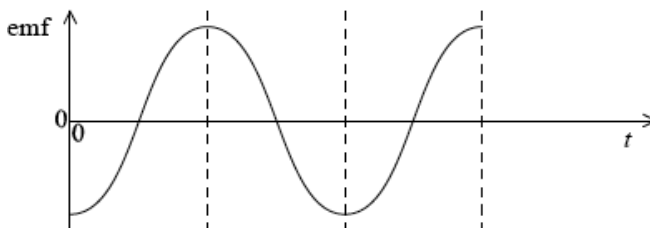
current produces a (time changing) magnetic field;

field changes with time;

which produces a time changing flux in the coil;



or



same frequency as current graph;

$\pm 90^\circ$  phase shift;

- c. if the coil position/orientation relative to the cables is the same in all measurements;

if the coil distance from the cables is the same in all measurements;

the voltage measured across the coil is proportional to current in the cable;

# Examiners report

- The chain of argument needed to be clear in answers. A correct statement of Faraday's Law should lead to the recognition that the current produces a magnetic field, that this field is changing, and that therefore a time changing flux exists inside the coil.
- Candidates could identify the similarity of frequency between graphs but the phase relationship usually defeated them.
- Candidates failed to rise to the challenge of this question or indeed to read it correctly. They were asked to explain how the voltmeter can be used to compare the values of currents in different cables. This involves making both the distance from the centre of the cable and the orientation common to both sets of measurements. It also involves the recognition by the candidate that the current is directly proportional to the reading on the voltmeter.

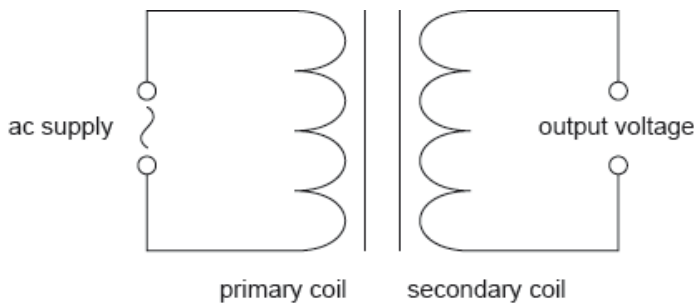
A capacitor consists of two parallel square plates separated by a vacuum. The plates are  $2.5 \text{ cm} \times 2.5 \text{ cm}$  squares. The capacitance of the capacitor is  $4.3 \text{ pF}$ .

- Calculate the distance between the plates. [1]
- The capacitor is connected to a  $16 \text{ V}$  cell as shown. [2]



Calculate the magnitude and the sign of the charge on plate A when the capacitor is fully charged.

- The capacitor is fully charged and the space between the plates is then filled with a dielectric of permittivity  $\epsilon = 3.0\epsilon_0$ . [2]  
Explain whether the magnitude of the charge on plate A increases, decreases or stays constant.
- In a different circuit, a transformer is connected to an alternating current (ac) supply. [3]



The transformer has 100 turns in the primary coil and 1200 turns in the secondary coil. The peak value of the voltage of the ac supply is  $220 \text{ V}$ . Determine the root mean square (rms) value of the output voltage.

- Describe the use of transformers in electrical power distribution. [3]

# Markscheme



a.  $d = \left\langle \frac{8.85 \times 10^{-12} \times 0.025^2}{4.3 \times 10^{-12}} \Rightarrow 1.3 \times 10^{-3} \text{ «m»} \right\rangle$

**[1 mark]**

b.  $6.9 \times 10^{-11} \text{ «C»}$

negative charge/sign

**[2 marks]**

c. charge increases

because capacitance increases **AND** pd remains the same.

**[2 marks]**

d. **ALTERNATIVE 1**

$$\varepsilon_s = \frac{1200}{100} \times 220$$

$$= 2640 \text{ «V»}$$

$$V_{\text{rms}} = \frac{2640}{\sqrt{2}} = 1870 \text{ «V»}$$

**ALTERNATIVE 2**

$$\text{(Primary) } V_{\text{rms}} = \frac{220}{\sqrt{2}} = 156 \text{ «V»}$$

$$\text{(Secondary) } V_{\text{rms}} = \frac{156 \times 1200}{100}$$

$$V_{\text{rms}} = 1870 \text{ «V»}$$

Allow ECF from MP1 and MP2.

Award **[2]** max for 12.96 V (reversing  $N_p$  and  $N_s$ ).

**[3 marks]**

e. step-up transformers increase voltage/step-down transformers decrease voltage

(step-up transformers increase voltage) from plants to transmission lines / (step-down transformers decrease voltage) from transmission lines to final utilizers

this decreases current (in transmission lines)

to minimize energy/power losses in transmission

**[3 marks]**

## Examiners report

a. [N/A]

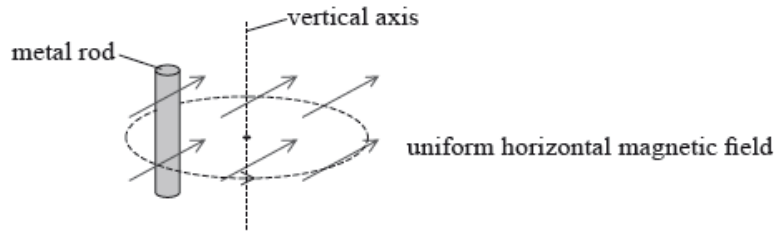
b. [N/A]

c. [N/A]

d. [N/A]

e. [N/A]

A vertical metal rod of length 0.25 m moves in a horizontal circle about a vertical axis in a uniform horizontal magnetic field.



The metal rod completes one circle of radius 0.060 m in 0.020 s in the magnetic field of strength 61 mT.

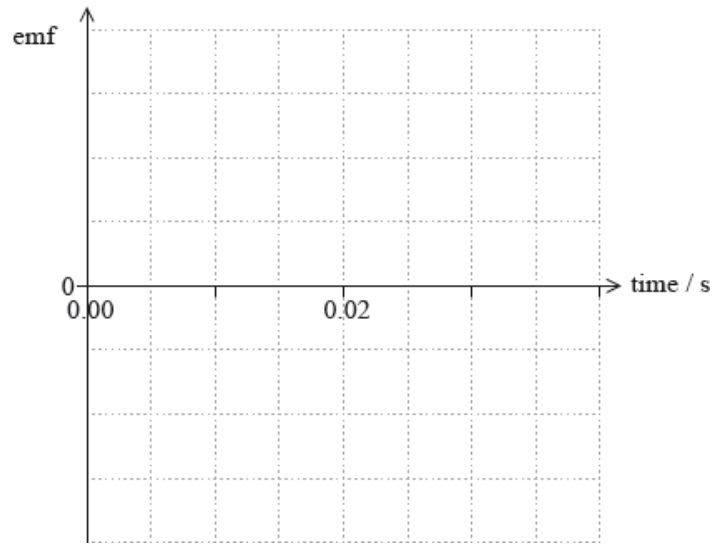
a. Define *magnetic flux*.

[1]

b. (i) Determine the maximum emf induced between the ends of the metal rod.

[5]

(ii) Using the axes, sketch a graph to show the variation with time of the emf of the metal rod.



## Markscheme

a. magnetic flux density/magnetic field strength normal to a surface  $\times$  area of surface;

*Allow fully explained equation or diagram.*

b. (i)  $v = \frac{1}{0.02} \times 2\pi \times 0.06$  ( $= 18.8 \text{ m s}^{-1}$ );

$$\varepsilon = (Blv) = 61 \times 10^{-3} \times 0.25 \times 18.8;$$

290 (mV);

*Award [3] for a bald correct answer.*

(ii) sinusoidal curve drawn; (*at least half a cycle required*)

with a period of 0.02 s;

*Accept any phase.*

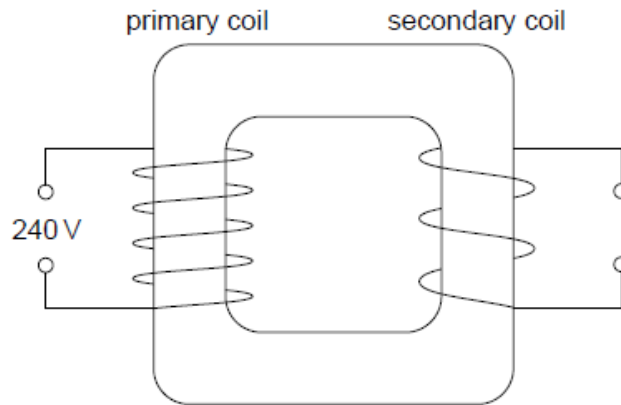
## Examiners report

a. A strong and complete definition was required here. It was often lacking. There were references to “magnetic field” or “magnetic strength”, and the angle between  $B$  and  $\square$  was often incorrectly defined. This standard bookwork left a lot to be desired.

b. (i) A standard error in this calculation was to misunderstand how to determine the speed of the rod. Some credit was allowed if this was incorrect. Many candidates recognised that the emf was related to  $Blv$  and the speed determination was their only error.

(ii) Space had been left on the graph for two complete cycles of the wave and this is what examiners expected to see. Very many candidates failed to think the problem through and assumed that the grid axes had been set up for one period. Most candidates realised that there was some sinusoidal behaviour for the emf. However, examiners saw a minority of very strange graphs.

The diagram shows a sketch of an ideal step-down transformer.



The number of turns in the primary coil is 1800 and that in the secondary coil is 90.

- a. State Faraday's law of induction. [2]
- b.i. Explain, using Faraday's law of induction, how the transformer steps down the voltage. [4]
- b.ii. The input voltage is 240 V. Calculate the output voltage. [2]
- c. Outline how energy losses are reduced in the core of a practical transformer. [2]
- d. Step-up transformers are used in power stations to increase the voltage at which the electricity is transmitted. Explain why this is done. [2]

## Markscheme

a. the size of the induced emf

is proportional/equal to the rate of change of flux linkage

*The word 'induced' is required here.*

*Allow correctly defined symbols from a correct equation. 'Induced' is required for MP1.*

b.i. varying voltage/current in primary coil produces a varying magnetic field

this produces a change in flux linkage / change in magnetic field in the secondary coil

a «varying» emf is induced/produced/generated in the secondary coil

voltage is stepped down as there are more turns on the primary than the secondary

*Comparison of number of turns is required for MP4.*

b.ii.output voltage =  $\frac{90 \times 240}{1800}$

= 12 «V»

c. laminated core reduces eddy currents

less thermal energy is transferred to the surroundings

d. for a certain power to be transmitted, large  $V$  means low  $I$

less thermal energy loss as  $P = I^2R$  / joule heating

## Examiners report

a. [N/A]

b.i. [N/A]

b.ii. [N/A]

c. [N/A]

d. [N/A]

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The following data are available for a natural gas power station that has a high efficiency.

Rate of consumption of natural gas	= 14.6 kg s <sup>-1</sup>
Specific energy of natural gas	= 55.5 MJ kg <sup>-1</sup>
Efficiency of electrical power generation	= 59.0 %
Mass of CO <sub>2</sub> generated per kg of natural gas	= 2.75 kg
One year	= 3.16 × 10 <sup>7</sup> s

b. Electrical power output is produced by several alternating current (ac) generators which use transformers to deliver energy to the national electricity grid. [4]

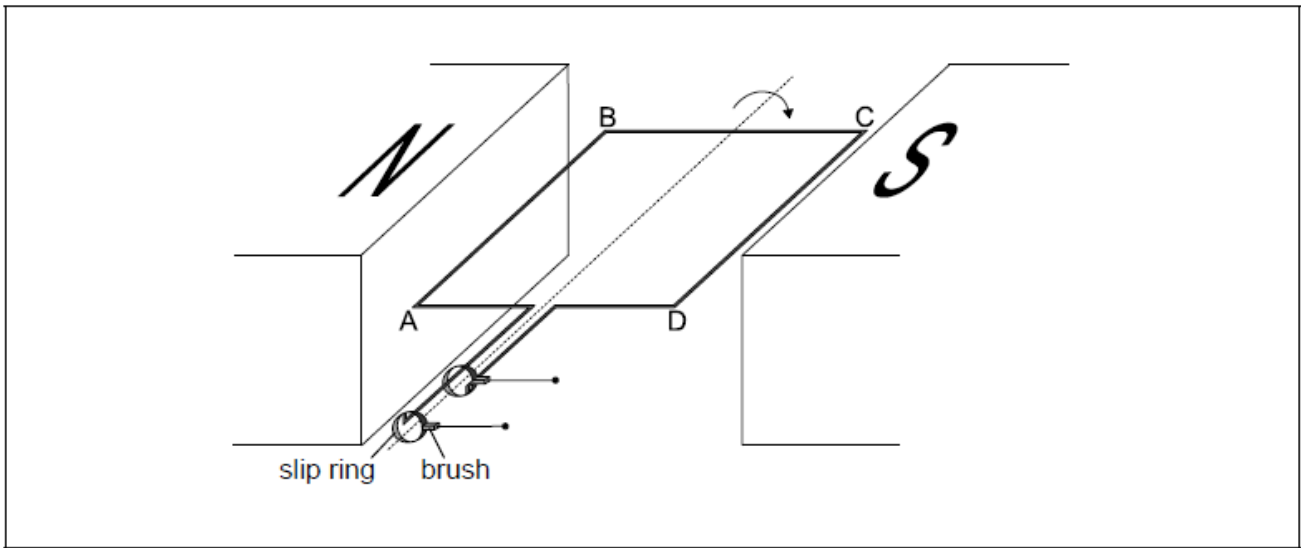
The following data are available. Root mean square (rms) values are given.

ac generator output voltage to a transformer	= 25 kV
ac generator output current to a transformer	= 3.9 kA
Transformer output voltage to the grid	= 330 kV
Transformer efficiency	= 96%

(i) Calculate the current output by the transformer to the grid. Give your answer to an appropriate number of significant figures.

(ii) Electrical energy is often delivered across large distances at 330 kV. Identify the main advantage of using this very high potential difference.

c. In an alternating current (ac) generator, a square coil ABCD rotates in a magnetic field. [5]



The ends of the coil are connected to slip rings and brushes. The plane of the coil is shown at the instant when it is parallel to the magnetic field. Only one coil is shown for clarity.

The following data are available.

Dimensions of the coil	= 8.5 cm×8.5 cm
Number of turns on the coil	= 80
Speed of edge AB	= 2.0 ms <sup>-1</sup>
Uniform magnetic field strength	= 0.34 T

- Explain, with reference to the diagram, how the rotation of the generator produces an electromotive force (emf) between the brushes.
- Calculate, for the position in the diagram, the magnitude of the instantaneous emf generated by a **single** wire between A and B of the coil.
- Hence, calculate the total instantaneous peak emf between the brushes.

## Markscheme

b. i

$$I = 0.96 \times \left( \frac{25 \times 10^3 \times 3.9 \times 10^3}{330 \times 10^3} \right)$$

Award **[2]** for a bald correct answer to 2 sf.

Award **[1 max]** for correct sf if efficiency used in denominator leading to 310 A or if efficiency ignored ( $e=1$ ) leading to 300 A (from 295 A but 295 would lose both marks).

=280 «A»

Must show two significant figures to gain MP2.

ii

higher V means lower  $I$  «for same power»

thermal energy loss depends on  $I$  or is  $I^2$  or is  $I^2 R$  so thermal energy loss will be less

Accept “heat” or “heat energy” or “Joule heating” for “thermal energy”.

Reference to energy/power dissipation is not enough.

c. i

«long» sides of coil AB/CD cut lines of flux

**OR**

flux «linkage» in coil is changed

«Faradays law:» induced emf depends on rate of change of flux linked

**OR**

rate at which lines are cut

“Induced” is required

Allow OWTTE or defined symbols if “induced emf” is given.

Accept “induced” if mentioned at any stage in the context of emf or accept the term “motional emf”.

Award [2 max] if there is no mention of “induced emf”.

emfs acting in sides AB/CD add / act in same direction around coil

process produces an alternating/sinusoidal emf

ii

$$Blv = 0.34 \times 8.5 \times 10^{-2} \times 2 = 0.058 \text{ «V»}$$

Accept 0.06V.

iii

$$160 \times (c)(ii) = 9.2 \text{ or } 9.3 \text{ or } 9.6 \text{ «V»}$$

Allow ECF from (c)(ii)

If 80 turns used in cii, give full credit for cii x 2 here.

## Examiners report

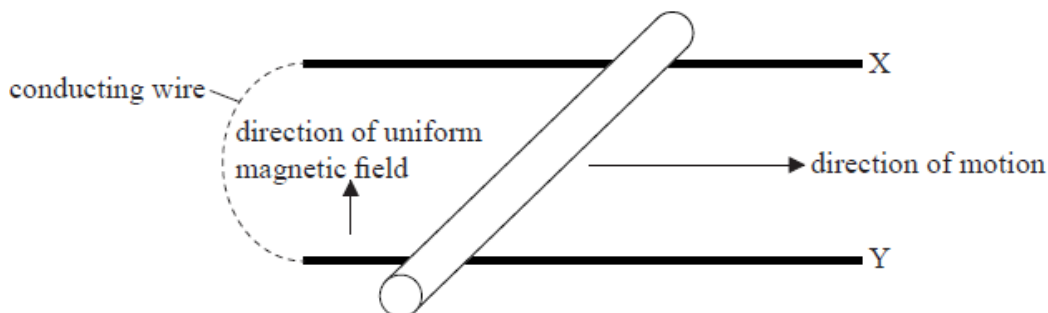
b. [N/A]

c. [N/A]

This question is about induced electromotive force (emf).

a. A rod made of conducting material is in a region of uniform magnetic field. It is moved horizontally along two parallel conducting rails X and Y. [4]

The other ends of the rails are connected by a thin conducting wire.



The speed of the rod is constant and is also at right angles to the direction of the uniform magnetic field.

(i) Describe, with reference to the forces acting on the conduction electrons in the rod, how an emf is induced in the rod.

(ii) An induced emf is produced by a rate of change of flux. State what is meant by a rate of change of flux in this situation.

b. The length of the rod in (a) is 1.2 m and its speed is  $6.2 \text{ m s}^{-1}$ . The induced emf is 15 mV.

[4]

- (i) Determine the magnitude of the magnetic field strength through which the rod is moving.
- (ii) Explain how Lenz's law relates to the situation described in (a).

## Markscheme

- a. (i) electrons are moving at right angles to the magnetic field;

electrons experience a force directed along the rod / charge is separated in the rod;

the work done by this force to achieve this separation leads to an induced

emf;

(ii) the product of magnitude of field strength and the rate at which the area is swept out by the rod is changing / the rate at which the rod cuts through field lines;

- b. (i)  $B = \frac{\epsilon}{vl}$ ;

*(must see the data book equation re-arranged or correctly aligning substitution with equation)*

$$= \left( \frac{15 \times 10^{-3}}{6.2 \times 1.2} \right) 2.0 \text{mT}; \text{ (accept 2+sf)}$$

*To award [2] both steps must be seen.*

(ii) Lenz's law states that the direction of the induced emf/current is such as to oppose the change producing it;

there is a current in the rod due to the induced emf;

the force on the current/rod due to the magnetic field is in the opposite direction to the force producing the motion of the rod;

## Examiners report

- a. It continues to be apparent that candidates find this a difficult area of the syllabus in which a clear and unshakeable understanding of the concepts is required.

(i) A good number did not consider the forces acting on the electrons as instructed and therefore gained few, if any, marks. Of the remainder, some were able to discuss the forced motion of the electrons in the field and how this leads to the direction of the forces on the electrons along the rod. It was rare to see a consideration of the connection between the work done on the electrons and the emf itself.

(ii) Only a few candidates could adequately explain what is meant by a rate of change of flux. The "rate of change" aspect was usually missing.

- b. (i) The calculation of magnetic field strength followed directly from a substitution into a Data Booklet equation and so was often well done apart from the inevitable power of ten errors by those who forgot the "m" in "mV".

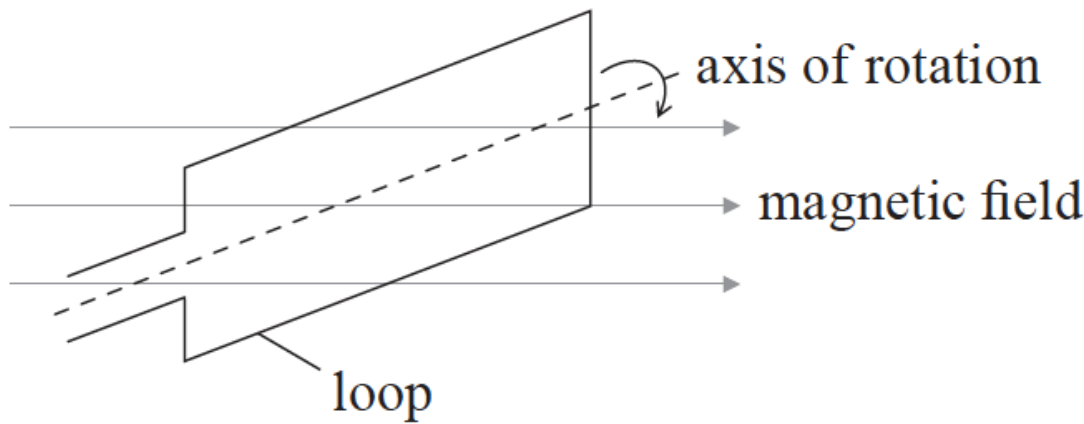
(ii) This was very poor indeed. Many could not even state Lenz's law adequately and could get no further. It was rare to see a good link made between the law itself and the induced current in the circuit.

---

This question is about induced electromotive force (emf).

a. A loop of copper wire in a region of uniform magnetic field is rotated about a horizontal axis.

[4]



The magnitude of the magnetic field strength is  $B$  and the area of the loop is  $A$ .

(i) State the minimum value and the maximum value of the magnetic flux linking the loop.

(ii) Outline with reference to Faraday's law why, if the speed of rotation of the loop is increased, the maximum emf induced in the loop is increased.

b. The loop in (a) is connected in series with a resistor of resistance  $15 \Omega$ . The root mean squared (rms) value of the sinusoidal current in the resistor is  $2.3 \text{ mA}$ .

[4]

(i) Explain what is meant by the rms value of a sinusoidal current.

(ii) Determine the maximum power dissipated in the resistor.

## Markscheme

a. (i) *minimum: zero /  $-BA$  (minus sign required)*

*maximum:  $BA$  } (both needed)*

(ii) *Look for these main points:*

*(Faraday's law states that the) induced emf equals/is proportional to the rate of change of flux/flux linkage; { (must see induced) speed greater so time for change shorter / flux (linkage) is unchanged; greater rate of change (of flux etc) gives a greater (induced) emf; Award [1 max] if answer states flux (linkage) change is larger.*

b. (i) (equivalent) direct current;

dissipating same power in a (fixed) resistor (as the rms current);

(ii) maximum current =  $(\sqrt{2} \times 2.3 =) 3.2/3.3 \text{ mA}$ ;

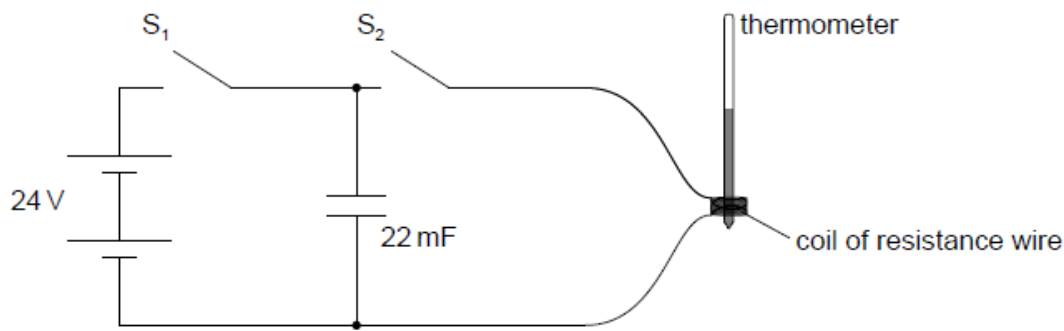
maximum power =  $(3.3^2 \times 15 =) 0.16 \text{ mW}$ ;

## Examiners report

a. [N/A]

b. [N/A]





A power supply of emf (electromotive force) 24 V and of negligible internal resistance is connected to a capacitor and to a coil of resistance wire using an arrangement of two switches. Switch  $S_1$  is closed and, a few seconds later, opened. Then switch  $S_2$  is closed.

- a. The capacitance of the capacitor is 22 mF. Calculate the energy stored in the capacitor when it is fully charged. [1]
- b. The resistance of the wire is  $8.0 \Omega$ . Determine the time taken for the capacitor to discharge through the resistance wire. Assume that the capacitor is completely discharged when the potential difference across it has fallen to 0.24 V. [3]
- c.i. The mass of the resistance wire is 0.61 g and its observed temperature rise is 28 K. Estimate the specific heat capacity of the wire. Include an appropriate unit for your answer. [2]
- c.ii. Suggest **one** other energy loss in the experiment and the effect it will have on the value for the specific heat capacity of the wire. [2]

## Markscheme

a.  $\frac{1}{2}CV^2 = \frac{1}{2} \times 0.22 \times 24^2 = \text{«J»}$

b.  $\frac{1}{100} = e^{-\frac{t}{8.0 \times 0.022}}$

$$\ln 0.01 = -\frac{t}{8.0 \times 0.022}$$

0.81 «s»

c.i.  $c = \frac{Q}{m \times \Delta T}$

**OR**

$$\frac{6.3}{0.00061 \times 28}$$

370 J kg<sup>-1</sup> K<sup>-1</sup>

Allow ECF from 3(a) for energy transferred.

Correct answer only to include correct unit that matches answer power of ten.

Allow use of g and kJ in unit but must match numerical answer, eg: 0.37 J kg<sup>-1</sup> K<sup>-1</sup> receives **[1]**

c.ii **ALTERNATIVE 1**

some thermal energy will be transferred to surroundings/along connecting wires/to thermometer

estimate «of specific heat capacity by student» will be larger «than accepted value»

**ALTERNATIVE 2**

not all energy transferred as capacitor did not fully discharge

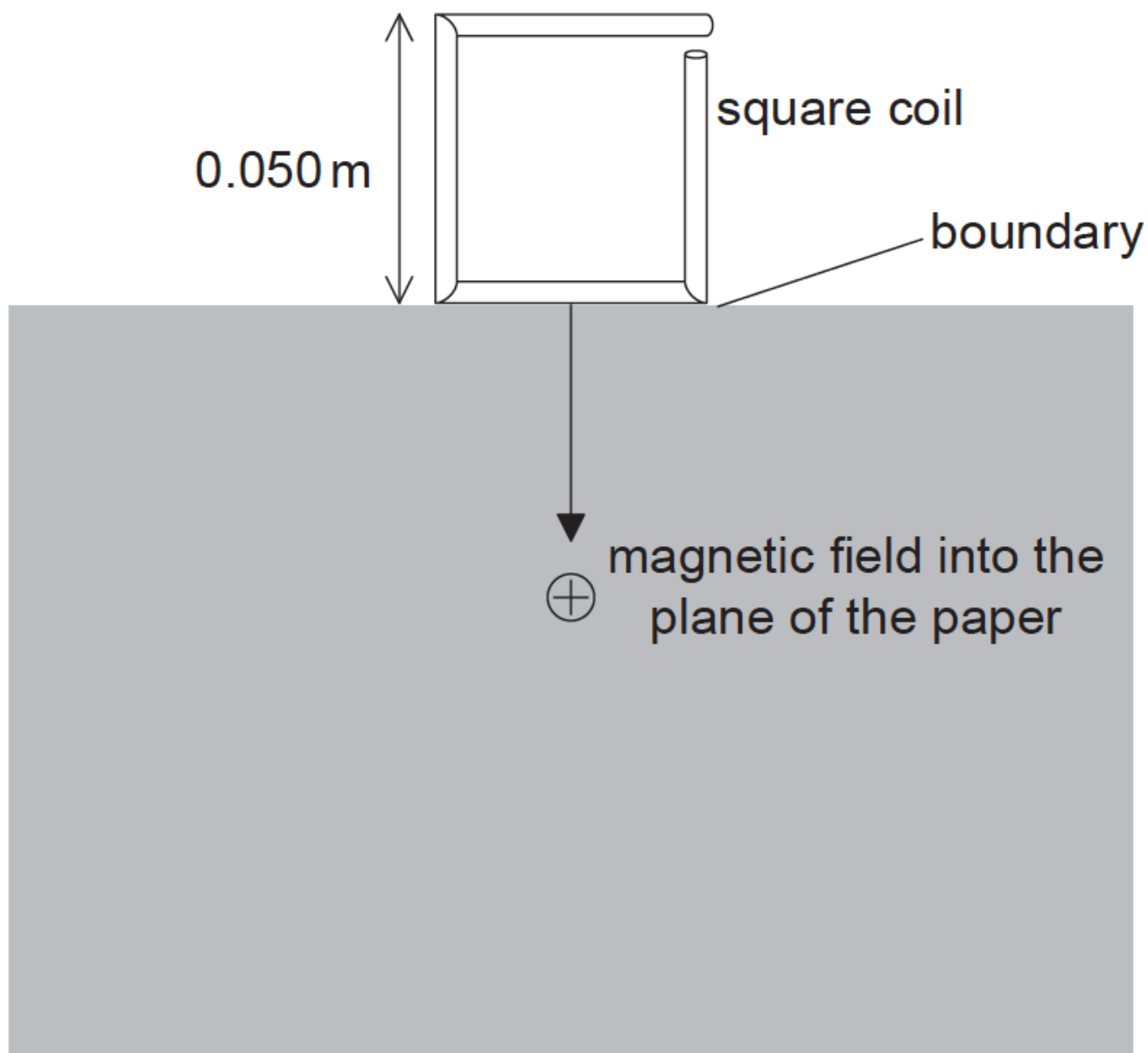
so estimate «of specific heat capacity by student» will be larger «than accepted value»

## Examiners report

- a. [N/A]
- b. [N/A]
- c.i. [N/A]
- c.ii. [N/A]

This question is about changing magnetic fields.

A single-turn conducting square coil is released and falls vertically from rest. At the instant it is released, the coil is at the boundary of a region of a uniform horizontal magnetic field directed into the plane of the paper as shown. The ends of the coil are not joined together.



Each side of the coil is 0.050 m long. The dimensions of the magnetic field region are greater than that of the coil. The magnetic field strength is 25 mT.

- a. Calculate the electromotive force (emf) induced in the coil at the instant just before the whole of the coil enters the magnetic field. [3]
- b. Suggest why the time taken for the whole of the coil to enter the magnetic field increases if the coil is a continuous loop. [3]

## Markscheme

- a. speed as the whole of the coil enters the field =  $\sqrt{2 \times 9.81 \times 0.05}$  (=0.99 ms<sup>-1</sup>);

$$\left(\varepsilon = (-) \frac{\Delta\varphi}{\Delta t}\right) = 0.05 \times 0.99 \times 25 \times 10^{-3};$$

1.23(mV) **or** 1.24(mV); (allow use of  $g=10$  to give 1.25(mV))

*Award [3] for a bald correct answer.*

*Use of factor 4 appears if candidate thinks all sides of coil contribute to emf [2 max].*

- b. current (induced) in the coil;

this will act so as to oppose the movement / reference to Lenz's law;

force will be upwards/resistive/counteracts the effect of gravitational force;

## Examiners report

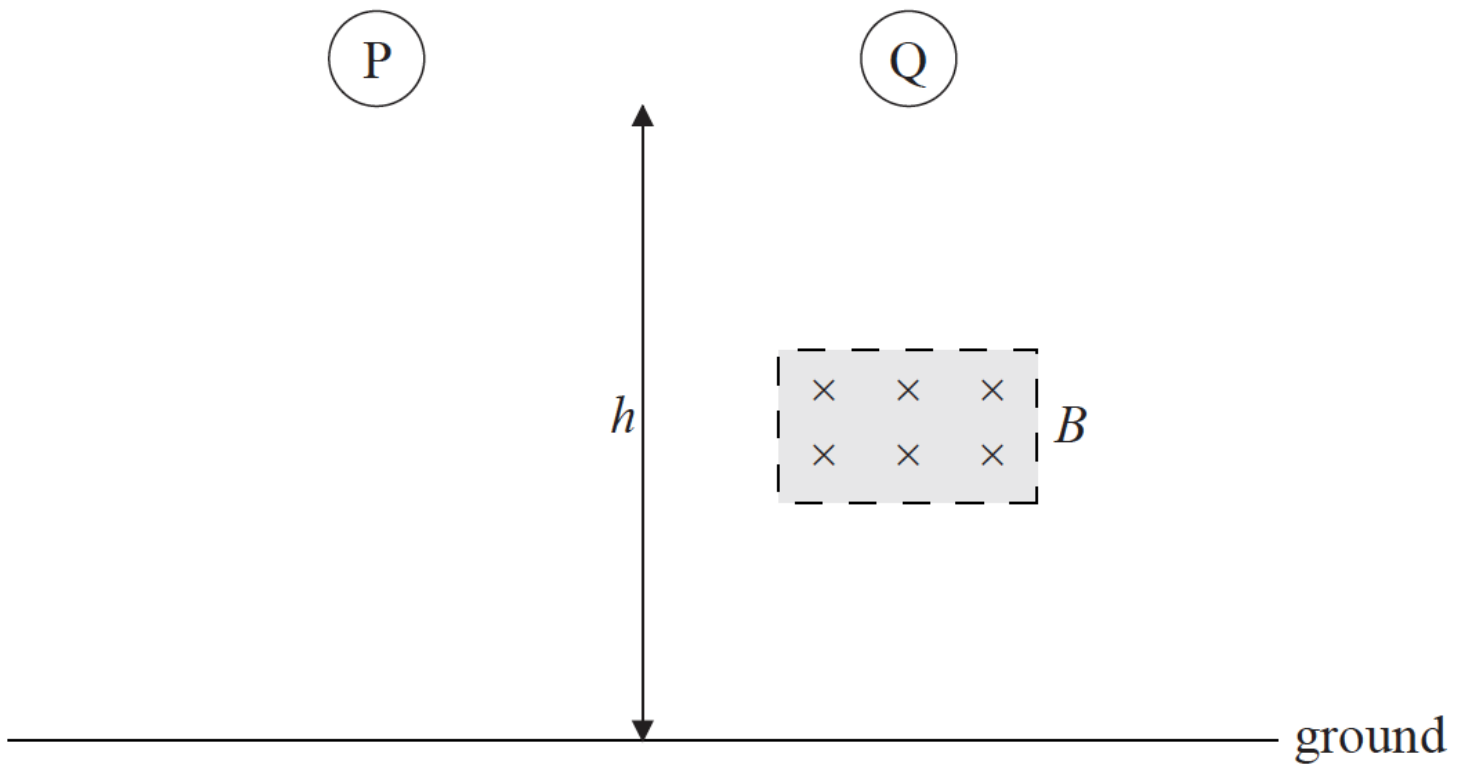
a. [N/A]

b. [N/A]

---

This question is about electromagnetic induction.

- a. State Lenz's law. [1]
- b. Two identical aluminium balls are dropped simultaneously from the same height. Ball P falls through a region with no magnetic field. Ball Q falls through a region of uniform horizontal magnetic flux density  $B$ . [4]



Explain why ball Q takes longer than ball P to reach the ground.

## Markscheme

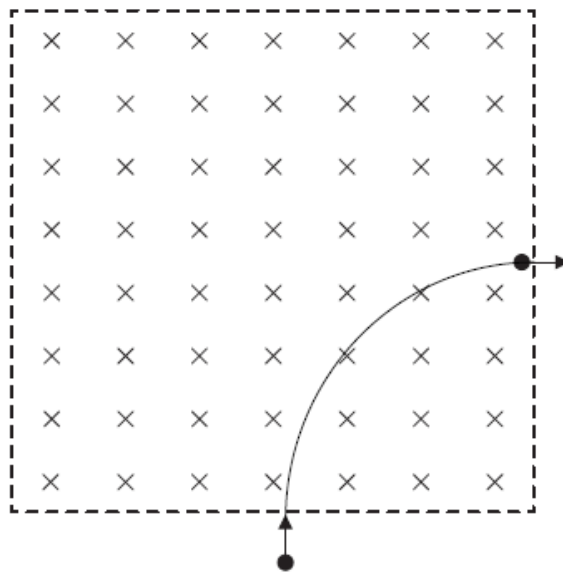
- a. induced emf/induced current acts so as to oppose the change causing it;
- b. ball Q enters/leaves magnetic field / experiences changing flux;
- so an emf/current is induced;
- this causes a magnetic field;
- which opposes the motion of / exerts an upward force on ball Q;
- or in terms of energy:*
- ball Q moves through a magnetic field / experiences changing flux;
- so an emf/current is induced;
- current causes dissipative heating due to resistance;
- some kinetic energy changes to thermal energy;

## Examiners report

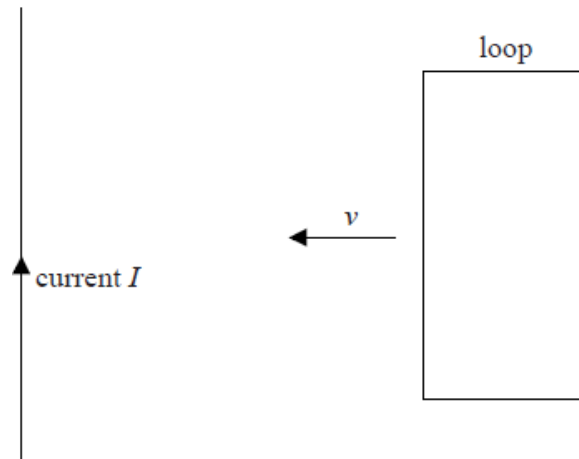
- a. [N/A]
- b. [N/A]

This question is about motion in a magnetic field.

An electron, that has been accelerated from rest by a potential difference of 250 V, enters a region of magnetic field of strength 0.12 T that is directed into the plane of the page.



- a. The electron's path while in the region of magnetic field is a quarter circle. Show that the time the electron spends in the region of magnetic field is  $7.5 \times 10^{-11}$  s. [1]
- c. A square loop of conducting wire is placed near a straight wire carrying a constant current  $I$ . The wire is in the same plane as the loop. [4]



The loop is made to move with constant speed  $v$  towards the wire.

- (i) Explain, by reference to Faraday's and Lenz's laws of electromagnetic induction, why work must be done on the loop.  
 (ii) Suggest what becomes of the work done on the loop.

## Markscheme

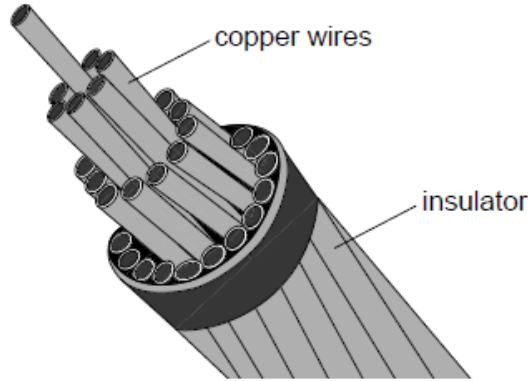
a.  $t = \frac{1}{4} \frac{2\pi \times 4.5 \times 10^{-4}}{9.4 \times 10^6}$ ;  
 $= 7.5 \times 10^{-11}$  s

- c. (i) the flux in the loop is changing and so (by Faraday's law) an emf will be induced in the loop;  
 (by Lenz's law) the induced current will be (counter-clockwise) and so there will be a magnetic force opposing the motion;  
 requiring work to be done on the loop;  
 (ii) it is dissipated as thermal energy (due to the resistance) in the loop / radiation;

## Examiners report

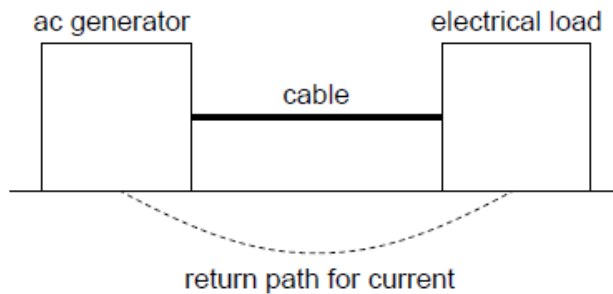
- a. [N/A]
- c. [N/A]

A cable consisting of many copper wires is used to transfer electrical energy from an alternating current (ac) generator to an electrical load. The copper wires are protected by an insulator.

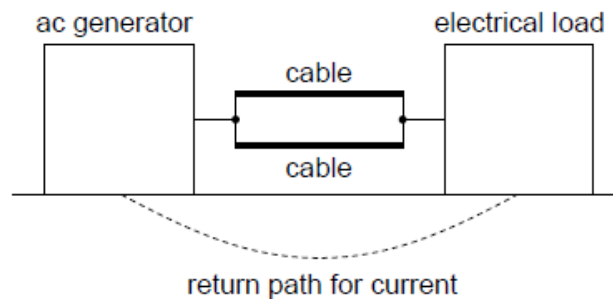


The cable consists of 32 copper wires each of length 35 km. Each wire has a resistance of  $64 \Omega$ . The cable is connected to the ac generator which has an output power of 110 MW when the peak potential difference is 150 kV. The resistivity of copper is  $1.7 \times 10^{-8} \Omega \text{ m}$ .

output power = 110 MW



To ensure that the power supply cannot be interrupted, two identical cables are connected in parallel.



The energy output of the ac generator is at a much lower voltage than the 150 kV used for transmission. A step-up transformer is used between the generator and the cables.

- b.i. Calculate the radius of each **wire**. [2]
- b.ii. Calculate the peak current in the **cable**. [1]
- b.iii. Determine the power dissipated in the cable per unit length. [3]
- c. Calculate the root mean square (rms) current in each cable. [1]
- d. The two cables in part (c) are suspended a constant distance apart. Explain how the magnetic forces acting between the cables vary during the course of one cycle of the alternating current (ac). [2]
- e.i. Suggest the advantage of using a step-up transformer in this way. [2]
- e.ii. The use of alternating current (ac) in a transformer gives rise to energy losses. State how eddy current loss is minimized in the transformer. [1]

## Markscheme

b.i.  $\text{area} = \frac{1.7 \times 10^{-3} \times 35 \times 10^3}{64} \llcorner = 9.3 \times 10^{-6} \text{ m}^2 \llcorner$

$\text{radius} = \llcorner \sqrt{\frac{9.3 \times 10^{-6}}{\pi}} \llcorner = 0.00172 \text{ m}$

b.ii.  $I_{\text{peak}} = \llcorner \frac{P_{\text{peak}}}{V_{\text{peak}}} \llcorner = 730 \llcorner \text{ A} \llcorner$

b.iii. resistance of cable identified as  $\llcorner \frac{64}{32} \llcorner = 2 \Omega$

$\frac{\text{power}}{35000}$  seen in solution

plausible answer calculated using  $\frac{2I^2}{35000}$   $\llcorner$ plausible if in range  $10 \text{ W m}^{-1}$  to  $150 \text{ W m}^{-1}$  when quoted answers in (b)(ii) used $\llcorner$   $31 \llcorner \text{ W m}^{-1} \llcorner$

Allow **[3]** for a solution where the resistance per unit metre is calculated using resistivity and answer to (a) (resistance per unit length of cable =  $5.7 \times 10^{-5} \text{ m}$ )

Award **[2 max]** if  $64 \Omega$  used for resistance (answer  $\times 32$ ).

An approach from  $\frac{V^2}{R}$  or VI using  $150 \text{ kV}$  is incorrect (award **[0]**), however allow this approach if the pd across the cable has been calculated (pd dropped across cable is  $1.47 \text{ kV}$ ).

c.  $\llcorner \frac{\text{response to (b)(ii)}}{2\sqrt{2}} \llcorner = 260 \llcorner \text{ A} \llcorner$

d. wires/cable attract whenever current is in same direction

charge flow/current direction in both wires is always same  $\llcorner$ but reverses every half cycle $\llcorner$

force varies from 0 to maximum

force is a maximum twice in each cycle

Award **[1 max]** if response suggests that there is repulsion between cables at any stage in cycle.

e.i. higher voltage gives lower current

$\llcorner$ energy losses depend on current $\llcorner$  hence thermal/heating/power losses reduced

e.ii. laminated core

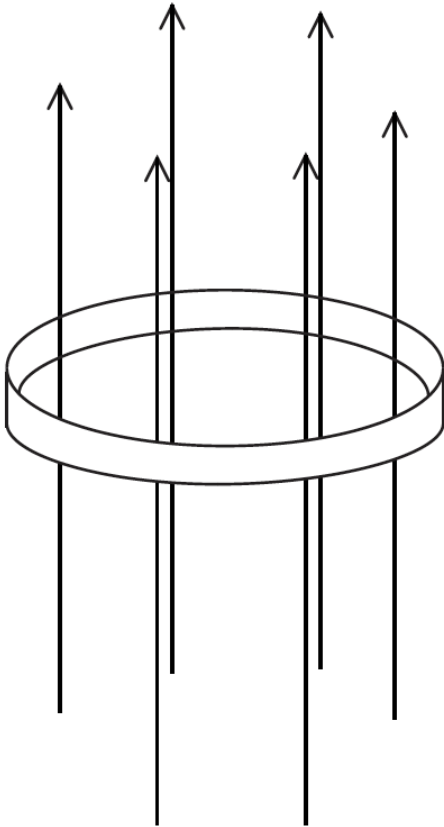
## Examiners report

- b.i. [N/A]
- b.ii. [N/A]
- b.iii. [N/A]
- c. [N/A]
- d. [N/A]
- e.i. [N/A]
- e.ii. [N/A]

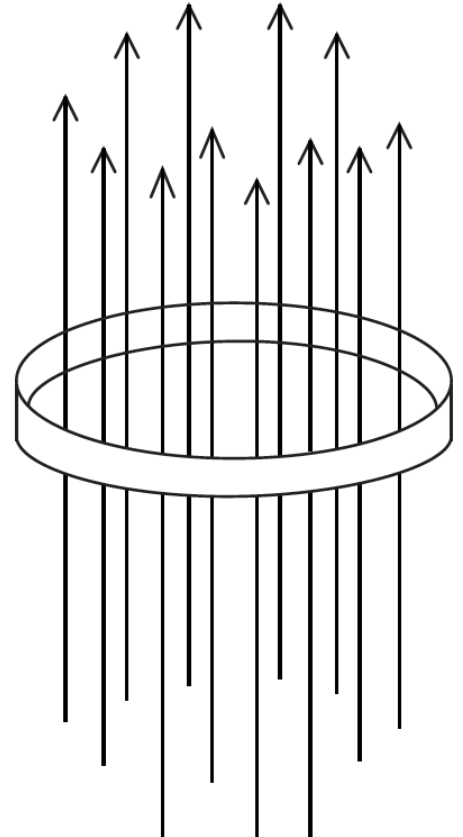
This question is about electromagnetic induction.

A metal ring is placed in a magnetic field which is directed upwards. The magnetic flux through the ring increases over a time interval.

Before



After



a. State and explain the direction of the current induced in the ring during this change.

[3]

b. The following data are available.

[3]

- Resistance of ring =  $3.0 \times 10^{-3} \Omega$
- Initial magnetic flux =  $1.2 \times 10^{-5} \text{Wb}$
- Final magnetic flux =  $2.4 \times 10^{-5} \text{Wb}$
- Time interval =  $2.0 \times 10^{-3} \text{s}$



Calculate the average current induced in the ring.

## Markscheme

- a. field caused by (induced) current must be downwards;  
to oppose the change that produced it;  
hence the current must be clockwise;

b.  $\varepsilon = \left( \frac{\Delta\Phi}{\Delta t} = \right) \frac{2.4 \times 10^{-5} - 1.2 \times 10^{-5}}{2.0 \times 10^{-3}}$  or  $6.0 \times 10^{-3}(\text{v})$ ;

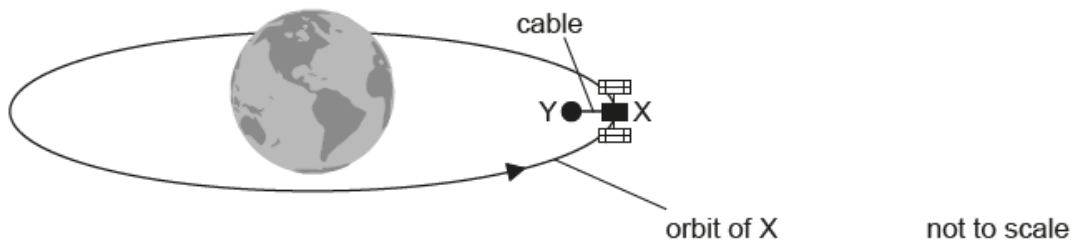
$$I = \left( \frac{\varepsilon}{R} = \frac{6.0 \times 10^{-3}}{3.0 \times 10^{-3}} = \right) 2.0 \text{ (A)};$$

Award **[2]** for a bald correct answer.

## Examiners report

- a. This was generally very well answered with candidates recognizing how Lenz's Law relates to the situation. The point that was most commonly missed was the direction of the field caused by the induced current.
- b. As with many of the calculation questions on this paper, this was very well answered.

There is a proposal to power a space satellite X as it orbits the Earth. In this model, X is connected by an electronically-conducting cable to another smaller satellite Y.



Satellite Y orbits closer to the centre of Earth than satellite X. Outline why

The cable acts as a spring. Satellite Y has a mass  $m$  of  $3.5 \times 10^2$  kg. Under certain circumstances, satellite Y will perform simple harmonic motion (SHM) with a period  $T$  of 5.2 s.

- a. Satellite X orbits 6600 km from the centre of the Earth. [2]

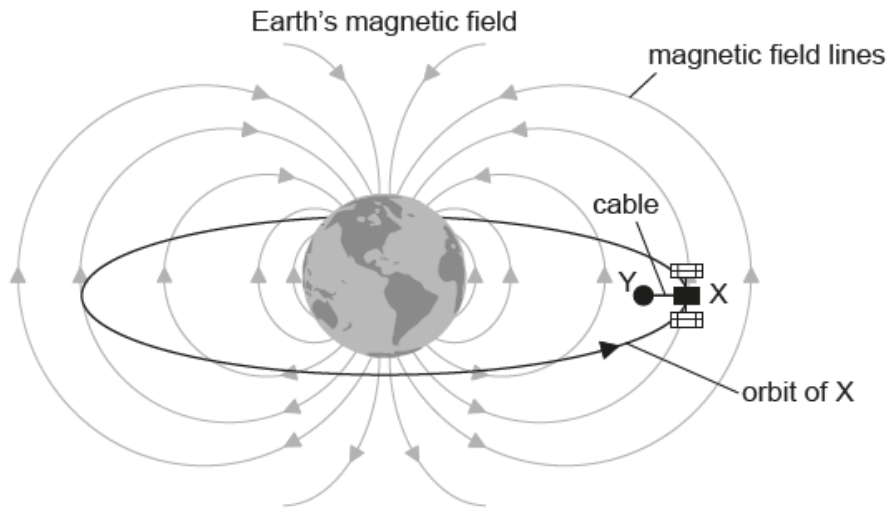
Mass of the Earth =  $6.0 \times 10^{24}$  kg

Show that the orbital speed of satellite X is about  $8 \text{ km s}^{-1}$ .

- b.i. the orbital times for X and Y are different. [1]

- b.ii. satellite Y requires a propulsion system. [2]

- c. The cable between the satellites cuts the magnetic field lines of the Earth at right angles. [3]



not to scale

Explain why satellite X becomes positively charged.

- d. Satellite X must release ions into the space between the satellites. Explain why the current in the cable will become zero unless there is a method for transferring charge from X to Y. [3]
- e. The magnetic field strength of the Earth is  $31 \mu\text{T}$  at the orbital radius of the satellites. The cable is 15 km in length. Calculate the emf induced in the cable. [2]
- f.i. Estimate the value of  $k$  in the following expression. [3]

$$T = 2\pi\sqrt{\frac{m}{k}}$$

Give an appropriate unit for your answer. Ignore the mass of the cable and any oscillation of satellite X.

- f.ii. Describe the energy changes in the satellite Y-cable system during one cycle of the oscillation. [2]

## Markscheme

a.  $\ll v = \sqrt{\frac{GM_E}{r}} \gg = \sqrt{\frac{6.67 \times 10^{-11} \times 6.0 \times 10^{24}}{6600 \times 10^3}}$

7800 «m s<sup>-1</sup>»

Full substitution required

Must see 2+ significant figures.

- b.i. Y has smaller orbit/orbital speed is greater so time period is less

Allow answer from appropriate equation

Allow converse argument for X

- b.ii. to stop Y from getting ahead

to remain stationary with respect to X

otherwise will add tension to cable/damage satellite/pull X out of its orbit

- c. cable is a conductor and contains electrons

electrons/charges experience a force when moving in a magnetic field

use of a suitable hand rule to show that satellite Y becomes negative «so X becomes positive»

### Alternative 2

cable is a conductor

so current will flow by induction flow when it moves through a B field

use of a suitable hand rule to show current to right so «X becomes positive»

*Marks should be awarded from either one alternative or the other.*

*Do not allow discussion of positive charges moving towards X*

d. electrons would build up at satellite Y/positive charge at X

preventing further charge flow

by electrostatic repulsion

unless a complete circuit exists

e. « $\mathcal{E} = Blv \Rightarrow 31 \times 10^{-6} \times 7990 \times 15000$

3600 «V»

*Allow 3700 «V» from  $v = 8000 \text{ m s}^{-1}$ .*

f.i. use of  $k = \frac{4\pi^2 m}{T^2} \Rightarrow \frac{4 \times \pi^2 \times 350}{5.2^2}$

510

$\text{N m}^{-1}$  **or**  $\text{kg s}^{-2}$

*Allow MP1 and MP2 for a bald correct answer*

*Allow 500*

*Allow N/m etc.*

f.ii.  $E_p$  in the cable/system transfers to  $E_k$  of Y

and back again twice in each cycle

*Exclusive use of gravitational potential energy negates MP1*

## Examiners report

a. [N/A]

b.i. [N/A]

b.ii. [N/A]

c. [N/A]

d. [N/A]

e. [N/A]

f.i. [N/A]

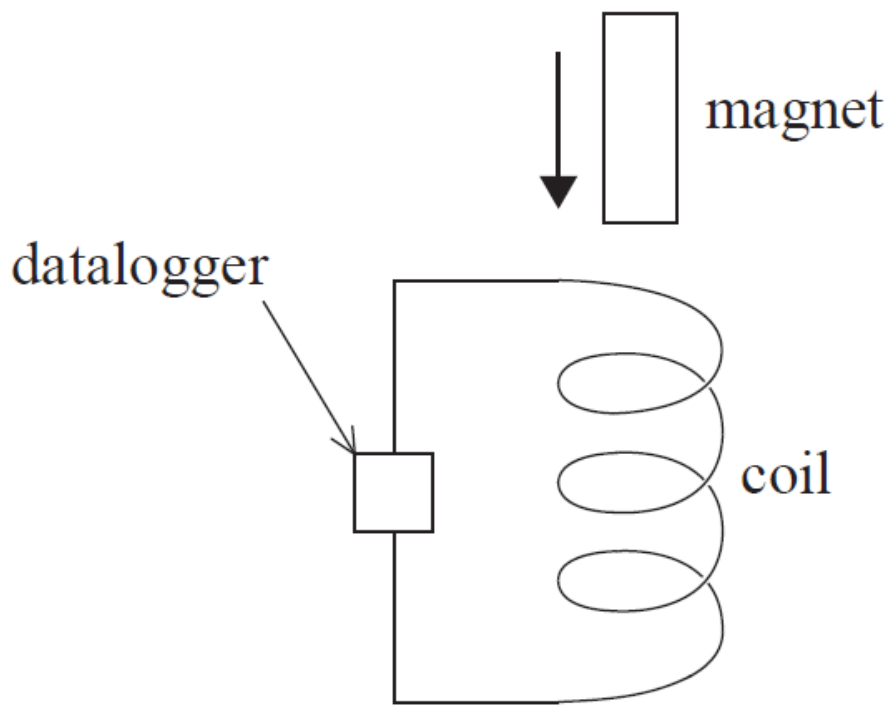
f.ii. [N/A]

This question is in **two** parts. **Part 1** is about electromagnetic induction. **Part 2** is about nuclear fusion.

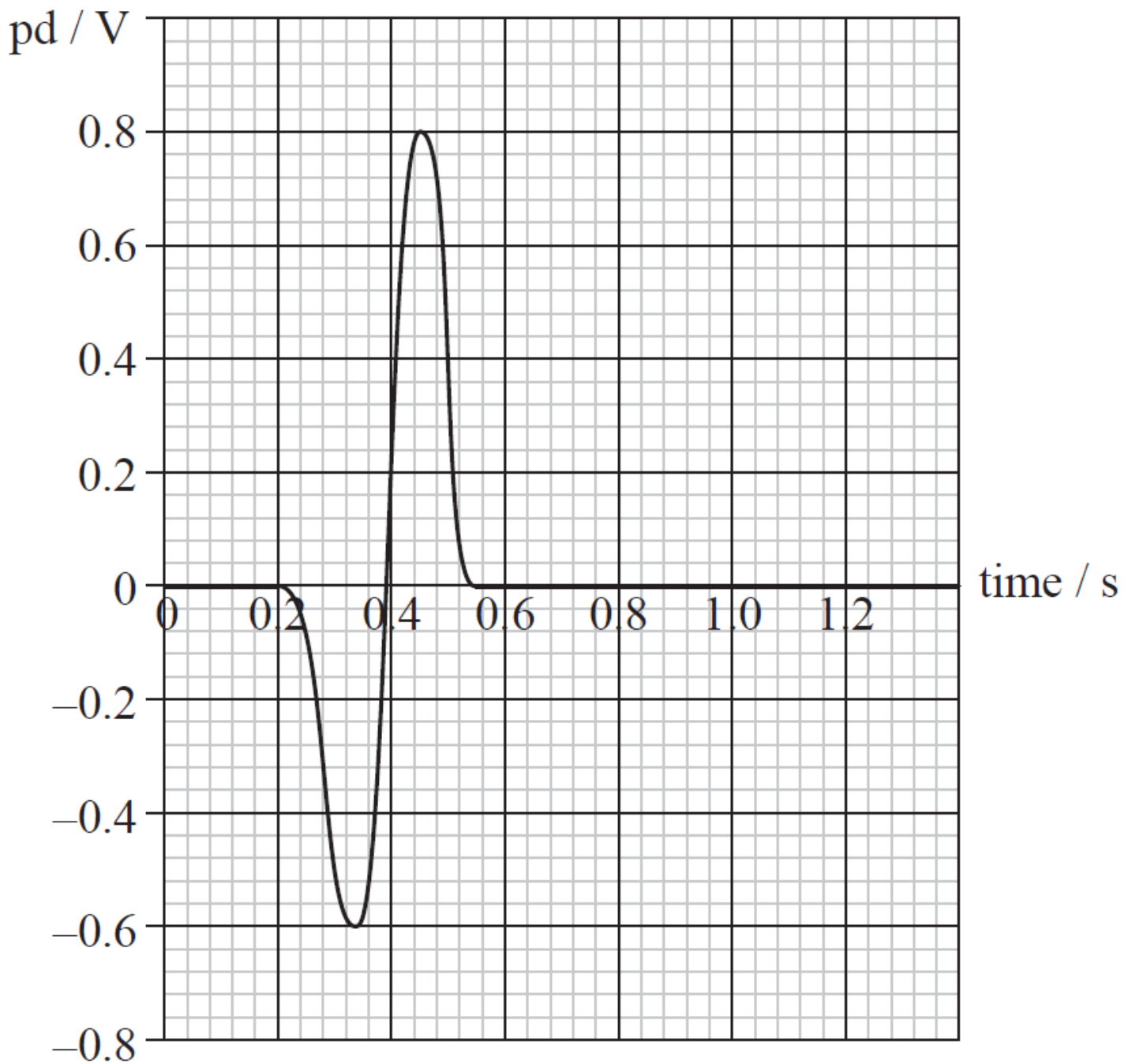
### Part 1 Electromagnetic induction

a. A bar magnet falls vertically from rest through a coil of wire. The potential difference (pd) across the coil is recorded by a datalogger.

[6]



The graph shows the variation with time of the pd across the coil.



(i) Explain, with reference to Faraday's and Lenz's laws, the shape of the graph.

(ii) The coil has 1500 turns. Calculate the magnitude of the maximum rate of change of magnetic flux.

b. The magnet is now suspended from a spring. The magnet is displaced vertically and starts to oscillate in and out of the coil. A sinusoidal alternating current of rms value 280 nA is induced in the coil. [5]

(i) State in words how the rms value of the alternating current relates to a direct current of 280 nA.

(ii) The coil has a resistance of  $1.5\text{M}\Omega$ . Calculate the peak voltage across the coil.

(iii) Explain what effect the generation of the current has on the oscillation of the magnet.

## Markscheme

a. (i) rate of change of flux (linkage) leads to induced emf (Faraday);

direction of emf tends to oppose the change (Lenz);

thus emf in one direction as magnet enters and in the opposite direction as it leaves coil;

magnet going faster so second peak larger;

magnet going faster so width of second peak is less;

(ii) attempted use of  $\varepsilon = -N \frac{\Delta\phi}{\Delta t}$ ;

recognition that the maximum pd is 0.8 (V);

$\left( \frac{\Delta\phi}{\Delta t} = -\frac{0.8}{1500} = - \right) 5.3 \times 10^{-4} \text{ (Wbs}^{-1}\text{)}$ ;

b. (i) the value of the direct current (or voltage) that dissipates same power (in a resistor);

*Do not allow  $\frac{I_0}{\sqrt{2}}$  etc.*

(ii)  $I_0=396$  (mA);

$V_0=I_0R=0.59$  (V);

(iii) damps oscillation / OWTTE;

dissipation of energy in coil/magnet;

## Examiners report

a. (i) This was generally poorly answered, with candidates often failing to refer to Faraday's and Lenz's laws or the specifics of the graph.

(ii) Many candidates used the correct value for the potential difference but were unsure of the meaning of rate of change of magnetic flux; it was commonly believed that this was simply  $\phi$  which left candidates searching for a time value.

b. (i) The definition of the rms current in terms of the equivalent direct current was very poorly known and many simply said that it was the peak value divided by root 2.

(ii) Few managed to do this well with the most common (incorrect) answer being 0.42V.

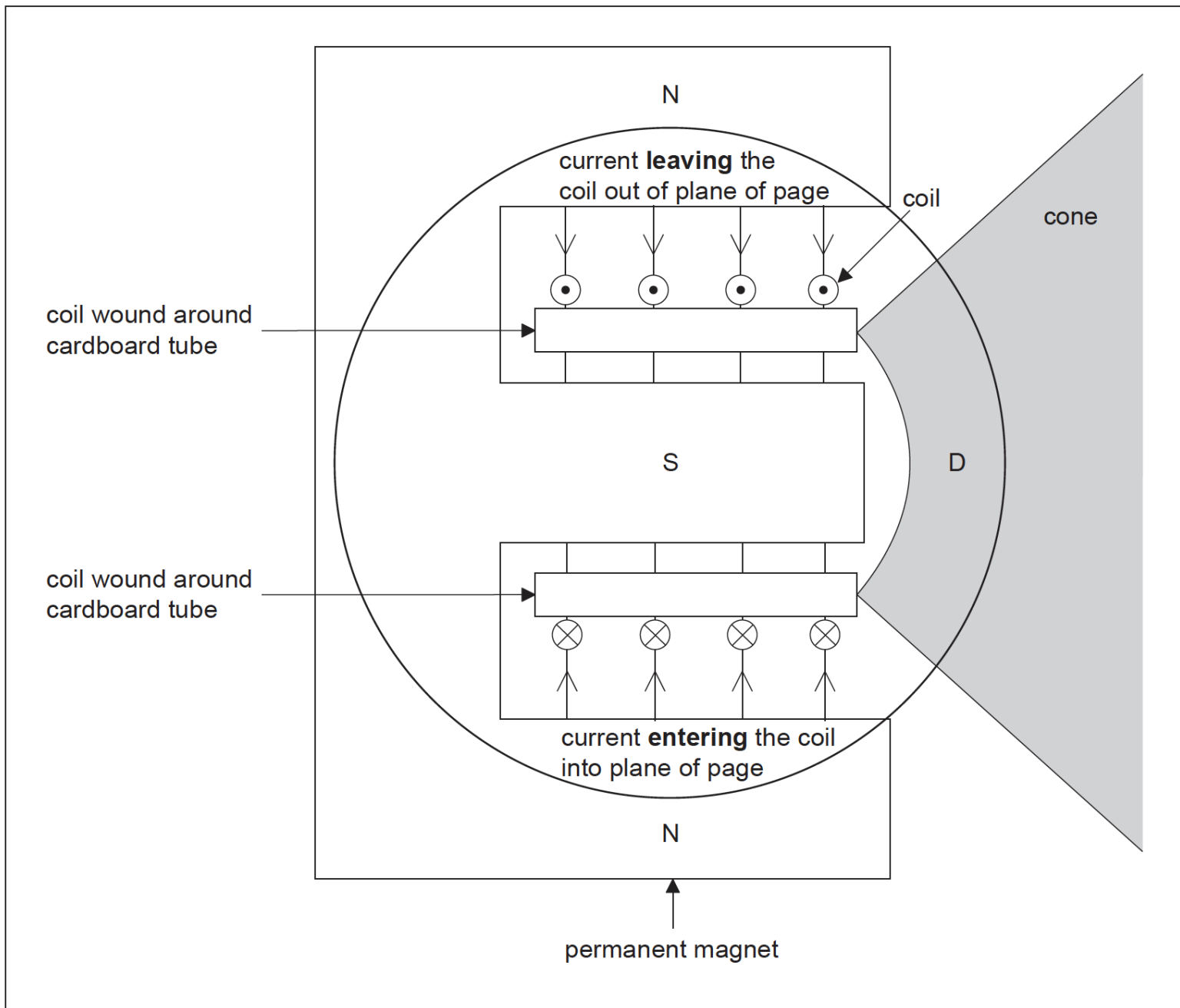
(iii) Although many hinted at damping, few candidates overtly mentioned it or related it to the dissipation of energy in the coil.

---

This question is in two parts. **Part 1** is about the electrical and magnetic characteristics of a loudspeaker. **Part 2** is about vibrations and waves.

### **Part 1** Electrical and magnetic characteristics of a loudspeaker

The diagram shows the main features of a loudspeaker L. A current-carrying coil is positioned within the magnetic field provided by a permanent magnet. The diagram also shows the directions of the magnetic field and of the current in the coil at a particular instant. The dust cap D prevents dust from blocking the gap between the cardboard tube and the south pole of the magnet.



The coil consists of 150 turns, each of average diameter 2.5 cm. The magnetic field of the permanent magnet has strength 0.40 mT. The peak current in the coil is 0.45 mA.

- Identify, **on the diagram**, the direction of the force on the coil with the current directions shown. [2]
- Calculate the maximum magnetic force acting on the coil. [3]
- Explain, with reference to electromagnetic induction, the effect of the motion of the coil on the current. [3]

## Markscheme

- force in correct location on diagram, *ie* arrow on coil;

force direction to the right;

*Award [1 max] if any other forces drawn.*

b.  $L = (2\pi rN) = 2 \times \pi \times 1.25 \times 10^{-2} \times 150 = (11.8) \text{ m};$

$F = (BIL) = 0.40 \times 10^{-3} \times 0.45 \times 10^{-3} \times 11.8;$

$= 2.1 \times 10^{-6} \text{ N} / 2.1 \mu\text{N}$

d. (as the coil moves the) conductor cuts the magnetic field / there is a change in flux linkage;

induces an emf across the coil / a current through the coil;

opposes the driving potential difference;

reduces the (net) current;

## Examiners report

a. [N/A]

b. [N/A]

d. [N/A]

This question is about the emf induced in a coil.

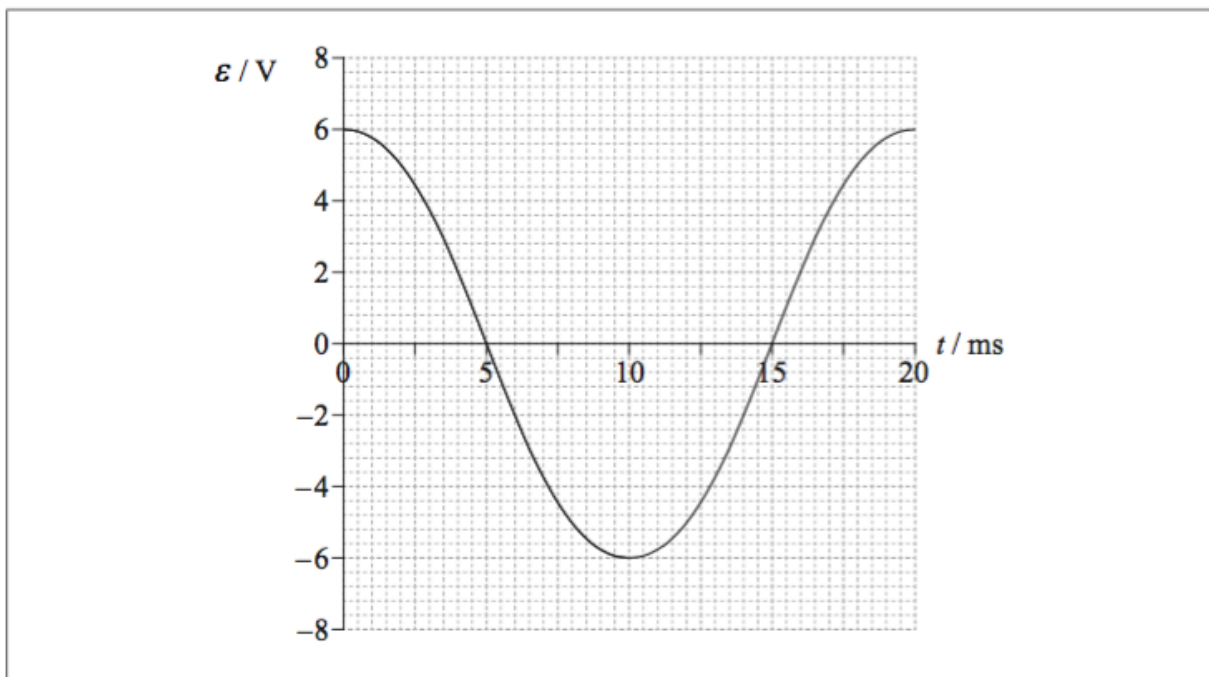
a. Define *magnetic flux*.

[2]

b. A coil is rotated at constant speed in a region of uniform magnetic field.

[3]

The graph shows the variation with time  $t$  of the emf  $\varepsilon$  induced in the coil for one cycle of rotation.



(i) On the graph label, with the letter T, a time at which the flux linkage in the coil is a maximum.

(ii) Use the graph to determine the rate of change of flux at  $t=4.0$ ms. Explain your answer.

(iii) Calculate the root mean square value of the induced emf.



# Markscheme

- a. the product of (the magnitude of) the normal component of magnetic field strength;  
and area through which it passes/with which it is associated;

**or**

$\phi = BA \cos \theta$  ;  
all terms defined/shown on a diagram;

- b. (i) letter T clearly marked at 5.0ms **or** 15ms;

(ii)  $2.0\text{V/Wbs}^{-1}$ ;  
emf equals rate of change of flux; *{(clear statement or equation must be present to award this mark)}*  
*Use of slope to obtain answer is incorrect – this yields a value of 1.8.*

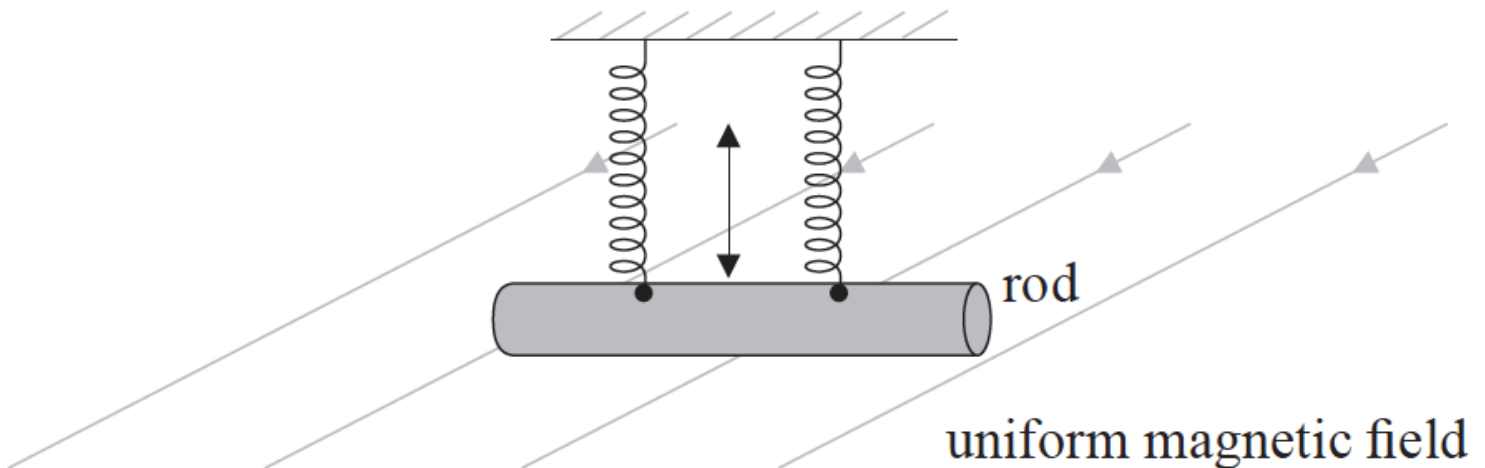
(iii) 4.2V;

# Examiners report

- a. Definitions of magnetic flux were mixed, ranging from complete and secure statements of the appropriate equation (with clear definition of the angle between the normal to the area and the magnetic field strength) to vague attempts that mentioned flux without a consideration of the direction between area and field direction.
- b. (i) Many candidates wrongly identified either 0 ms, 10 ms or 20 ms as the point at which the flux linkage was a maximum.
- (ii) Those that had a clear understanding of the relationship between emf and rate of change of flux moved quickly and unambiguously to the correct answer. Those who did not understand the physics evaluated the gradient at 4.0 ms and failed to gain credit.
- (iii) The calculation of rms induced emf was well done by the vast majority of candidates.

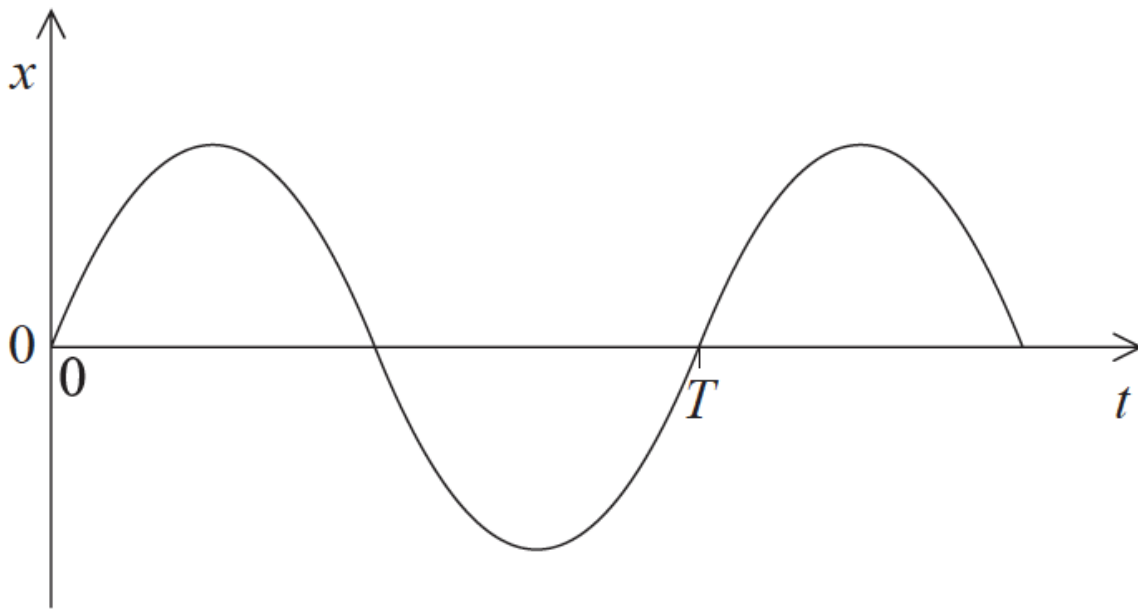
## Part 2 Electromagnetic induction

The diagram shows a horizontal metal rod suspended by two vertical insulated springs.



The rod moves vertically up and down with simple harmonic motion with a time period  $T$  at right angles to a uniform magnetic field.

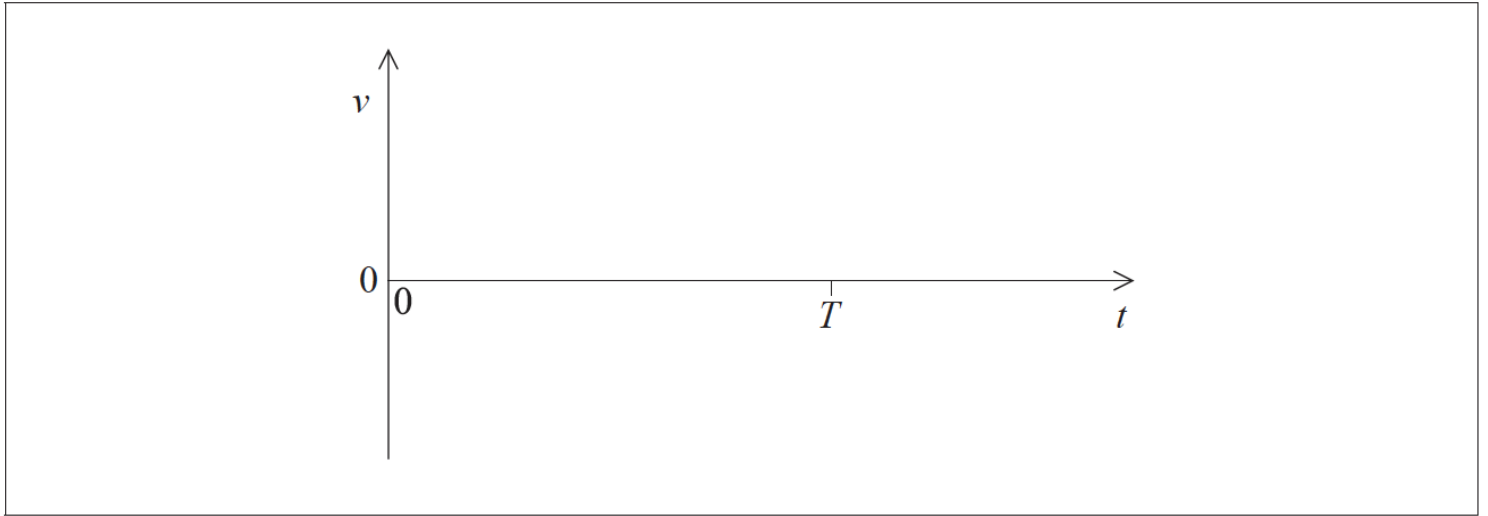
The diagram shows the variation with time  $t$  of the vertical displacement  $x$  of the rod.



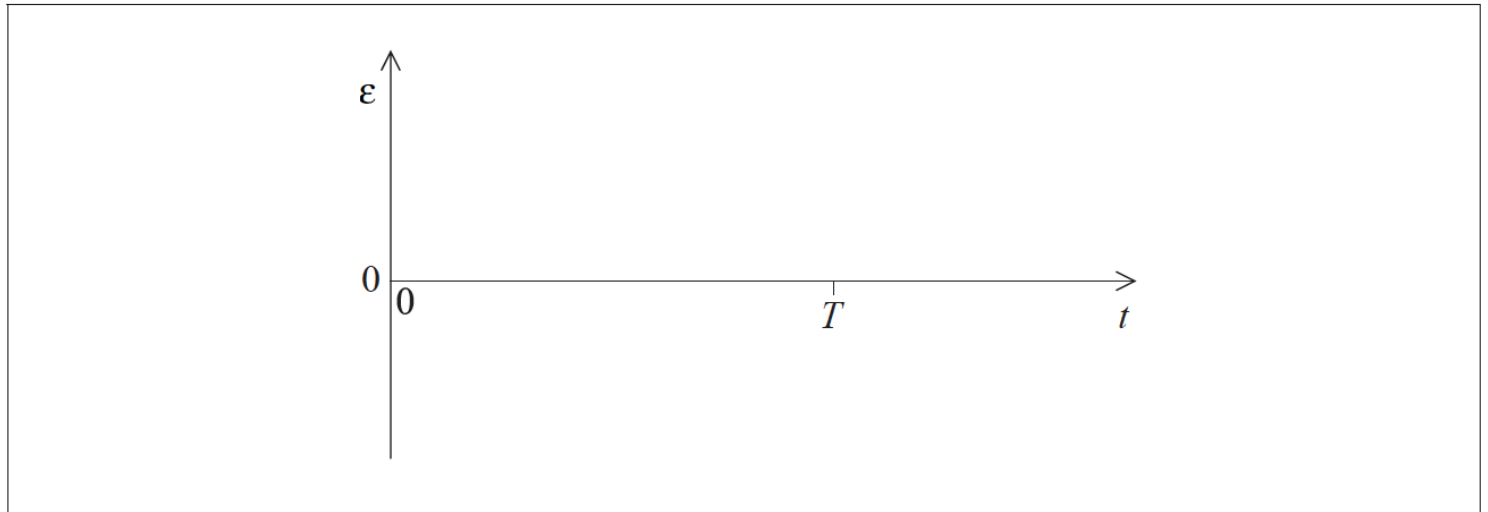
a. On the axes provided, draw a graph to show

[3]

(i) the variation with time  $t$  of the vertical velocity  $v$  of the rod.



(ii) the variation with time  $t$  of the emf generated between the ends of the rod.



- b. The length of the rod is 0.18 m and the magnitude of the magnetic field is  $58 \mu\text{T}$ . The frequency of the simple harmonic motion is 2.5 Hz. The amplitude of the motion is  $8.2 \times 10^{-2}$  m. [3]

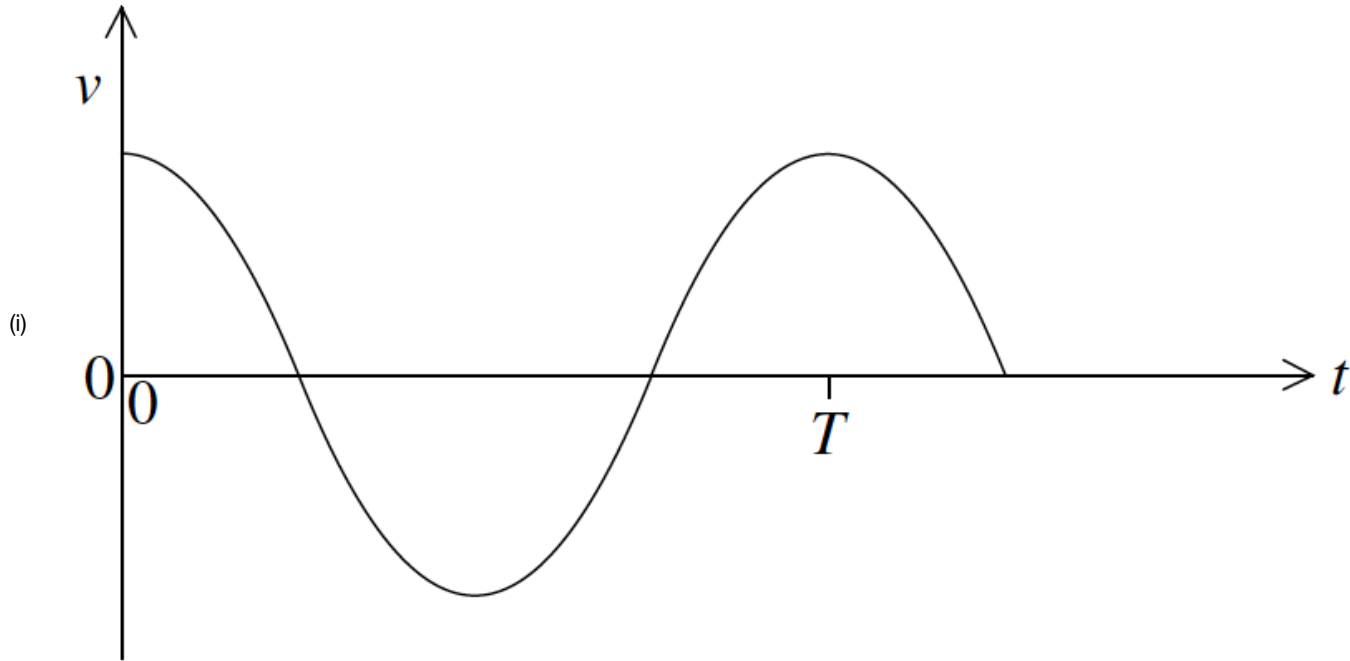
Determine the magnitude of the maximum emf  $\epsilon_{\text{max}}$  between the ends of the rod.

- c. The frequency of the motion is doubled without any change in the amplitude of the motion. [4]

State and explain the changes to the variation with time  $t$  of the emf  $\epsilon$  generated as a result of this change in frequency.

## Markscheme

a.



cosine wave same frequency as original;  
phase correct;

(ii) emf in phase or antiphase with answer to (a)(i);

- b. max speed  $= 8.2 \times 10^{-2} \times 2\pi \times 2.5 (= 1.29 \text{ms}^{-1})$ ;

$$\epsilon = 58 \times 10^{-6} \times 0.18 \times 1.29;$$

13.5  $\mu\text{V}$ ;

- c. frequency of the emf doubles / period halves;

because same change of flux in half the time / because frequency of emf must equal frequency of oscillation;

maximum emf doubles;

maximum speed doubles / flux changes at twice rate;

## Examiners report

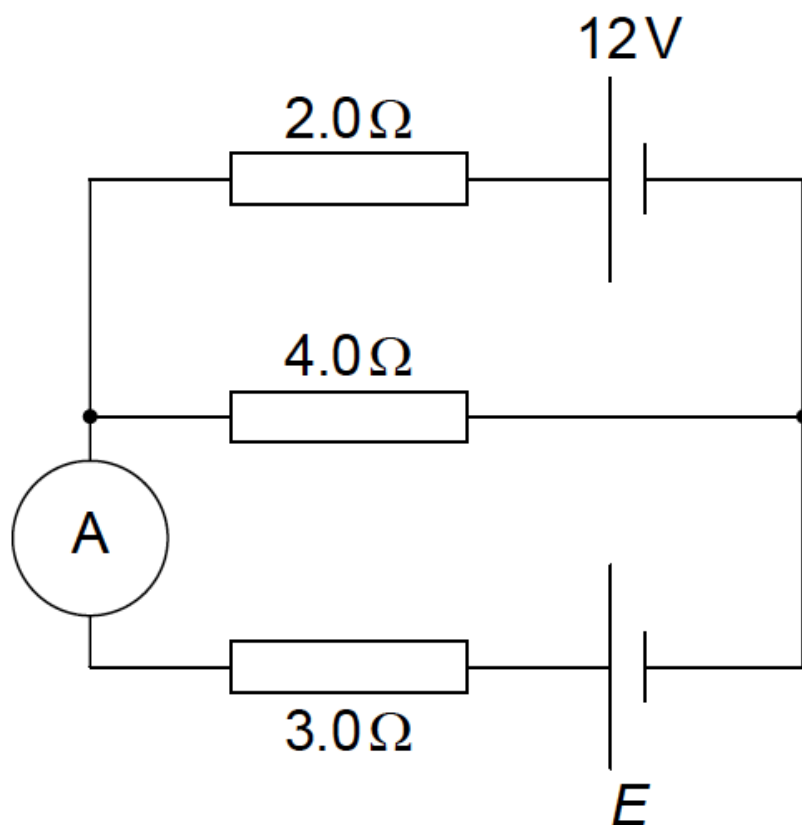
a. [N/A]

b. [N/A]

c. [N/A]

a. Two cells of negligible internal resistance are connected in a circuit.

[2]

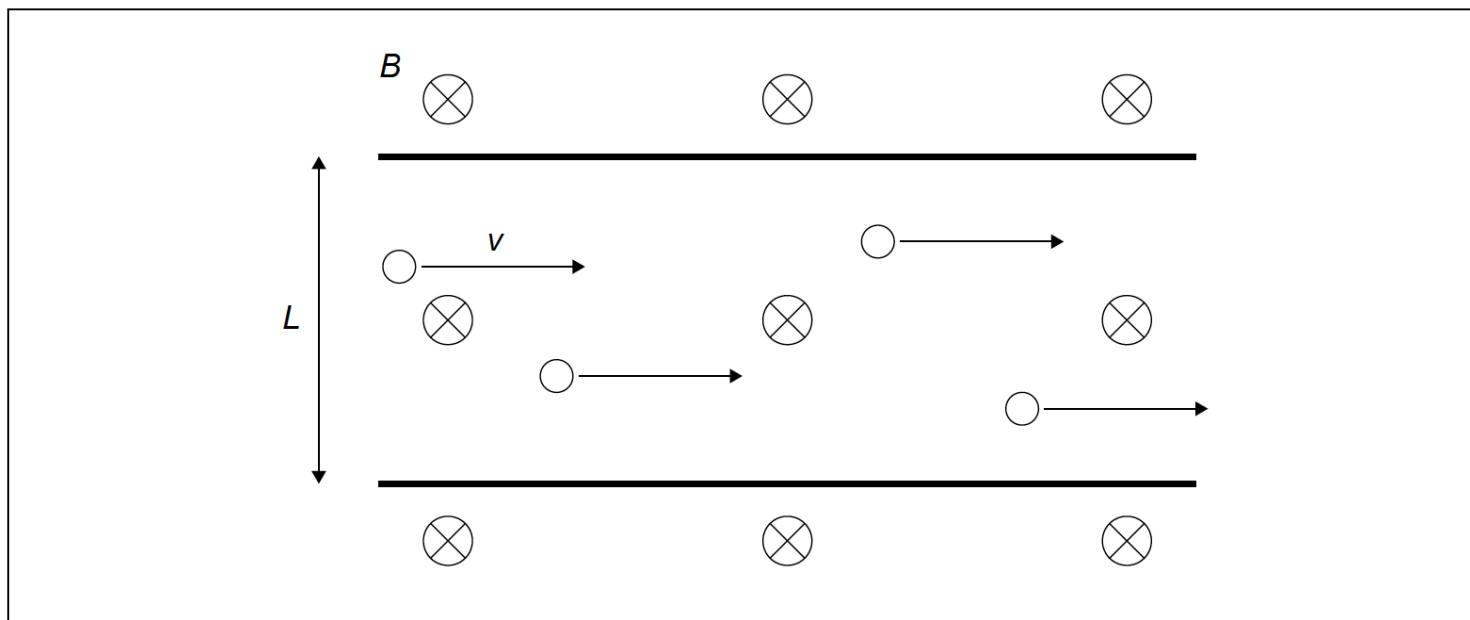


The top cell has electromotive force (emf) 12V. The emf of the lower cell is unknown. The ideal ammeter reads zero current.

Calculate the emf  $E$  of the lower cell.

b. The diagram shows charge carriers moving with speed  $v$  in a metallic conductor of width  $L$ . The conductor is exposed to a uniform magnetic field  $B$  that is directed into the page. [3]

field  $B$  that is directed into the page.



(i) Show that the potential difference  $V$  that is established across the conductor is given by  $V = vBL$ .

(ii) On the diagram, label the part of the conductor where negative charge accumulates.

# Markscheme

## a. ALTERNATIVE 1

correct application of Kirchhoff to at least one loop

$$E = 4.0 \times 2.0 = 8.0 \text{ V}$$

### FOR EXAMPLE

$12 = 2.0I_1 + 4.0I_2$  for top loop with loop anticlockwise

«but  $I_2 = I_1$  as  $I_3 = 0$ »

« $E = 8.0 \text{ V}$ »

### ALTERNATIVE 2

«recognition that situation is simple potential divider arrangement»

$$\text{pd across } 4\Omega \text{ resistor} = \frac{12 \times 4}{(2+4)}$$

$$= 8 \text{ V}$$

Award [0] for any answer that begins with the treatment as parallel resistors.

## b. (i)

### ALTERNATIVE 1

equating electric to magnetic force  $qE = qvB$

$$\text{substituting } E = \frac{V}{L}$$

«to get given result»

### ALTERNATIVE 2

$$V = \frac{\text{work done}}{Q} \text{ AND work done} = \text{force} \times \text{distance}$$

$$\text{work done} = qv = Bqv \times L$$

«to get given result»

### (ii)

some mark indicating lower surface of conductor

### OR

indication that **positive** charge accumulates at top of conductor

Do not allow negative or positive at top **and** bottom.

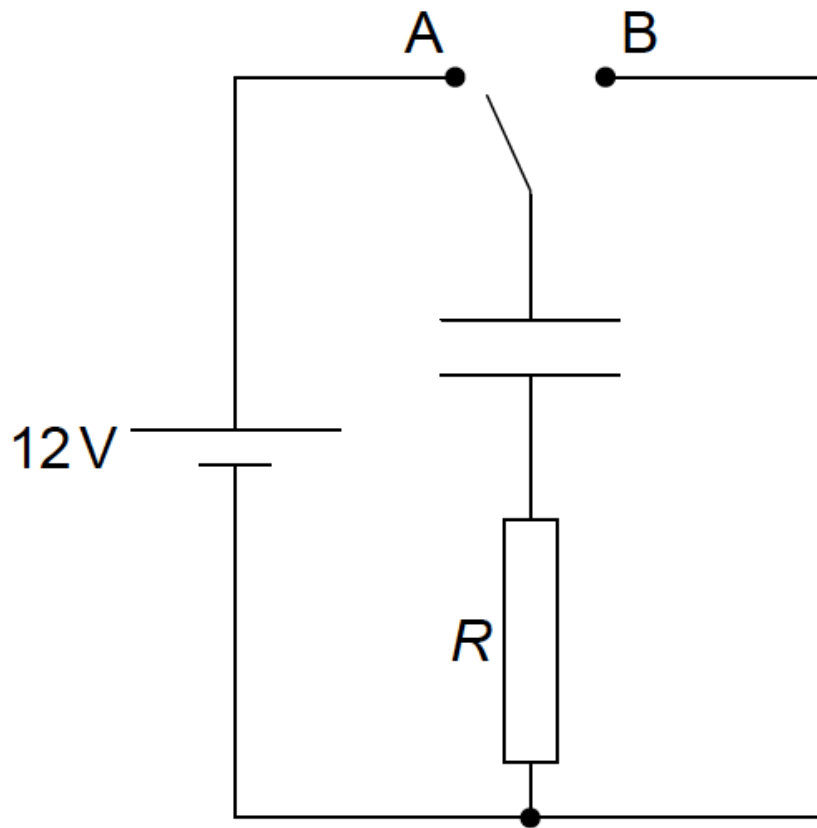
# Examiners report

a. [N/A]

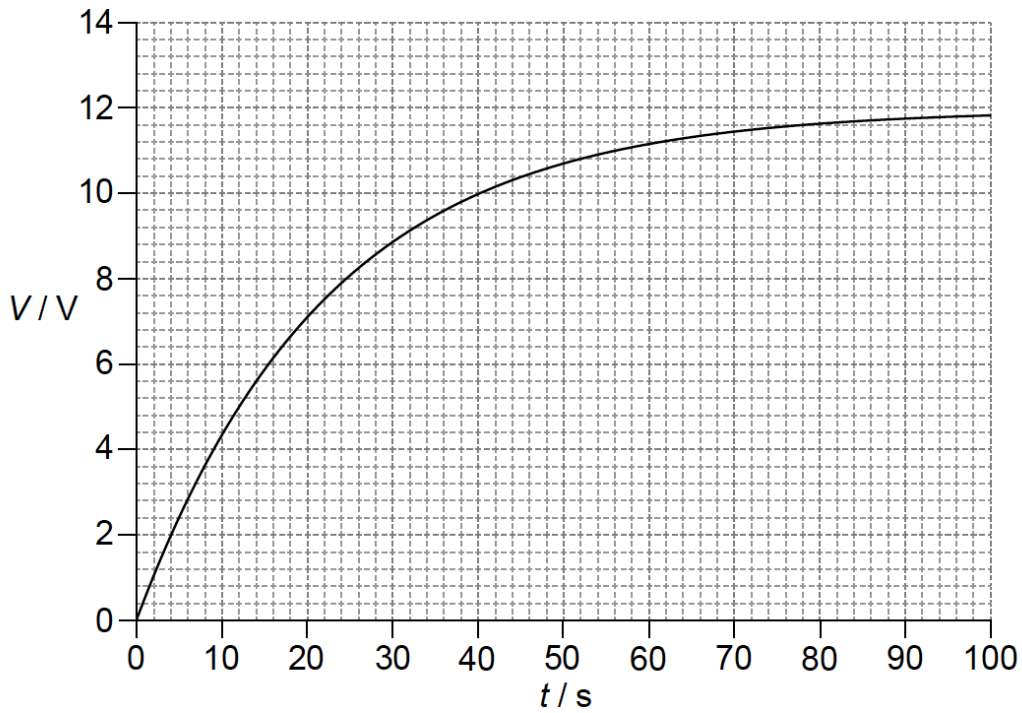
b. [N/A]

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An uncharged capacitor in a vacuum is connected to a cell of emf 12V and negligible internal resistance. A resistor of resistance  $R$  is also connected.



At  $t=0$  the switch is placed at position A. The graph shows the variation with time  $t$  of the voltage  $V$  across the capacitor. The capacitor has capacitance  $4.5\mu\text{F}$  in a vacuum.



a. On the axes, draw a graph to show the variation with time of the voltage across the resistor. [2]

b. (i) The time constant of this circuit is 22s. State what is meant by the time constant. [2]

(ii) Calculate the resistance  $R$ .

c. A dielectric material is now inserted between the plates of the fully charged capacitor. State the effect, if any, on

[2]

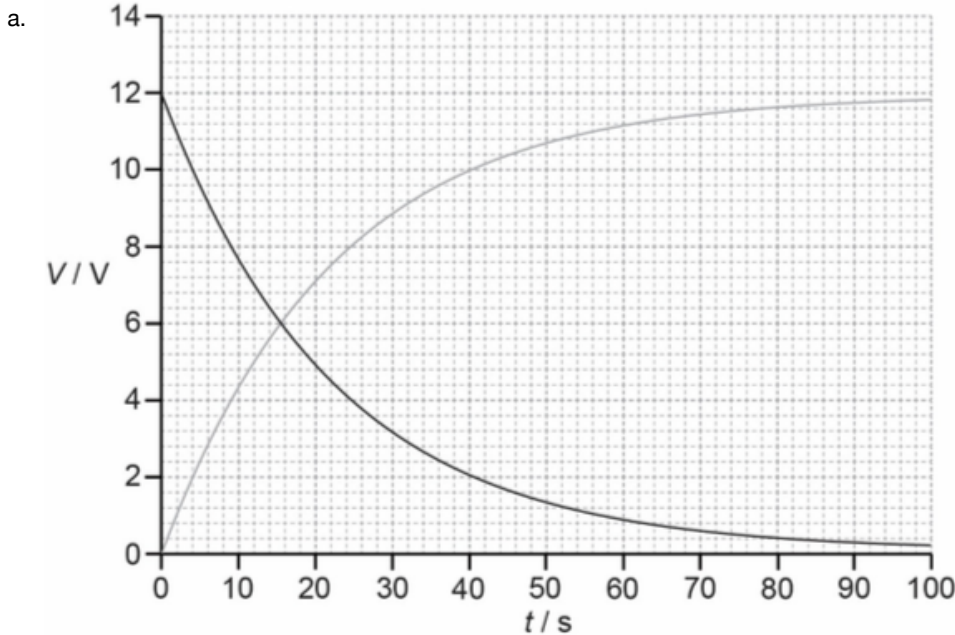
(i) the potential difference across the capacitor.

(ii) the charge on one of the capacitor plates.

d. (i) The permittivity of the dielectric material in (c) is twice that of a vacuum. Calculate the energy stored in the capacitor when it is fully charged. [3]

(ii) The switch in the circuit is now moved to position B and the fully charged capacitor discharges. Describe what happens to the energy in (d)(i).

## Markscheme



general shape starting at 12 V

crosses at 6 V

*Line must not touch time axis for MP2.*

*Allow tolerance of one square in 12 V (start) and 6 V (crossing).*

b. (i)

the time for the voltage/charge/current «in circuit» to drop to  $\frac{1}{e}$  **or** 37% of its initial value

«as the capacitor discharges»

**OR**

time for voltage/charge/current «in circuit» to increase to  $\left(1 - \frac{1}{e}\right)$  **or** 63% of its final value

«as the capacitor charges»

(ii)

$$R = \ll \frac{22}{4.5 \times 10^{-6}} = \gg 4.9 \times 10^6 \Omega$$

c. (i)

no change

**OR**

«remains at» 12 V

(ii)  
increases  
**OR**  
doubles

Allow “doubles” in the light of (d).

d. (i)

recognises that new capacitance is 9.0  $\mu\text{F}$

$$E = \ll \frac{1}{2} CV^2 = \frac{1}{2} \times 9.0 \times 10^{-6} \times 12^2 \gg = 0.65\text{mJ or } 6.5 \times 10^{-4}\text{J}$$

Allow 11.8 V (value on graph at  $t=100\text{s}$ ).

(ii)  
energy goes into the resistor/surroundings

**OR**  
«energy transferred» into thermal/internal energy form

Do not accept “dissipated” without location or form.

Do not allow “heat”.

## Examiners report

- a. [N/A]
  - b. [N/A]
  - c. [N/A]
  - d. [N/A]
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