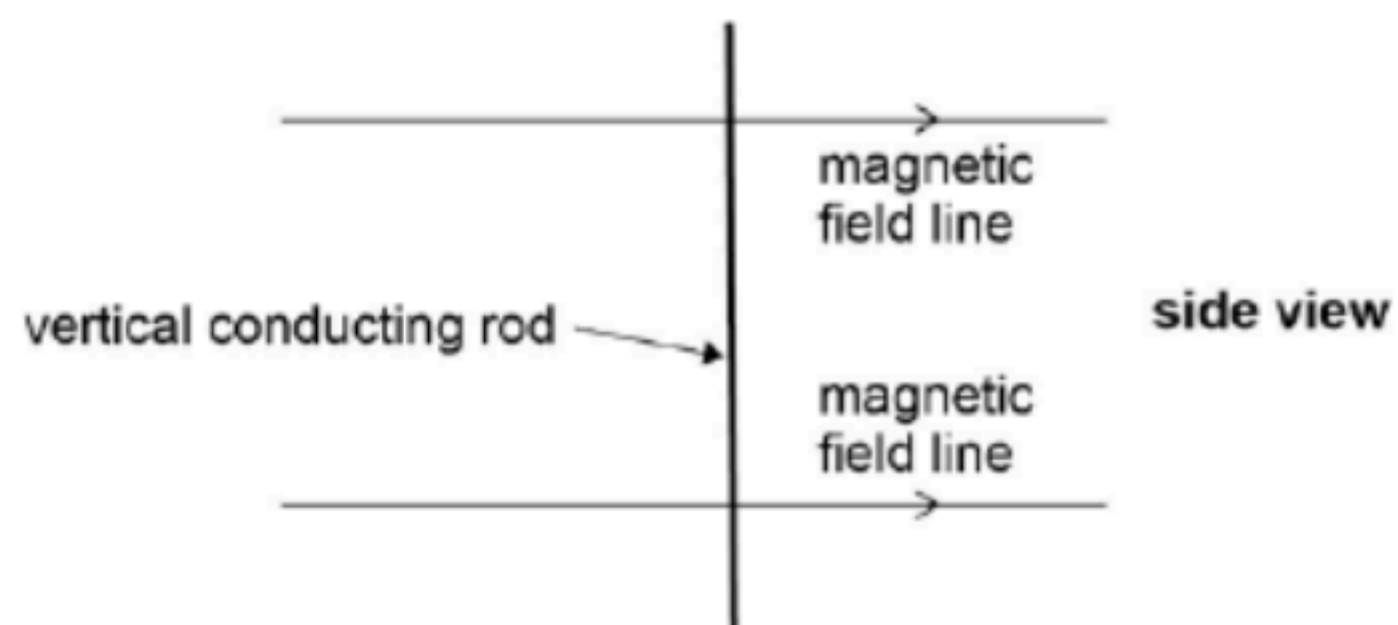


1

A vertical conducting rod of length l is moved at a constant velocity v through a uniform horizontal magnetic field of flux density B .



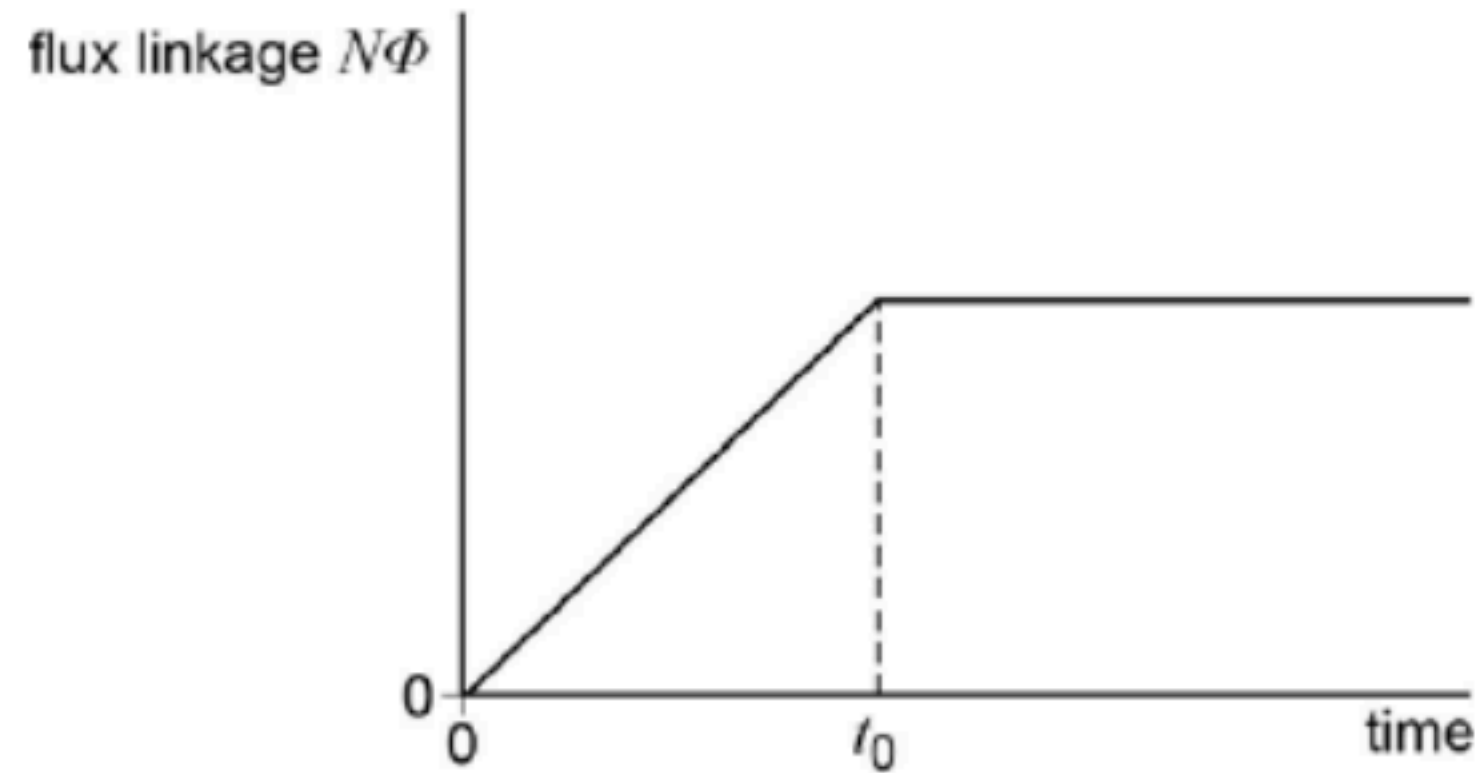
Which of the rows gives a correct expression for the induced emf between the ends of the rod for the stated direction of the motion of the rod?

	Direction of motion	Induced emf	
A	Vertical	$\frac{B}{lv}$	☐
B	Horizontal at right angles to the field	Blv	☐
C	Vertical	Blv	☐
D	Horizontal at right angles to the field	$\frac{B}{lv}$	☐

(Total 1 mark)

2

The graph shows how the flux linkage, $N\Phi$, through a coil changes when the coil is moved into a magnetic field.



The emf induced in the coil

- A** decreases then becomes zero after time t_0 .
- B** increases then becomes constant after time t_0 .
- C** is constant then becomes zero after time t_0 .
- D** is zero then increases after time t_0 .

☐☐☐☐

(Total 1 mark)

3

A train is travelling at 20 m s^{-1} along a horizontal track through a uniform magnetic field of flux density $4.0 \times 10^{-5} \text{ T}$ acting vertically downwards.

What is the emf induced between the ends of an axle 1.5 m long?

- A** $3.0 \times 10^{-6} \text{ V}$
- B** $5.3 \times 10^{-4} \text{ V}$
- C** $1.2 \times 10^{-3} \text{ V}$
- D** $7.5 \times 10^5 \text{ V}$

(Total 1 mark)

4

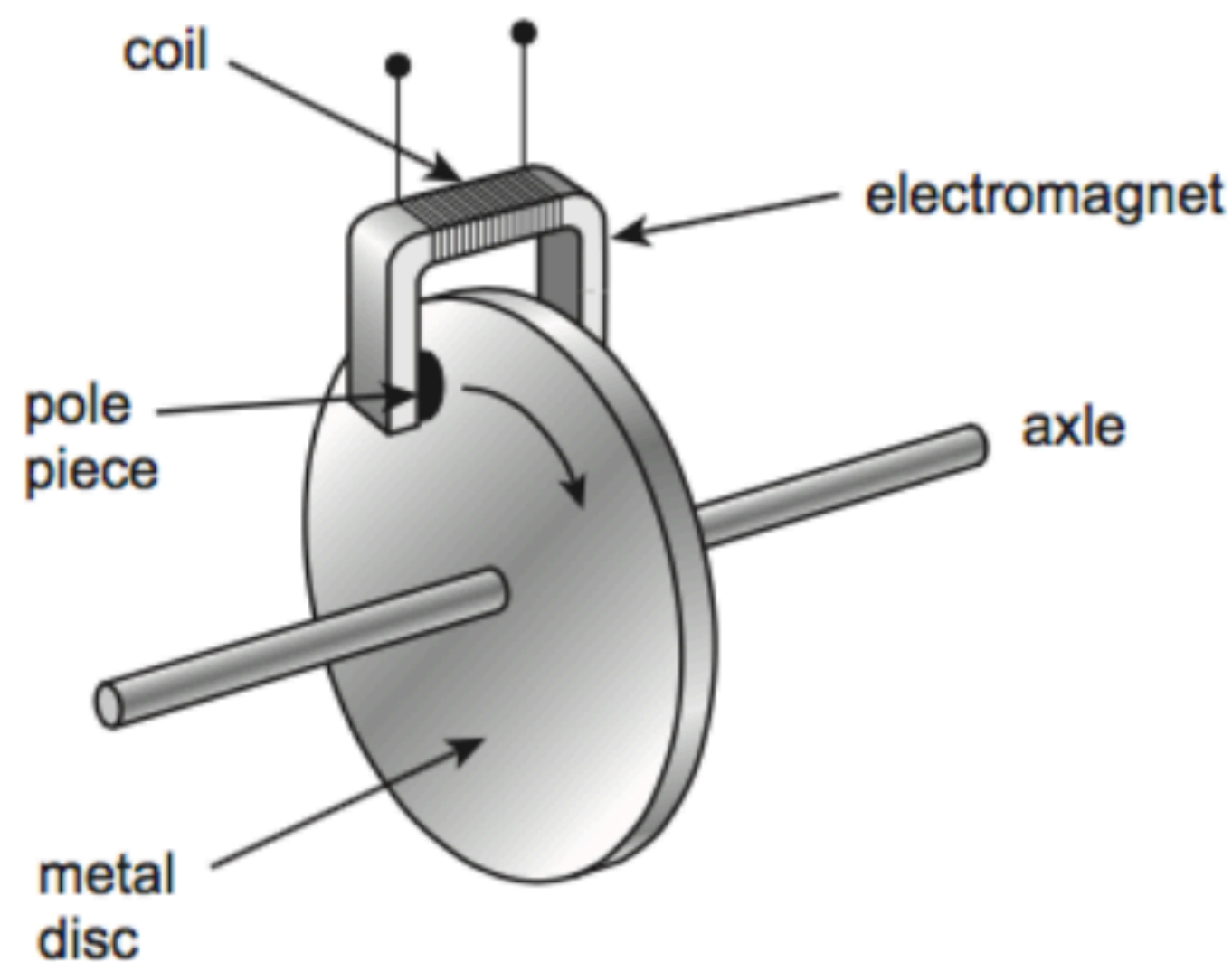
- (a) State, in words, the two laws of electromagnetic induction.

Law 1 _____

Law 2 _____

(3)

- (b) The diagram below illustrates the main components of one type of electromagnetic braking system. A metal disc is attached to the rotating axle of a vehicle. An electromagnet is mounted with its pole pieces placed either side of the rotating disc, but not touching it. When the brakes are applied, a direct current is passed through the coil of the electromagnet and the disc slows down.



- (i) Explain, using the laws of electromagnetic induction, how the device in the diagram acts as an electromagnetic brake.

(3)

- (ii) A conventional braking system has friction pads that are brought into contact with a moving metal surface when the vehicle is to be slowed down.
State **one** advantage and **one** disadvantage of an electromagnetic brake compared to a conventional brake.

Advantage _____

Disadvantage _____

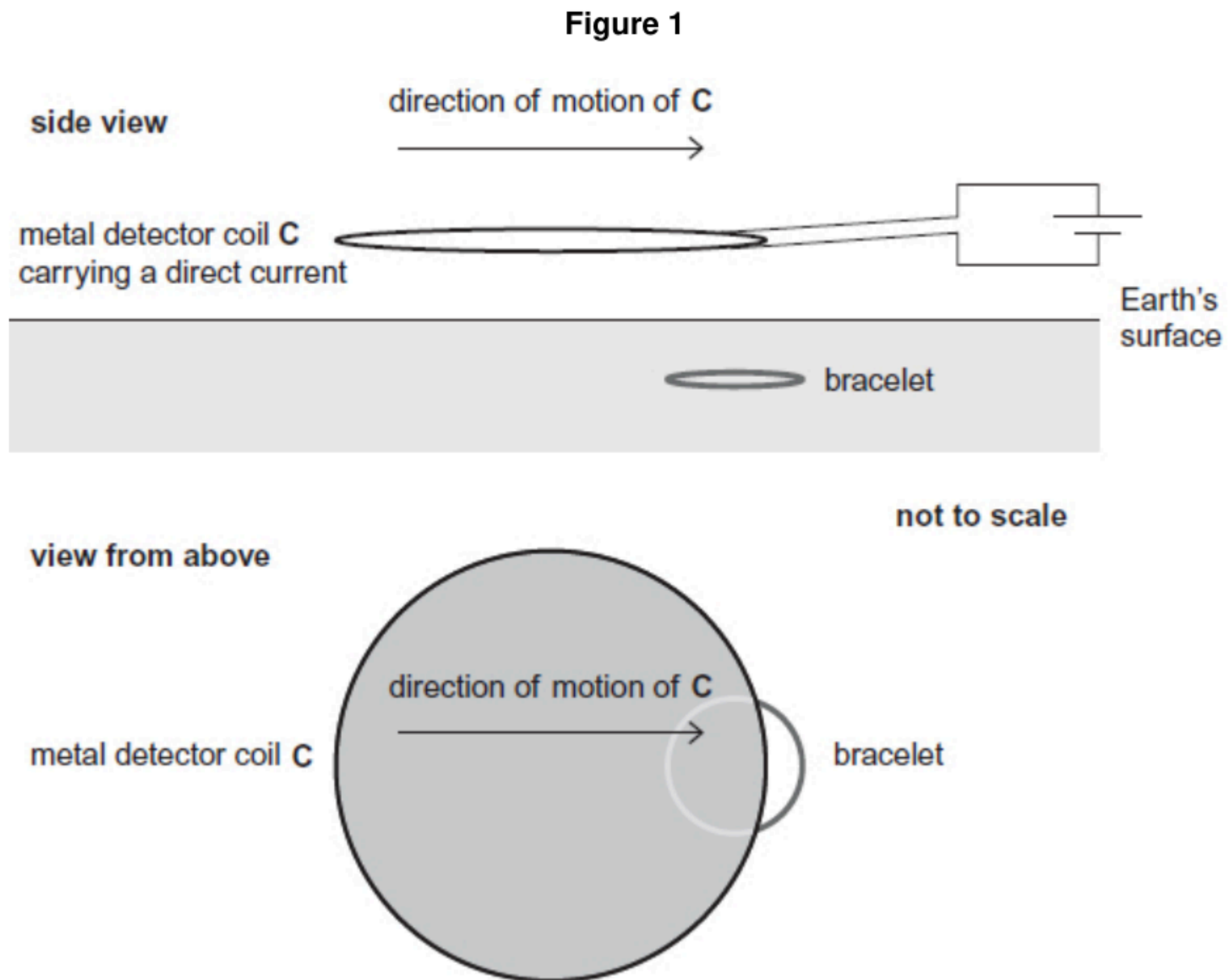
(2)

(Total 8 marks)

5

A metal detector is moved horizontally at a constant speed just above the Earth's surface to search for buried metal objects

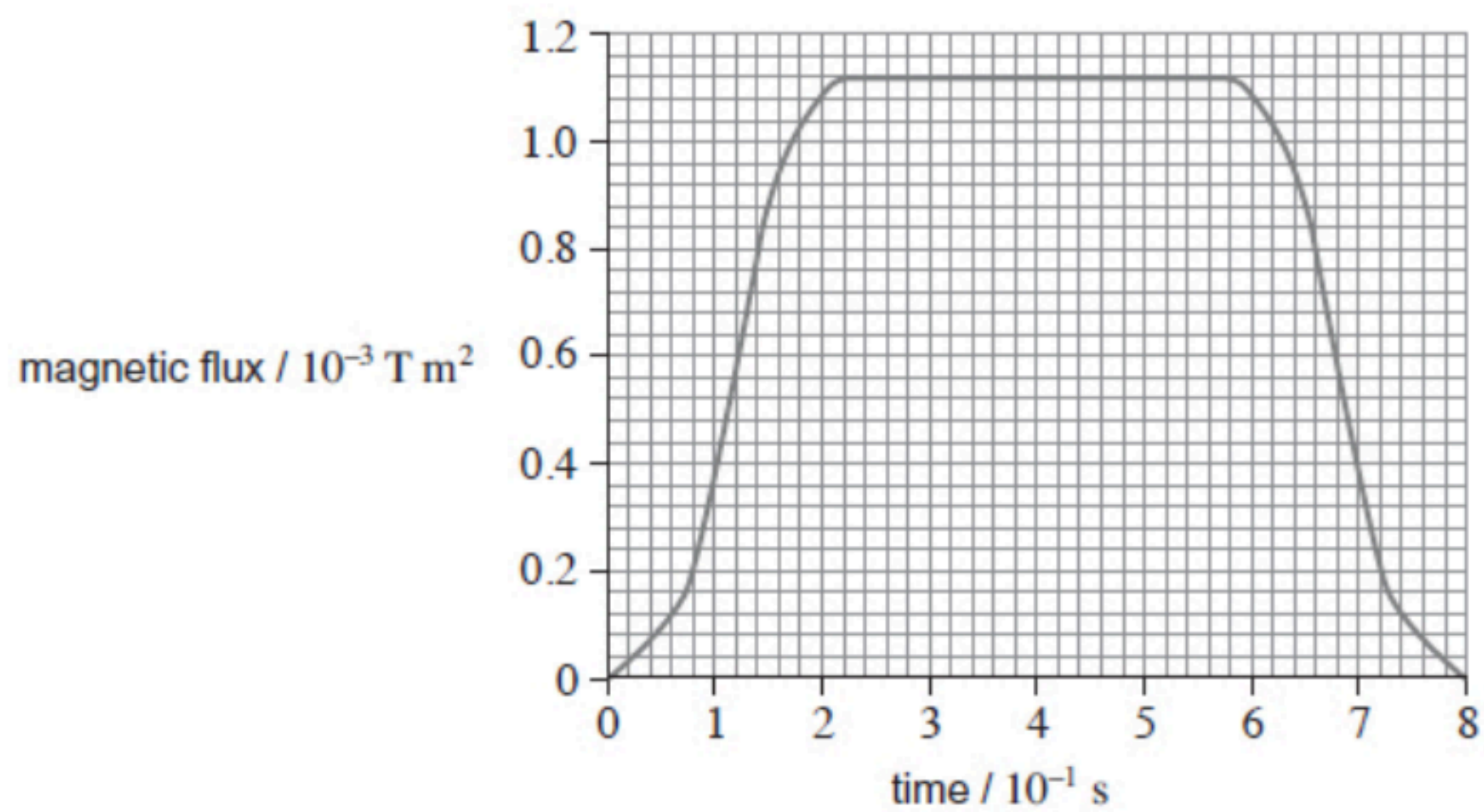
Figure 1 shows the coil **C** of a metal detector moving over a circular bracelet made from a single band of metal. The planes of the coil and the bracelet are both horizontal.



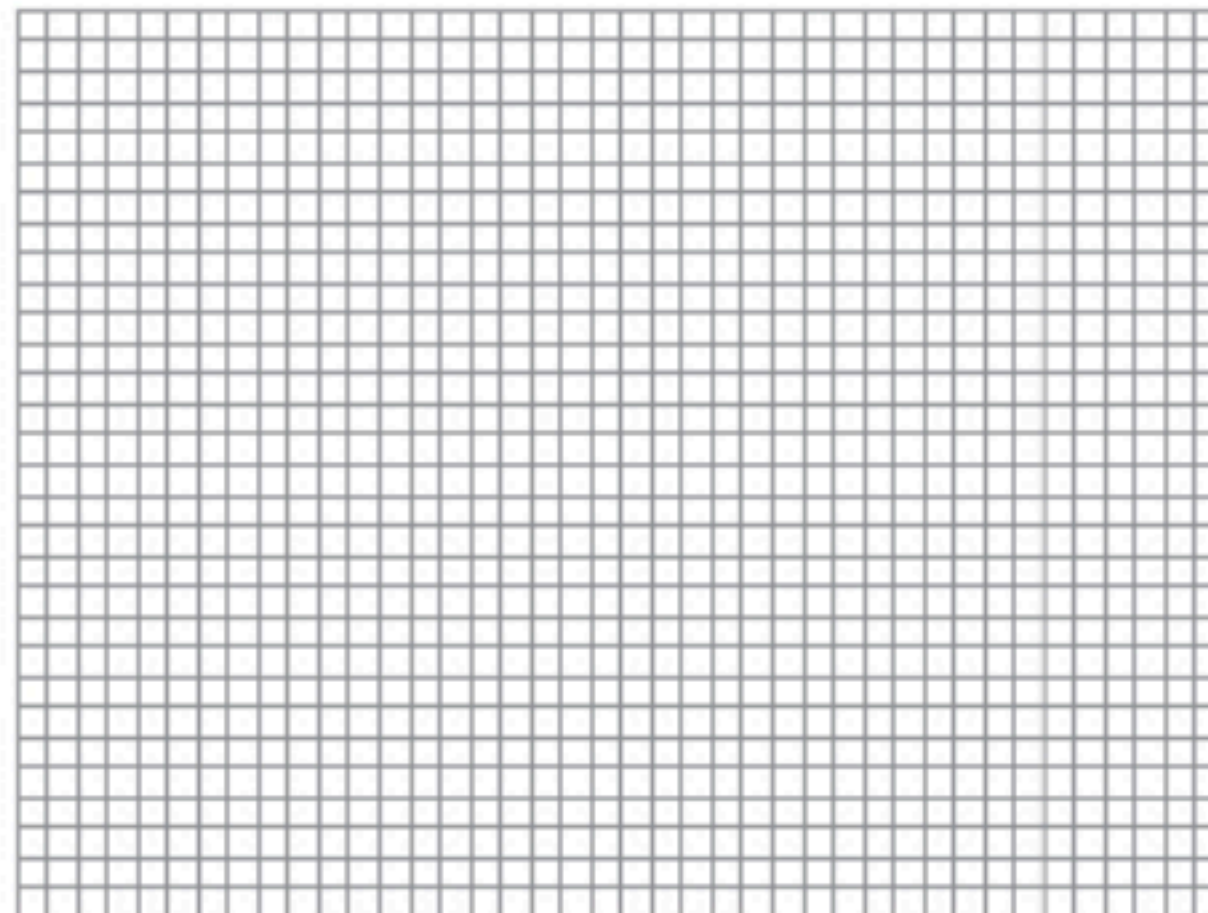
In this metal detector, **C** carries a direct current so that the magnetic flux produced by **C** does not vary. The bracelet is just below the surface, so the flux is perpendicular to the plane of the bracelet. The field is negligible outside the shaded region of **C**.

Figure 2 shows how the magnetic flux through the bracelet varies with time when **C** is moving at a constant velocity.

Figure 2



- (a) (i) Sketch a graph on the grid to show how the emf induced in the bracelet varies with time as **C** moves across the bracelet. Use the same scale on the time axis as in **Figure 2**.



- (ii) Use the laws of Faraday and Lenz to explain the shape of your graph.

(4)

- (b) The velocity at which **C** is moved is 0.28 m s^{-1} .

Show that the diameter of the bracelet is about 6 cm.

(1)

- (c) Determine the magnetic flux density of the field produced by **C** at the position of the bracelet.

magnetic flux density _____ T

(2)

- (d) Determine the maximum emf induced in the bracelet.

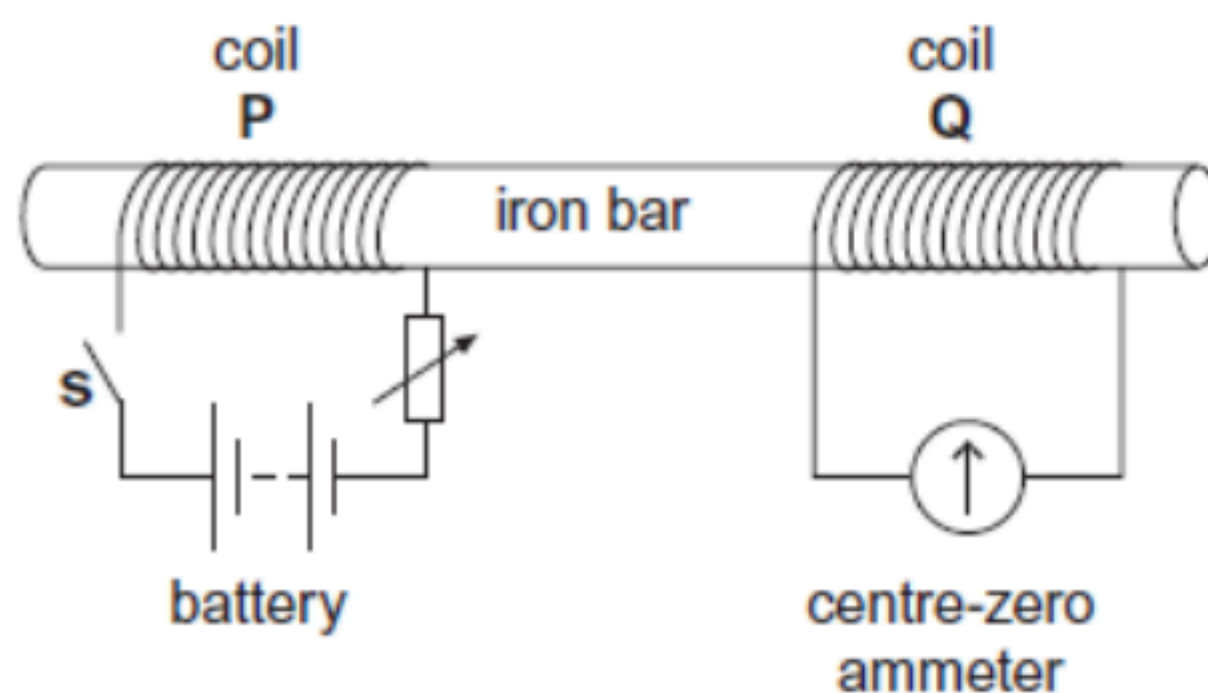
maximum emf _____ V

(3)

6

- (a) **Figure 1** shows two coils, **P** and **Q**, linked by an iron bar. Coil **P** is connected to a battery through a variable resistor and a switch **S**. Coil **Q** is connected to a centre-zero ammeter.

Figure 1



- (i) Initially the variable resistor is set to its minimum resistance and **S** is open. Describe and explain what is observed on the ammeter when **S** is closed.

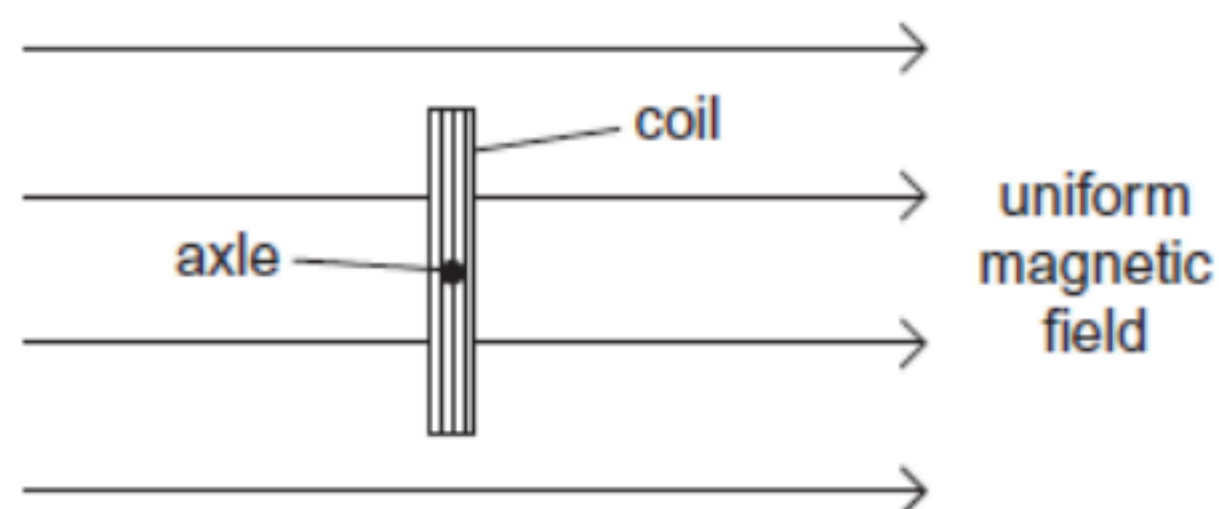
(3)

- (ii) With **S** still closed, the resistance of the variable resistor is suddenly increased. Compare what is now observed on the ammeter with what was observed in part (i). Explain why this differs from what was observed in part (i).

(2)

- (b) **Figure 2** shows a 40-turn coil of cross-sectional area $3.6 \times 10^{-3} \text{ m}^2$ with its plane set at right angles to a uniform magnetic field of flux density 0.42 T.

Figure 2



- (i) Calculate the magnitude of the magnetic flux linkage for the coil.
State an appropriate unit for your answer.

flux linkage _____ unit _____

(2)

- (ii) The coil is rotated through 90° in a time of 0.50 s.
Determine the mean emf in the coil.

mean emf _____ V

(2)

(Total 9 marks)

7

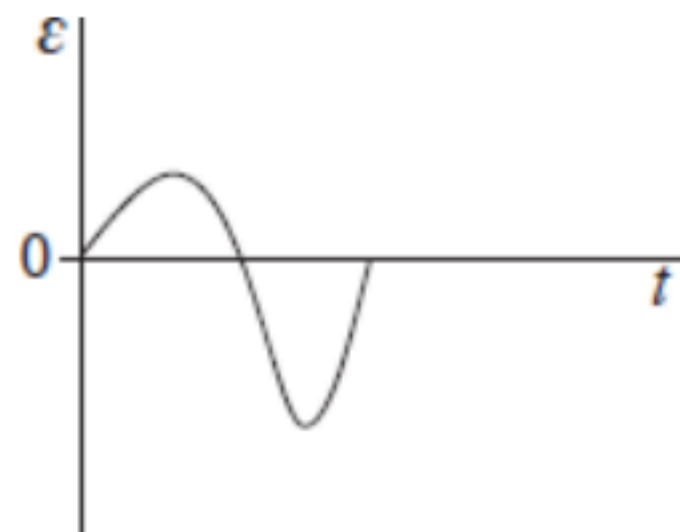
In which one of the following applications does electromagnetic induction **not** take place?

- A** the generators at a nuclear power station
- B** the ac power adapter for a laptop computer
- C** the wings of an aircraft cutting through the Earth's magnetic field
- D** the back up capacitor of an electric timer

(Total 1 mark)

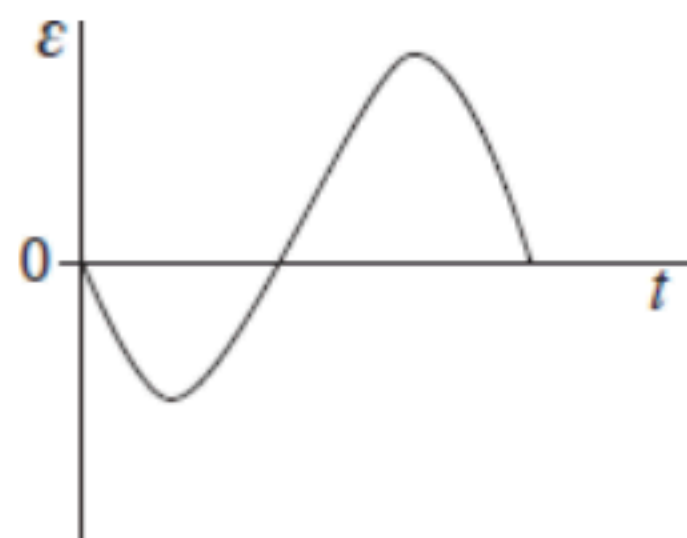
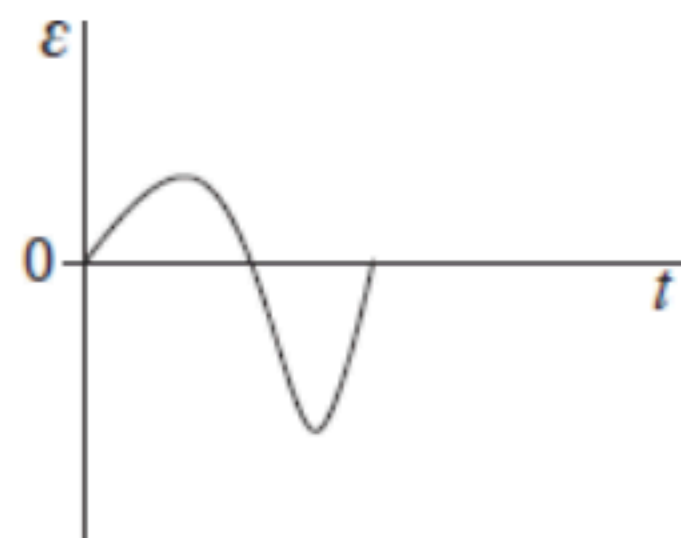
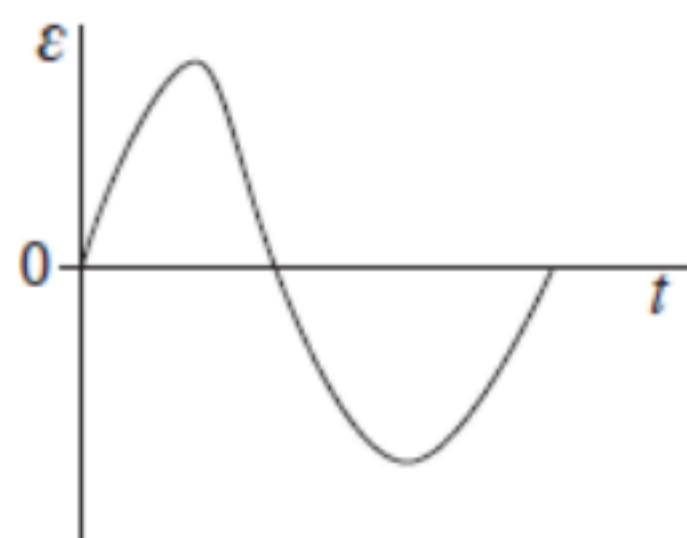
8

When a magnet is dropped through an aluminium ring an emf is induced. A data logger connected to the ring records the variation of the induced emf ε with time t as shown below.



In a second experiment, the magnet is dropped from a greater height.

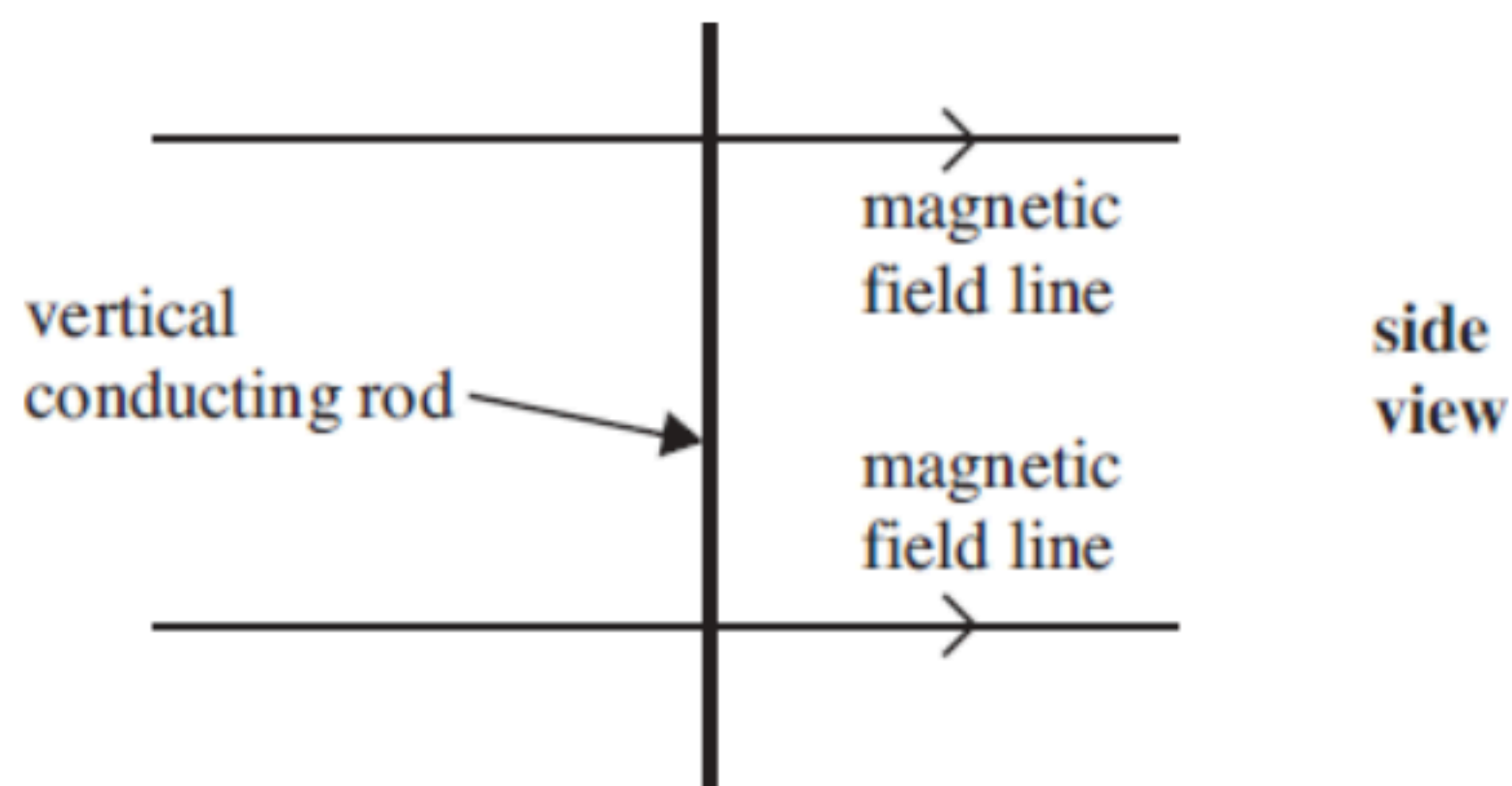
Which one of the following graphs best represents the induced emf in the second experiment?

**A****B****C****D**

(Total 1 mark)

9

A vertical conducting rod of length l is moved at a constant velocity v through a uniform horizontal magnetic field of flux density B .



Which line, **A** to **D**, in the table gives a correct expression for the induced emf for the stated direction of the motion of the rod?

	direction of motion	induced emf
A	vertical	$\frac{B}{lv}$
B	horizontal at right angles to the field	Blv
C	vertical	Blv
D	horizontal at right angles to the field	$\frac{B}{lv}$

(Total 1 mark)

10

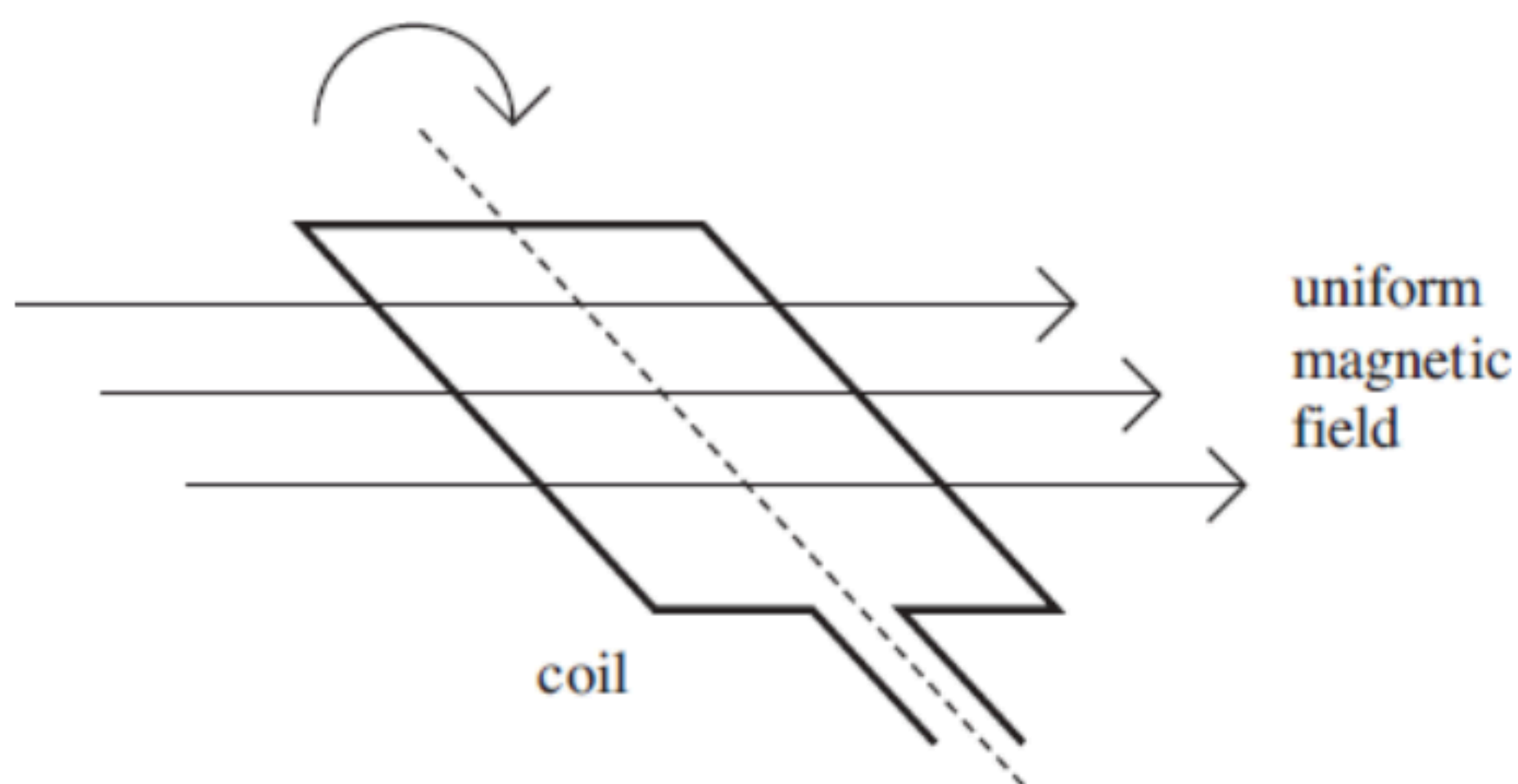
The magnetic flux through a coil of 5 turns changes uniformly from 15×10^{-3} Wb to 7.0×10^{-3} Wb in 0.50 s. What is the magnitude of the emf induced in the coil due to this change in flux?

- A** 14 m V
- B** 16 m V
- C** 30 m V
- D** 80 m V

(Total 1 mark)

11

A rectangular coil is rotated in a uniform magnetic field.



When the coil is rotated at a constant rate, an alternating emf ε is induced in it. The variation of emf ε , in volts, with time t , in seconds, is given by

$$\varepsilon = 20 \sin (100 \pi t)$$

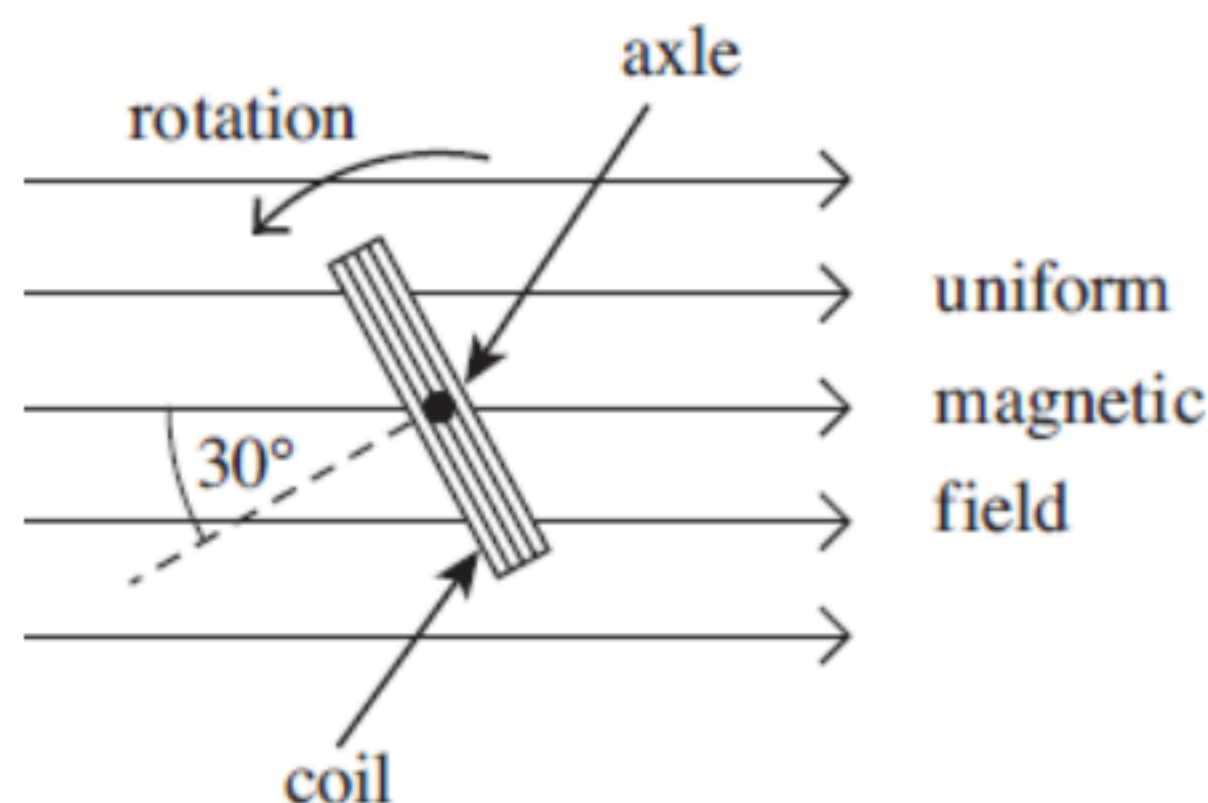
Which line, **A** to **D**, in the table gives the peak value ε_0 and the frequency f of the induced emf?

	ε_0 / V	f / Hz
A	10	50
B	10	100
C	20	50
D	20	100

(Total 1 mark)

A rectangular coil is rotating anticlockwise at constant angular speed with its axle at right angles to a uniform magnetic field. **Figure 1** shows an end-on view of the coil at a particular instant.

Figure 1



- (a) At the instant shown in **Figure 1**, the angle between the normal to the plane of the coil and the direction of the magnetic field is 30° .

- (i) State the minimum angle, in degrees, through which the coil must rotate from its position in **Figure 1** for the emf to reach its maximum value.

angle _____ degrees

(1)

- (ii) Calculate the minimum angle, in radians, through which the coil must rotate from its position in **Figure 1** for the flux linkage to reach its maximum value.

angle _____ radians

(2)

- (b) **Figure 2** shows how, starting in a different position, the flux linkage through the coil varies with time.

- (i) What physical quantity is represented by the gradient of the graph shown in **Figure 2**?

(1)

- (ii) Calculate the number of revolutions per minute made by the coil.

revolutions per minute _____

(2)

Figure 2

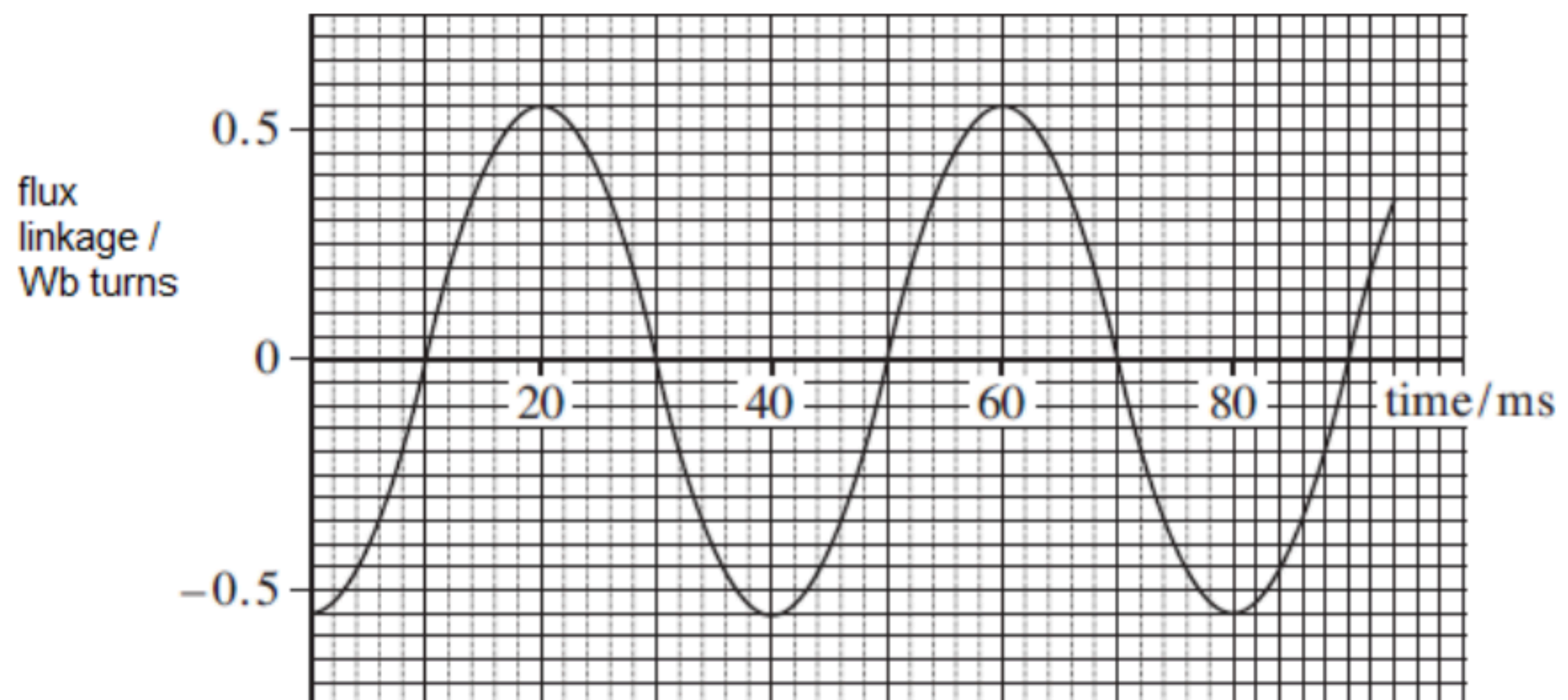
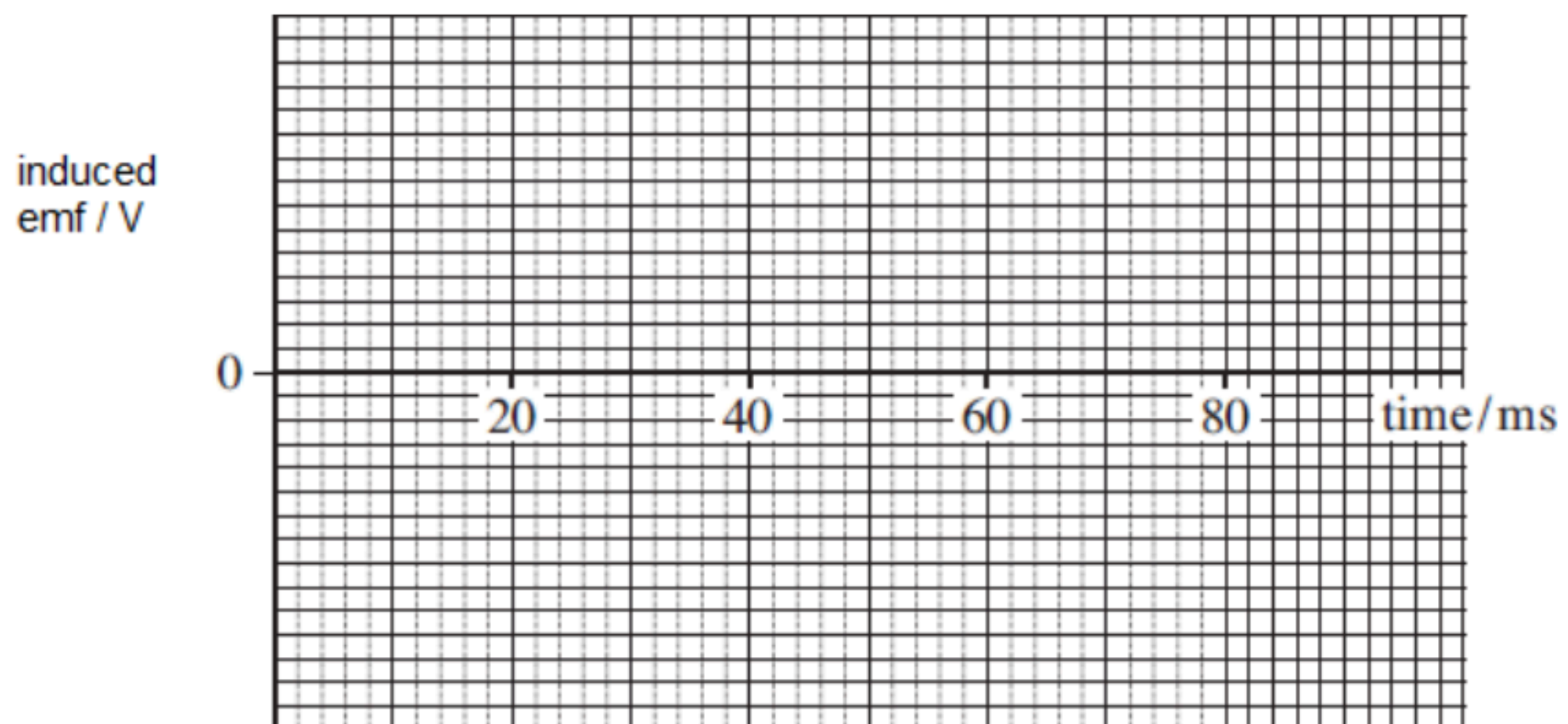


Figure 3



(iii) Calculate the peak value of the emf generated.

peak emf _____ V

(3)

(c) Sketch a graph on the axes shown in **Figure 3** above to show how the induced emf varies with time over the time interval shown in **Figure 2**.

(2)

- (d) The coil has 550 turns and a cross-sectional area of $4.0 \times 10^{-3} \text{m}^2$.

Calculate the flux density of the uniform magnetic field.

flux density _____ T

(2)

(Total 13 marks)

13

The output electromotive force (emf) of a simple ac generator can be increased by any of the four factors listed.

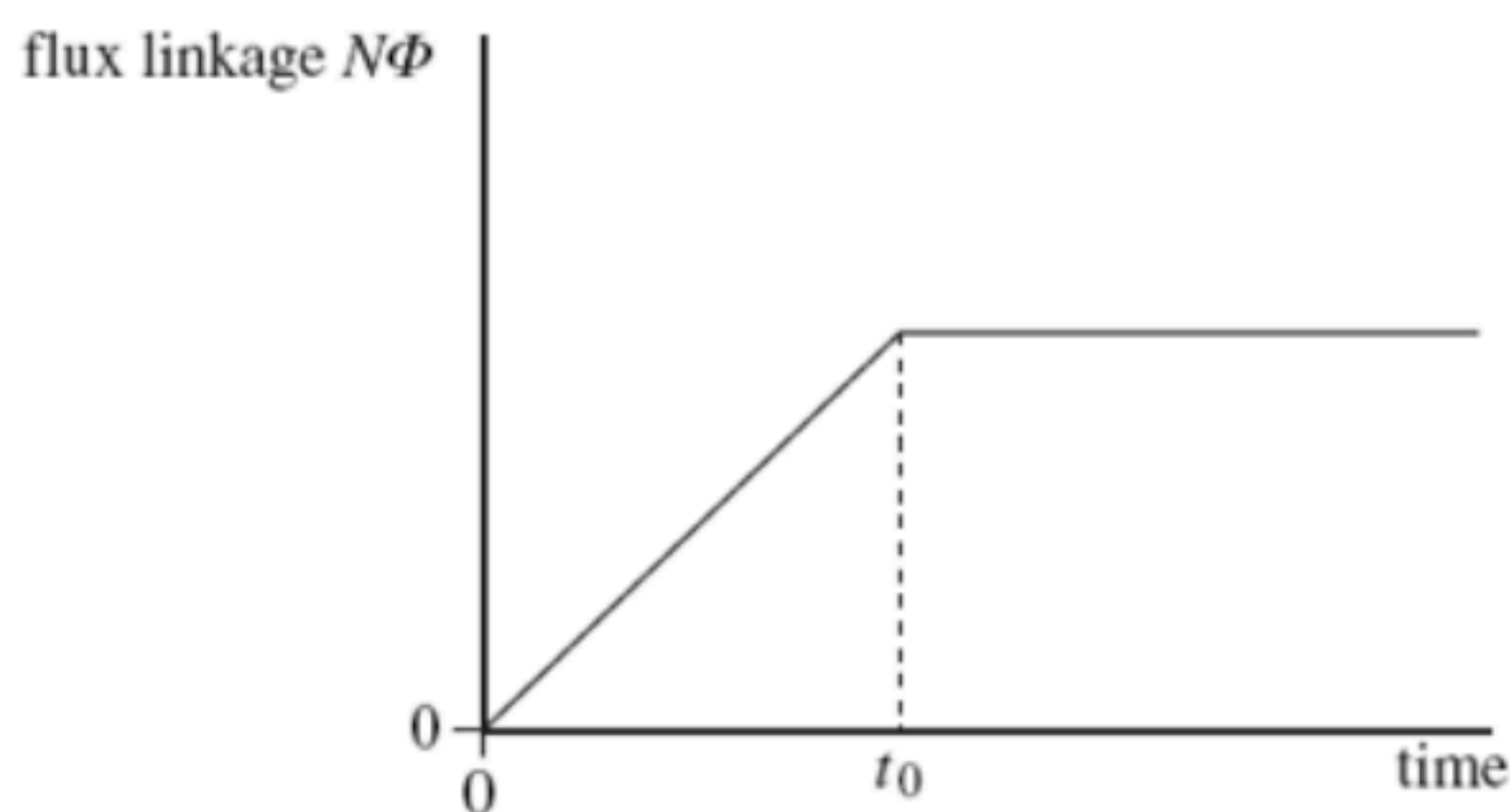
Which one of these factors should **not** be changed if the frequency of the output is to remain unaffected when the emf is increased?

- A the area of the coil
- B the number of turns on the coil
- C the speed of rotation
- D the strength of the magnetic field

(Total 1 mark)

14

The graph shows how the flux linkage, $N\Phi$, through a coil changes when the coil is moved into a magnetic field.

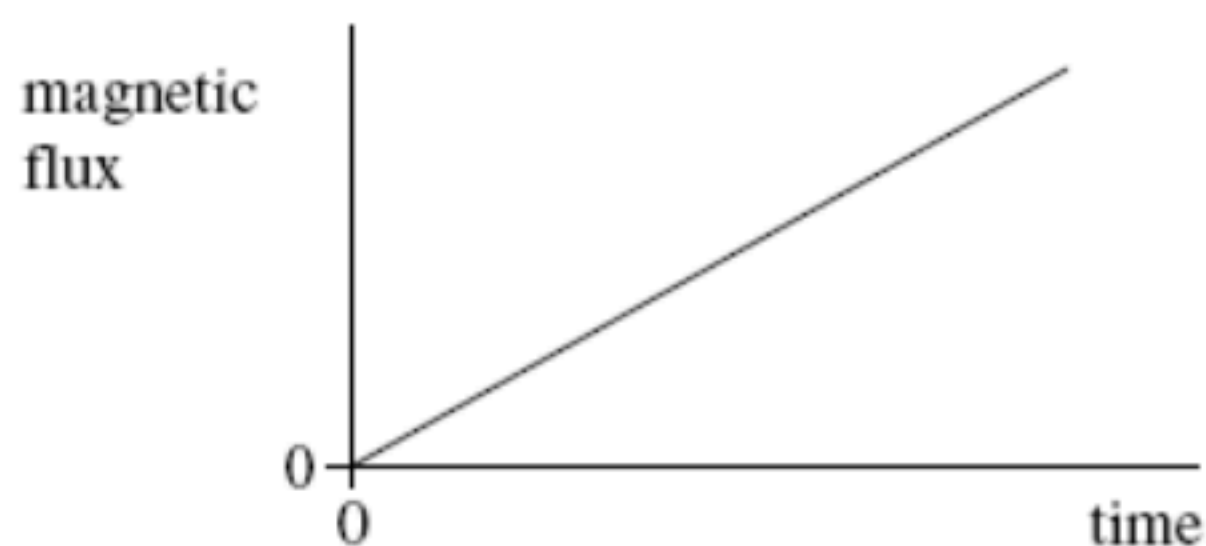


The emf induced in the coil

- A increases then becomes constant after time t_0 .
- B is constant then becomes zero after time t_0 .
- C is zero then increases after time t_0 .
- D decreases then becomes zero after time t_0 .

15

The graph shows how the magnetic flux passing through a loop of wire changes with time.



What feature of the graph represents the magnitude of the emf induced in the coil?

- A** the area enclosed between the graph line and the time axis
- B** the area enclosed between the graph line and the magnetic flux axis
- C** the inverse of the gradient of the graph
- D** the gradient of the graph

(Total 1 mark)

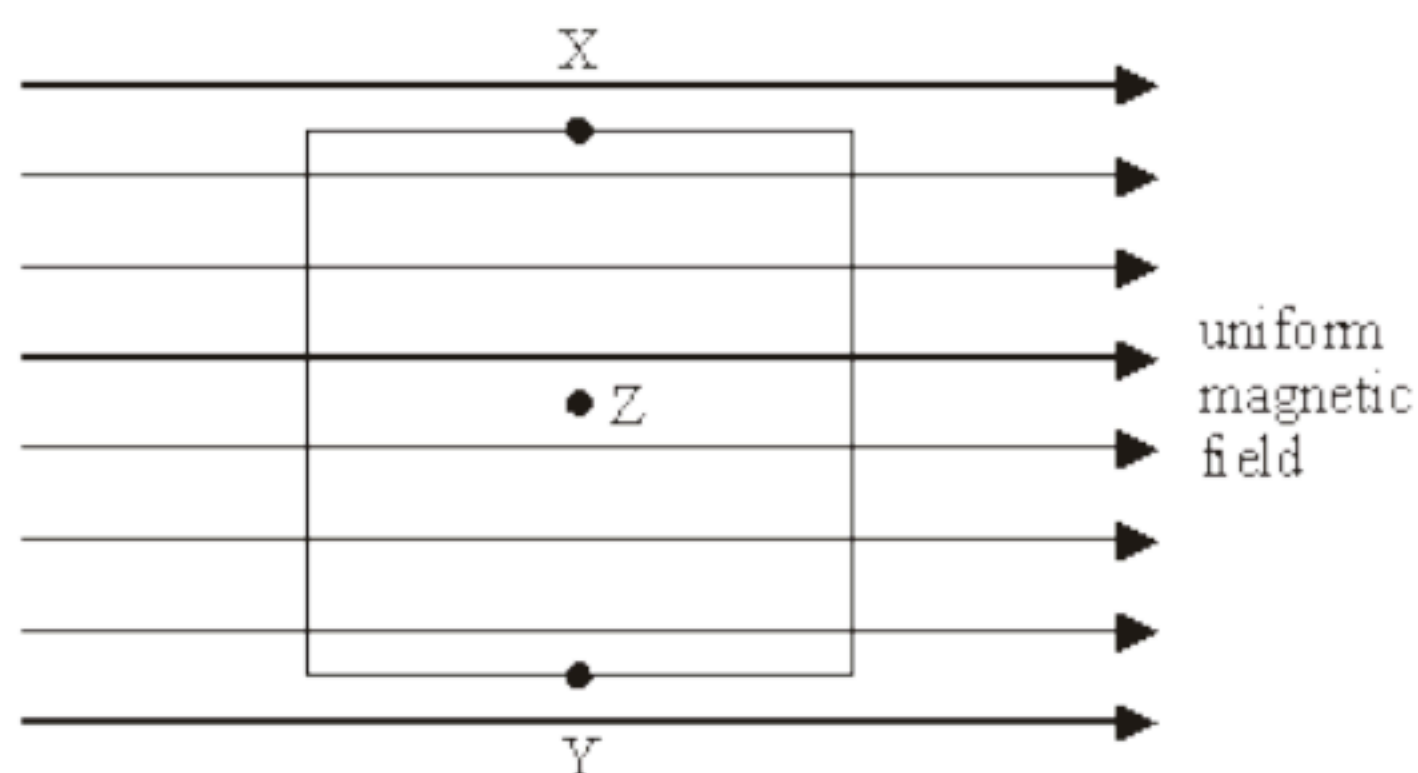
16

An aircraft, of wing span 60 m, flies horizontally at a speed of 150 m s^{-1} . If the vertical component of the Earth's magnetic field in the region of the plane is $1.0 \times 10^{-5} \text{ T}$, what emf is induced across the wing tips of the plane?

- A** 0.09 V
- B** 0.90 V
- C** 9.0 V
- D** 90 V

(Total 1 mark)

17



The diagram shows a square coil with its plane parallel to a uniform magnetic field. Which one of the following would induce an emf in the coil?

- A** movement of the coil slightly to the left
- B** movement of the coil slightly downwards
- C** rotation of the coil about an axis through XY
- D** rotation of the coil about an axis perpendicular to the plane of the coil through Z

(Total 1 mark)

18

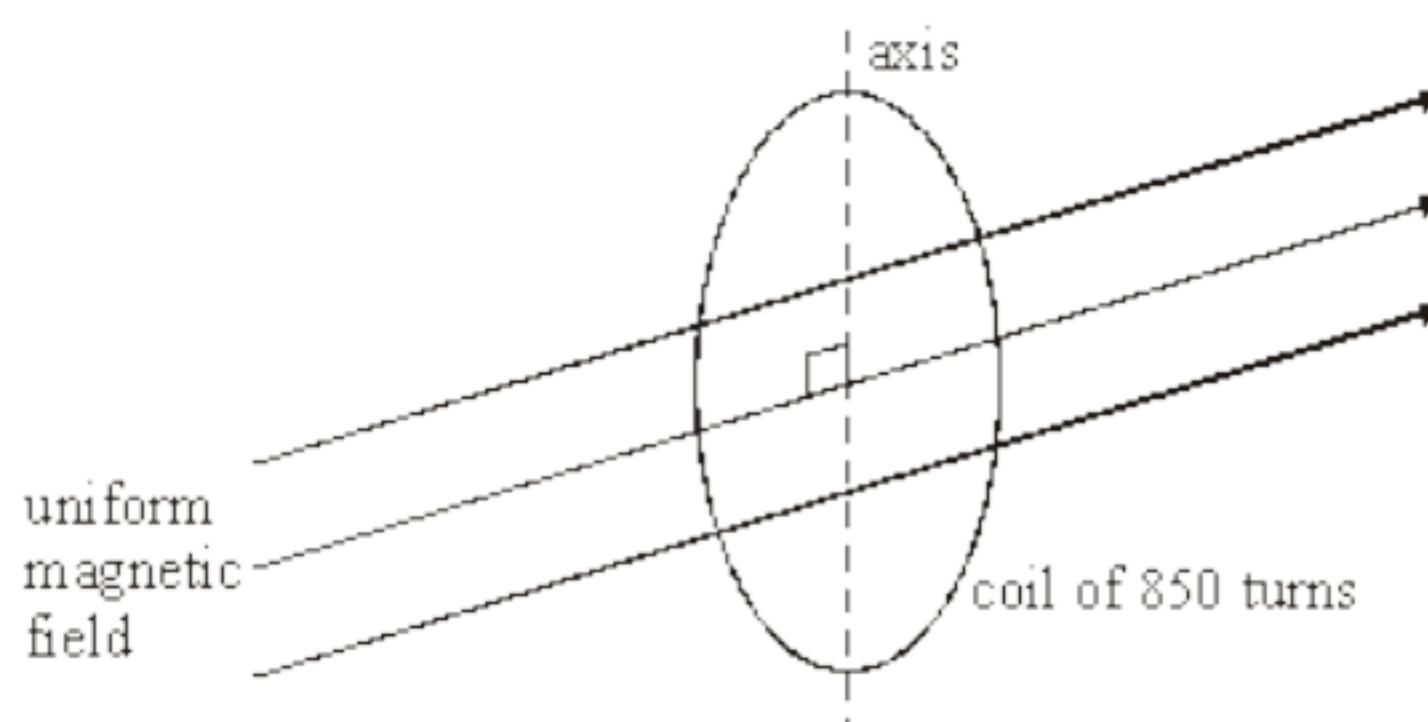


Figure 1

A circular coil of diameter 140 mm has 850 turns. It is placed so that its plane is perpendicular to a horizontal magnetic field of uniform flux density 45 mT, as shown in **Figure 1**.

- (a) Calculate the magnetic flux passing through the coil when in this position.

(2)

- (b) The coil is rotated through 90° about a vertical axis in a time of 120 ms.

Calculate

- (i) the change of magnetic flux linkage produced by this rotation,

- (ii) the average emf induced in the coil when it is rotated.

(4)

(Total 6 marks)

19

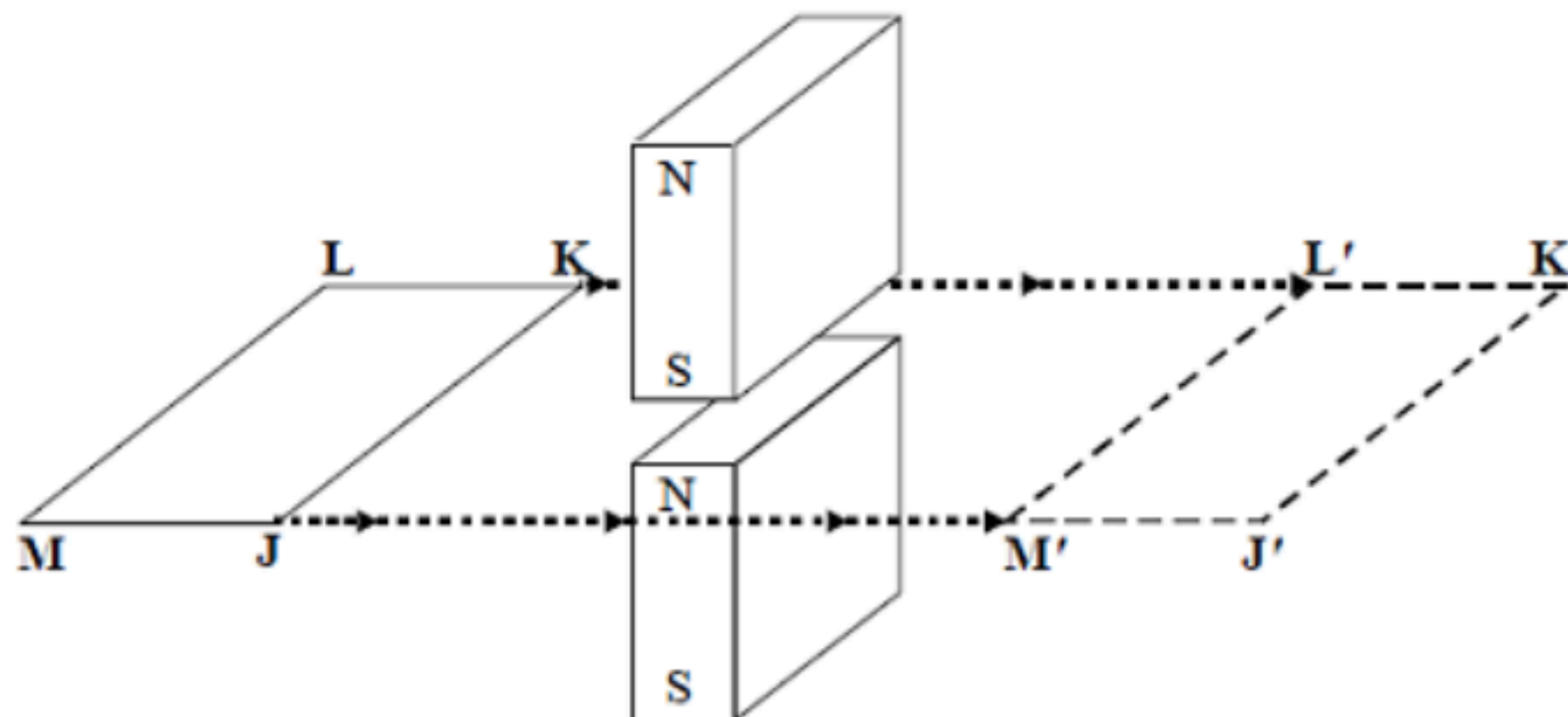
The magnetic flux threading a coil of 100 turns drops from 5×10^{-3} Wb to zero in 0.1 s. The average induced e.m.f., in V, is

- A** 0.05
B 0.5
C 5
D 20

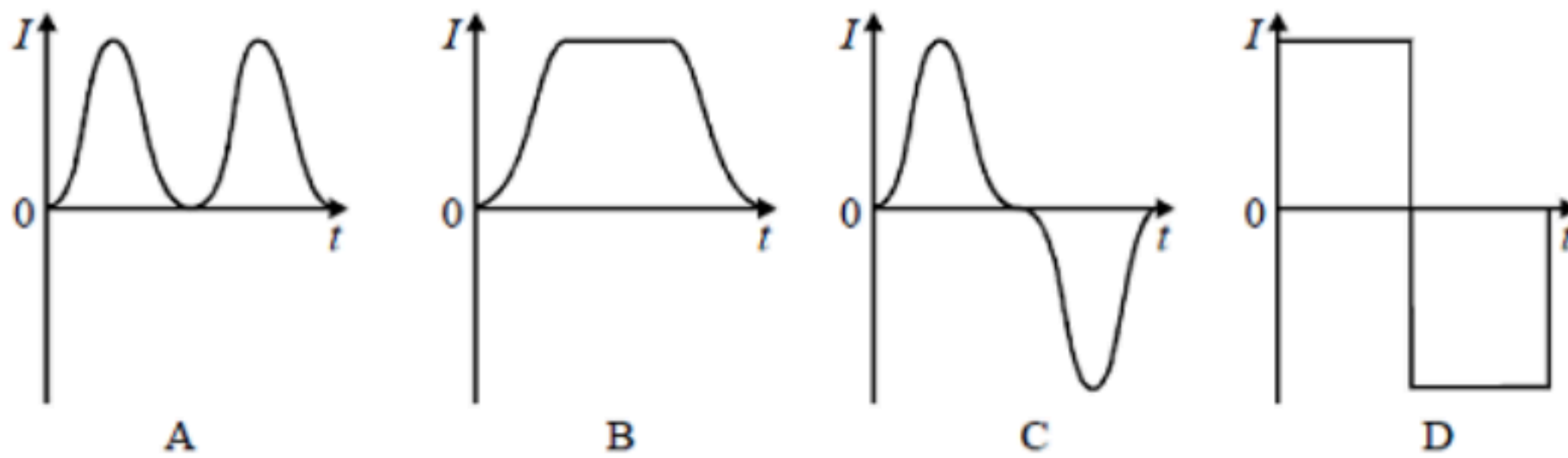
(Total 1 mark)

20

A rectangular conducting loop is pulled horizontally through the gap between two vertical magnets as shown in the diagram.



Which one of the graphs best represents the variation of loop current I with time t as the loop moves at a constant speed from **JKLM** to **J'K'L'M'**?



(Total 1 mark)

21

A metal aircraft with a wing span of 42 m flies horizontally with a speed of 1000 km h^{-1} in a direction due east in a region where the vertical component of the flux density of the Earth's magnetic field is $4.5 \times 10^{-5} \text{ T}$.

- (a) Calculate the flux cut per second by the wings of the aircraft.

- (b) Determine the magnitude of the potential difference between the wing tips, stating the law which you are applying in this calculation.

- (c) What would be the change in the potential difference, if any, if the aircraft flew due west?

(Total 6 marks)

Mark schemes

1	B		[1]
2	C		[1]
3	C		[1]
4	(a) (Faraday's law) (induced) emf $\propto$ rate of change of flux (linkage) ✓ (Lenz's law) <u>direction of</u> induced emf (or current) ✓ is such as to oppose the change (in flux) producing it ✓ <i>In either order.</i> <i>Allow "(induced) emf = rate of change of flux linkage".</i> <i>Ignore incorrect reference to names of laws.</i>	3	
	(b) (i) current in coil produces magnetic field or flux (that passes through disc) ✓ rotating disc cuts flux inducing / producing emf or current (in disc) ✓ induced (eddy) currents (in disc) interact with magnetic field ✓ force on (eddy) currents slows (or opposes) rotation (of disc) ✓ Alternative for last two points: (eddy) currents in disc cause heating of disc ✓ energy for heating comes from ke of disc or vehicle (which is slowed) ✓	max 3	
	(ii) Advantage: any one ✓ - no material (eg pads or discs or drums) to wear out - no pads needing replacement - no additional (or fewer) moving parts Disadvantage: any one ✓ - ineffective at low speed or when stationary - dependent on vehicle's electrical system remaining in working order - requires an electrical circuit (or source of electrical energy) to operate whereas pads do not <i>Answers must refer to advantages and disadvantages of the <u>electromagnetic</u> brake.</i> <i>Only accept points from these lists.</i>	2	[8]

5

- (a) (i) graph showing two pulses one at start and the other at the end with no emf between the pulses

Positive and negative pulses shown

Similar shaped 'curved' pulses : negative between 0 and 0.22 ± 0.02 s and positive pulse 0.58 ± 0.02 and 0.8

3

- (ii) emf induced when the flux is changing or induced emf depends on the rate of change of flux

emf induced when flux changes between 0 and 0.2(2) s and / or between 0.6(0.58)s and 0.8 s

OR

no change in flux between 0.2 and 0.6 so no induced emf

Induced emf / current produces a field to oppose the change producing it.

Flux linking bracelet increases as the bracelet enters the field produced by C and decreases as it leaves so opposite emfs

4

- (b) (Takes 0.21 s or 0.22 s for flux to change from 0 to maximum so)
diameter = $0.28 \times 0.21 = 0.059$ (0.588) (m)
or $0.28 \times 0.22 = 0.062$ (0.616) (m)

must be to at least 2sf

1

- (c) Area of bracelet = 3.14×0.031^2

$$B = 1120 \times 10^{-6} / (3.14 \times 0.031^2) = 0.38 \text{ (T)}$$

$B = 0.40$ T if 3 cm used for radius

Condone incorrect power of 10

Allow answers in range 0.38T to 0.41 T (depends on value used for r)

2

- (d) Use of steepest gradient of graph or tangent drawn on Figure 2
Correct data from tangent or points on the steepest part of the graph
10 to 11 mV

3

[13]

6

- (a) (i) meter deflects then returns to zero ✓
 current produces (magnetic) field / flux ✓
 change in field / flux through Q induces emf ✓
 induced emf causes current in Q (and meter) ✓

Deflection to right (condone left) then zero is equivalent to 1st mark.

Accept momentary deflection for 1st point.

“Change in field / flux induces current in Q” is just ✓ from the last two marking points.

max 3

- (ii) meter deflects in opposite direction (or to left, or ecf) ✓
 field / flux through P is reduced ✓
 induces emf / current in opposite direction ✓

Ignore references to magnitude of deflection.

max 2

- (b) (i) flux linkage ($= n\Phi = nBA$) $= 40 \times 0.42 \times 3.6 \times 10^{-3}$
 $= 6.0(5) \times 10^{-2}$ ✓

Unit mark is independent.

Allow 6×10^{-2} .

Wb turns ✓

Accept 60 mWb turns if this unit is made clear.

Unit: allow Wb.

2

- (ii) change in flux linkage $= \Delta(n\Phi) = 6.05 \times 10^{-2}$ (Wb turns) ✓

$$\text{induced emf} \left(= \frac{\Delta(n\Phi)}{\Delta t} \right) = \frac{6.05 \times 10^{-2}}{0.50} = 0.12(1) \text{ (V)} \quad \checkmark$$

Essential to appreciate that 6.05×10^{-2} is change in flux linkage for 1st mark. Otherwise mark to max 1.

2

[9]

7

D

[1]

8

D

[1]

9

B

[1]

10

D

[1]

11

C

12

- (a) (i) 60 (degrees) ✓

1

- (ii) angle required is
- 150°
- ✓

which is $5\pi/6$ [or 2.6(2)] (radians) ✓*Correct answer in radians scores both marks.*

2

- (b) (i) (magnitude of the induced) emf ✓

Accept "induced voltage" or "rate of change of flux linkage", but not "voltage" alone.

1

- (ii) frequency
- $\left(= \frac{1}{T} \right) = \frac{1}{40 \times 10^{-3}}$
- ✓ (= 25 Hz)

no of revolutions per minute = $25 \times 60 = 1500$ ✓*1500 scores both marks.**Award 1 mark for $40\text{s} \rightarrow 1.5 \text{ rev min}^{-1}$.*

2

- (iii) maximum flux linkage (
- $=BAN$
-) = 0.55 (Wb turns) ✓

$$\text{angular speed } \omega \left(= \frac{2\pi}{T} \right) = \frac{2\pi}{40 \times 10^{-3}} \quad \checkmark \quad (= 157 \text{ rad s}^{-1})$$

peak emf ($= BAN\omega$) = $0.55 \times 157 = 86(.4)$ (V) ✓

[or, less accurately, use of gradient method ✓

$$\{\text{e.g. } \varepsilon \left(= \frac{\Delta(N\Phi)}{\Delta t} \right) = \frac{0.5 - (-0.5)}{(16 - 4) \times 10^{-3}} = \frac{1.0}{12 \times 10^{-3}} \} = 83 (\pm 10)$$

(V) ✓ ✓

(max 2 for (iii) for values between 63 and 72 V or 94 and 103V)

3

- (c) sinusoidal shape of constant period 40 ms ✓

Mark sequentially.*Graph must cover at least 80ms.*

correct phase (i.e. starts as a minus sin curve) ✓

*For 2nd mark, accept + sin curve.**Perfect sin curves are not expected.*

2

(d) $BAN = 0.55 \therefore \text{flux density } B = \frac{0.55}{4.0 \times 10^{-3} \times 550} \checkmark$
 $= 0.25(0) \text{ (T)} \checkmark$

OR by use of ϵ from (b)(iii) and f from
 (b)(ii) substituted in $\epsilon = BAN(2\pi f)$.

2

(Total 13 marks)

13 C [1]

14 B [1]

15 D [1]

16 A [1]

17 C [1]

18 (a) $\Phi (= BA) = 45 \times 10^{-3} \times \pi \times (70 \times 10^{-3})^2 \text{ (1)}$
 $= 6.9 \times 10^{-4} \text{ Wb (1) } (6.93 \times 10^{-4} \text{ Wb})$

2

(b) (i) $N\Delta\Phi (= NBA - 0) = 850 \times 6.93 \times 10^{-4} \text{ (1)}$
 $= 0.59 \text{ (Wb turns) (1) } (0.589 \text{ (Wb turns)})$
 (if $\Phi = 6.9 \times 10^{-4}$, then 0.587 (Wb turns))
 (allow C.E. for value of Φ from (a))

(ii) induced emf $(= N \frac{\Delta\Phi}{\Delta t}) = \frac{0.589}{0.12} \text{ (1)}$
 $= 4.9 \text{ V (1) } (4.91 \text{ V})$

(allow C.E. for value of Wb turns from (ii))

4

[6]

19 C [1]

20 C [1]

21

(a) $1000 \text{ km hr}^{-1} = \frac{1000 \times 10^3}{3600} \text{ m s}^{-1}$

flux cut per second = $B \times$ area swept out per second $\left[\text{or } 4.5 \times 10^{-5} \times 42 \times \frac{10^4}{36} \right] \text{ (1)}$
 $= 0.52 \text{ Wb (1)}$

(b) induced e.m.f. equals flux cut per second [or equation and symbols defined] **(1)**
 $\therefore E = 0.52 \text{ V (1)}$

(c) direction of p.d. reversed **(1)**

[6]