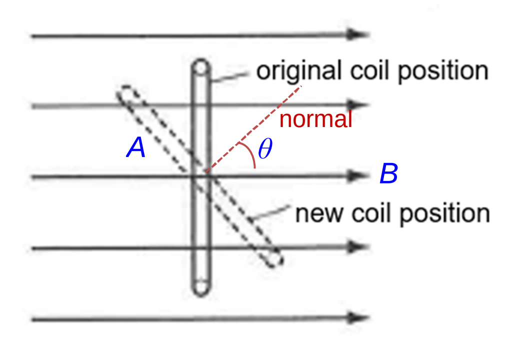
1



During the rotation,

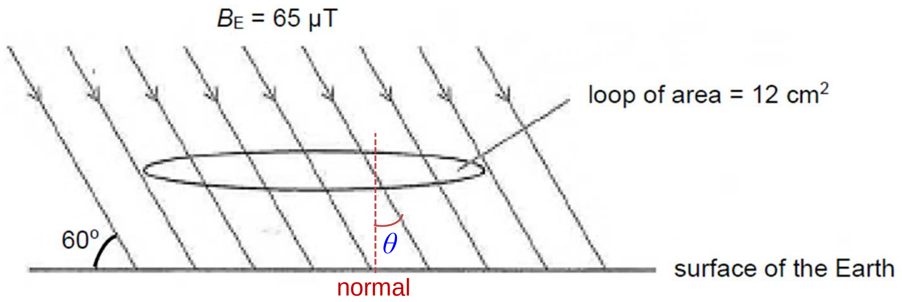
- there is no change in magnetic flux density B passing through the coil
- the change in total magnetic flux is given by:

  $\Phi_f - \Phi_i = BA\cos\theta - BA\cos 0^\circ = BA(\cos\theta - 1)$, which is negative

  $\Rightarrow \Phi$ decreases

Answer: C

2

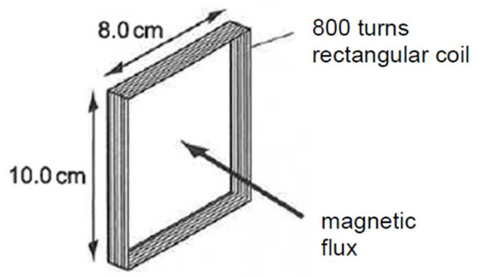


magnetic flux through the loop of wire:

$$\Phi = BA\cos\theta = (65\times10^{-6}\ \text{T})(12\times10^{-4}\ \text{m}^2)\cos 30^\circ = 6.8\times10^{-8}$$

Answer: B

3

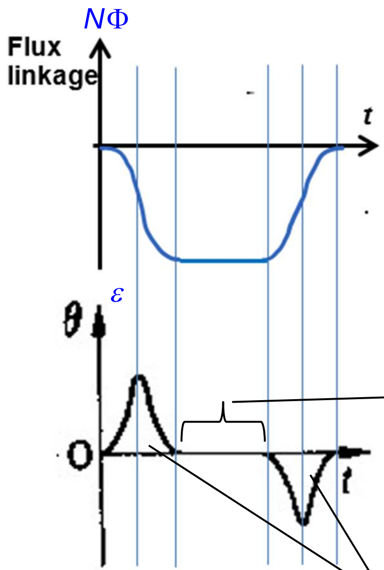


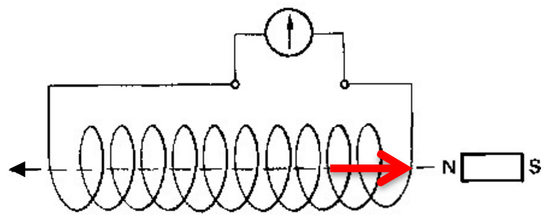
magnetic flux density, B
magnetic flux, $\Phi = BA = B \times (8.0 \times 10^{-3})$
magnetic flux linkage, $N\Phi = 800\ \Phi = 6.4B$

	magnetic flux density / T	magnetic flux / Wb	magnetic flux linkage / Wb turns
A	3.4	2.7×10^{-2} ✓	220 ✗ **22**
B	2.7×10^{-2}	3.4 ✗ $\mathbf{2.2 \times 10^{-4}}$	2700 ✗ **0.173**
C	3.4×10^{-4}	4.2×10^{-2} ✗ $\mathbf{2.7 \times 10^{-6}}$	34 ✗ $\mathbf{2.2 \times 10^{-3}}$
D	4.2×10^{-2}	3.4×10^{-4} ✓	0.27 ✓

Answer: D

4 **B**





normal to area of coils of solenoid

When the whole magnet remains well within the long solenoid, with the flux linkage being the maximum and remaining unchanged, the induced e.m.f. remains zero. (Faraday's law)

$$\varepsilon = -\frac{dN\Phi}{dt}$$

$$\Rightarrow \Delta N\Phi = -\int_{t_1}^{t_2} \varepsilon dt$$

$=$ area under $\varepsilon - t$ graph

When magnet is entering and leaving the solenoid, the total change in flux linkage (area under the graph) is the same.

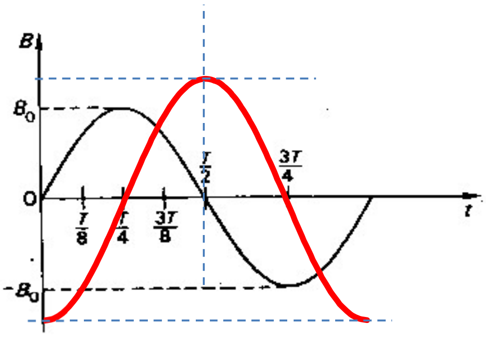
Since speed is constant, the change of flux linkage in entering and leaving the solenoid would take place over the same period of time, hence induced e.m.f. have the same maximum value. (Faraday's Law)

5 **D** *T*/2

Since $\varepsilon = -\frac{dN\Phi}{dt} = -\frac{d(NBA)}{dt} = -NA\frac{dB}{dt}$, induced e.m.f is the largest when the gradient of the graph is the steepest.

$$\varepsilon = -\frac{dN\Phi}{dt} = -NA\frac{dB}{dt} = -NA\frac{d\left(B_0 \sin\omega t\right)}{dt} = -\left(NAB_0\omega\right)\cos\omega t = -\varepsilon_0 \cos\omega t$$

Note: $\omega = 2\pi f = \frac{2\pi}{T}$



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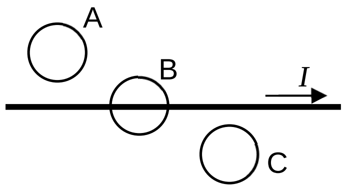
6 Direction of induced current in loop

A: clockwise

B: no induced current

C: counter-clockwise



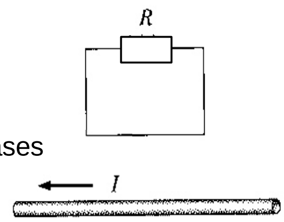
Explanation for direction of induced current in loop A:

The increase in current in the wire causes increasing magnetic flux linkage out of the plane of loop A. By Lenz's law, the induced current due to the induced e.m.f. must flow to reduce the flux linkage out of the plane of the loop. Thus, clockwise current flows through loop A.

---

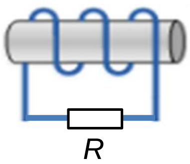
7 (a) Since I decreases, magnetic flux linkage into the plane through the coil decreases. Hence by Lenz's law, the current due to the induced e.m.f. must flow to increase the flux linkage into the plane of the coil. Thus, clockwise current flows through the loop and flows from <u>left to right through *R*</u>.

current I decreases
rapidly to zero

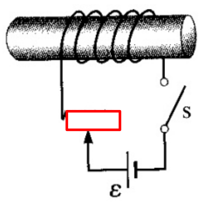


(b)

i. first, the switch is closed
ii. then the variable resistor in series with the cell is decreased
iii. then the circuit containing resistor *R* is moved to the left
iv. then the switch is opened.



A



B

(i) When the switch is first closed in B, the current flowing increases from 0 to a steady value, causing increasing leftward magnetic flux linkage through the coil in A. By Lenz's law, the induced magnetic field is rightward to oppose the change. To produce this induced field, the induced current must be clockwise as seen from the left of coil (from the fish's point of view). Thus, the current flows from right to left through *R*.

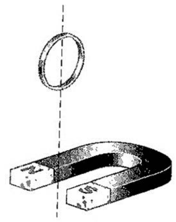
(ii) When the variable resistor in B is decreased, the current flowing in B increases, causing increasing leftward magnetic flux linkage through the coil in A. By Lenz's law, the induced magnetic field is rightward to oppose the change. To produce this induced field, the induced current must be clockwise as seen from the left of coil. Thus, the current flows from right to left through *R*.

(iii) Motion of the circuit A to the left causes decreasing leftward magnetic flux linkage through coil in A. By Lenz's law, the induced magnetic field is leftward to oppose the change. To produce this induced field, the induced current must be anticlockwise as see from the left of coil. Thus, current flows from left to right through *R*.

(iv) When the switch is opened, the current flowing in circuit B decreases from its steady value to 0, causing decreasing leftward magnetic flux linkage through the coil in A. By Lenz's law, the induced magnetic field is leftward to oppose the change. To produce this induced field, the induced current must be anticlockwise as seen from the left of coil. Thus, the current flows from left to right through *R*.

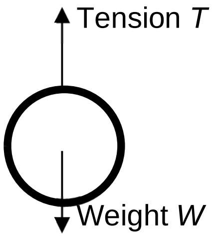
---

8 (a)(i) When the loop drops between the poles of the magnet from above, there is an increase in flux through the loop. From Lenz's law, the current due to the induced e.m.f. flows in a direction such that it produces magnetic fields that oppose the increase in magnetic flux. Hence, the induced current would be clockwise to produce a magnetic field pointing opposite to the magnetic field of the magnet.



(ii) When the loop drops below the poles of the magnet, there is a decrease in flux through the loop. From Lenz's law, the current due to the induced e.m.f. flows in a direction such that it produces magnetic fields that oppose the decrease in magnetic flux. Hence, the induced current would be anti-clockwise to produce a magnetic field in the same direction as the magnetic field of the magnet.

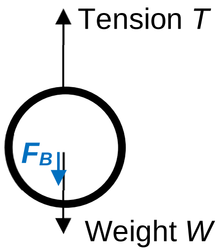
(b)(i) Considering the free body diagram of the loop of wire when it is away from the magnet:



At constant speed,
$T = W$

When the loop is below the magnet, there is a increase in magnetic flux linkage through the loop as it is being pulled upwards. From Lenz's law, the current due to

the induced e.m.f. flows in a direction such that the coil experiences a downward force $\boldsymbol{F_B}$ to oppose the upward motion of the loop.
(The induced magnetic forces repel the magnet when the ring is approaching.)



At constant speed,

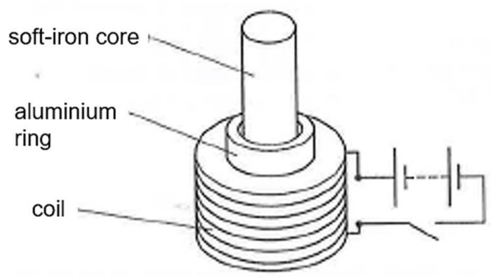
$$T = W + F_B$$

Hence the tension of the string is greater than the weight of the loop.

(ii) When the loop is above the magnet, there is an decrease in magnetic flux linkage through the loop as it is being pulled upwards. From Lenz's law, the current due to the induced e.m.f. flows in a direction such that the coil experiences a downward force $\boldsymbol{F_B}$ to oppose the upward motion of the loop.
(The induced magnetic forces attract the magnet when the ring is receding.)

Similarly, the tension of the string is greater than the weight of the loop.

9



When the switch is closed, a current flows in the coil which produces a magnetic field in the coil.

[B1]

The soft-iron core links all the magnetic flux from the coil to the aluminium ring.

[B1]

This results in an increase in magnetic flux linkage through the ring and according to Faraday's law, an e.m.f. is induced in the ring.

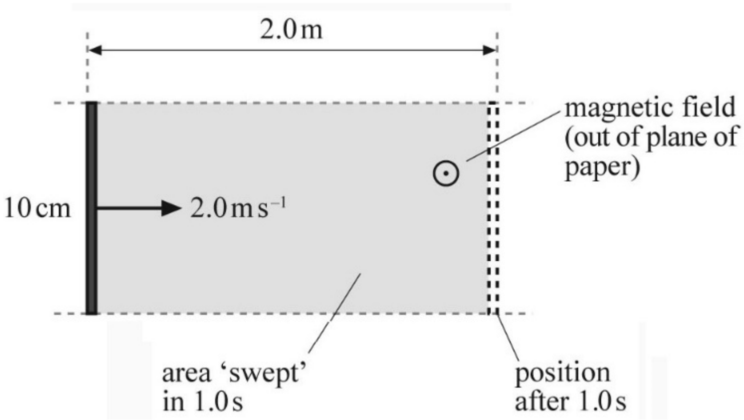
[B1]

From Lenz's law, the current in the ring produced by this induced e.m.f. flows in a direction to oppose this increase in magnetic flux linkage through the ring. This results in the ring moving vertically away from the coil.

[B1]

10 (a) distance = speed × time = (2.0 m s^{-1}) × (1.0 s) = 2.0 m

(b)



(c) Area swept = length × distance travelled = (0.10 m) × (2.0 m) = 0.20 m^2

Change in magnetic flux = area swept × magnetic flux density
= (0.20 m^2) × (0.050 T)
= 1.0×10^{-2} Wb

(d) Magnitude of e.m.f. = rate of change of magnetic flux linkage

$$\varepsilon = \frac{\Delta(N\Phi)}{\Delta t} \quad (N = 1)$$

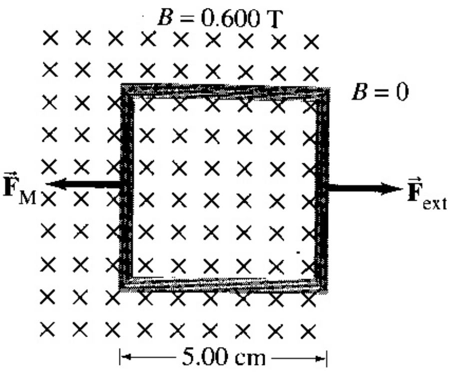
$$\varepsilon = \frac{1.0\times10^{-2}}{1.0} = 1.0 \times 10^{-2}\text{ V} \quad (1\text{ Wb s}^{-1} = 1\text{ V})$$

(e) $E = BLv = 0.050 \times 0.10 \times 2.0 = 1.0 \times 10^{-2}$ V

11 (a) $\Delta N\Phi$ = final flux linkage – initial flux linkage
$= NA(B_f - B_i)$
= (100) (0.0500^2) (0 – 0.600) = – 0.15 Wb-turns

(b)

$$\varepsilon = -\frac{dN\Phi}{dt}$$
$$\approx -\frac{\Delta N\Phi}{t}$$
$$= \frac{0.15}{0.100} = 1.5\text{ V}$$



(c)

$$I = \frac{\varepsilon}{R}$$
$$= \frac{1.5}{100} = 15\text{ mA}$$

(d) Energy $= I^2Rt$
$= (0.015^2)(100)(0.100) = 2.25$ mJ

(e) Energy consideration:
Since the coil is moving at a constant speed, there is no change in its kinetic energy, $\Delta E_k = 0$.

ΔU_{int} = energy dissipated in the coil (increase in internal energy) $= 2.25\text{mJ}$

work done by external force acting on the coil, $W_{ext} = F_{ext}d = F_{ext}(0.0500)$

Conservation of energy: $\Delta E_k + \Delta U_{\text{int}} = W_{\text{ext}}$

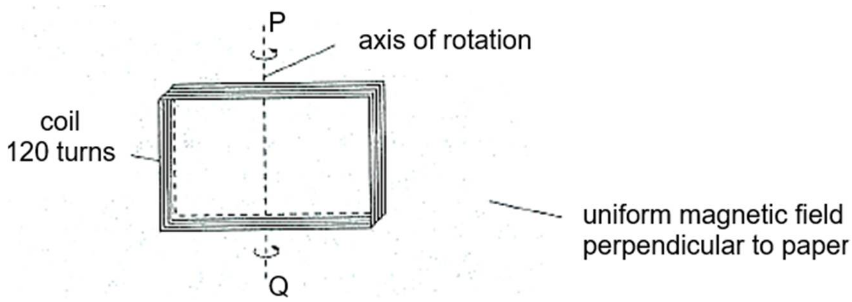
$$\Rightarrow 0 + 2.25 \times 10^{-3} = F_{ext}(0.0500)$$

$$\Rightarrow F_{ext} = \frac{2.25 \times 10^{-3}}{0.0500} = 0.045\text{N}$$

Force consideration:
Since the coil is moving at a constant speed

$$F_{ext} = F_M = NBIL$$
$$= (100)(0.600)(15 \times 10^{-3})(0.0500)$$
$$= 0.045 \text{ N}$$

12



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12 (a) (i)

As the coil is rotated about PQ, the magnetic flux linkage (= $NBA\cos\theta$) through the coil changes since the area perpendicular to the magnetic field changes.

[B1]

By Faraday's law of electromagnetic induction, an e.m.f. is induced in the coil and the magnitude of the induced e.m.f. is proportional to the rate of change of the magnetic flux linkage.

[B1]

This e.m.f. is largest when the rate of change of magnetic flux linkage is greatest, when the normal of the coil is perpendicular to the magnetic field.

[B1]

As the magnetic flux linkage changes sinusoidally, so does the rate of change of magnetic flux linkage and hence the e.m.f. induced in the coil varies sinusoidally as well.

[B1]

(a) (ii) 1. maximum e.m.f. $= \frac{6.8}{2} \times 0.050 = 0.17$ V

(a) (ii) 2. period, $T = \dfrac{10 \times 0.0080}{2} = 0.040$ s

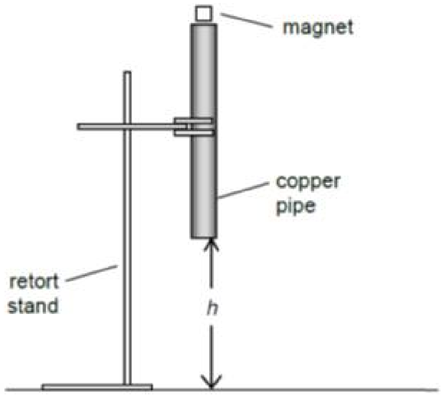
frequency, $f = \dfrac{1}{T} = 25$ Hz

12 (b) Given $E_o = NBA\omega$

$$0.17 = 120B\left(1.3 \times 10^{-3}\right)\left[2\pi\left(25\right)\right]$$

$$B = 6.9 \times 10^{-3}\ \text{T}$$

13 (a) Although copper pipe is a non-magnetic metal, it is still a conducting pipe.



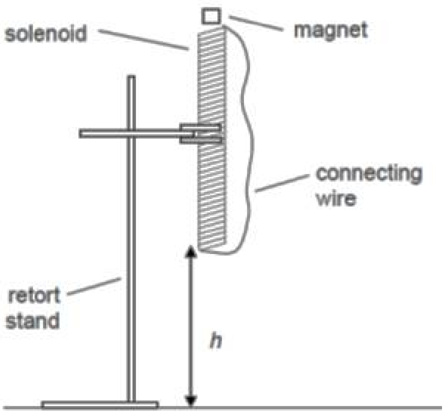
Force consideration:

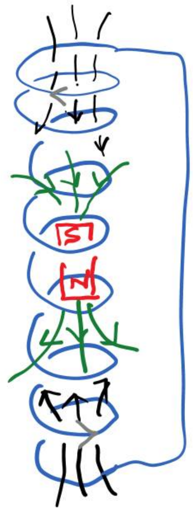
- as the magnet falls, the copper pipe cuts the magnetic flux.
- e.m.f. / curents are induced in the copper pipe.
- induced current creates magnetic force acting on the magnet.
- the force opposes motion of magnet, so it slows down.

Energy consideration:

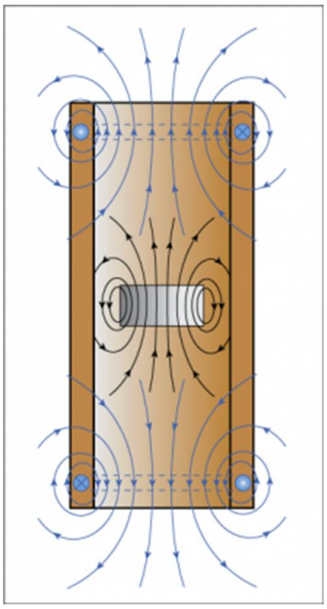
- as the magnet falls, the copper pipe cuts the magnetic flux.
- e.m.f / currents are induced in the copper pipe.
- heating of pipe (in resistance of pipe) and energy is taken/derived from energy of falling magnet
- less energy available for motion so magnet has acceleration less than *g*.

(b) When the magnet is completely inside the solenoid, the induced e.m.f. above and below the magnet are opposite in direction. Hence the net e.m.f. induced is zero. Therefore, there is no induced current in the solenoid, and the magnet does not experience any opposing force (except at the point of entry and exit of the solenoid).





13 (a) Supplementary answer:



Model the tube as a stack of rings. (It isn't, of course, but the main effect does not depend on conduction along the tube axis.) Assume the N pole of the magnet to be pointing up.

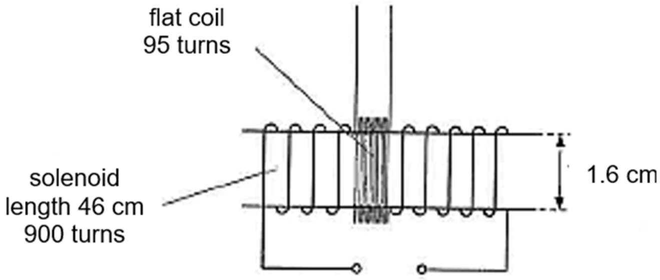
As the magnet falls through the pipe, it causes increasing upward flux through a given ring underneath it. This produces an e.m.f. in that ring tending to generate a "downward" flux to oppose the change and current is induced, which runs around the perimeter of the pipe in the clockwise direction as viewed from above - i.e., a current into the page on the left and out of the page on the right. The dashed blue lines show a representative current loop going into the page on the left side and coming out of the page on the right side. The field produced by this current loop is indicated by the blue lines with arrows. It looks a lot like the field from the magnet, except it is upside-down; the falling magnet has its S pole facing down, while the current loop has its S pole facing up.

A similar effect occurs above the falling magnet. It causes decreasing upward flux through a given ring above it. This produces an e.m.f. in that ring tending to generate an 'upward" flux to oppose the change. In this case, current is generated in the opposite direction (counterclockwise as viewed from above) and produces a field with the S pole facing down.

The two current loops both oppose the effects of the falling magnet. The falling magnet with its S pole facing downward encounters a magnetic field from the lower current loop with its S pole facing upwards. Since like magnetic poles repel each other, this field tries to push the disk magnet back upwards. Similarly, the upper current loop produces a field with its S pole facing downwards. This S pole pulls on the nearby N pole of the magnet and tries to pull it back upwards. Together, the two current loops combine to slow the fall of the magnet.

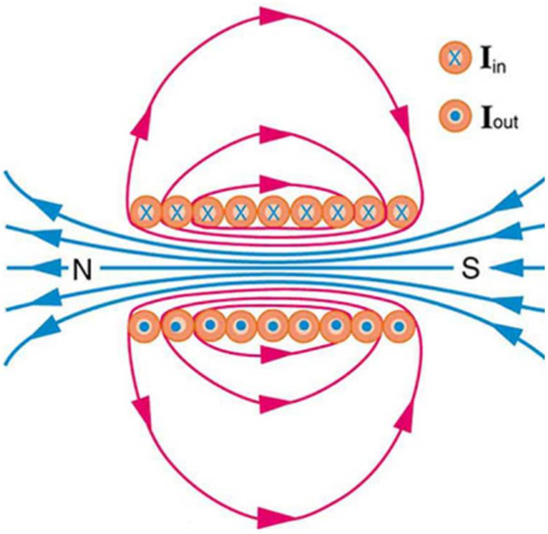
How come it still falls?
If the tube were a perfect conductor, any induced e.m.f. would generate a current big enough to completely compensate any attempted change in flux, and a strong enough magnet would simply stop falling. It is only because copper has a finite conductivity that the magnet ever comes out the bottom; the opposing force increases as the weight accelerates the magnet, eventually reaching a terminal velocity determined by the magnet's strength to weight ratio and the conductivity of the tube.

14



(a) (i) $B = \mu_0 nI = \left(4\pi \times 10^{-7}\right)\left(\dfrac{900}{46 \times 10^{-2}}\right)(2.4) = 5.9 \times 10^{-3}\ \text{T}$

(ii) The magnitude of the flux density at the ends of the solenoid is half of that at the centre, as shown by the spreading of field lines at the ends of the solenoid.



The relationship between magnetic flux density at the ends and centre of a solenoid can be understood through the continuous loop nature of magnetic field lines. Since magnetic field lines cannot begin or end (no magnetic monopoles exist), they must form complete circuits by emerging from one end, looping around externally, and entering the other end. While these field lines are concentrated and parallel within the solenoid's centre, they must spread out at the ends to complete their return path, creating the fringe field. This spreading of the same magnetic flux over a larger area at the ends naturally results in a field strength there that is half that at the centre.

(b) (i) during the time t = 0 to t = 1.5 ms,

$$\varepsilon = -\frac{d(N\Phi)}{dt} = -\frac{\Delta(N\Phi)}{\Delta t} = -\frac{(N\Phi)_f - (N\Phi)_i}{\Delta t} \quad ; \quad [\Phi = BA]$$

$$= -\frac{0-(95)(5.9\times10^{-3})\left[\frac{\pi}{4}(1.6\times10^{-2})^2\right]}{1.5\times10^{-3}} = 0.075 \text{ V}$$

when the current is 3.2 A,

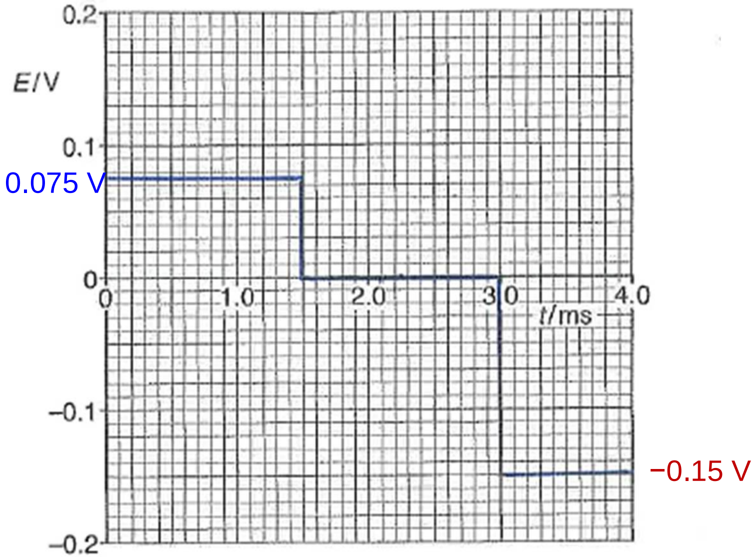
$$B = \mu_0 nI = (4\pi\times10^{-7})\left(\frac{900}{46\times10^{-2}}\right)(3.2) = 7.9\times10^{-3} \text{ T}$$

during the time t = 3.0 ms to t = 4.0 ms,

$$\varepsilon = -\frac{d(N\Phi)}{dt} = -\frac{\Delta(N\Phi)}{\Delta t} = -\frac{(N\Phi)_f - (N\Phi)_i}{\Delta t} \quad ; \quad [\Phi = BA]$$

$$= -\frac{(95)(7.9\times10^{-3})\left[\frac{\pi}{4}(1.6\times10^{-2})^2\right]-0}{1.0\times10^{-3}} = -0.15 \text{ V}$$

(b) (ii)



Note: To illustrate the e.m.f. behaviour: a constant positive magnitude from 0 to 1.5 ms, zero magnitude from 1.5 to 3.0 ms, and a constant negative magnitude from 3.0 to 4.0 ms.

15 (a) (i)	50 mT
(ii)	Flux linkage = NBA $= (150)(50 \times 10^{-3})(0.40 \times 10^{-4}) = 3.0 \times 10^{-4}$ Wb
(b) (i)	New flux linkage = $NB_{new}A = (150)(8.0 \times 10^{-3})(0.40 \times 10^{-4})$ $= 4.8 \times 10^{-5}$ Wb Decrease in flux linkage = 2.52×10^{-4} Wb
(ii)	Average e.m.f. = average rate of change of flux linkage $= (2.52 \times 10^{-4}) / (0.30)$ $= 8.4 \times 10^{-4}$ V
(c)	For a small change in distance *x*, the change in flux linkage decreases as distance increases, so speed must increase to keep (time) rate of change (of flux linkage) constant. **Or** Change in flux linkage decreases as distance increases at constant speed, hence e.m.f./rate of flux linkage decreases as *x* increases. So, increase speed to keep rate constant. Mathematically, $\varepsilon = -\frac{dN\Phi}{dt} = -NA\frac{dB}{dt} = -NA\frac{dB}{dx}\frac{dx}{dt} = -NA\frac{dB}{dx}v.$ Since $\frac{dB}{dx}$ decreases with increasing *x*, *v* must increase with increasing *x* to keep ε constant.

End