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ELECTROMAGMETIC INDUCTION

CBSE-XII

PHYSICS

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ELECTROMAGNETIC INDUCTION

POINTS TO REMEMBER

1. Electromagnetic Induction

The phenomenon of generation of induced emf and induced current due to change in magnetic field lines associated with a closed circuit is called electromagnetic induction.

2. Magnetic Flux

Magnetic flux through a surface of area A placed in a uniform magnetic field is $\phi_m = \vec{B}.\vec{A} = BA\cos\theta$, θ being angle between $\vec{B}$ and normal to $\vec{A}$. If magnetic field is not uniform, then $\phi_m = \int_A \vec{B}.d\vec{A}$, where integral extends for whole area A.

The SI unit of magnetic flux is weber. Magnetic flux is a scalar quantity; because of being scalar product of two vectors $\vec{B}$ and $\vec{A}$.

3. Faraday's Laws of Electromagnetic Induction

(*i*) Whenever there is a change in magnetic flux linked with a coil, an emf is induced in the coil. The induced emf is proportional to the rate of change of magnetic flux linked with the coil.

i.e., $\varepsilon \propto \frac{\Delta\phi}{\Delta t}$

(*ii*) emf induced in the coil opposes the change in flux, *i.e.*,

$$\varepsilon \propto -\frac{\Delta\phi}{\Delta t} \Rightarrow \varepsilon = -k\frac{\Delta\phi}{\Delta t}$$

where k is a constant of proportionality.

Negative sign represents opposition to change in flux.

In SI system ϕ is in weber, t in second, ε in volt, when $k = 1, \varepsilon = -\frac{\Delta\phi}{\Delta t}$

If the coil has N-turns, then $\varepsilon = -N\frac{\Delta\phi}{\Delta t}$

4. Induced Current and Induced Charge

If a coil is closed and has resistance R, then current induced in the coil,

$$I = \frac{\varepsilon}{R} = -\frac{N}{R}\frac{\Delta\phi}{\Delta t}$$

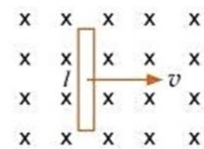
Induced charge, $q = I\,\Delta t = -\frac{N\Delta\phi}{R} = \frac{\text{Total flux linkage}}{\text{Resistance}}$

POINTS TO REMEMBER

5. Lenz's Law

It states that the direction of induced emf is such that it tends to produce a current which opposes the change in magnetic flux producing it.

6. EMF Induced in a Moving Conducting Rod



EMF induced in a conducting rod of length l moving with velocity v in a magnetic field of induction B, such that B, l and v are mutually perpendicular, is given by

$$\varepsilon = Bvl$$

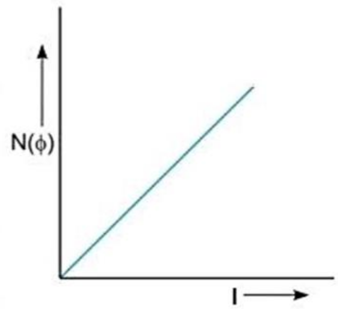
force required to keep the rod in constant motion is $F = BIL = \frac{B^2 l^2 v}{r}$

7. Self Induction

When the current in a coil is changed, an induced emf is produced in the same coil. This phenomenon is called self-induction. If L is self-inductance of coil, then

$$N\phi \propto I \text{ or } N\phi = LI \Rightarrow L = \frac{N\phi}{I}$$

L is also called coefficient of self induction.



The graph between effective magnetic flux ($N\phi$) and current I is straight line of slope self inductance L.

Also induced emf $\varepsilon = -L\frac{\Delta I}{\Delta t}$

The unit of self inductance is henry (H). The self induction acts as inertia in electrical circuits; so it is also called electrical inertia.

The self inductance of a solenoid consisting core of relative permeability μ_r is $L = \mu_r \mu_0 n^2 A l$

where $n = \frac{N}{l}$ is the number of turns per metre length.

8. Mutual Induction

When two coils are placed nearby and the current in one coil (often called primary coil) is changed, the magnetic flux linked with the neighbouring coil (often called secondary coil) changes; due to which an emf is induced in the neighbouring coil. This effect is called the mutual induction. If M is mutual inductance of two coils, then $\phi_2 \propto I_1$ or $\phi_2 = MI_1$

Definition of mutual inductance: $M = \frac{\phi_2}{I_1}$.

The mutual inductance of two coils is defined as the magnetic flux linked with the secondary coil when the current in primary coil is 1 ampere.

Also induced emf in secondary coil $\varepsilon_2 = -M\frac{\Delta I_1}{\Delta t} \Rightarrow M = -\frac{\varepsilon_2}{\Delta I_1/\Delta t}$.

The mutual inductance of two coils is defined as the emf induced in the secondary coil when the rate of change of current in the primary coil is 1 A/s.

The SI unit of mutual inductance is also henry (H). The mutual inductance of two coils does not depend on the fact which coil carries the current and in which coil emf is induced *i.e.*, $M_{12} = M_{21} = M$

This is also called reciprocity theorem of mutual inductance.

If L_1 and L_2 are self-inductances of two coils with 100% flux linkage between them, then $M = \sqrt{L_1 L_2}$, otherwise $M = k\sqrt{L_1 L_2}$, where k is coefficient of flux linkage between the coils.

Mutual Inductance of solenoid-coil system

$$M = \frac{\mu_0 N_1 N_2 A}{l}$$

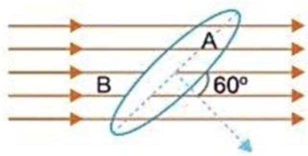
where A is area of coil, l is length of solenoid, N_1 is number of turns in solenoid and N_2 is number of turns in coil.

Multiple Choice Questions

Choose and write the correct option(s) in the following questions.

1. **Whenever the flux linked with a circuit changes, there is an induced emf in the circuit. This emf in the circuit lasts**
   (*a*) for a very short duration
   (*b*) for a long duration
   (*c*) forever
   (*d*) as long as the magnetic flux in the circuit changes.

2. **An area $A = 0.5\ m^2$ shown in the figure is situated in a uniform magnetic field $B = 4.0\ Wb/m^2$ and its normal makes an angle of 60° with the field. The magnetic flux passing through the area A would be equal to**

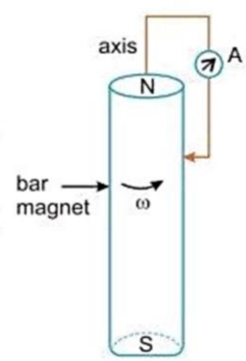


   (*a*) 2.0 weber (*b*) 1.0 weber (*c*) $\sqrt{3}$ weber (*d*) 0.5 weber

3. **A square of side L meters lies in the X-Y plane in a region, where the magnetic field is given by $B = B_o(2\hat{i} + 3\hat{j} + 4\hat{k})\,T$, where B_o is constant. The magnitude of flux passing through the square is** [*NCERT Exemplar*]
   (*a*) $2\,B_o L^2$ Wb (*b*) $3\,B_o L^2$ Wb (*c*) $4\,B_o L^2$ Wb (*d*) $\sqrt{29}\,B_o L^2$ Wb

4. **A loop, made of straight edges has six corners at $A(0, 0, 0)$, $B(L, 0, 0)$, $C(L, L, 0)$, $D(0, L, 0)$ $E(0, L, L)$ and $F(0, 0, L)$. A magnetic field $B = B_o(\hat{i} + \hat{k})\,T$ is present in the region. The flux passing through the loop $ABCDEFA$ (in that order) is** [*NCERT Exemplar*]
   (*a*) $B_o L^2$ Wb (*b*) $2\,B_o L^2$ Wb (*c*) $\sqrt{2}\,B_o L^2$ Wb (*d*) $4\,B_o L^2$ Wb

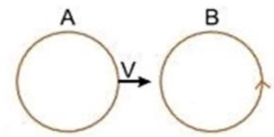
5. **An emf is produced in a coil, which is not connected to an external voltage source. This can be due to** [*NCERT Exemplar*]
   (*a*) the coil being in a time varying magnetic field.
   (*b*) the coil moving in a time varying magnetic field.
   (*c*) the coil moving in a constant magnetic field.
   (*d*) the coil is stationary in external spatially varying magnetic field, which does not change with time.



6. **A cylindrical bar magnet is rotated about its axis (Figure given alongside). A wire is connected from the axis and is made to touch the cylindrical surface through a contact. Then** [*NCERT Exemplar*]
   (*a*) a direct current flows in the ammeter A.
   (*b*) no current flows through the ammeter A.
   (*c*) an alternating sinusoidal current flows through the ammeter A with a time period $T = 2\pi/\omega$.
   (*d*) a time varying non-sinusoidal current flows through the ammeter A.

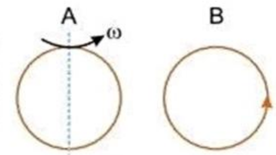
7. **A copper ring is held horizontally and a magnet is dropped through the ring with its length along the axis of the ring. The acceleration of the falling magnet is**
   (*a*) equal to that due to gravity
   (*b*) less than that due to gravity
   (*c*) more than that due to gravity
   (*d*) depends on the diameter of the ring and the length of the magnet

8. There are two coils A and B as shown in the figure. A current starts flowing in B as shown, when A is moved towards B and stops when A stops moving. The current in A is counter clockwise. B is kept stationary when A moves. We can infer that *[NCERT Exemplar]*



(*a*) there is a constant current in the clockwise direction in A.
(*b*) there is a varying current in A.
(*c*) there is no current in A.
(*d*) there is a constant current in the counterclockwise direction in A.

9. Same as the above problem except the coil *A* is made to rotate about a vertical axis refer to the figure. No current flows in *B* if *A* is at rest. The current in coil *A*, when the current in *B* (at $t = 0$) is counterclockwise and the coil *A* is as shown at this instant, $t = 0$, is *[NCERT Exemplar]*



(*a*) constant current clockwise. (*b*) varying current clockwise.
(*c*) varying current counterclockwise. (*d*) constant current counterclockwise.

10. Lenz's law is essential for
(*a*) conservation of energy (*b*) conservation of mass
(*c*) conservation of momentum (*d*) conservation of charge

11. The self inductance *L* of a solenoid of length *l* and area of crosssection *A*, with a fixed number of turns *N* increases as *[NCERT Exemplar]*
(*a*) *l* and *A* increase. (*b*) *l* decreases and *A* increases.
(*c*) *l* increases and *A* decreases. (*d*) both *l* and *A* decrease.

12. A thin circular ring of area *A* is held perpendicular to a uniform magnetic field of induction *B*. A small cut is made in the ring and a galvanometer is connected across its ends in such a way that the total resistance of the circuit is *R*. When the ring is suddenly squeezed to zero area, the charge flowing through the galvanometer is

(*a*) $\frac{BR}{A}$ (*b*) $\frac{AB}{R}$ (*c*) ABR (*d*) $\frac{B^2A}{R^2}$

13. A circular coil expands radially in a region of magnetic field and no electromotive force is produced in the coil. This can be because *[NCERT Exemplar]*
(*a*) the magnetic field is constant.
(*b*) the magnetic field is in the same plane as the circular coil and it may or may not vary.
(*c*) the magnetic field has a perpendicular (to the plane of the coil) component whose magnitude is decreasing suitably.
(*d*) there is a constant magnetic field in the perpendicular (to the plane of the coil) direction.

14. A thin diamagnetic rod is placed vertically between the poles of an electromagnet. When the current in the electromagnet is switched on, then the diamagnetic rod is pushed up, out of the horizontal magnetic field. Hence the rod gains gravitational potential energy. The work required to do this comes from

(*a*) the current source
(*b*) the magnetic field
(*c*) the lattice structure of the material of the rod
(*d*) the induced electric field due to the changing magnetic field

15. A circular loop of radius *r*, carrying a current *I* lies in *y-z* plane with its centre at the origin. The net magnetic flux through the loop is *[CBSE 2020 (55/4/1)]*

(*a*) directly proportional to *r*
(*b*) zero
(*c*) inversely proportional to *r*
(*d*) directly proportional to *I*

16. The self-inductance of a solenoid of 600 turns is 108 mH. The self-inductance of a coil having 500 turns with the same length, the same radius and the same medium will be *[CBSE 2022 (55/2/4), Term-1]*

(*a*) 95 mH (*b*) 90 mH (*c*) 85 mH (*d*) 75 mH

17. The current in the primary coil of a pair of coils changes from 7A to 3A in 0.04 s. The mutual inductance between the two coils is 0.5 H. The induced emf in the secondary coil is *[CBSE 2022 (55/2/4), Term-1]*

(*a*) 50 V (*b*) 75 V (*c*) 100 V (*d*) 220 V

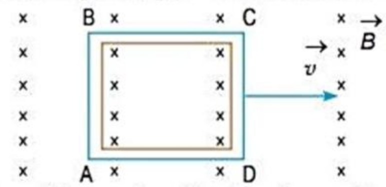
18. A conducting square loop of side '*L*' and resistance '*R*' moves in its plane with the uniform velocity '*v*' perpendicular to one of its sides. A magnetic induction '*B*' constant in time and space pointing perpendicular and into the plane of the loop exists everywhere as shown in the figure. The current induced in the loop is *[CBSE Sample Paper-2022, Term-1]*

(*a*) BLv/R clockwise

(*b*) BLv/R anticlockwise

(*c*) $2BLv/R$ anticlockwise

(*d*) zero



19. Two coils are placed close to each other. The mutual inductance of the pair of coils depends upon the *[CBSE Sample Paper-2022, Term-1]*

(*a*) rate at which current change in the two coils

(*b*) relative position and orientation of the coils

(*c*) rate at which voltage induced across two coils

(*d*) currents in the two coils

20. The magnetic flux linked with the coil (in weber) is given by the equation,

$$\phi = 5t^2 + 3t + 16$$

The induced EMF in the coil at time, $t = 4$ will be *[CBSE Sample Paper-2022, Term-1]*

(*a*) – 27 V (*b*) – 43 V (*c*) – 108 V (*d*) 210 V

21. A circular loop of radius 0.3 cm lies parallel to much bigger circular loop of radius 20 cm. The centre of the small loop is on the axis of the bigger loop. The distance between their centres is 15 cm. If a current of 2.0 A flows through the smaller loop, then the flux linked with the bigger loop is *[CBSE Sample Paper-2022, Term-1]*

(*a*) 3.3×10^{-11} weber (*b*) 6×10^{-11} weber (*c*) 6.6×10^{-9} weber (*d*) 9.1×10^{-11} weber

22. If both the number of turns and core length of an inductor is doubled keeping other factors constant, then its self-inductance will be *[CBSE Sample Paper-2022, Term-1)]*

(*a*) unaffected (*b*) doubled (*c*) halved (*d*) quadrupled

23. A circular coil of radius 8.0 cm and 40 turns is rotated about its vertical diameter with an angular speed off $\frac{25}{\pi}$ rad s^{-1} in a uniform horizontal magnetic field of magnitude 3.0×10^{-2} T. The maximum emf induced in the coil is *[CBSE 2023 (55/1/1)]*

(*a*) 0.12 V (*b*) 0.15 V (*c*) 0.19 V (*d*) 0.22 V

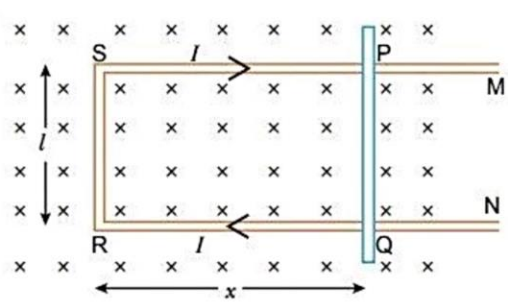
24. Figure shows a rectangular conductor *PSRQ* in which movable arm *PQ* has a resistance '*r* and resistance of *PSRQ* is negligible. The magnitude of emf induced when *PQ* is moved with a velocity $\vec{v}$ does not depend on *[CBSE 2020 (55/4/1)]*

(*a*) magnetic field $\vec{B}$

(*b*) velocity field $\vec{v}$

(*c*) resistance (r)

(*d*) length of *PQ*



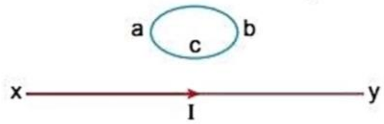
25. **The direction of induced current in the loop *abc* is** [*CBSE 2023 (55/4/1)*]

(*a*) along *abc* if *I* decreases

(*b*) along *acb* if *I* increases

(*c*) along *abc* if *I* constant

(*d*) along *abc* if *I* increases



Answers

1. (*d*)	**2.** (*b*)	**3.** (*c*)	**4.** (*b*)	**5.** (*a*), (*b*), (*c*)	**6.** (*b*)	**7.** (*b*)
8. (*d*)	**9.** (*a*)	**10.** (*a*)	**11.** (*b*)	**12.** (*b*)	**13.** (*b*), (*c*)	**14.** (*a*)
15. (*b*)	**16.** (*d*)	**17.** (*a*)	**18.** (*d*)	**19.** (*b*)	**20.** (*b*)	**21.** (*d*)
22. (*b*)	**23.** (*c*)	**24.** (*c*)	**25.** (*d*)			

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Assertion-Reason Questions

In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.

(*a*) *Both A and R are true and R is the correct explanation of A.*

(*b*) *Both A and R are true but R is not the correct explanation of A.*

(*c*) *A is true but R is false.*

(*d*) *A is false and R is also false.*

1. **Assertion(*A*)** : An emf is induced in a closed loop where magnetic flux is varied. The induced field $\vec{E}$ is not a conservative field.

   Reason (*R*) : The line integral $\oint \vec{E}.\vec{dl}$ around a closed path is non-zero. [*AIIMS 2006*]

2. **Assertion(*A*)** : Faraday established induced emf experimentally.

   Reason (*R*) : Magnetic flux can produce an induced emf.

3. **Assertion(*A*)** : The direction of induced emf is always such as to oppose the changes that causes it.

   Reason (*R*) : The direction of induced emf is given by Lenz's law .

4. **Assertion(*A*)** : Acceleration of a vertically falling magnet through a horizontal metallic ring is less than *g*.

   Reason (*R*) : Current induced in the ring opposes the fall of magnet.

5. **Assertion(*A*)** : Only a change of magnetic flux will maintain an induced current in the coil.

   Reason (*R*) : The presence of a large magnetic flux will maintain an induced current in the coil.

6. **Assertion(*A*)** : The presence of large magnetic flux through a coil maintains a current in the coil, if the circuit is continuous.

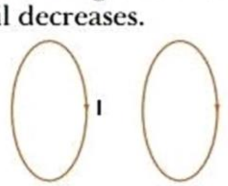
   Reason (*R*) : Only a change in magnetic flux will maintain an induced current in the coil. [*AIIMS 2018*]

7. **Assertion(*A*)** : If we use a battery across the primary of a step up transformer, then voltage is also obtained across secondary.

   Reason (*R*) : Battery gives a time varying current, so there is a change in magnetic flux through the secondary of transformer and hence, emf is induced across secondary.

8. **Assertion(*A*)** : Two identical co-axial circular coils carry equal currents circulating in same direction. If coils approach each other, the current in each coil decreases.

   Reason (*R*) : When coils approach each other, the magnetic flux linked with each coil increases. According to Lenz's law, the induced current in each coil will oppose the increase in magnetic flux, hence, the current in each coil will decrease.



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9. **Assertion** (*A*) : When a rod moves in a transverse magnetic field, an emf is induced in the rod; the end becomes magnetic with end *A* positive.

Reason (*R*) : A Lorentz force *evB* acts on free electrons, so electrons move from *B* to *A*, thus by making end *A* positive and end *B* negative.

10. **Assertion** (*A*) : In the phenomenon of mutual induction, self-induction of each of the coils persists

Reason (*R*) : Self-induction arises when strength of current in same coil changes. In mutual induction, current is changed in both individual coils.

Answers

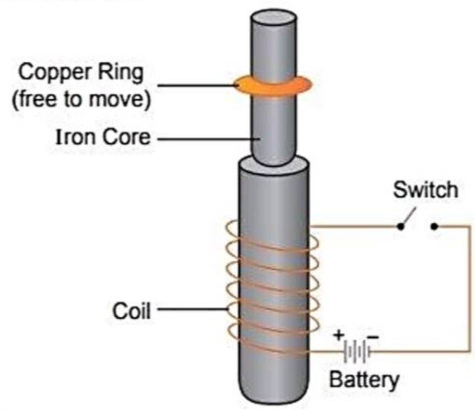
1. (*a*) **2.** (*c*) **3.** (*b*) **4.** (*a*) **5.** (*c*) **6.** (*d*) **7.** (*a*)
8. (*a*) **9.** (*b*) **10.** (*b*)

COMPETENCY-FOCUSED QUESTIONS AS PER NEP

Case-based/Passage-based Questions

Read the paragraph given below and answer the questions that follow:

Electromagnetic Induction: Consider the experimental set up shown in the figure. This jumping ring experiment is an outstanding demonstration of some simple laws of Physics. A conducting non-magnetic ring is placed over the vertical core of a solenoid. When current is passed through the solenoid, the ring is thrown off. [*CBSE 2023 (55/2/1), Modified*]



(*i*) **The direction of induced current in the ring in jumping ring experiment is such that the polarity developed in the ring is same as that of the polarity on the face of the coil, then ring will jump up due to**

(*a*) attractive force when the switch is closed in the circuit.
(*b*) repulsive force when the switch is closed in the circuit.
(*c*) attractive force when the switch is closed in the circuit.
(*d*) repulsive force when the switch is closed in the circuit.

(*ii*) **What will happen if the terminals of the battery are reversed and the switch is closed?**

(*a*) Ring will not be jump.
(*b*) Ring will jump again.
(*c*) Current will not induced in the ring.
(*d*) none of these

(*iii*) **The jumping ring experiment based on which of the following law?**

(*a*) Lenz's Law (*b*) Faraday's law
(*c*) Snell's Law (*d*) both (*a*) and (*b*)

(iv) Two identical circular loops *A* and *B* of metal wire are lying on a table without touching each other. Loop *A* carries a current which increases with time. In response the loop *B*

(a) remains stationary.

(b) is attracted by loop *A*.

(c) is repelled by loop *A*.

(d) rotates about its centre of mass with centre of mass fixed.

OR

An emf of 200 V is induced in a circuit when current in the circuit falls from 5 A to 0 A in 0.1 second. The self-inductance of the circuit is

(a) 3.5 H (b) 3.9 H

(c) 4 H (d) 4.2 H

Explanations

(i) (b) The direction of induced current in the ring is such that the polarity developed in the ring is same as that of the polarity on the face of the coil, hence it will jump up due to repulsive force.

(ii) (b) The polarity of the induced current in the ring will get reversed on changing the terminals of the battery, so the ring will jump again.

(iii) (d) **Lenz's law:** It states that the polarity of induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produces it.

Faraday's law of EMI:

Whenever there is change in magnetic flux through a coil, an emf is induced.

The magnitude of the induced emf in a coil is equal to the time rate of change of change of magnetic flux through the coil.

(iv) (c) Opposite currents are induced in loops, so loops repel each other.

OR

(c) Self inductance, $L = \dfrac{e}{\left(\dfrac{\Delta I}{\Delta t}\right)} = \dfrac{200}{\left(\dfrac{5}{0.1}\right)} = 4\text{ H}$

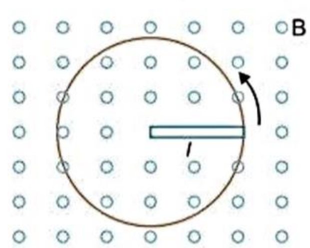
CONCEPTUAL QUESTIONS

Q. 1. Two spherical bobs, one metallic and the other of glass, of the same size are allowed to fall freely from the same height above the ground. Which of the two would reach earlier and why? **[*CBSE Delhi 2014*]**

Ans. Glass would reach earlier. This is because there is no effect of electromagnetic induction in glass, due to presence of earth's magnetic field, unlike in the case of metallic ball.

Q. 2. A 1.0 m metallic rod is rotated with an angular velocity of 400 rad/s about an axis normal to the rod passing through its one end. The other end of the rod is in contact with a circular metallic ring. A constant and uniform magnetic field of 0.5 T parallel to the axis exists everywhere. Calculate the emf developed between the centre and the ring. **[*NCERT*]**

Ans. EMF developed between the centre of ring and the point on the ring.



$$\varepsilon = \frac{1}{2}B\omega l^2$$

Given $B = 0.5$ T, $\omega = 400$ rad/s, $l = 1.0$ m.

$\therefore \quad \varepsilon = \frac{1}{2} \times 0.5 \times 400 \times (1.0)^2 = \mathbf{100\ volt}$

Q. 3. A long straight current carrying wire passes normally through the centre of circular loop. If the current through the wire increases, will there be an induced emf in the loop? Justify. [*CBSE Delhi 2017*]

Ans. No.

Justification: As the magnetic field due to current carrying wire will be in the plane of the circular loop, so magnetic flux will remain zero. Also, magnetic flux does not change with the change in current.

Q. 4. A solenoid with N loops of wire tightly wrapped around an iron-core is carrying an electric current I. If the current through this solenoid is reduced to half, then what change would you expect in inductance L of the solenoid? [*CBSE Sample Paper 2021*]

Ans. The inductance is given as,

$$L = \mu_0 \frac{N^2 A}{l}$$

Since the inductance does not depend upon the amount of current, the inductance of solenoid remains same.

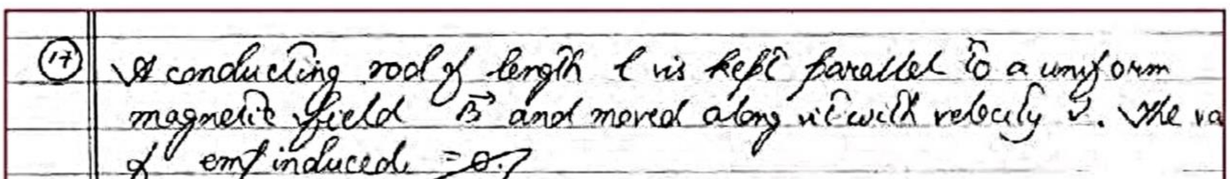
Q. 5. On what factors does the magnitude of the emf induced in the circuit due to magnetic flux depend? [*CBSE (F) 2013*]

Ans. It depends on the rate of change in magnetic flux (or simply change in magnetic flux).

$$|\varepsilon| = \frac{\Delta\phi}{\Delta t}$$

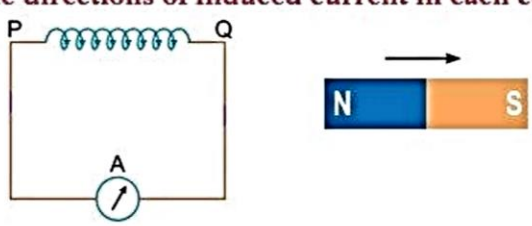
Q. 6. A conducting rod of length l is kept parallel to a uniform magnetic field $\vec{B}$. It is moved along the magnetic field with a velocity $\vec{v}$. What is the value of emf induced in the conductor. [*CBSE 2020 (55/2/1)*]

Ans.

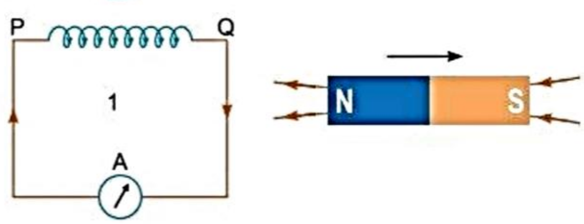

(17) A conducting rod of length l is kept parallel to a uniform magnetic field $\vec{B}$ and moved along it with velocity $\vec{v}$. The va of emf induced = 0.

[*Topper's Answer 2020*]

Q. 7. A bar magnet is moved in the direction indicated by the arrow between two coils PQ and CD. Predict the directions of induced current in each coil. [*CBSE (AI) 2012, 2017*]



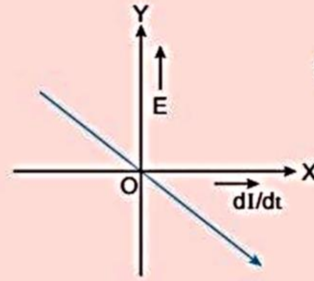
Ans.



In figure, N-pole is receding away coil (PQ), so in coil (PQ), the nearer faces will act as S-pole and in coil (CD) the nearer face will also act as S-pole to oppose the approach of magnet towards coil (CD), so currents in coils will flow clockwise as seen from the side of magnet. The direction of current will be from P to Q in coil (PQ) and from C to D in coil (CD).

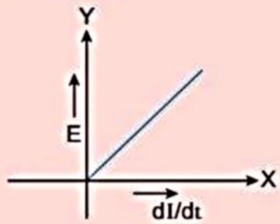
Q. 8. Plot a graph showing variation of induced e.m.f. with the rate of change of current flowing through a coil. **[CBSE 2020 (55/5/1)]**

Ans. Induced e.m.f. in a coil, $\varepsilon = -L\frac{dI}{dt}$



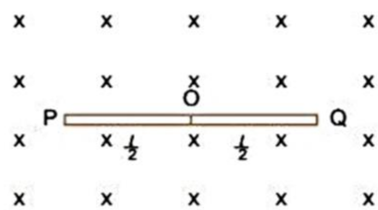
[Award one full mark even if the student just draws the graph without writing the expression of induced emf] **1**

(**Note:** Award this one mark if a student draws the graph in first quadrant as shown below,)



[CBSE Marking Scheme 2020 (55/5/1)]

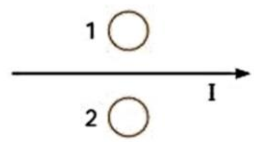
Q. 9. A metallic rod *PQ* of length *l* is rotated with an angular with an angular velocity ω in a magnetic field $\vec{B}$ about an axis passing through the mid-point *O* of the rod and perpendicular to the plane of paper as shown in the figure. What is the potential difference developed between the point *O* and *Q* of the rod? **[CBSE 2020 (55/2/3)]**



Ans. Emf induced in the rod, $\varepsilon = \frac{1}{2}B\omega l^2$

for Emf induced between O and Q, $\varepsilon = \frac{1}{2}B\omega\left(\frac{l}{2}\right)^2 = \frac{1}{8}B\omega l^2$

Q. 10. Predict the directions of induced currents in metal rings 1 and 2 lying in the same plane where current *I* in the wire is increasing steadily.



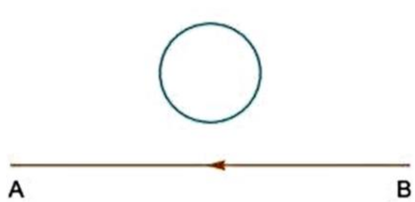
[CBSE, (AI) 2017]

Ans. 2. When current is increasing magnetic flux linked [redacted] with the two coils also increases. The $\vec{B}$ due to the current element in 2 is into the plane and 1 is out of the plane. Since flux increases direction of induced current is oppo such that the $\vec{B}$ due to it is opposite to the original flux. So the induced current in the loop 1 is in clockwise direction and 2 is in anticlockwise direction

[Topper's Answer 2017]

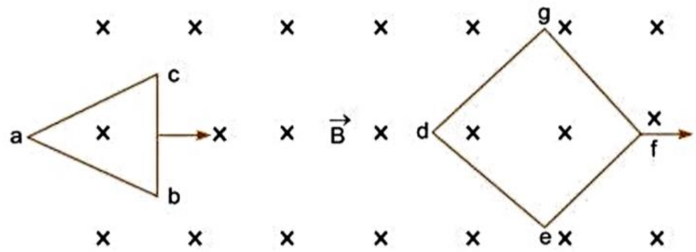
Q. 11. The electric current flowing in a wire in the direction from *B* to *A* is decreasing. Find out the direction of the induced current in the metallic loop kept above the wire as shown.

[CBSE (AI) 2014]



Ans. The current in the wire produces a magnetic field vertically downward in the vicinity of the coil. When the current in wire *BA* decreases, according to Lenz's law, the current induced in the coil opposes this decrease; so the current in the coil will be in clockwise direction.

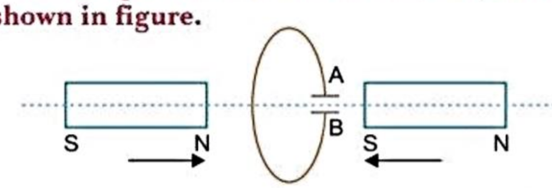
Q. 12. Two loops of different shapes are moved in the region of a uniform magnetic field pointing downward. The loops are moved in the directions shown by arrows. What is the direction of induced current in each loop? **[*CBSE (F) 2010*] [*HOTS*]**



Ans. Loop *abc* is entering the magnetic field, so magnetic flux linked with it begins to increase. According to Lenz's law, the current induced opposes the increases in magnetic flux, so current induced will be **anticlockwise** which tends to decrease the magnetic field.

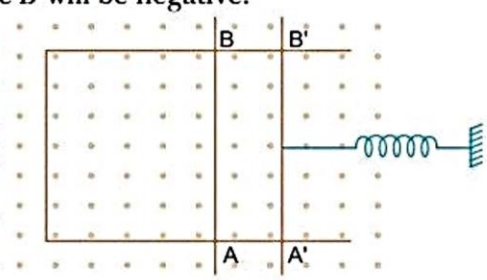
Loop *defg* is leaving the magnetic field; so flux linked with it tends to decrease, the induced current will be **clockwise** to produce magnetic field downward to oppose the decrease in magnetic flux.

Q. 13. Predict the polarity of the capacitor *C* connected to coil, which is situated between two bar magnets moving as shown in figure. **[*CBSE Delhi 2011, (AI) 2017*]**



Ans. Current induced in coil will oppose the approach of magnet; therefore, left face of coil will act as *N*-pole and right face as *S*-pole. For this the current in coil will be anticlockwise as seen from left, therefore, the plate *A* of capacitor will be positive and plate *B* will be negative.

Q. 14. A rectangular wire frame, shown below, is placed in a uniform magnetic field directed upward and normal to the plane of the paper. The part *AB* is connected to a spring. The spring is stretched and released when the wire *AB* has come to the position *A′ B′* ($t = 0$) How would the induced emf vary with time? Neglect damping. **[*HOTS*]**



Ans. When the spring is stretched and released, the wire *AB* will execute simple harmonic (sinusoidal) motion. So, the displacement of wire *AB* at any instant will be

$$x = -a\cos\omega t \quad [\text{at } t = 0, x = -a]$$

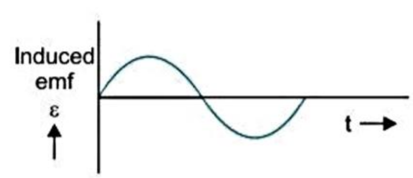
Magnetic flux linked with the loop at any instant,

$$\phi(t) = BA = Blx = -Bla\cos\omega t \qquad [\because A = lx]$$

By Faraday's law, emf induced across AB,

$$\varepsilon(t) = \frac{-d\phi}{dt} = \frac{-d}{dt}(-Bla\cos\omega t)$$

$$= Bla\omega\sin\omega t = \varepsilon_0\sin\omega t \qquad [\because \varepsilon_0 = Bla\omega]$$



Sinusoidal variation of induced emf

where $a = BB' = AA'$ is the amplitude of motion and ω is angular frequency.

Clearly induced emf $\varepsilon(t)$ Varies sinusoidally with time.

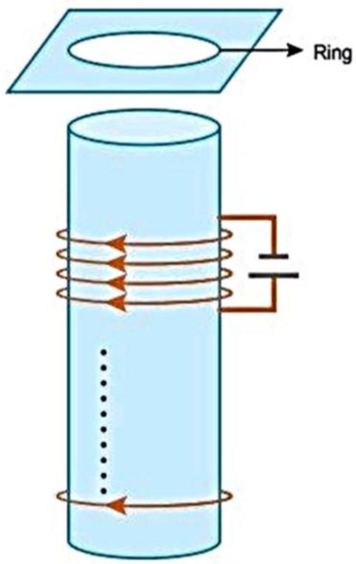
Q. 15. A wire in the form of a tightly wound solenoid is connected to a *DC* source, and carries a current. If the coil is stretched so that there are gaps between successive elements of the spiral coil, will the current increase or decrease? Explain. [*NCERT Exemplar*]

Ans. The current will increase. As the wires are pulled apart the flux will leak through the gaps. Lenz's law demands that induced emf resist this decrease, which can be done by an increase in current.

Q. 16. A solenoid is connected to a battery so that a steady current flows through it. If an iron core is inserted into the solenoid, will the current increase or decrease? Explain. [*NCERT Exemplar*]

Ans. The current will decrease. As the iron core is inserted in the solenoid, the magnetic field increases and the flux increases. Lenz's law implies that induced emf should resist this increase, which can be achieved by a decrease in current. However, this change will be momentarily.

Q. 17. Consider a metal ring kept (supported by a cardboard) on top of a fixed solenoid carrying a current *I* (in figure). The centre of the ring coincides with the axis of the solenoid. If the current in the solenoid is switched off, what will happen to the ring? [*NCERT Exemplar*]

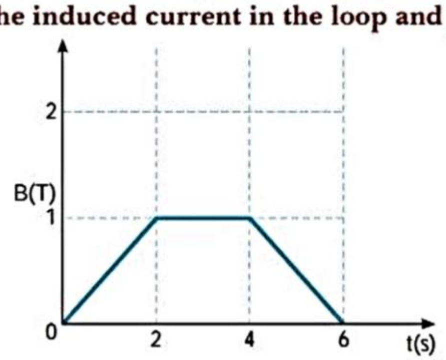


Ans. When the current in the solenoid decreases a current flows in the same direction in the metal ring as in the solenoid. Thus there will be a downward force. This means the ring will remain on the cardboard. The upward reaction of the cardboard on the ring will increase.

Very Short Answer Questions

Each of the following questions are of 2 marks.

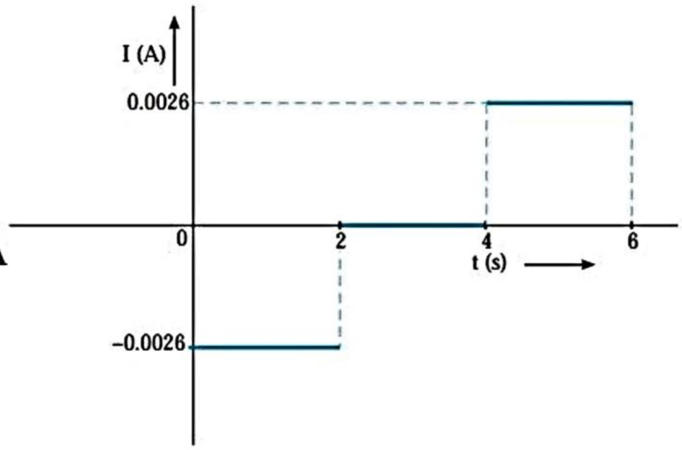
Q. 1. The magnetic field through a circular loop of wire 12 cm in radius and 8.5 Ω resistance, changes with time as shown in the figure. The magnetic field is perpendicular to the plane of the loop. Calculate the induced current in the loop and plot it as a function of time. [*CBSE (F) 2017*]



Ans. We know,

$$\varepsilon = \frac{-d\phi}{dt} = \frac{-d(BA)}{dt} = -A\frac{dB}{dt}$$

$$I = \frac{\varepsilon}{R} = \frac{-A\left(\frac{dB}{dt}\right)}{R} = \frac{-\pi r^2\left(\frac{dB}{dt}\right)}{R}$$



For 0< t< 2

$$I = \frac{-3.14(0.12)^2 \times 1}{2\times 8.5} = -\mathbf{0.0026\ A}$$

For, 2 < t < 4

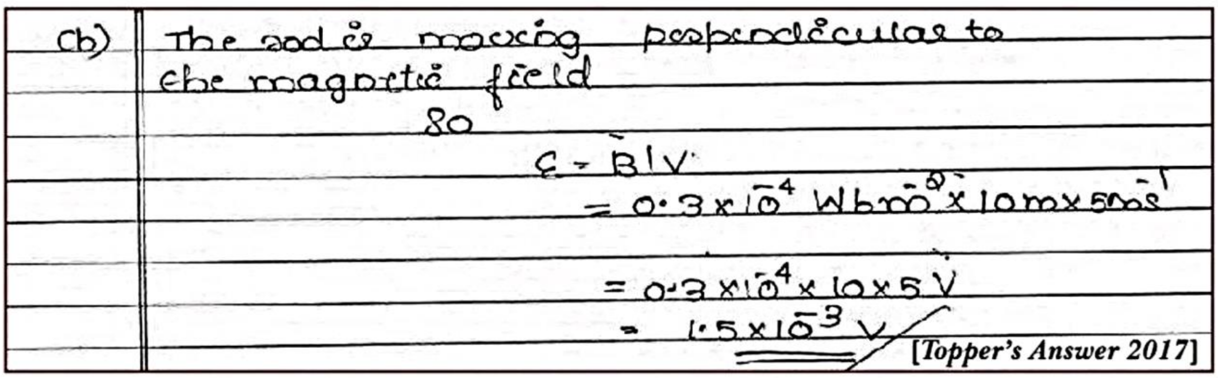
$$\frac{dB}{dt} = 0 \quad \Rightarrow \quad I = 0$$

For, 4 < t < 6

$$I = +\ \mathbf{0.0026\ A}$$

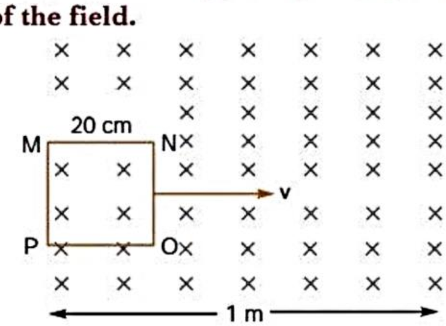
Q. 2. A horizontal conducting rod 10 m long extending from east to west is falling with a speed 5 ms^{-1} at right angles to the horizontal component of the Earth's magnetic field 0.3×10^{-4} Wbm^{-2}. Find the instantaneous value of the emf induced in the rod. [*CBSE (AI) 2017*]

Ans.


(b) The rod is moving perpendicular to the magnetic field
so
$\varepsilon = Blv$
$= 0.3\times10^{-4}\ \text{Wb m}^{-2} \times 10\,\text{m} \times 5\,\text{m s}^{-1}$
$= 0.3\times10^{-4}\times10\times5\ \text{V}$
$= 1.5\times10^{-3}\ \text{V}$

[*Topper's Answer 2017*]

Q. 3. A square loop *MNOP* of side 20 cm is placed horizontally in a uniform magnetic field acting vertically downwards as shown in the figure. The loop is pulled with a constant velocity of 20 cms^{-1} till it goes out of the field.



(*i*) Depict the direction of the induced current in the loop as it goes out of the field. For how long would the current in the loop persist?

(*ii*) Plot a graph showing the variation of magnetic flux and induced emf as a function of time.

[*CBSE Panchkula 2015*]

Ans. (*i*) Clockwise *MNOP*.

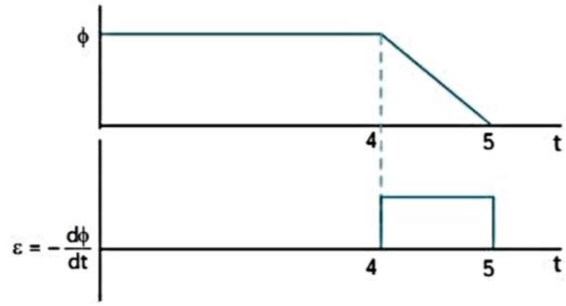
$$v = 20\text{ cm/s};\ d = 20\text{ cm}$$

Time taken by the loop to move out of magnetic field

$$t = \frac{d}{v} = \frac{20}{20} = \mathbf{1s}$$

Induced current will last for 1 second till the length 20 cm moves out of the field.

(*ii*)



Q. 4. A coil of wire enclosing an area 100 cm^2 is placed with its plane making an angle 60° with the magnetic field of strength 10^{-1}T. What is the flux through the coil? If magnetic field is reduced to zero in 10^{-3} s, then find the induced emf. **[*CBSE Sample Paper 2021*]**

Ans. Given, $A = 100\text{ cm}^2 = 100 \times 10^{-4}\text{ m}^2 = 10^{-2}\text{ m}^2$, $B = 10^{-1}$ T

Angle made by coil with magnetic field = 60°

Angle made by normal to plane of coil with magnetic field = 30°

Flux, $\phi = BA\cos\theta$

$$= 10^{-1} \times 10^{-2} \times \cos 30° = \frac{\sqrt{3}}{2} \times 10^{-3}\text{ Wb}$$

After $t = 10^{-3}$ s, $B = 0$

$$\text{Induce emf, } E = -\frac{d\phi}{dt} = -\left(\frac{0 - \frac{\sqrt{3}}{2}\times 10^{-3}}{10^{-3}}\right) = \frac{\sqrt{3}}{2}\text{V}$$

Q. 5. The energy stored in a solenoid of inductance *L* is *U*. The number of turns per unit length of the solenoid is doubled. Keeping the current and all other factors same, find (*a*) change in inductance of the solenoid, and (*b*) the final energy stored in the inductor. [*CBSE 2020 (55/3/2)*]

Ans. (*a*) Self-inductance, $L = \mu_0 \mu_r n^2 Al$

or alternatively, $L \propto n^2$ ½

So, L becomes, 4 times ½

(*b*) Energy stored, $U = \frac{1}{2} LI^2$ ½

As L increases 4 times, energy also increases 4 times. ½

[*CBSE Marking Scheme 2020 (55/3/2)*]

Q. 6. (*i*) Define mutual inductance.

(*ii*) A pair of adjacent coils has a mutual inductance of 1.5 H. If the current in one coil changes from 0 to 20 A in 0.5 s, what is the change of flux linkage with the other coil? [*CBSE Delhi 2016*]

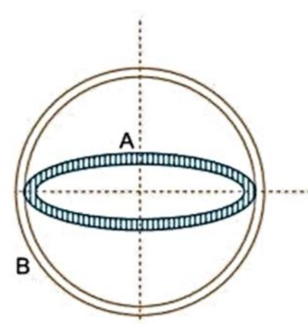
Ans. (*i*) Mutual inductance of two coils is the magnetic flux linked with the secondary coil when a unit current flows through the primary coil,

i.e., $\phi_2 = MI_1$ or $M = \frac{\phi_2}{I_1}$

(*ii*) Change of flux for small change in current

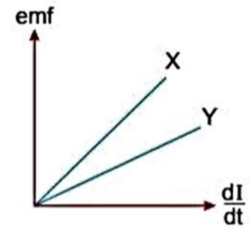
$$d\phi = MdI = 1.5\,(20 - 0)\text{ weber} = \mathbf{30\text{ weber}}$$

Q. 7. Two coils of wire *A* and *B* are placed mutually perpendicular as shown in figure. When current is changed in any one coil, will the current induce in another coil?



Ans. No; this is because the magnetic field due to current in coil (*A* or *B*) will be parallel to the plane of the other coil (*A* or *B*) Hence, the magnetic flux linked with the other coil will be zero and so no current will be induced in it.

Q. 8. The figure shows the variation of induced emf as a function of rate of change of current for two identical solenoids *X* and *Y*. One is air cored and the other is iron cored. Which one of them is iron cored? why? [*CBSE 2023 (55/4/1)*]



Ans. From the graph, slope $= \dfrac{\varepsilon}{\frac{dI}{dt}} = L$

Slope of *X* is more than that of *Y*. Hence *X* is iron-cored because inductance of iron cored coil is more than that of air-cored coil.

Q. 9. A small flat search coil of area 5 cm² with 140 closely wound turns is placed between the poles of a powerful magnet producing magnetic field 0.09 T and then quickly removed out of the field region. Calculate [*CBSE 2019 (55/3/1)*]

(*a*) change of magnetic flux through the coil, and

(*b*) emf induced in the coil.

Ans. (*a*) M flux $\phi_1 = N\vec{B}.\vec{A} = NBA\cos\theta$

$= NBA\cos 0° = NBA$

$= 140\times 0.09\times 5\times 10^{-4} = 63\times 10^{-4}$ Wb

$\phi_2 = NBA \quad [\because B = 0]$

$= 0$

Change in magnetic flux $= \phi_2 - \phi_1$

$= \mathbf{63 \times 10^{-2}}$ **Wb**

(*b*) εmf induced $= -\dfrac{d\phi}{dt} = \dfrac{-63\times 10^{-4}}{\Delta t}$.

[Here time is not given. Question is incomplete.]

Q. 10. A 0.5 m long solenoid of 10 turns/cm has area of cross-section 1 cm². Calculate the voltage induced across its ends if the current in the solenoid is changed from 1A to 2A in 0.1s. [*CBSE 2019 (55/3/1)*]

Ans. Induced voltage,

$|V| = L\dfrac{dI}{dt}$ ½

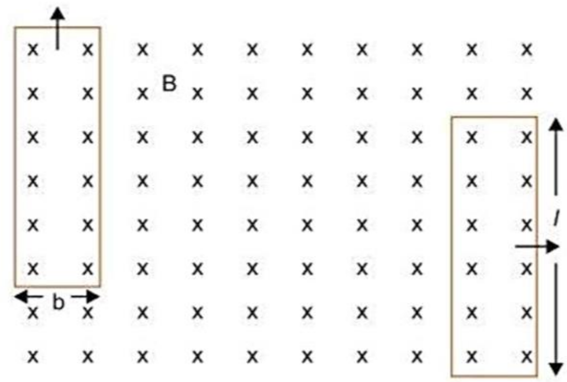
$\therefore \quad |V| = \mu_0 n^2 la\dfrac{dI}{dt}$ ½

$= 4\pi\times 10^{-7}\times (\dfrac{10}{10^{-2}})^2\times 0.5\times 110^{-4}\times \dfrac{(2-1)}{0.1}$ ½

$= 6.28\times 10^{-4}$ V or 0.628 mV ½

[*CBSE Marking Scheme 2019 (55/3/1)*]

Q. 11. A rectangular wire loop of sides 8 cm × 2 cm with a small cut is moving out of a region of uniform magnetic field of magnitude 0.3 T directed normal to the loop. What is the emf developed if the velocity of the loop is 1 cms⁻¹ in a direction normal to the (*i*) longer side (*ii*) shorter side of the loop? For how long does the induced voltage last in each case? [*NCERT*]



Ans. Given $l = 8$ cm $= 8 \times 10^{-2}$ m,

$b = 2$ cm $= 2 \times 10^{-2}$ m

$v = 1$ cm s^{-1} $= 1 \times 10^{-2}$ m/s, $B = 0.3$ T

(*i*) When velocity is normal to the longer side

Induced emf, $\varepsilon = Bvl$

$$= 0.3 \times 1 \times 10^{-2} \times 8 \times 10^{-2}$$

$$= \mathbf{24 \times 10^{-5}\ V}$$

emf will last only so long as the loop is in the magnetic field.

$$\text{Time taken} = \frac{\text{distance}}{\text{velocity}} = \frac{b}{v} = \frac{2 \times 10^{-2}}{1 \times 10^{-2}} = \mathbf{2\ s}$$

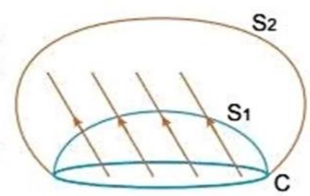
(*ii*) When velocity is normal to the shorter side

$$\varepsilon_2 = Bvb$$

$$= 0.3 \times 1 \times 10^{-2} \times 2 \times 10^{-2} = \mathbf{6 \times 10^{-5}\ V}$$

$$\text{Time taken} = \frac{l}{v} = \frac{8 \times 10^{-2}}{1 \times 10^{-2}} = \mathbf{8\ s}$$

Q. 12. Consider a closed loop C in a magnetic field (see figure). The flux passing through the loop is defined by choosing a surface whose edge coincides with the loop and using the formula $\phi = \vec{B_1}.d\vec{A_1} + \vec{B_2}.d\vec{A_2}$ ... Now if we chose two different surfaces S_1 and S_2 having C as their edge, would we get the same answer for flux. Justify your answer. **[*NCERT Exemplar*]**



Ans. One gets the same answer for flux. Flux can be thought of as the number of magnetic field lines passing through the surface (we draw $dN = BA$ lines in a area ΔA perpendicular to B). As field lines of B cannot end or start in space (they form closed loops), number of lines passing through surface S_1 must be the same as the number of lines passing through the surface S_2.

CONSTRUCTED RESPONSE QUESTIONS — AS PER NEP

Short Answer Questions

Each of the following questions are of 3 marks.

Q. 1. In an experimental arrangement of two coils C_1 and C_2 placed coaxially parallel to each other, find out the expression for the emf induced in the coil C_1 (of N_1 turns) corresponding to the change of current I_2 in the coil C_2 (of N_2 turns). **[*CBSE Chennai 2015*]**

Ans. Let ϕ_1 be the flux through coil C_1 (of N_1 turns) when current in coil C_2 is I_2. Then, we have

$$N_1\phi_1 = MI_2 \quad ...(i)$$

For current varying with time,

$$\frac{d(N_1\phi_1)}{dt} = \frac{d(MI_2)}{dt} \quad ...(ii)$$

Since induced *emf* in coil C_1 is given by

$$\varepsilon_1 = -\frac{d(N_1\phi_1)}{dt}$$

From (*ii*), $-\varepsilon_1 = M\left(\frac{dI_2}{dt}\right)$

$$\varepsilon_1 = -M\frac{dI_2}{dt} \quad \text{[from (i)]}$$

It shows that varying current in a coil induces emf in the neighbouring coil.

Q. 2. (*a*) **How does the mutual inductance of a pair of coils change when**

(*i*) distance between the coils is increased and

(*ii*) number of turns in the coils is increased? **[*CBSE (AI) 2013*]**

(*b*) **A plot of magnetic flux (ϕ) versus current (*I*), is shown in the figure for two inductors *A* and *B*. Which of the two has large value of self-inductance?** **[*CBSE Delhi 2010*]**

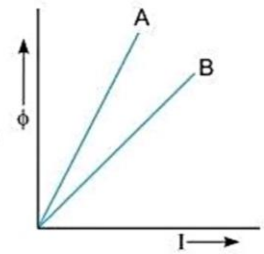
(*c*) **How is the mutual inductance of a pair of coils affected when**

(*i*) separation between the coils is increased?

(*ii*) the number of turns in each coil is increased?

(*iii*) a thin iron sheet is placed between the two coils, other factors remaining the same?

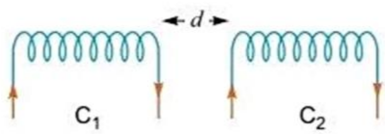
Justify your answer in each case. **[*CBSE (AI) 2013*]**



Ans. (*a*) (*i*) Mutual inductance decreases.

(*ii*) Mutual inductance increases.

Concept: (*i*) If distance between two coils is increased as shown in figure.



It causes decrease in magnetic flux linked with the coil C_2. Hence induced emf in coil C_2 decreases by relation $\varepsilon_2 = \frac{-d\varphi_2}{dt}$. Hence mutual inductance decreases.

(*ii*) From relation $M_{21} = \mu_0 n_1 n_2 Al$, if number of turns in one of the coils or both increases, means mutual inductance will increase.

(*b*) $\phi = LI \Rightarrow \frac{\phi}{I} = L$

The slope of $\frac{\phi}{I}$ of straight line is equal to self-inductance *L*. It is larger for inductor *A*; therefore inductor *A* has larger value of self inductance '*L*'.

(*c*) (*i*) When the relative distance between the coil is increased, the leakage of flux increases which reduces the magnetic coupling of the coils. So magnetic flux linked with all the turns decreases. Therefore, mutual inductance will be decreased.

(*ii*) Mutual inductance for a pair of coil is given by

$$M = K\sqrt{L_1 L_2}$$

where $L = \frac{\mu N^2 A}{l}$ and *L* is called self inductance. Therefore, when the number of turns in each coil increases, the mutual inductance also increases.

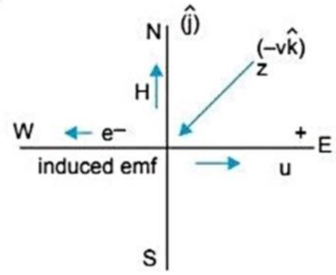
(*iii*) When a thin iron sheet is placed between the two coils, the mutual inductance increases because $M \propto$ permeability. The permeability of the medium between coils increases.

Q. 3. **A horizontal straight wire 10 m long extending from east to west is falling with a speed of 5.0 ms^{-1} at right angles to the horizontal component of earth's magnetic field equal to 0.30×10^{-4} Wbm^{-2}.** **[*NCERT*]**

(a) What is the instantaneous value of the emf induced in the wire?

(b) What is the direction of emf?

(c) Which emf of the wire is at the higher electrical potential?



Ans. (a) Instantaneous emf, $\varepsilon = B_n vl = Hvl$

Given, $H = 0.30 \times 10^{-4}$ T, $v = 5.0$ ms^{-1}, $l = 10$ m

$\therefore \quad \varepsilon = 0.30 \times 10^{-4} \times 5.0 \times 10 = 1.5 \times 10^{-3}$ V$=$**1.5 mV**

(b) By Fleming's right hand rule, the direction of induced current in wire is from west to east, therefore, direction of emf is from west to east.

(c) The direction of electron flow according to relation $\vec{F}_m = q\vec{v} \times \vec{B} = -e(-v\hat{k}) \times (B\hat{j}) = -evB\hat{i}$ *i.e.*, along negative *x*-axis, *i.e.*, from east to west.

The induced emf will oppose the flow of electrons from east to west, so eastern end will be at higher potential.

Q. 4. Define self-inductance of a coil. Show that magnetic energy required to build up the current I in a coil of self inductance L is given by $\frac{1}{2}LI^2$. [*CBSE Delhi 2012*]

OR

Define the term self-inductance of a solenoid. Obtain the expression for the magnetic energy stored in an inductor of self-inductance L to build up a current I through it. [*CBSE (AI) 2014*]

Ans. Self inductance – Using formula $\phi = LI$, if $I = 1$ Ampere then $L = \phi$

Self inductance of the coil is equal to the magnitude of the magnetic flux linked with the coil, when a unit current flows through it.

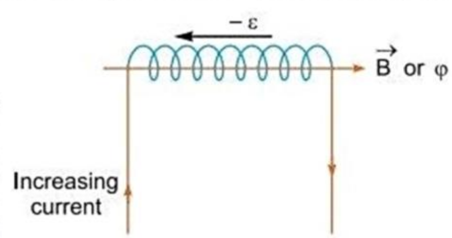
Alternatively

Using formula $|-\varepsilon| = L\frac{dI}{dt}$

If $\frac{dI}{dt} = 1$ A/s then $L = |-\varepsilon|$

Self inductance of the coil is equal to the magnitude of induced emf produced in the coil itself, when the current varies at rate 1 A/s.

Expression for magnetic energy



When a time varying current flows through the coil, back *emf* (−ε) produces, which opposes the growth of the current flow. It means some work needs to be done against induced emf in establishing a current *I*. This work done will be stored as magnetic potential energy.

For the current I at any instant, the rate of work done is

$$\frac{dW}{dt} = (-\varepsilon)I$$

Only for inductive effect of the coil $|-\varepsilon| = L\frac{dI}{dt}$

$$\therefore \quad \frac{dW}{dt} = L\left(\frac{dI}{dt}\right)I \quad \Rightarrow \quad dW = LI\,dI$$

From work-energy theorem,

$$dU = LI\,dI$$

$$\therefore \quad U = \int_0^I LI dI = \frac{1}{2}LI^2$$

Q. 5. A long solenoid of radius *r* consists of n turns per unit length. A current $I = I_0 \sin \omega t$ flows in the solenoid. A coil of *N* turns is wound tightly around it near its centre. What is:

(*a*) the induced emf in the coil?

(*b*) the mutual inductance between the solenoid and the coil? [*CBSE 2023 (55/1/1)*]

Ans. Here, $I = I_0 \sin \omega t.$

For solenoid, $B = \mu_0 nI$

Magnetic flux, $\phi = BA = \mu_0 nI \times \pi r^2 = \mu_0 n\pi r^2 I_0 \sin \omega t.$

(*a*) *Emf* induced, $e = -\dfrac{Nd\phi}{dt} = -\dfrac{Nd}{dt}(BA) = -N\mu_0 n\pi r^2 \omega I_0 \cos \omega t$

$= -(\mu_0 I_0 \,\omega\, Nn\pi r^2) \cos \omega t = -e_0 \cos \omega t$

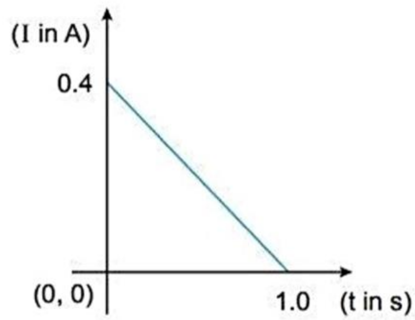
where, peak *emf*, $e_0 = \mu_0 I_0 \,\omega N n \pi r^2$

(*b*) Mutual inductance between the coil and solenoid,

$\phi = MI$

$\therefore \quad M = \dfrac{N\phi}{I} = \dfrac{\mu_0 Nn\pi r^2 I_0 \sin \omega t}{I_0 \sin \omega t} = \mu_0 Nn\pi r^2$

Q. 6. When a conducting loop of resistance 10 Ω and area 10 cm^2 is removed from an external magnetic field acting normally, the variation of induced current-*I* in the loop with time *t* is as shown in the figure. [*CBSE 2020 (55/5/1)*]



Find the

(*a*) total charge passed through the loop.

(*b*) change in magnetic flux through the loop.

(*c*) magnitude of the magnetic field applied.

Ans. (*a*) total charge passed through the loop (*Q*)

Q = area under the *I-t* graph ½

$= \dfrac{1}{2} \times 0.4 \times 1$ coulomb $= 0.2$ C ½

(*b*) Change in magnetic flux,

Total charge passing $= \left(\dfrac{\text{Change in magnetic flux}}{\text{R}}\right)$ ½

Change in magnetic flux $= [R \times 0.2 \text{ C}]$

$= [10 \times 0.2]$ Wb $= 2$ Wb ½

(*c*) Magnitude of magnetic field applied,

Let *B* be the magnitude of the magnetic field applied.

Initial magnetic flux $= B \times (10 \times 10^{-4})$ Wb

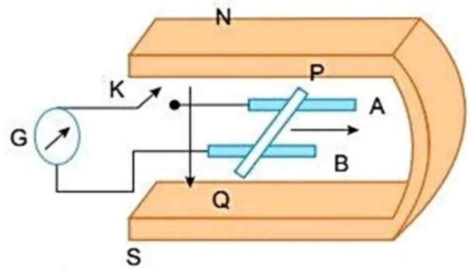
Final magnetic flux = zero

Change in magnetic flux $= (B \times 10^{-3} - 0) = 2$ ½

$\therefore \quad B = 2 \times 10^3$ Wb/m^2 ½

[*CBSE Marking Scheme 2020 (55/5/1)*]

Q. 7. **Figure shows a metal rod *PQ* of length *l*, resting on the smooth horizontal rails *AB* positioned between the poles of a permanent magnet. The rails, rod and the magnetic field *B* are in three mutually perpendicular directions. A galvanometer *G* connects the rails through a key '*K*'. Assume the magnetic field to be uniform. Given the resistance of the closed loop containing the rod is *R*.**



(i) Suppose *K* is open and the rod is moved with a speed *v* in the direction shown. Find the polarity and the magnitude of induced emf.

(ii) With *K* open and the rod moving uniformly, there is no net force on the electrons in the rod *PQ* even though they do experience magnetic force due to the motion of the rod. Explain.

(iii) What is the induced emf in the moving rod if the magnetic field is parallel to the rails instead of being perpendicular? **[*CBSE Sample Paper 2018*]**

Ans. (*i*) The magnitude of the induced emf is given by

$$|\varepsilon| = Blv\sin\theta$$

As the conductor *PQ* moves in the direction shown, the free electrons in it experience magnetic Lorentz force. By Fleming's left hand rule, the electrons move from the end *P* towards the end *Q*. Deficiency of electrons makes the end *P* positive while the excess of electrons makes the end *Q* negative.

(*ii*) The magnetic Lorentz force $[\vec{F}_m = -e(\vec{v}\times\vec{B})]$ is cancelled by the electric force $[\vec{F}_m = e\vec{E}]$ exerted by the electric field set up by the opposite charges at its ends.

(*iii*) In this case, the angle θ made by the rod with the field $\vec{B}$ is zero.

$$\therefore \quad \varepsilon = Blv\sin 0° = 0$$

This is because the motion of the loop does not cut across the field lines. There is no change in magnetic flux. So the induced emf is zero.

Q. 8. **Two concentric circular loops of radius 1 cm and 20 cm are placed coaxially.**

(i) Find mutual inductance of the arrangement.

(ii) If the current passed through the outer loop is changed at a rate of 5 A/ms, find the emf induced in the inner-loop. Assume the magnetic field on the inner loop to be uniform.

[*CBSE 2020 (55/5/1)*]

Ans. (*i*) Imagine a current *I* to flow through the largest coil.

Magnetic flux linked with the smaller coil,

$$\phi = B_{centre}\times\pi\times 10^{-4}\text{ Wb} \qquad \tfrac{1}{2}$$

$$= \frac{\mu_0 I}{2\times 20\times 10^{-2}}\times\pi\times 10^{-4}\text{ Wb}$$

Also, we know,

$$\phi = MI$$

$$\therefore \quad M = \frac{\mu_0\pi}{4}\times 10^{-3}\text{ H} \qquad \tfrac{1}{2}$$

$$= \frac{4\pi\times 10^{-7}\pi\times 10^{-3}}{4}\text{ H}$$

$$= 9.9\times 10^{-10}\text{ H}$$

$$= 10^{-9}\text{ H} \qquad \tfrac{1}{2}$$

(*ii*) e.m.f. induced $= -M\dfrac{dI}{dt}$ ½

$= -10^{-9} \times \dfrac{5}{10^{-3}}$ V ½

$= -5 \times 10^{-6}$ V ½

Alternatively,

e.m.f. induced $= -\dfrac{d\phi}{dt}$

$= -\dfrac{d}{dt}(B_c A_i) = -A_i \dfrac{dB_c}{dt}$ ½

$= -A_i \dfrac{d}{dt}\left(\dfrac{\mu_0 I}{2R}\right)$

$= -\dfrac{A_i \mu_0}{2R}\dfrac{dI}{dt}$

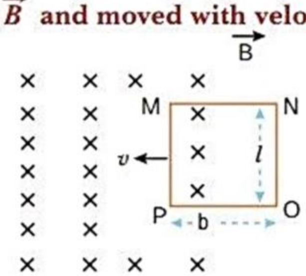
$= -\dfrac{\pi \times 10^{-4} \times 4\pi \times 10^{-7} \times 5}{2 \times (20 \times 10^{-2}) \times 10^{-3}}$ V ½

$= -\dfrac{20\pi^2 \times 10^{-6}}{2 \times 20}$ V

$= -5 \times 10^{-6}$ V ½

[*CBSE Marking Scheme 2020 (55/5/1)*]

Q. 9. The figure shows a rectangular conducting frame *MNOP* of resistance *R* placed partly in a perpendicular magnetic field $\vec{B}$ and moved with velocity $\vec{v}$ as shown in the figure.



Obtain the expressions for the

(*a*) force acting on the arm '*ON*' and its direction, and

(*b*) Power required to move the frame to get a steady emf induced between the arms *MN* and *PO*. [*CBSE 2019 (55/4/1)*]

Ans. (*a*) The induced emf in the moving conductor *MNOP*

$e = Blv$ ½

The induced correct, $i = \dfrac{e}{R} = \dfrac{Blv}{R}$

Force on the arm 'ON' $F = Bil$ ½

$= \dfrac{B^2 l^2 v}{R}$ ½

The force is directed in the direction opposite to velocity of rod (v). ½

Note: Award the last half mark if the student write $F = 0$ as $B = 0$ is the position shown

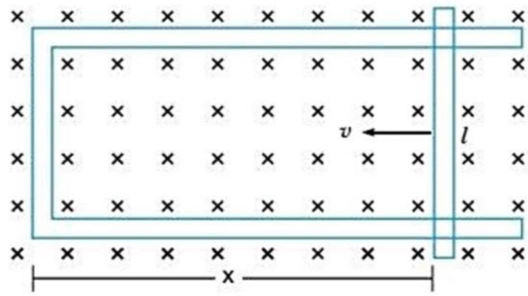
(*b*) Power $P = F \times v$ ½

$= \dfrac{B^2 l^2 v^2}{R}$ ½

Note: Award the last half mark if the student write $P = 0$ as $B = 0$ is the position shown.

[*CBSE Marking Scheme 2019 (55/4/1)*]

Q. 10. (*a*) **A rod of length *l* is moved horizontally with a uniform velocity '*v*' in a direction perpendicular to its length through a region in which a uniform magnetic field is acting vertically downward. Derive the expression for the emf induced across the ends of the rod.**



(*b*) **How does one understand this motional emf by invoking the Lorentz force acting on the free charge carriers of the conductor? Explain.** [*CBSE (AI) 2014*]

Ans. (*a*) Suppose a rod of length '*l*' moves with velocity *v* inward in the region having uniform magnetic field *B*.

Initial magnetic flux enclosed in the rectangular space is $\phi = |B|lx$

As the rod moves with velocity $-v = \frac{dx}{dt}$

Using Lenz's law

$$\varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(Blx) = Bl\left(-\frac{dx}{dt}\right)$$

$\therefore \quad \varepsilon = Blv$

(*b*) Suppose any arbitrary charge '*q*' in the conductor of length '*l*' moving inward in the field as shown in figure, the charge *q* also moves with velocity *v* in the magnetic field *B*.

The Lorentz force on the charge '*q*' is $F = qvB$ and its direction is downwards.

So, work done in moving the charge '*q*' along the conductor of length *l*

$$W = F.l$$

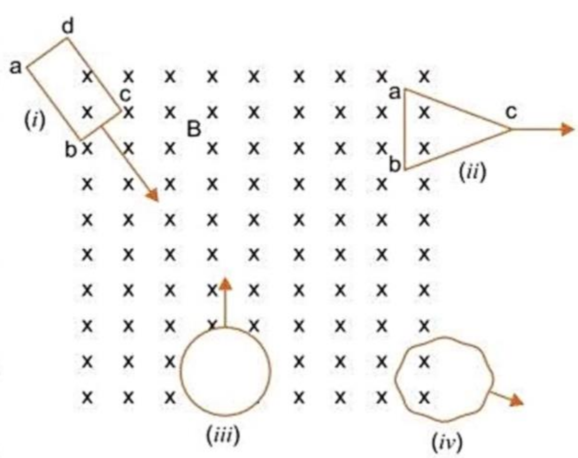
$$W = qvBl$$

Since emf is the work done per unit charge

$$\therefore \quad \varepsilon = \frac{W}{q} = Blv$$

This equation gives emf induced across the rod.

Q. 11. Figure shows planar loops of different shapes moving out of or into a region of magnetic field which is directed normal to the plane of loops downwards. Determine the direction of induced current in each loop using Lenz's law. [*CBSE (AI) 2010, (F) 2014*]



Ans. (*a*) In Fig. (*i*) the rectangular loop *abcd* and in Fig. (*iii*) circular loop are entering the magnetic field, so the flux linked with them increases; The direction of induced currents in these coils, will be such as to oppose the increase of magnetic flux; hence the magnetic field due to current induced will be upward, *i.e.*, currents induced will flow *anticlockwise*.

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(*b*) In Fig. (*ii*), the triangular loop *abc* and in fig. (*iv*) the zig-zag shaped loop are emerging from the magnetic field, therefore magnetic flux linked with these loops decreases. The currents induced in them will tend to increase the magnetic field in downward direction, so the currents will flow *clockwise*.

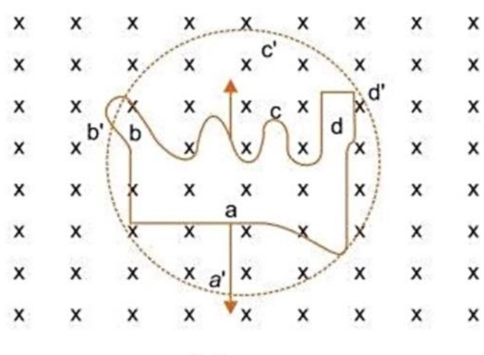
Thus in fig. (*i*) current flows anticlockwise,

in fig. (*ii*) current flows clockwise,

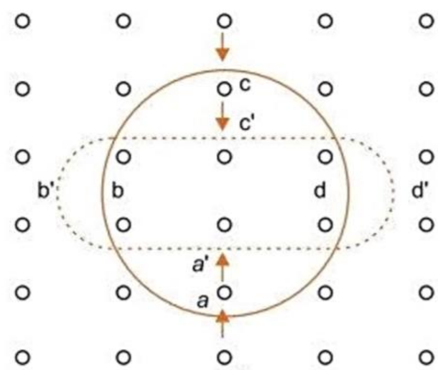
in fig. (*iii*) current flows anticlockwise,

in fig. (*iv*) current flows clockwise.

Q. 12. Use Lenz's law to determine the direction of induced current in the situation described by following figs.



(a)



(b)

(*a*) A wire of irregular shape turning into a circular shape.

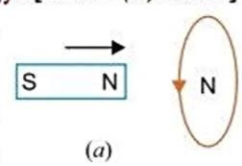
(*b*) A circular loop being deformed into a narrow straight wire. **[*CBSE (F) 2014*]**

Ans. (*a*) For the given periphery the area of a circle is maximum. When a coil takes a circular shape, the magnetic flux linked with coil increases, so current induced in the coil will tend to decrease the flux and so will produce a magnetic field upward. As a result the current induced in the coil will flow anticlockwise *i.e.,* along *a'd'c'b'*.

(*b*) For given periphery the area of circle is maximum. When circular coil takes the shape of narrow straight wire, the magnetic flux linked with the coil decreases, so current induced in the coil will tend to oppose the decrease in magnetic flux; hence it will produce upward magnetic field, so current induced in the coil will flow anticlockwise *i.e.,* along *a' d' c' b'*.

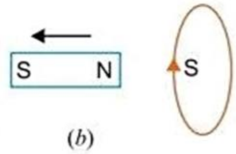
Q. 13. Show that Lenz's law is in accordance with the law of conservation of energy. [*CBSE (F) 2017*]

Ans. **Lenz's law:** According to this law "*the direction of induced current in a closed circuit is always such as to oppose the cause that produces it*."



(*a*)

Example: When the north pole of a coil is brought near a closed coil, the direction of current induced in the coil is such as to oppose the approach of north pole. For this the nearer face of coil behaves as north pole. This necessitates an anticlockwise current in the coil, when seen from the magnet side [fig. (*a*)]



(*b*)

Similarly when north pole of the magnet is moved away from the coil, the direction of current in the coil will be such as to attract the magnet. For this the nearer face of coil behaves as south pole. This necessitates a clockwise current in the coil, when seen from the magnet side [fig. (*b*)].

Conservation of Energy in Lenz's Law: In each case whenever there is a relative motion between a coil and the magnet, a force begins to act which opposes the relative motion. Therefore to maintain the relative motion, a mechanical work must be done. This work appears in the form of electric energy of coil. Thus, *Lenz's law is based on principle of conservation of energy*.

CONSTRUCTED RESPONSE QUESTIONS AS PER NEP

Long Answer Questions

Each of the following questions are of 5 marks.

Q. 1. (*a*) **What is induced emf? Write Faraday's law of electromagnetic induction. Express it mathematically.**

(*b*) **A conducting rod of length '*l*', with one end pivoted, is rotated with a uniform angular speed 'ω' in a vertical plane, normal to a uniform magnetic field '*B*'. Deduce an expression for the emf induced in this rod.** [*CBSE Delhi 2013, 2012*]

If resistance of rod is *R*, what is the current induced in it?

Ans. (*a*) **Induced emf:** The emf developed in a coil due to change in magnetic flux linked with the coil is called the induced emf.

Faraday's Law of Electromagnetic Induction: On the basis of experiments, Faraday gave two laws of electromagnetic induction:

1. *When the magnetic flux linked with a coil or circuit changes, an emf is induced in the coil.*

If coil is closed, the current is also induced. The emf and current last so long as the change in magnetic flux lasts. *The magnitude of induced emf is proportional to the rate of change of magnetic flux linked with the circuit*. Thus if $\Delta\phi$ is the change in magnetic flux linked in time Δt then rate of change of flux is $\frac{\Delta\phi}{\Delta t}$,

So emf induced $$\varepsilon \propto \frac{\Delta\phi}{\Delta t}$$

2. *The emf induced in the coil (or circuit) opposes the cause producing it.*

$$\varepsilon \propto -\frac{\Delta\phi}{\Delta t}$$

Here the negative sign shows that the induced emf 'ε' opposes the change in magnetic flux.

$$\varepsilon = -K\frac{\Delta\phi}{\Delta t}$$

where K is a constant of proportionality which depends on units chosen for ϕ, t and ε. In SI system the unit of flux ϕ is weber, unit of time t is second and unit of emf ε is volt and $K=1$

$$\therefore \quad \varepsilon = -\frac{\Delta\phi}{\Delta t}$$

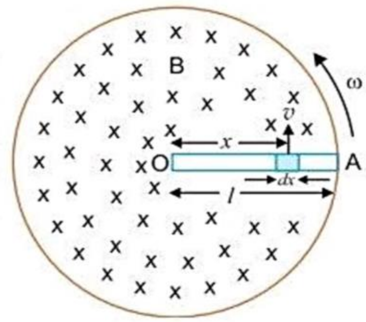
If the coil contains N turns of insulated wire, then the flux linked with each turn will be same and the emf induced in each turn will be in the same direction, hence the emfs of all turns will be added. Therefore the emf induced in the whole coil,

$$\varepsilon = -N\frac{\Delta\phi}{\Delta t} = -\frac{\Delta(N\phi)}{\Delta t}$$

$N\phi$ is called the ***effective magnetic flux*** or the ***number of flux linkages*** in ***the coil and may be denoted by*** ψ.

(*b*) Expression for Induced emf in a Rotating Rod

Consider a metallic rod *OA* of length *l* which is rotating with angular velocity ω in a uniform magnetic field *B*, the plane of rotation being perpendicular to the magnetic field. A rod may be supposed to be formed of a large number of small elements. Consider a small element of length *dx* at a distance *x* from centre. If *v* is the linear velocity of this element, then area swept by the element per second = *v dx*



The emf induced across the ends of element

$$d\varepsilon = B\frac{dA}{dt} = Bv\,dx$$

But $v = x\omega$

∴ $d\,\varepsilon = B\,x\,\omega\,dx$

∴ The emf induced across the rod

$$\varepsilon = \int_0^l B\,x\omega\,dx = B\omega\int_0^l x\,dx$$

$$= B\omega\left[\frac{x^2}{2}\right]_0^l = B\omega\left[\frac{l^2}{2} - 0\right] = \frac{B\omega l^2}{2}$$

Current induced in rod $I = \frac{\varepsilon}{R} = \frac{1}{2}\frac{B\omega l^2}{R}$.

If circuit is closed, power dissipated $= \frac{\varepsilon^2}{R} = \frac{B^2\omega^2 l^4}{4R}$

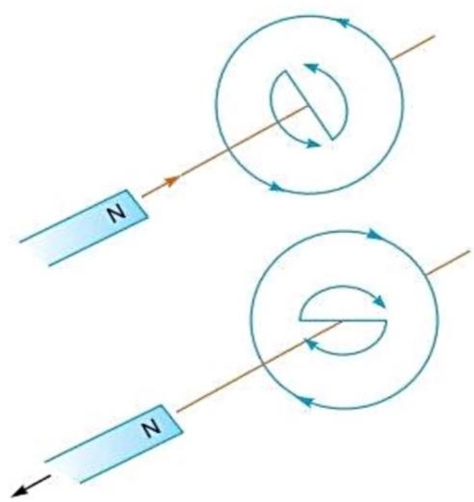
Q. 2. (*a*) **Describe a simple experiment (or activity) to show that the polarity of emf induced in a coil is always such that it tends to produce an induced current which opposes the change of magnetic flux that produces it.**

(*b*) **The current flowing through an inductor of self inductance L is continuously increasing. Plot a graph showing the variation of**

(*i*) **Magnetic flux versus the current**

(*ii*) **Induced emf versus *dI/dt***

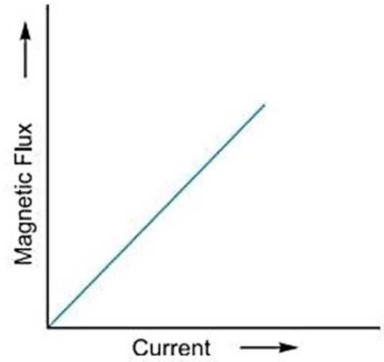
(*iii*) **Magnetic potential energy stored versus the current.** [*CBSE Delhi 2014*]



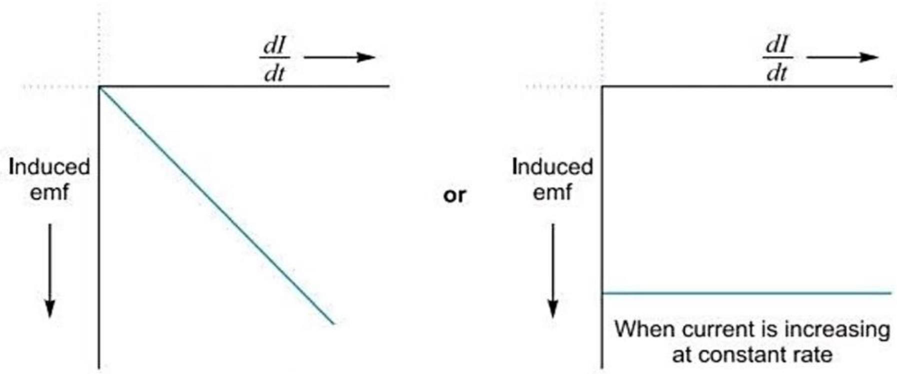
Ans. (*a*) When the North pole of a bar magnet moves towards the closed coil, the magnetic flux through the coil increases. This produces an induced emf which produces (or tend to produce if the coil is open) an induced current in the anti-clockwise sense. The anti-clockwise sense corresponds to the generation of North pole which opposes the motion of the approaching N pole of the magnet. The face of the coil, facing the approaching magnet, then has the same polarity as that of the approaching pole of the magnet. The induced current, therefore, is seen to oppose the change of magnetic flux that produces it.

When a North pole of a magnet is moved away from the coil, the current (*I*) flows in the clock-wise sense which corresponds to the generation of South pole. The induced South pole opposes the motion of the receding North pole.

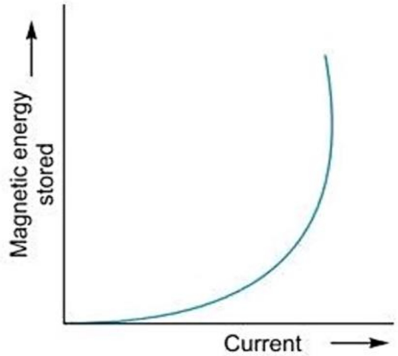
(*b*) (*i*) Magnetic flux versus the current



(*ii*) Induced emf versus dI/dt



(*iii*) Magnetic energy stored versus current



Q. 3. Derive expression for self inductance of a long air-cored solenoid of length *l*, cross-sectional area *A* and having number of turns *N*. **[*CBSE 2023* (*55/2/1*), (*55/4/1*)]**

Ans. Self Inductance of a long air-cored solenoid:

Consider a long air solenoid having '*n*' number of turns per unit length. If current in solenoid is *I*, then magnetic field within the solenoid, $B = \mu_0 nI$ ...(*i*)

where $\mu_0 = 4\pi \times 10^{-7}$ henry/metre is the permeability of free space.

If *A* is cross-sectional area of solenoid, then effective flux linked with solenoid of length *l* is $\phi = NBA$ where $N = nl$ is the number of turns in length '*l*' of solenoid.

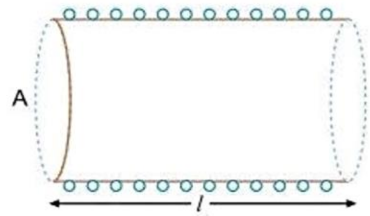
$\therefore \quad \phi = (nl\, BA)$

Substituting the value of *B* from (*i*)

$\therefore \quad \phi = \mu_0 n^2 AlI$

$\therefore$ Self-inductance of air solenoid

$$L = \frac{\phi}{I} = \mu_0 n^2 Al$$



If N is the total number of turns in length l then

$$n = \frac{N}{l}$$

$$\therefore \text{ Self-inductance } L = \mu_0\left(\frac{N}{l}\right)^2 Al$$

$$= \frac{\mu_0 N^2 A}{l}$$

Remark: If solenoid contains a core of ferromagnetic substance of relative permeability μ_r, then

$$\text{self inductance, } L = \frac{\mu_r \mu_0 N^2 A}{l}.$$

Q. 4. What is meant by the term 'mutual inductance' of a pair of coils? Obtain an expression for the mutual inductance of two long coaxial solenoids, each of length l but having different number of turns N_1 and N_2 and radii r_1 and r_2 ($r_2 > r_1$). ***[CBSE 2023 (55/3/1)]***

OR

(a) Define mutual inductance and write its SI units. ***[CBSE 2019 (55/1/1)]***

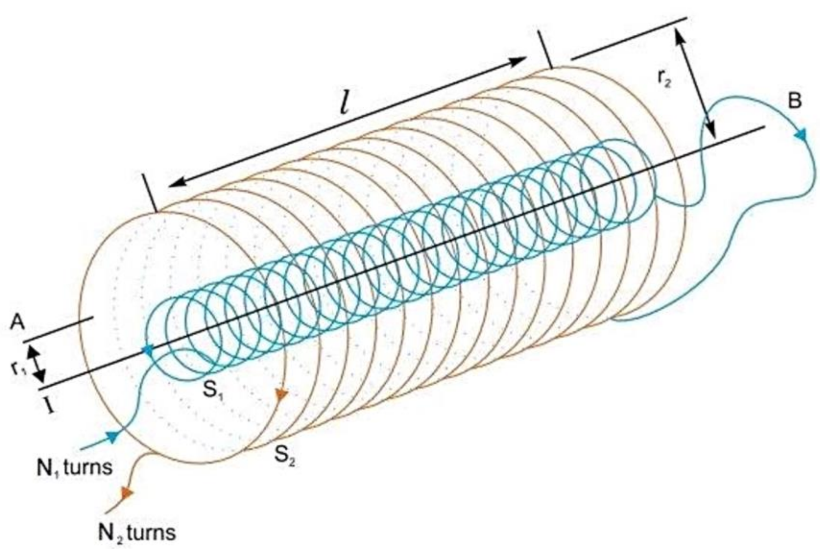
(b) Derive an expression for the mutual inductance of two long co-axial solenoids of same length wound one over the other.

(c) In an experiment, two coils C_1 and C_2 are placed close to each other. Find out the expression for the emf induced in the coil C_1 due to a change in the current through the coil C_2.

[CBSE Delhi 2015]

Ans. (a) When current flowing in one of two nearby coils is changed, the magnetic flux linked with the other coil changes; due to which an emf is induced in it (other coil). This phenomenon of electromagnetic induction is called the mutual induction. The coil, in which current is changed is called the primary coil and the coil in which emf is induced is called the secondary coil. **The SI unit of mutual inductance is henry.**

(b) Mutual inductance is numerically equal to the magnetic flux linked with one coil (secondary coil) when unit current flows through the other coil (primary coil).



Consider two long co-axial solenoids, each of length l. Let n_1 be the number of turns per unit length of the inner solenoid S_1 of radius r_1, n_2 be the number of turns per unit length of the outer solenoid S_2 of radius r_2.

Imagine a time varying current I_2 through S_2 which sets up a time varying magnetic flux ϕ_1 through S_1.

$\therefore \quad \phi_1 = M_{12}(I_2)$ ...(i)

where, M_{12} = Coefficient of mutual inductance of solenoid S_1 with respect to solenoid S_2

Magnetic field due to the current I_2 in S_2 is

$$B_2 = \mu_0 n_2 I_2$$

$\therefore$ Magnetic flux through S_1 is

$$\phi_1 = B_2 A_1 N_1$$

where, $N_1 = n_1 l$ and l = length of the solenoid

$$\phi_1 = (\mu_0 n_2 I_2)(\pi r_1^2)(n_1 l)$$

$$\phi_1 = \mu_0 n_1 n_2 \pi r_1^2 l I_2 \quad ...(ii)$$

From equations (i) and (ii), we get

$$M_{12} = \mu_0 n_1 n_2 \pi r_1^2 l \quad ...(iii)$$

Let us consider the reverse case.

A time varying current I_1 through S_1 develops a flux ϕ_2 through S_2.

$\therefore \quad \phi_2 = M_{21}(I_1)$ ...(iv)

where, M_{21} = Coefficient of mutual inductance of solenoid S_2 with respect to solenoid S_1

Magnetic flux due to I_1 in S_1 is confined solely inside S_1 as the solenoids are assumed to be very long.

There is no magnetic field outside S_1 due to current I_1 in S_1.

The magnetic flux linked with S_2 is

$$\therefore \quad \phi_2 = B_1 A_1 N_2 = (\mu_0 n_1 I_1)(\pi r_1^2)(n_2 l)$$

$$\phi_2 = \mu_0 n_1 n_2 \pi r_1^2 l I_1 \quad ...(v)$$

From equations (iv) and (v), we get

$$M_{21} = \mu_0 n_1 n_2 \pi r_1^2 \quad ...(vi)$$

From equations (iii) and (vi), we get

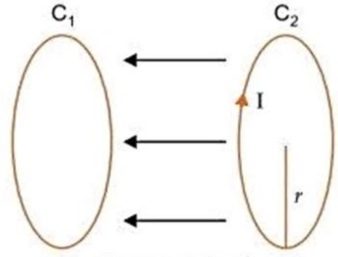
$$M_{12} = M_{21} = M = \mu_0 n_1 n_2 \pi r_1^2 l$$

We can write the above equation as

$$M = \mu_0 \left(\frac{N_1}{l}\right)\left(\frac{N_2}{l}\right)\pi r_1^2 \times l$$

$$M = \frac{\mu_0 N_1 N_2 \pi r_1^2}{l}$$

(c) When the current in coil C_2 changes, the flux linked with C_1 changes. This change in flux linked with C_1 induces emf in C_1.



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Flux linked with C_1 = flux of C_2

$$\phi_{12} = B.A = \frac{\mu_0 I}{2r}.A$$

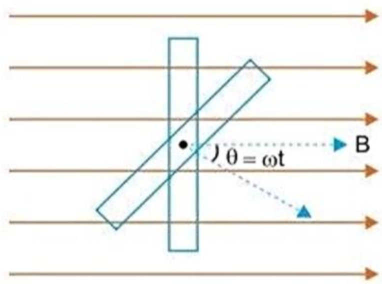
Emf induced in $C_1 = \frac{d\phi_{12}}{dt} = \frac{d}{dt}\frac{\mu_0 AI}{2r} = \frac{\mu_0 A}{2r} \times \frac{dI}{dt}$

Q. 5. A coil of number of turns N, area A is rotated at a constant angular speed ω, in a uniform magnetic field B and connected to a resistor R. Deduce expression for

(i) maximum emf induced in the coil.

(ii) power dissipation in the coil.

Ans. (i) Suppose initially the plane of coil is perpendicular to the magnetic field B. When coil rotates with angular speed ω, then after time t, the angle between magnetic field $\vec{B}$ and normal to plane of coil is $\theta = \omega t$.



∴ At this instant magnetic flux linked with the coil $\phi = BA \cos \omega t$

If coil constants, N-turns, then emf induced in the coil

$$\varepsilon = -N\frac{d\phi}{dt} = -N\frac{d}{dt}(BA \cos \omega t)$$

$$= + NBA\, \omega \sin \omega t \qquad \ldots(i)$$

∴ For maximum value of emf ε,

$\sin \omega t = 1$

∴ Maximum emf induced, $\varepsilon_{max} = \boldsymbol{NBA\, \omega}$

(ii) If R is resistance of coil, the current induced, $I = \frac{\varepsilon}{R}$

∴ Instantaneous power dissipated, $P = \varepsilon I = \varepsilon\left(\frac{\varepsilon}{R}\right) = \frac{\varepsilon^2}{R}$

$$= \frac{N^2B^2A^2\omega^2\sin^2\omega t}{R} \qquad \text{[using (i)]}$$

Average power dissipated in a complete cycle is obtained by taking average value of $\sin^2\omega t$ over a complete cycle which is $\frac{1}{2}$

i.e., $(\sin^2\omega t)_{av} = \frac{1}{2}$

∴ Average power dissipated, $P_{av} = \boldsymbol{\frac{N^2B^2A^2\omega^2}{2R}}$

Q. 6. State Faraday's law of electromagnetic induction.

Figure shows a rectangular conductor $PQRS$ in which the conductor PQ is free to move in a uniform magnetic field B perpendicular to the plane of the paper. The field extends from $x = 0$ to $x = b$ and is zero for $x > b$. Assume that only the arm PQ possesses resistance r. When the arm PQ is pulled outward from $x = 0$ to $x = 2b$ and is then moved backward to $x = 0$ with constant

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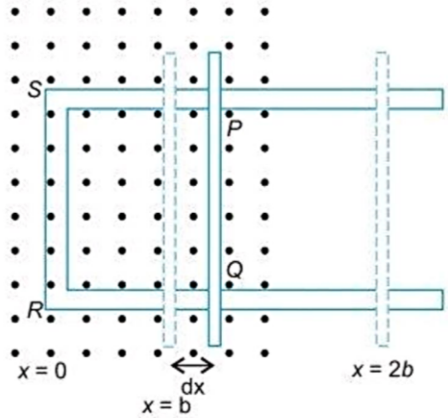
speed v, obtain the expressions for the flux and the induced emf. Sketch the variations of these quantities with distance $0 \le x \le 2b$. *[CBSE (AI) 2010, (North) 2016]*



Ans. Refer to Point 3 of Points to remember.

Let length of conductor $PQ = l$

When PQ moves a small distance from x to $x + dx$ then magnetic flux linked $= BdA = Bldx$

The magnetic field is from $x = 0$ to $x = b$, to so final magnetic flux

$$= \sum Bldx = Bl\sum dx = Blx \text{ (increasing)}$$

We consider forward motion from $x = 0$ to $x = 2b$

$$\phi = Blx\ ,\ 0 \le x < b$$
$$= Blb\ ,\ b \le x < 2b$$

Mean magnetic flux from $x = 0$ to $x = b$ is $\frac{1}{2}Blb$

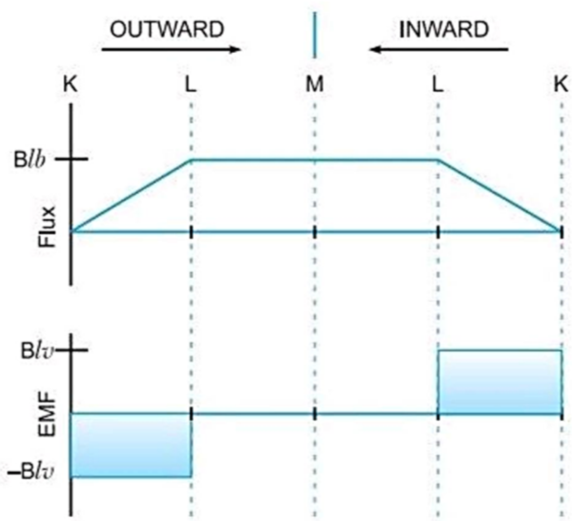
Induced emf, $\varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(Bldx) = -Bl\frac{dx}{dt} = -Blv$ for, $0 \le x < b$

where $v = \frac{dx}{dt}$ velocity of arm PQ from $x = 0$ to $x = b$.

$$\varepsilon = -\frac{d}{dt}(Blb) = 0 \text{ for, } b \le x < 2b$$

During return from $x = 2b$ to $x = b$ the induced emf is zero; but now area is decreasing so magnetic flux is decreasing, and induced emf will be in opposite direction.

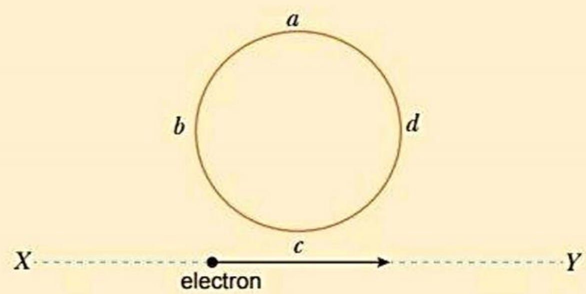
$$\varepsilon = Blv$$



Questions for Practice

1. Choose and write the correct option in the following questions.

(*i*) An electron moves on a straight line path *XY* as shown. The *abcd* is a coil adjacent to the path of electron. What will be the direction of current, if any, induced in the coil?



(*a*) The current will reverse its direction as the electron goes past the coil
(*b*) No current induced
(*c*) *abcd*
(*d*) *adcb*

(*ii*) A magnet is dropped with its north pole towards a closed circular coil placed on a table then
(*a*) looking from above, the induced current in the coil will be anti-clockwise.
(*b*) the magnet will fall with uniform acceleration.
(*c*) as the magnet falls, its acceleration will be reduced.
(*d*) no current will be induced in the coil.

(*iii*) The magnetic flux linked with a coil at any instant '*E*' is given by

$$\phi = 10t^2 - 50t + 250 \text{ Wb}$$

The induced emf at $t = 3$ s is
(*a*) – 190 V (*b*) – 10 V (*c*) 10 V (*d*) 190 V

(*iv*) A coil of area 100 cm^2 is kept at an angle of 30° with a magnetic field 10^{-1} T. The magnetic field is reduced to zero in 10^{-4} s. The induced emf in the coil is [*CBSE 2022 (55/2/4), Term-1*]
(*a*) $5\sqrt{3}$ V (*b*) $50\sqrt{3}$ V (*c*) 5.0 V (*d*) 50.0 V

(*v*) An air-cored solenoid with length 30 cm, area of cross-section 25 cm^2 and number of turns 800, carries a current of 2.5 A. The current is suddenly switched off in a brief time of 10^{-3}s. Ignoring the variation in magnetic field near the ends of the solenoid, the average back emf induced across the ends of the open switch in the circuit would be [*CBSE Sample Paper-2022) Term-1*]
(*a*) zero (*b*) 3.125 volts (*c*) 6.54 volts (*d*) 16.74 volts

2. ***In the following questions, a statement of Assertion (A) is followed by a statement of Reason (R). Choose the correct answer out of the following choices.***
(a) Both A and R are true and R is the correct explanation of A.
(b) Both A and R are true but R is not the correct explanation of A.
(c) A is true but R is false.
(d) A is false and R is also false.

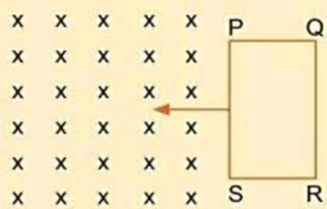
Assertion (*A*) : In the phenomenon of mutual induction, self-induction of each of the coils persists.

Reason (*R*) : Self-induction arises when strength of current in same coil changes. In mutual induction, current is changed in both individual coils.

3. Two identical coils, one of copper and the other of aluminium are rotated with the same angular speed in an external magnetic field. In which of the two coils will the induced current be more? **[*CBSE 2020 (55/3/1)*]**

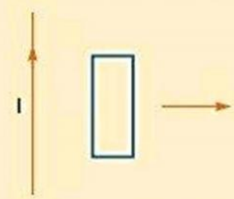
4. Predict the direction of induced current in metal rings 1 and 2 when current *I* in the wire is steadily decreasing.

5. The closed loop *PQRS* is moving into a uniform magnetic field acting at right angles to the plane of the paper as shown. State the direction of the induced current in the loop. **[*CBSE (F) 2012*]**



6. A planar loop of rectangular shape is moved within the region of a uniform magnetic field acting perpendicular to its plane. What is the direction and magnitude of the current induced in it? **[*CBSE Ajmer 2015*]**

7. A rectangular loop of wire is pulled to the right, away from the long straight wire through which a steady current *I* flows upwards. What is the direction of induced current in the loop? **[*CBSE (F) 2010*]**



8. A rectangular loop and a circular loop are moving out of a uniform magnetic field region to a field free region with a constant velocity. In which loop do you expect the induced emf to be a constant during the passage out of the field region? The field is normal to the loop. **[*CBSE (AI) 2010*]**

9. A rectangular coil rotates in a uniform magnetic field. Obtain an expression for induced emf and current at any instant. Also find their peak values. Show the variation of induced emf versus angle of rotation (ωt) on a graph.

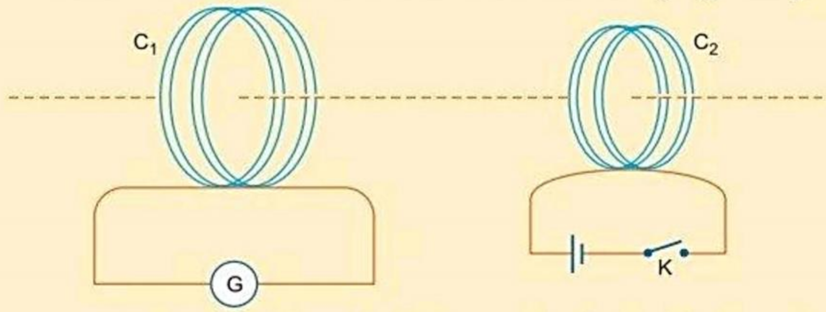
10. Two coplanar and concentric coils 1 and 2 have respectively the number of turn N_1 and N_2 of radii r_1 and r_2 ($r_2 >> r_1$) Deduce the expression for mutual inductance of this system. **[*CBSE 2020 (55/3/1)*]**

11. An iron bar falling through the hollow region of a thick cylindrical shell made of copper experiences a retarding force. What can you conclude about the nature of the iron bar ? Explain.

12. State Lenz's Law. A metallic rod held horizontally along east-west direction, is allowed to fall under gravity. Will there be an emf induced at its ends? Justify your answer. **[*CBSE Delhi 2013*]**

13. A rectangular conductor *LMNO* is placed in a uniform magnetic field of 0.5 T. The field is directed perpendicular to the plane of the conductor. When the arm *MN* of length of 20 cm is moved towards left with a velocity of 10 ms^{-1}. Calculate the emf induced in the arm. Given the resistance of the arm to be 5 Ω (assuming that other arms are of negligible resistance), find the value of the current in the arm. **[*CBSE (AI) 2013*]**

14. A current is induced in coil C_1 due to the motion of current carrying coil C_2.



(*a*) Write any two ways by which a large deflection can be obtained in the galvanometer G.

(*b*) Suggest an alternative device to demonstrate the induced current in place of a galvanometer. **[*CBSE Delhi 2011*]**

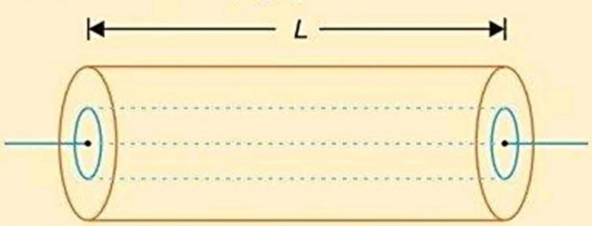
15. The closed loop (*PQRS*) of wire is moved out of a uniform magnetic field at right angles to the plane of the paper as shown in the figure. Predict the direction of the induced current in the loop. **[*CBSE (F) 2012*]**

16. Current in a circuit falls from 5.0 A to 0.0 A in 0.1 s. If an average emf of 200 V is induced, calculate the self-induction of the circuit. **[*CBSE (F) 2011*]**

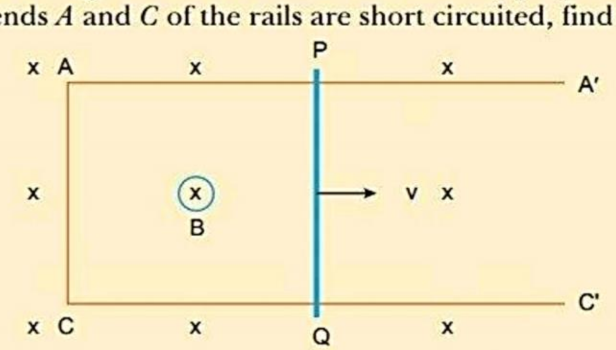
17. A long solenoid with 15 turns per cm has a small loop of area 2.0 cm^2 placed inside normal to the axis of the solenoid. The current carried by the solenoid changes steadily from 2 A to 4 A in 0.1 s, what is the induced emf in the loop while the current is changing? **[*CBSE (F) 2016*]**

18. A jet plane is travelling westward at a speed of 1800 km/h. What is the potential difference developed between the ends of a wing 25 m long? Its earth's magnetic field at the location has a magnitude of 5.0×10^{-4} T and the dip angle is 30°. **[*CBSE (AI) 2009*]**

19. Figure shows two long coaxial solenoids, each of length '*L*'. The outer solenoid has an area of cross-section A_1 and number of turns/length n_1. The corresponding values for the inner solenoid are A_2 and n_2. Write the expression for self inductance L_1, L_2 of the two coils and their mutual inductance M. Hence show that $M < \sqrt{L_1 L_2}$.



20. A conducting rod *PQ* of length 20 cm and resistance 0.1 Ω rests on two smooth parallel rails of negligible resistance *AA*′ and *CC*′. It can slide on the rails and the arrangement is positioned between the poles of a permanent magnet producing uniform magnetic field B = 0.4 T. The rails, the rod and the magnetic field are in three mutually perpendicular directions as shown in the figure. If the ends *A* and *C* of the rails are short circuited, find the



(*i*) external force required to move the rod with uniform velocity v = 10 cm/s, and

(*ii*) power required to do so. **[*CBSE 2020 (55/1/1)*]**

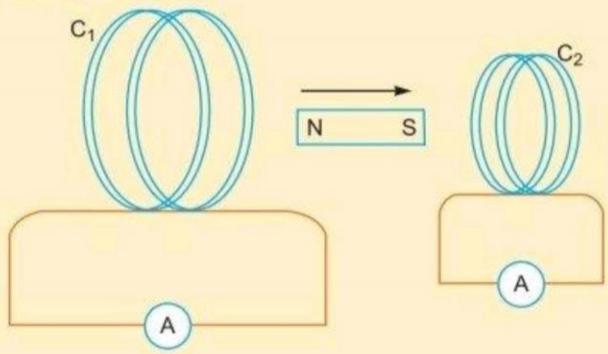
21. State Lenz's law. Illustrate, by giving an example, how this law helps in predicting the direction of the current in a loop in the presence of a changing magnetic flux.

In a given coil of self-inductance of 5 mH, current changes from 4 A to 1 A in 30 ms. Calculate the emf induced in the coil.

22. Two identical loops, one of copper and the other of aluminium, are rotated with the same angular speed in the same magnetic field. Compare (*i*) the induced emf and (*ii*) the current produced in the two coils. Justify your answer. **[*CBSE (AI) 2010*]**

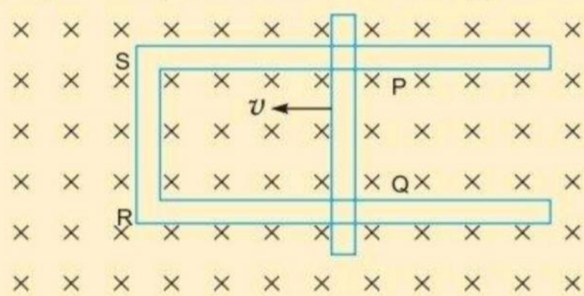
23. A wheel with 8 metallic spokes each 50 cm long is rotated with a speed of 120 rev/min in a plane normal to the horizontal component of the Earth's magnetic field. The Earth's magnetic field at the plane is 0.4 G and the angle of dip is 60°. Calculate the emf induced between the axle and the rim of the wheel. How will the value of emf be affected if the number of spokes were increased? **[*CBSE (AI) 2013*]**

24. A magnet is quickly moved in the direction indicated by an arrow between two coils C_1 and C_2 as shown in the figure. What will be the direction of induced current in each coil as seen from the magnet? Justify your answer. **[*CBSE Delhi 2011*]**



25. The currents flowing in the two coils of self-inductance $L_1 = 16$ mH and $L_2 = 12$ mH are increasing at the same rate. If the power supplied to the two coils are equal, find the ratio of (*i*) induced voltages, (*ii*) the currents and (*iii*) the energies stored in the two coils at a given instant. **[*CBSE (F) 2014*]**

26. Figure shows a rectangular loop conducting *PQRS* in which the arm *PQ* is free to move. A uniform magnetic field acts in the direction perpendicular to the plane of the loop. Arm *PQ* is moved with a velocity v towards the arm *RS*. Assuming that the arms *QR*, *RS* and *SP* have negligible resistances and the moving arm *PQ* has the resistance *r*, obtain the expression for (*i*) the current in the loop (*ii*) the force and (*iii*) the power required to move the arm *PQ*. **[*CBSE Delhi 2013*]**



Answers

1. (*i*) (*a*) (*ii*) (*a*) (*iii*) (*b*) (*iv*) (*c*) (*v*) (*d*)

2. (*i*) (*b*)

13. 1 V, 0.2 A **16.** 4H **17.** 7.5 μV **18.** 3.1 V

20. (*i*) 6.4×10^{-3} N (*ii*) 6.4×10^{-4} W **21.** 0.5 V **23.** 3.14×10^{-5} V

25. (*i*) $\frac{4}{3}$ (*ii*) $\frac{3}{4}$ (*iii*) $\frac{3}{4}$