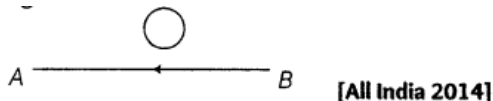# Chapter 6. Electromagnetic Induction

## 1 Mark Questions

**1.**The electric current flowing in a wire in the direction from B to A Find out the direction of the induced current in the metallic loop kept the wire as shown in the figure.



[All India 2014]

**Ans.**According to Lenz's law, the direction of induced current will oppose the cause of its production. So, the current in loop will induce in such a way that it will support the current flowing in the wire i.e., in the same direction. So, the direction of current in the loop will be clockwise

**2.**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 wduld reach earlier and why? [Delhi 2014]

**Ans.**The glass bob will reach earlier on ground as acceleration due to gravity is independent of mass of the falling bodies. Being insulator, no induced current is developed in it due to the earth's magnetic field.

**3.**A flexible wire of irregular shape, abed as shown in the figure, turns into a circular shape when placed in a region field which is directed normal to the plane of the loop away from the reader. Predict the direction of the induced current in the wire.[Foreign 2014]
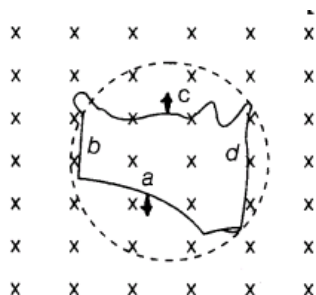


**Ans.**The wire is expanding to from a circle, which means that force is acting outwards on each part of the wire because of the magnetic field (acting in the downwards direction). The direction of the induced current should be such that it will produce magnetic field in upward direction (towards the reader). Hence, the force on the wire will be towards inward direction, i.e. induced current is flowing in anti-clockwise direction in'the loop from cbadc.

**4.**In the given figure, a bar magnet is quickly moved towards a conducting loop having a capacitor. Predict the polarity of the plates A and B of the capacitor[All India 2014 C;2010;Hots]
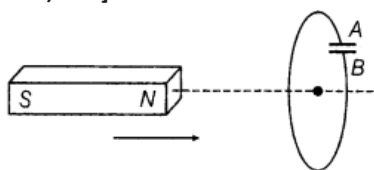
Ans.

> As, the magnet moves towards the coil, flux linked with the coil increases, hence according to the Lenz's law, it will oppose the change.

Here, the North pole is approaching the magnet, so the induced current in the face of loop viewed from left side will flow in such a way that it will behave like North pole, so South pole developed in loop when viewed from right hand side of the loop. The flow of induced current is clockwise, hence A acquires positive polarity and B negative. **(1)**

**5.** 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. [Delhi 2013]

**Ans.** Lenz's law states that the induced emf of induced current is a circuit which always opposes the cause that produces it.Yes, emf will be induced in the rod as there is change in magnetic flux.When a metallic rod held horizontally along East-West direction, is allowed to fall freely under gravity i.e. fall from North to South, the intensity of magnetic lines of the

earth's magnetic field changes through it, i.e. the magnetic flux changes and hence the induced emf in it

**6.** State the Faraday's law of electromagnetic induction. [Foreign 2009,2012]

**Ans.**

On the basis of his experiment, Faraday gave the following two laws:

**First law** Whenever magnetic flux linked with a circuit changes, an emf is induced in it which lasts, so long as change in flux continuous. **(1/2)**

**Second law** The emf induced in loop or closed circuit is directly proportional to the rate of change of magnetic flux linked with the loop

i.e. $e \propto \dfrac{(-)\,d\phi}{dt}$ or $e = -N\dfrac{d\phi}{dt}$

where, $N$ = number of turns in the coil. Negative sign indicates the Lenz's law. **(1/2)**

**7.** The closed loop PQRS of wire is moved into a uniform magnetic field at right angles to the plaue of the paper as shown in the figure. Predict the direction of the induced current in the loop.
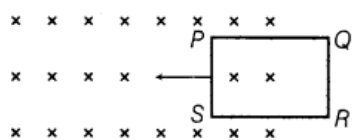


[Foreign 2012]

**Ans.** Since, magnetic flux increasing when the loop moves into uniform magnetic field. So the induced current should oppose this increase. Thus, flow will be from QPSRQ. i.e. anti-clockwise

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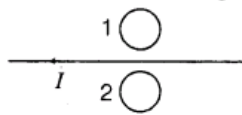


[Delhi 2012]

**Ans.**Current in the wire is steadily decreasing, so the induced current in rings 1 and 2 will flow in such a way that it opposes the decrease of current
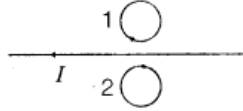


So, it will flow in same direction. Now, from the figure, it is clear that the direction of induced current in (i) ring 1 is clockwise.
(ii) ring 2 is anti-clockwise

**9.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.**
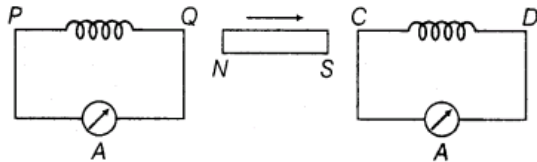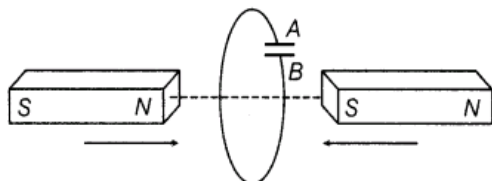


[All India 2012]

**Ans.**

> ? According to Lenz's law, induced current always flows in such a direction that it opposes the change in magnetic flux responsible for its production.

From the figure, it is clear that North pole of the magnet is moving away from coil $PQ$, so the direction of current at end $Q$ will flow in such a way that it will oppose the away moment of North pole, so it has to act as South pole. Hence, the direction of current will be anti-clockwise. Again, the South pole is approaching towards coil $CD$, so end $C$ of the coil will act as South pole (to oppose the approaching of South pole). Hence, the direction of current will be clockwise.     **(1)**

# 2 Marks Questions

**10.Predict the polarity of the capacitor in the situation described by adjoining as shown in figure. Explain the reason too.**



[HOTS; Delhi 2013C, 2011; All India 2011]

**Ans.**According to figure shown in the question, induced current is in anti-clockwise, when seen from left hand side and its direction is in clockwise when seen from right hand side. Thus, direction of induced    current  is in clockwise sense.This implies that plate A of the capacitor is at the higher potential than plate B, i.e. B is as negative plate while  A  is  as positive plate.

11.A metallic rod of length L is rotated with angular frequency of co with one end hinged at the centre and the other end at the circumference of a circular metallic ring of radius L, about an axis passing through the centre and perpendicular to the plane of the ring. A constant and uniform magnetic field B parallel to the axis is present everywhere. Deduce the expression for the emf between the centre and the metallic ring. [Delhi 2012]

Ans.

> To calculate the induced emf, first we have to find the change in flux. Here change in flux occurs due to change in area because of revolution of the rod. Then we can calculate the induced emf.

Angular velocity of rod, $\omega = \dfrac{2\pi}{T}$

where, $T$ = time period

∴ Charge in flux in one revolution

$$= BA = B\,(\pi L^2) \qquad \text{(1)}$$

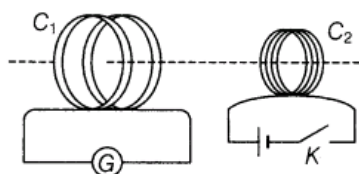According to Faraday's law of EMI, magnitude of induced emf

$$e = \dfrac{\Delta\phi}{\Delta T} = \dfrac{B\pi L^2}{T}$$

$$e = \dfrac{B\pi L^2}{\left(\dfrac{2\pi}{\omega}\right)} \qquad \left[\because T = \dfrac{2\pi}{\omega}\right]$$

$$\text{(1/2)}$$

$$e = \dfrac{1}{2}B\omega L^2 \qquad \text{(1/2)}$$

This is required expression.

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



(i)Write any two ways by which a large deflection can be obtained in the galvanometer G
(ii)Suggest an alternative device to demonstrate the induced current in place of a galvanometer. [Delhi 2011]

Ans.

> Large deflection means a high current for short time. So, to produce large deflection, induced current should be high and to produce high induced current, rate of change of flux should be high, i.e. more change in flux in less time.

(i) Large deflection in the galvanometer can be obtained when change in magnetic flux is fast. So,

(a)by moving quickly, the coil $C_2$ towards C1, or by moving quickly the coil $C_2$ away from C,.
(b)by switching off and on the key.
(ii) Alternating device in place of galvanometer can be LED or bulb.

13.A magnet is quickly moved in the direction indicated by an arrow between two coils Q and $C_2$ as shown in the figure.
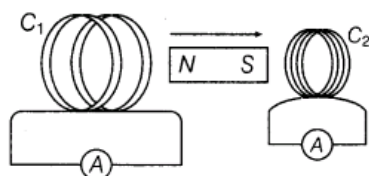


**What will be the direction of induced current in each coil as seen from the magnet? Justify your answer.   [Foreign 2011]**

**Ans.**As N-pole of the magnet is moving away from the coil $C_1$ therefore the coil will behave as South-pole and opposes the motion of the magnet. This implies the current in the coil is anti-clockwise. Also in coil $C_2$, it behaves as S-pole in order to repel the coming magnet. This implies current in the coil is anti-ciockwise.

14.**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.[All India 2010]**

**Ans.**(i)The induced emf in both the loops will be same as areas of the loop and time periods are same as they are identical and rotated with same angular speed.

(ii)The current induces in Cu coil is more than Al coil as Cu coil have got lesser resistance and

$$I \propto \frac{1}{R} \quad \text{(for the same voltage)}$$

15.**(i)When primary coil P is moved towards secondary coil S (as shown in the figure below), the galvanometer shows momentary deflection. What can be done to have larger deflection in the galvanometer with the same battery?**
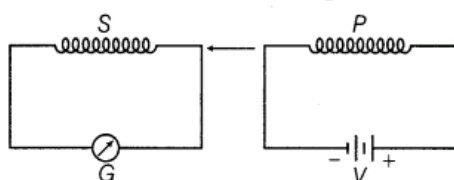


*(ii)* State the related law.
[Delhi 2010]

**Ans.**The coil P should be moved quickly towards or away from the coil 5.The laws involved here are Faraday's law of electromagnetic induction.

On the basis of his experiment, Faraday gave the following two laws:

**First law** Whenever magnetic flux linked with a circuit changes, an emf is induced in it which lasts, so long as change in flux continuous.                          (1/2)

**Second law** The emf induced in loop or closed circuit is directly proportional to the rate of change of magnetic flux linked with the loop

i.e.     $e \propto \dfrac{(-) d\phi}{dt}$     or     $e = -N \dfrac{d\phi}{dt}$
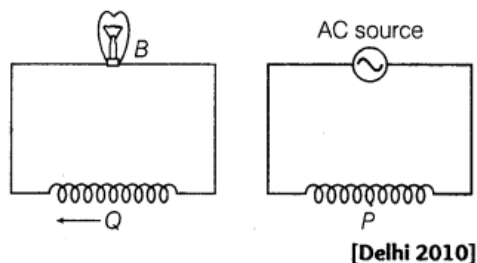
where, $N =$ number of turns in the coil. Negative sign indicates the Lenz's law.   (1/2)

16.A coil O is connected to low voltage bulb B and placed near another coil P as shown in the figure. Give reasons to explain the following observations.
(i)The bulb Blights.
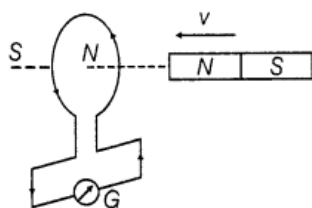(ii)Bulb gets dimmer. If the coil Q is moved towards left.

[Delhi 2010]

Ans.

> The current, responsible for the lighting of the bulb is of the induced nature, which depends on change of flux.

(i) Due to varying current in $P$, the flux linked with $P$ change and hence $Q$ changes, which in turn induces the emf in $Q$ and bulb $B$ lights. **(1)**

(ii) When $Q$ is moved left or it goes away from $P$, the lesser flux charge takes place in $Q$. This leads to decrease the value of rate of change of magnetic flux and hence, lesser emf and bulb $B$ gets dimmer. **(1)**

**17. State the law that gives the polarity of the induced emf.** [All India 2009]

**Ans.** Lenz's law gives the polarity of induced emf. The induced emf (or current) always opposes the cause that produces it.

Lenz's law The induced emf of induced current is a circuit which always opposes the cause that produces it.



When North pole of the bar magnet approaches towards the loop, the induced current in coil is anti-clockwise (forming North pole of current loop) when viewed from magnetic side. The face of coil being North pole opposes the arrival of North pole of magnet. Hence, opposes the cause that produces it.   Also, certain amount of work has to be done by external agency to bring the North pole near the coil in against of force of repulsion applied by induced current loop. The work done by external agency appears in the form of electrical energy. So, Lenz's law is a consequence of the principle of law of conservation of energy

**18. State Lenz's law. Give one example to illustrate this law. The Lenz's law is a consequence of the principle of conservation of energy. Justify this statement.** [All India 2009 ]
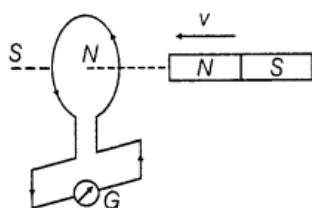
**Ans.** Lenz's law The induced emf of induced current is a circuit which always opposes the cause that produces it.



When North pole of the bar magnet approaches towards the loop, the induced current in coil is anti-clockwise (forming North pole of current loop) when viewed from magnetic side. The face of coil being North pole opposes the arrival of North pole of magnet. Hence, opposes the cause that produces it.    Also, certain amount of work has to be done by external agency to

bring the North pole near the coil in against of force of repulsion applied by induced current loop. The work done by external agency appears in the form of electrical energy. So, Lenz's law is a consequence of the principle of law of conservation of energy

### 3 Marks Questions

**19.(i) A rod of length / 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.**
**(ii) How does one understand this motional emf by invoking the Lorentz force acting on the free charge carriers of the conductor? Explain. [All India 2014]**

**Ans.**(i)Consider a straight conductor moving with velocity v and U shaped conductor placed in perpendicular magnetic field as shown in the figure.
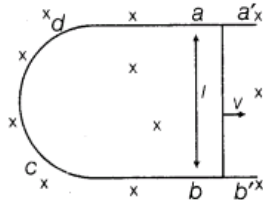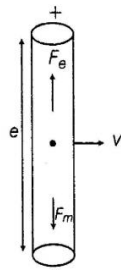


Let conductor shifts from $ab$ to $a'b'$ in time $dt$, then change in magnetic flux

$d\phi = B \times$ change in area

$\qquad = B \times (\text{area } a'b'ab) = B \times (l \times v\,dt)$

$\therefore \quad \dfrac{d\phi}{dt} = Bvl$ \hfill (1)

$\therefore$ Induced emf $|e| = \dfrac{d\phi}{dt} = Bvl$

(ii) During motion, free $e^-$ are shifted at one end due to magnetic force so due to polarisation of rod electric field is produced which applies electric force on free $e^-$ on opposite direction.



At equilibrium of Lorentz force,

$\qquad F_e + F_m = 0$

$\qquad q\mathbf{E} + q(\mathbf{v} \times \mathbf{B}) = 0$

$\qquad \mathbf{E} = -\mathbf{v} \times \mathbf{B} = \mathbf{B} \times \mathbf{v}$

$\qquad |\mathbf{E}| = |Bv\sin 90|$

$\qquad \dfrac{dv}{dr} = Bu$

$\therefore \qquad P_D = Bvl$ \hfill (1)

**20.** Consider the motion of a charged particle of mass $m$ and charge **q** moving with velocity **v** in a magnetic field **B**.
  (a) If **v** is perpendicular to **B**, then show that its describes a circular path having angular frequency $\omega = qB/m$.
  (b) If the velocity **v** has a component parallel to the magnetic field **B**, then trace the path described by the particle. Justify your answer.

**[All India 2014C]**

Ans.

(a) Force acting on the charged particle, moving with a velocity **v**, in a magnetic field **B**.

$$\mathbf{F} = q(\mathbf{v} \times \mathbf{B})$$

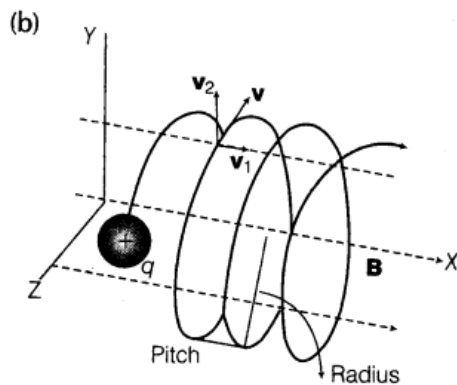As, $\mathbf{v} \perp \mathbf{B}$, $|\text{Force}| = qvB$

Since $\mathbf{F} \perp \mathbf{v}$, it acts as a centripetal force and makes the particle move in a circular path, in the plane, perpendicular to the magnetic field.

$$\therefore \quad qvB = \frac{mv^2}{r}$$

$$\therefore \quad r = \frac{mv}{qB}$$

Now, $\quad \omega = \frac{v}{r}$

$$\therefore \quad \omega = \frac{qB}{m}$$

(b)



Component of velocity v parallel to magnetic field, will make the particle move along the field. Perpendicular component of velocity v, will cause the particle to move along a circular path in the plane perpendicular to the magnetic field. Hence, the particle will travel the helix path.

**21.** (i) State Faraday's law of electromagneticinduction.

(ii) A jet plane is travelling towards west at a speed of 1800 km/h. What is the voltage difference developed between the ends of the wing having a span of 25 m, if the earth's magnetic field at the location has magnitude of $5 \times 10^{-4}$ T and the dip angle is 30°?

[All India 2009]

Ans.

(i) **For statement of Faraday's law of electromagnetic induction**
Refer to Ans. 6. **(1)**

(ii) Here, $v = 1800$ km/h

$$= 1800 \times \frac{5}{18} = 500 \text{ m/s}$$

(towards West)

$$d = 25 \text{ m}$$
$$B_e = 5 \times 10^{-4} \text{ T}$$

Angle of dip, $\delta = 30° = \frac{\pi}{6}$ rad

On flying the plane towards West, it intersects the vertical component of magnetic field which is given by

$$V = B_e \sin \delta = 5 \times 10^{-4} \sin 30°$$
$$= 2.5 \times 10^{-4} \text{ T}$$

where, $V$ = vertical component of magnetic field

∵ $\quad PD = v\,(V)\,l$ **(1)**

∴ $\quad PD = 500 \times (2.5 \times 10^{-4}) \times 25$
$$PD = 3.125 \text{ V} \qquad \textbf{(1)}$$

**22.** A coil of number of turns $N$, area $A$ is rotated at a constant angular speed $\omega$, in a uniform magnetic field $B$ and connected to a resistor $R$. Deduce expressions for

(i) maximum emf induced in the coil.

(ii) power dissipation in the coil.
**[Delhi 2008]**

Ans.

(i) Initially, area vector **A** of coil makes an angle $\theta$ with the direction of magnetic field.

Let coil rotates by an angle $\theta$ with the magnetic field in time $t$.

$$\therefore \quad \omega = \frac{\theta}{t}, \ \theta = \omega t \qquad \ldots(i)$$

$\therefore$ Magnetic flux linked with each turn of rectangular coil,

$$\phi = BA \cos \theta = BA \cos \omega t$$

$$\therefore \quad \frac{d\phi}{dt} = -BA \omega \sin \omega t$$

where, $\omega = 2\pi f$

$\Rightarrow$ For $N$ turn,

$$-N \frac{d\phi}{dt} = BNA\omega \sin \omega t \qquad \ldots(ii)$$

But by Faraday's law, **(1)**

$$e = -N \frac{d\phi}{dt} \qquad \ldots(iii)$$

From Eqs. (ii) and (iii), we get

Induced emf, $e = NBA\omega \sin \omega t$

where, $\omega = 2\pi f$

$$e = NBA\,(2\pi f)\sin \omega t$$

$$e = (2\pi f NBA)\sin \omega t$$

$$e = e_0 \sin \omega t \qquad \ldots(iv)$$

where, $e_0 =$ maximum or peak value of emf induced in coil and given by
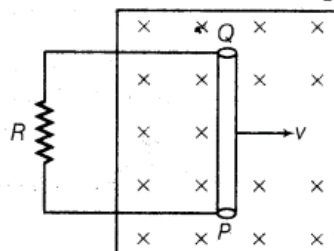
$$e_0 = 2\pi f NBA \qquad \textbf{(1)}$$

(ii) Power dissipated $= \dfrac{V_{rms}^2}{R} = \dfrac{e_{rms}^2}{R}$

where, $R$ is the resistance.

$$\because \quad e_{rms} = \frac{e_0}{\sqrt{2}} = \frac{NBA\omega}{\sqrt{2}}$$

$$\therefore \quad P_{av} = \frac{\left(\dfrac{NBA\omega}{\sqrt{2}}\right)^2}{R} = \frac{N^2 B^2 A^2 \omega^2}{2R} \qquad \textbf{(1)}$$

23. A conducting rod PQ, of length $l$, connected to a resistor R, is moved at a uniform speed v, normal to a uniform magnetic field B, as shown in the figure



(i) Deduce the expression for the emf induced in the conductor.

(ii) Find the force required to move the rod in the magnetic field.

(iii)Mark the direction of induced current in the conductor.[Foreign 2008]

Ans.

> To calculate the induced emf, rate of change of flux needs to be calculated first. Here magnetic field is uniform, so change in flux is taking place due to change in area swept by loop. By calculating the rate of change of area, we can calculate rate of change of flux, i.e. induced emf.

(i) Let the lengths of horizontal arms of circuit are $x_1$ and $x_2$ at instants, $t_1$ and $t_2$ respectively.
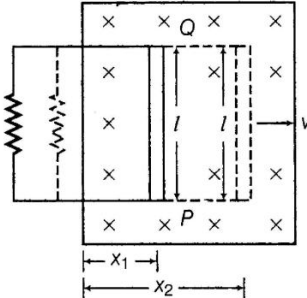


∴ Area of loop inside the magnetic field,

$$A_1 = lx_1, A_2 = lx_2$$

∴ $$\Delta A = A_2 - A_1 = l(x_2 - x_1) = l\Delta x$$

$$\Delta\phi = B\Delta A = Bl\Delta x$$

∴ $$\frac{\Delta\phi}{\Delta t} = Bl\frac{\Delta x}{\Delta t} = Blv$$

By Faraday's law of induced emf (in magnitude),

$$e = \frac{\Delta\phi}{\Delta t} = vBl$$

∴ $$e = vBl \qquad (1)$$

(ii) ∴ Current ($I$) in the loop,

$$I = \frac{e}{R} = \frac{vBl}{R}$$

Force required must be equal to magnetic force acting on conductor $PQ$ in the opposite directions.

∴ $$F = IBl \sin 90°$$

$$= \left(\frac{vBl}{R}\right)Bl$$

$$F = \frac{vB^2l^2}{R} \qquad (1)$$

(iii) By Fleming's right hand rule, the direction of flow of current is along anti-clockwise direction. (1)

24. Figure shows a rectangular conducting loop PQRS in which arm RS of length *l* is movable. The loop is kept in a uniform magnetic field B directed downward perpendicular to the plane of the loop. The arm RS is moved with a uniform speed v.
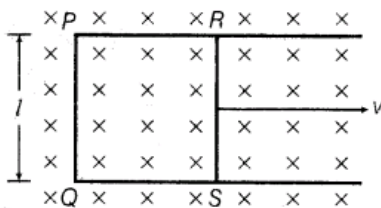


Deduce an expression for

(a) the emf induced across the arm RS

(b) the external force required to move the arm and

(c) the power dissipated as heat.[All India 2009]

**Ans.**

According to the question,
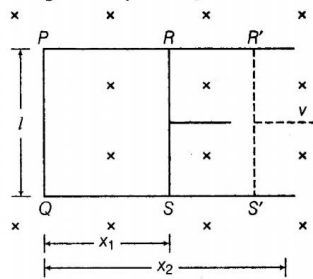


(i) Let, RS moves with speed $v$ rightward and also RS is at distances $x_1$ and $x_2$ from PQ at instants $t_1$ at $t_2$, respectively.

∴ At $t_1$, flux linked with loop 1, i.e. PQRS,

$$\phi_1 = B(lx_1)$$

Similarly, at instant $t_2$, flux linked with loop 2

$$\phi_2 = Bl(x_2)$$

∴ Change in flux,

$$\Delta\phi = \phi_2 - \phi_1 = Bl(x_2 - x_1)$$
$$\Delta\phi = Bl\Delta x$$

$$\Rightarrow \quad \frac{\Delta\phi}{\Delta t} = Bl\frac{\Delta x}{\Delta t} = Blv \quad \left[\because v = \frac{\Delta x}{\Delta t}\right]$$

By Faraday's law, magnitude of induced emf,

$$V = vBl \tag{1}$$

(ii) If resistance of loop is R, then $I = \dfrac{vBl}{R}$

∴ Magnetic force $= IBl \sin 90°$

$$= \left(\frac{vBl}{R}\right)Bl = \frac{vB^2l^2}{R}$$

∴ External force must be equal to magnetic force and in opposite directions.

∴ External force $= \dfrac{vB^2l^2}{R}$ **(1)**

(iii) As, $P = I^2R = \left(\dfrac{vBl}{R}\right)^2 \times R = \dfrac{v^2B^2l^2}{R^2} \times R$ **(1)**

∴ $P = \dfrac{v^2B^2l^2}{R}$

## 5 Marks Questions

25.(i) 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 a current which opposes the change of magnetic flux that produces it. (ii) The current flowing through an inductor of self-inductance L is continuously increasing. Plot a graph showing the variation of
(a)magnetic flux versusthe current
(b)induced emf versus dl/dt
(c)magnetic potential energy stored versusthe current.[Delhi 2014]

**Ans**.(i)The coil P should be moved quickly towards or away from the coil 5.The laws involved here are Faraday's law of electromagnetic induction.

On the basis of his experiment, Faraday gave the following two laws:

**First law** Whenever magnetic flux linked with a circuit changes, an emf is induced in it which lasts, so long as change in flux continuous. **(1/2)**

**Second law** The emf induced in loop or closed circuit is directly proportional to the rate of change of magnetic flux linked with the loop
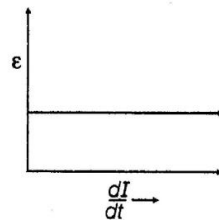
i.e. $e \propto \dfrac{(-)\,d\phi}{dt}$ or $e = -N\dfrac{d\phi}{dt}$

where, $N$ = number of turns in the coil. Negative sign indicates the Lenz's law. **(1/2)**

(ii) (a) **Magnetic flux *versus* current**
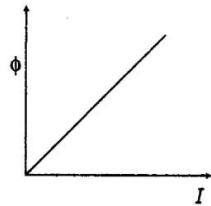


(b) **Induced emf *versus* $\dfrac{dI}{dt}$**



$e = -L\dfrac{dI}{dt}$

$\dfrac{dI}{dt}$ is positive and $e$ is negative and constant. **(1)**

(c) **Magnetic potential energy stored versus current**
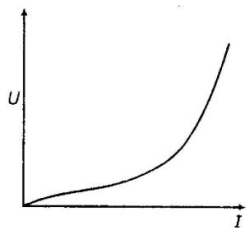


$U = \dfrac{1}{2}LI^2 \Rightarrow U \propto I^2$

26. A metallic rod of length l and resistance R is rotated with a frequency v, with one end hinged at the centre and the other end at the circumference of a circular metallic ring of radius l, about an axis passing through the centre and perpendicular to the plane of the ring. A constant and uniform magnetic field ft parallel to the axis is present everywhere.
(a) Derive the expression for the induced emf and the current in the rod.
(b) Due to the presence of the . current in the rod and of the magnetic field, find the expression for the magnitude and direction of the force acting on this rod.
(c) Hence, obtain the expression for the power required to rotate the rod. [All India 2014 C]
Ans.

(a) In the one revolution

change of area, $dA = \pi l^2$

∴ Change of magnetic flux.

$d\phi = \mathbf{B} \cdot \mathbf{A} = BdA \cos 0°$

$\quad\quad = B\pi l^2$

Period of revolution $T$

(i) Induced emf $(\varepsilon) = \dfrac{B\pi l^2}{T} = B\pi l^2 v$

(ii) Induced current in the rod,

$$I = \frac{\varepsilon}{R} = \frac{\pi v B l^2}{R}$$

(b) Force acting on the rod,

$$F = IlB = \frac{\pi v B^2 l^3}{R}$$

The external force required to rotate the rod opposes the Lorentz force acting on the rod/external force acts in the direction opposite to the Lorentz force

(c) Power required to rotate the rod.

$$P = Fv = \frac{\pi v B^2 l^3 v}{R}$$

27. 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.
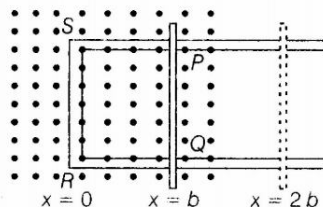


The field extends from $x = 0$ to $x = b$ and is zero for $x > b$.

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 speed *v*, obtain the expressions for the flux and the induced emf.

Sketch the variation of these quantities with distance $0 \le x \le 2b$.

[All India 2010]

Ans.

**For statement of Faraday's law** Refer to Ans 4.

(1)

***Case I*** When $PQ$ moves forward.

(i) For $0 \leq x < b$

Magnetic field $B$ exists in the region.

∴ Area of loop $PQRS = lx$

∴ Magnetic flux linked with loop $PQRS$,

$$\phi = BA = Blx$$

$$\phi = Blx \qquad ...(i) \ (b > x \geq 0)$$

(ii) For, $2b \geq x \geq b$

$$B = 0$$

∴ Flux linked with loop $PQRS$ is uniform and given by

$$\phi' = Blb \qquad ...(ii)$$

$$x = b \qquad \qquad \textbf{(1/2)}$$

**Forward journey**

Thus, for $b > x \geq 0$

flux, $\phi = Blx$

$\Rightarrow \qquad \phi \propto x$

For $\qquad 2b \geq x \geq b$

Flux, $\qquad \phi = Bbl \qquad \qquad$ (constant)

**Return journey**

For $\qquad b \leq x \leq 2b$,

$\qquad \phi = $ constant $= Bbl \qquad \qquad$ **(1)**

For $\qquad 0 \leq x \leq b$,

$\qquad \phi = Blx \qquad \qquad$ (decreasing)

**Graphical representation**
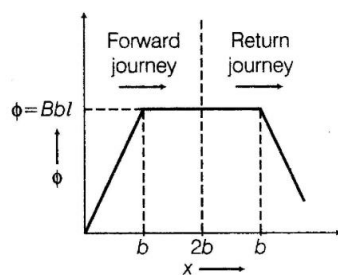


**(1/2)**

***Case II*** For $\qquad b > x \geq 0, \ B = 0$

As, $\qquad \phi = Blx$

$\Rightarrow \qquad \dfrac{d\phi}{dt} = Bl\dfrac{dx}{dt} = Bvl \qquad \left[ \because v = \dfrac{dx}{dt} \right]$

Induced emf,

$$e = -\dfrac{d\phi}{dt} = -vBl$$

For $\qquad 2b \geq x \geq b$,

As, $\phi' = Bbl$

$$\frac{d\phi'}{dt} = 0$$

$\Rightarrow \qquad e = 0 \qquad$ **(1)**

**Forward journey**

For $\qquad b > x \geq 0$

$\qquad\qquad e = -vBl$

For $\qquad 2b \geq x \geq b$

$\qquad\qquad e = 0$

**Backward journey**

For $\qquad b > x \geq 0$

$\qquad\qquad e = vBl$

For $\qquad 2b \geq x \geq b,$

$\qquad\qquad e = 0$

Variation of induced emf
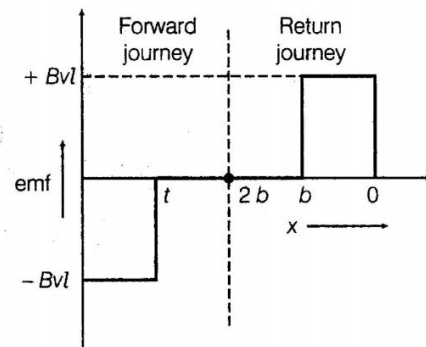


**(1)**

# EddyCurrents and Self and Mutual Induction

## 1 Mark Questions

**1.Why is the core of a transformer laminated?** [Delhi 2013 c]

Ans.

The core of a transformer is laminated because of preventing eddy current being produced in the core. (1)

**2.The motion of copper plate is damped, when it is allowed to oscillate between the two poles of a magnet. What is the cause this damping?** [All India 2013]

**Ans**As, the copper plates oscillate in the magnetic field between the two poles of the magnet, there is a continuous change of magnetic flux linked with the pendulum. Due to this eddy currents are set up in copper plate which try to oppose the motion of the plate (according to plate the Lenz's law) and finally bring it to rest.

**3.A light metal disc on the top of an electromagnet is thrown up as the current is switched on. Why? Give reason.** [All India 2013]

Ans.

When the current begins to grow through the electromagnet, the magnetic flux through the disc begins to increase. This sets up eddy current in the disc in the same direction as that of the electromagnetic current. (1/2)

Thus, if the upper surface of electromagnetic acquires $N$-polarity, the lower surface of the

disc also acquires $N$-polarity. As, same magnetic poles repel each other, the light metallic disc is thrown up. (1/2)

**4.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?** [All India 2013]

Ans.

(i) A $\phi = MI$, with the increase in the distance between the coils the magnetic flux linked with the secondary coil decreases and hence, the mutual inductance of the two coils will decreases with the increase of separation between them. (1/2)

(ii) Mutual inductance of two coils can be found out by $M = \mu_0 n_1 n_2 Al$, i.e. $M \propto n_1 n_2$, so, with the increase in number of turns mutual inductance increases. (1/2)

**5.How can the self-inductance of a given coil having N number of turns, area of cross-section A and lengths / be increased?** [Forign 2009; Delhi 2012]

**Ans.**The self-inductance can be increased by the help of electric fields. It does not depend on the current through circuit but depends upon the permeability of material from which the core is made up off.

6.Define self-inductance of a coil. Write its SI unit. [All India 2010]

Ans.

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

Also, self-inductance of a coil, is equal to the emf induced in coil, when rate of change of current in coil is 1 A/s .

SI unit of self inductance is 1 Henry (H)

$$1H = 1 V\text{-}s/A \qquad (1)$$

**NOTE** Any one definition is sufficient.

7.A plot of magnetic flux versus current (I) is shown in the figure for two inductions A and B Which of two has larger value of self-inductance?  [Delhi 2010]

Ans.

Self-inductance of the inductor, $L = \phi / I$.

The slope of $I - \phi$ graph gives self-inductance of the coil.

Inductor $A$ have got greater slope than inductor $B$, therefore self-inductance of $A$ is greater than self-inductance of $B$. (1)

8.Define mutual inductance. Give its SI unit.  [Foreign 2009]

Ans.

The mutual inductance of two inductor is equal to magnetic flux linked with one inductor when unit current flows through another conductor. (1)

or

The mutual inductance of two inductors is equal to emf induced in one coil, when rate of change of current in other coil is unity.

SI unit of mutual inductance = Henry (H)

$$1H = 1V\text{-}s/A \qquad (1)$$

**NOTE** Any one definition is sufficient.

**9.Mention any two useful applications of eddy currents.[Delhi 2009 C]**
**Ans**.(i) Magnetic brake.
(ii) Magnetic furnace.

**10The coils in certain galvanometers, have a fixed core made of a non-magnetic metallic material. Why does the oscillating coil come to rest so quickly in such a core?**
**Ans.**Due to eddy currents produced in core whitih opposes the cause (deflection of coil), that produces it.

# 2 Marks Questions

**11.What are eddy currents? Write their tWO applications.          [All India 2012]**
**Ans.**Eddy current Eddy currents are the currents induced in the bulk pieces of conductors when the amount of magnetic flux linked with the conductor changes.Eddy currents can be minimised by taking laminated core, consists of thin metallic sheet insulated from each other by varnish instead of a single solid mass. The plane of the sheets should be kept perpendicular to the direction of the currents. The insulation provides high resistance hence, eddy current gets minimised
**Applications** (i) Electromagnetic damping (ii) Induction furnace.

**12.Define mutual inductance between two long coaxial solenoids. Find out the expression for the mutual inductance of inner solenoid of length / having the radius $r_x$ and the number of turns per unit length due to the second outer solenoid of same length and $n_2$ number of turns per unit length.  [Delhi 2012]**
**Ans.**

> 💡 Due to change in the current in the one coil flux linked with the other coil is changing, we will calculate mutual inductance on this basis.

The phenomenon of generation of induced emf in a long solenoid due to a change of current in another neighbouring coaxial solenoid is known as mutual induction.     **(1)**

**13.** Current in e circuit fails steadily bum AU A to 0.0 A in 10 ms. ii an average emf of 200 V is induced, then calculate the self-inductance of the Circuit.     [Foreign 2011]

**Ans.**

The mutual induction for the pair of the solenoids is

$$M = \frac{\mu_0 n_1 n_2 A}{l} \qquad \text{(1)}$$

$$\Delta I = -2 \text{ A}$$
$$\Delta t = 10 \times 10^{-3} \text{ s}$$
$$V = 200 \text{ V}$$
$$L = ?$$

$\because$ Induced emf, $e = -L \dfrac{\Delta I}{\Delta t}$ \qquad (1)

$$200 = -L \left( \frac{-2}{10 \times 10^{-3}} \right)$$
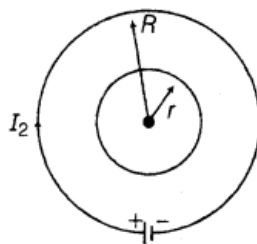
$$200 = L \times 2 \times 10^2$$

$\therefore$ Self-induction, $L = 1 \text{H}$ \qquad (1)

**14.** Two concentric circular coils, one of small radius r and the other of large radius R, such that R >>r, are placed coaxially with centres coinciding. Obtain the mutual inductance of the a rran element.

**Ans.**

Let a current $I_2$ **flows** through the outer circular coil of radius R. The magnetic field at the centre of the coil is

$$B_2 = \frac{\mu_0 I_2}{2R}$$



(1)

As $r \ll R$, hence field $B_2$ may be considered to be constant over the entire cross-sectional area of inner coil of radius r. Hence, magnetic flux linked with the smaller coil will be

$$\phi_1 = B_2 A_1 = \frac{\mu_0 I_2}{2R} \cdot \pi r^2$$

As, by definition $\phi_1 = M_{12} I_2$

Now mutual inductance, $M_{12} = \dfrac{\phi_1}{I_2}$

$$= \frac{\mu_0 \pi r^2}{R}$$

But $M_{12} = M_{21} =$ suppose, $M$

$\therefore \qquad M = \dfrac{\mu_0 \pi r^2}{R}$ \qquad (1)

**15.** Two concentric circular coils C1 and $C_2$, radius r1 and $r_2$ (r1<<r$_2$) respectively are kept coaxially.  If current is passed through $C_2$, then find an expression  for  mutual inductance between the two coils.
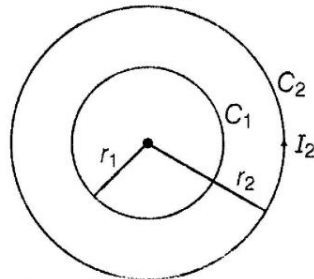
[All India 2009,2011 C; Foreign 2011]

**Ans.**

Let current $I_2$ passes through the coil $C_2$.

Magnetic field at centre due to current loop $C_2$

$$B_2 = \frac{\mu_0 N_2 I_2}{2r_2}$$



where, $N_2$ = number of turns in coil $C_2$ **(1/2)**

∴ Total magnetic flux linked with coil $C_1$

$$\phi_1 = N_1 B_2 A_1 \qquad \text{(1/2)}$$

$$\phi_1 = N_1 \left( \frac{\mu_0 N_2 I_2}{2r_2} \right) (\pi r_1^2)$$

But, $\qquad \phi = \mu I_2$

$\Rightarrow \qquad MI_2 = \frac{\mu_0 N_1 N_2 I_2}{2r_2} \pi r_1^2$

$$M = \frac{\mu_0 \pi N_1 N_2 r_1^2}{2 r_2} \qquad \text{(1)}$$

**16.** A source of emf $\varepsilon$ is used to establish a current $I$ through a coil of self-inductance $L$. Show that the work done by the source of build up the current $I$ is $\frac{1}{2} LI^2$.

[Delhi 2010C]

Ans.

The source of emf $\varepsilon$ establishes current in coil in opposition of induced emf (Lenz's rule) and hence does the work for the same. This work done by source stores in the form of magnetic energy in the coil.

Let, $I$ current flows through the coil of self-inductance $L$ at any instant $t$ when rate of change of current in coil is $\dfrac{dI}{dt}$.

$\therefore$ Induced emf, $E = -L\dfrac{dI}{dt}$     (1)

$\therefore$ Work done in establishing the current in small time interval $dt$ is given by

$$dW = Pdt = -EIdt = -\left(-L\dfrac{dI}{dt}\right)Idt$$

$$dW = LIdI$$

$\therefore$ Total work done in increasing the current from zero to $I$.

$\therefore$      $W = \int_0^I LI\,dI = L\int_0^I I\,dI$

$$= L\left[\dfrac{I^2}{2}\right]_0^I = \dfrac{1}{2}L(I^2 - 0^2)$$

$$W = \dfrac{1}{2}LI^2$$

This work is stored as the energy in the inductor.     (1)

17.Derive an expression for the self-inductance of a long air-cored solenoid of length / and number of turns N. [Delhi 2008]

Ans.

. Let the radius and length of air cored solenoid are $r$ and $l$, respectively such that $r \ll l$ and having $n$ turns per unit length.

$\therefore$      $n = \dfrac{N}{l}$     ...(i)

$N$ = total number of turns

If, $I$ current flows through the coil, then magnetic field is given by

$$B = \mu_0 nI \qquad (1)$$

$\therefore$ Magnetic flux linked with each turn

$$\phi = BA = \mu_0 nIA$$

$\therefore$ Total magnetic flux linked with solenoid

$$N\phi = (\mu_0 nIA)N$$

But,      $N\phi = LI$

where, $L$ is coefficient of self-induction.

$$(\mu_0 nIA)N = LI$$

$$L = \mu_0 nAN = \mu_0\left(\dfrac{N}{l}\right)AN$$

$$L = \dfrac{\mu_0 AN^2}{l} \qquad (1)$$

This is required expression.

18.Define mutual inductance and write its SI unit. Write the expression for the mutual inductance between a pair of circular coil of radii r and R (.R > r). [Foreign 2008]

Ans.

The mutual inductance of two inductor is equal to magnetic flux linked with one inductor when unit current flows through another conductor. (1)

or

The mutual inductance of two inductors is equal to emf induced in one coil, when rate of change of current in other coil is unity.

SI unit of mutual inductance = Henry (H)

$$1H = 1V-s/A \qquad (1)$$

**NOTE** Any one definition is sufficient.

Mutual inductance of pair of circular coils,

$$M = \frac{(\mu_0 \pi) N_1 N_2 r^2}{2R} \qquad (1)$$

where, $N_1$ and $N_2$ are number of turns in inner and outer coil of radii $r$ and $R$, respectively.

19. Derive an expression for the self-inductance of a long solenoid of N number of turns containing a medium of relative permeability $u_r$. [Foreign 2008]

**Ans.**

. Let the radius and length of air cored solenoid are $r$ and $l$, respectively such that $r \ll l$ and having $n$ turns per unit length.

$$\therefore \qquad n = \frac{N}{l} \qquad \ldots(i)$$

$N$ = total number of turns

If, $I$ current flows through the coil, then magnetic field is given by

$$B = \mu_0 nI \qquad (1)$$

$\therefore$ Magnetic flux linked with each turn

$$\phi = BA = \mu_0 nIA$$

$\therefore$ Total magnetic flux linked with solenoid

$$N\phi = (\mu_0 nIA)N$$

But, $\qquad N\phi = LI$

where, $L$ is coefficient of self-induction.

$$(\mu_0 nIA)N = LI$$

$$L = \mu_0 nAN = \mu_0 \left(\frac{N}{l}\right) AN$$

$$L = \frac{\mu_0 AN^2}{l} \qquad (1)$$

This is required expression.

For a core of medium of relative permeability $\mu_r$.

$$\therefore \qquad L = \frac{(\mu_0 \mu_r) N^2 A}{l} \qquad (1/2)$$

20. The flux linked with a large circular coil of radius $R$ is $0.5 \times 10^{-3}$ Wb. When a current of 0.5 A flows through a small neighbouring coil of radius $r$, calculate the coefficient of mutual inductance for the given pair of coils.

If the current through the small coil suddenly falls to zero, what would be its effect in the larger coil? [Delhi 2008C]

**Ans.**

Flux linked with larger coil of radius,
$$R = 0.5 \times 10^{-3} \text{ Wb}$$
and $\quad I = 0.5 \text{ A}$

flows through neighbouring coil of radius $r$.
Total flux ($\phi$) linked with one coil $= MI$
[$I$ current flows in neighbour coil]
$$\therefore \quad 0.5 \times 10^{-3} = M \times 0.5$$
$$M = 10^{-3} \text{ H} \quad \textbf{(1)}$$

With the fall of current in small coil to zero, the magnetic flux linked with long coil decrease to zero quickly which in turn produces large induced emf in it. **(1)**

21. A large circular coil of radius R and a small circular coil of radius r are put in vicinity of each other. If the coefficient of mutual induction for this pair equals 1 mH, what would be the flux linked with the larger coil when a current of 0.5 A flows through the smaller coil? When the current in the smaller coil falls to zero, what would be its effect in the larger coil? [Delhi 2008 C]

Ans.

According to the question,
Mutual inductance for a given power of coil
$$M = 1\text{mH} = 1 \times 10^{-3} \text{ H}$$
$$I = 0.5 \text{ A}$$
$\therefore$ Total magnetic flux linked with larger coil,
$$\phi = MI$$
$$\phi = (1 \times 10^{-3}) \times 0.5$$
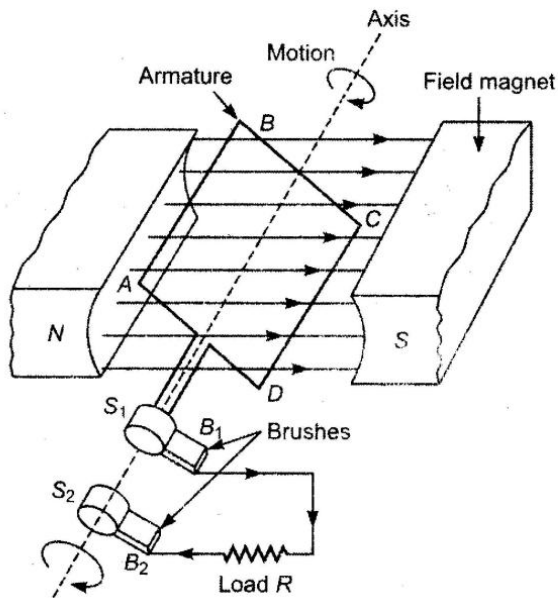$$\phi = 5 \times 10^{-4} \text{ Wb} \quad \textbf{(1)}$$

## 3 Marks Questions

22. (i) Draw a schematic sketch of an AC generator describing its basic elements. State briefly its working principle. Show a plot of variation of (a) magnetic flux and (b) alternating emf versus time generated by a loop of wire rotating in a magnetic field, (ii) Why is choke coil needed in the use of fluorescent tubes with AC mains?   [Delhi 2014]

Ans.

Whenever amount of magnetic flux linked with a coil changes, an emf induced in the coil. It lasts so long as the change in magnetic flux through the coil continues.
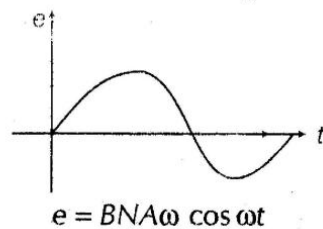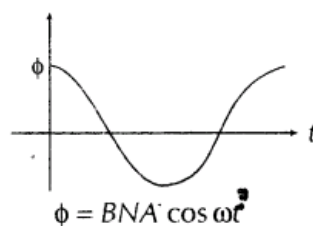
**(1)**



**Working** When a closed armature coil rotates in a uniform magnetic field with its axis perpendicular to the magnetic field, the magnetic flux linked with the loop changes and emf induces in the coil. Let initially angle between area vector of coil and magnetic field $B$ is $0°$. Thereafter, $AB$ comes downward and $CD$ upward then by Fleming's right hand rule induced current flows from $B$ to $A$.

During the next half revolution, when $CD$ comes downward end $AB$ upward then current flows from $C$ to $D$. During the first half rotation, current flows through $BAS_2B_2RB_1DC$ and during next half rotation along $CDB_1RB_2S_2AB$.

(a) **Variation of alternating emf with time**



$$e = BNA\omega \cos \omega t$$

(b) **Variation of magnetic flux with time**



$$\phi = BNA \cos \omega t$$

(ii) The choke coil is used to reduce the current. As its power factor is zero, it reduces the current without wasting the power.

**(1)**

23. 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.[All India 2014]

Ans.

(i) **Self-Inductance** Self-inductance is the property of a coil by virtue of which, the coil opposes any change in the strength of current flowing through it by inducing an emf in itself.

The induced emf is also called **back emf**. When the current in a coil is switched on, the self-induction opposes the growth of the current and when the current is switched off, the self-induction opposes the decay of the current.

So, self-induction is also called the **inertia of electricity**.
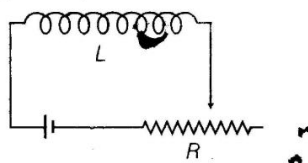


(ii) **Self-Inductance of long Solenoid** A long solenoid is one whose length is very large as compared to its area of cross-section. The magnetic field $(B)$ at any point inside such a solenoid is practically constant and is given by

$$B = \frac{\mu_0 NI}{l} \qquad ...(i)$$

where, $\mu_0$ = absolute magnetic permeability of free space, $N$ = total number of turns in the solenoid

and $I$ = length of the solenoid.

∴ Magnetic flux through each turn of the solenoid,

$$\phi = B \times \text{area of the each turn}$$

$$\phi = \left(\mu_0 \frac{N}{l} I\right) A$$

where, $A$ = area of each turn of the solenoid.

Total magnetic flux linked with the solenoid = flux through each turn × total number of turns

$$N\phi = \mu_0 \frac{N}{l} IA \times N \qquad \text{...(ii)}$$

If $L$ is coefficient of self-inductance of the solenoid, then

$$\therefore \quad N\phi = LI \qquad \text{...(iii)}$$

From Eqs. (ii) and (iii), we get

$$LI = \mu_0 \frac{N}{l} IA \times N$$

or

$$L = \frac{\mu_0 N^2 A}{l} \qquad \textbf{(1)}$$

If core is of any other magnetic material $\mu$ is placed, then

$$\mu = \mu_0 \mu_r$$

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

The magnitude of emf is given by

$$|e| \text{ or } e = L\frac{dI}{dt}$$

Multiplying ($I$) to both sides, we get

$$eI\, dt = LI\, dI \qquad \text{...(iv)}$$

But

$$I = \frac{dq}{dt}$$

or $\quad Idt = dq$

Also, work done ($dW$) = Voltage ($e$)

$$\times \text{ Charge } (dq)$$

or $\quad dW = e \times dq = eIdt$

Substituting these values in Eq. (iv), we get

$$dW = LIdI \qquad \text{...(v)}$$

Total work done in increasing the current from zero to $I_0$, we have

By integrating both sides of Eq. (v), we get

$$\int_0^w dW = \int_0^{I_0} LIdI$$

$$W = \frac{1}{2} LI_0^2$$

This work done in increasing the current flowing through the inductor is stored as the potential energy ($U$) in the magnetic field of inductor $U = \frac{1}{2} L I_0^2 c$

24. The current flowing in the two coils of self-inductance =16 mH and L2 = 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 coil at a given instant. [Foreign 2014]

Ans.

Given,
$$L_1 = 16 \text{ mH},$$
$$L_2 = 12 \text{ mH}$$

(i) Induced voltage is given by

$$v = L\frac{dI}{dt} \implies v \propto L$$

$$\frac{v_1}{v_2} = \frac{L_1}{L_2} \quad \left(\text{as } \frac{dI}{dt} \text{ is same}\right)$$

$$\implies \quad \frac{v_1}{v_2} = \frac{16}{12} = \frac{4}{3} \qquad \qquad \dots \text{(i)}$$

(ii) Power $(P) = Iv$

Now,

$$\frac{I_1}{I_2} = \frac{v_2}{v_1} \qquad \qquad \text{(as } P \text{ is the same)}$$

$$\implies \quad \frac{I_1}{I_2} = \frac{3}{4} \qquad \qquad \dots \text{(ii)}$$

(iii) Energy stored is given by coil 1 and coil 2

$$E_1 = \frac{1}{2}L_1 I_1^2 \qquad \qquad \dots \text{(iii)}$$

$$E_2 = \frac{1}{2}L_2 I_2^2 \qquad \qquad \dots \text{(iv)}$$

On dividing Eqs. iii and (iv), we get

$$\frac{E_1}{E_2} = \frac{L_1 I_1^2}{L_2 I_2^2} = \frac{16}{12} \times \frac{9}{16} \quad \text{[from Eq. (ii)]}$$

$$\frac{E_1}{E_2} = \frac{3}{4}$$

**25.** Starting from the expression for the energy $W = \frac{1}{2}LI^2$, stored in a solenoid of self-inductance $L$ to build up the current $I$, obtain the expression for the magnetic energy in terms of the magnetic field $B$, area $A$ and length $l$ of the solenoid having $n$ number of turns per unit length. Hence, show that the energy density is given by $B^2/2\mu_0$.

**[Delhi 2013C]**

**Ans.**

Energy stored in the magnetic field

$$W = \frac{1}{2}LI^2$$

$$= \frac{1}{2}\frac{\mu_0 N^2 A}{L} \cdot \frac{B^2 L^2}{\mu_0^2 N^2}$$

$$= \frac{\mu_0^2}{2\mu_0}(AL)^2 \quad \left[\because L = \frac{\mu_0 N^2 A}{L}, B = \frac{\mu_0 NL}{L}\right]$$

**(2)**

We know that, energy density,

$$u_B = \frac{\text{Energy}}{\text{Volume}}$$

$$= \frac{B^2}{2\mu_0} \qquad \qquad [\because B = AL]$$

26.(i) Define self-inductance. Write its SI units.

(ii) Derive an expression for self-inductance of a long solenoid of length /, cross-sectional area A having N number of turns.[Delhi 2009]

Ans.(i)

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

Also, self-inductance of a coil, is equal to the emf induced in coil, when rate of change of current in coil is 1 A/s .

SI unit of self inductance is 1 Henry (H)

$$1H = 1V\text{-}s/A \qquad (1)$$

**NOTE** Any one definition is sufficient.

(ii)

• Let the radius and length of air cored solenoid are $r$ and $l$, respectively such that $r \ll l$ and having $n$ turns per unit length.

$$\therefore \qquad n = \frac{N}{l} \qquad \ldots (i)$$

$N$ = total number of turns

If, $I$ current flows through the coil, then magnetic field is given by

$$B = \mu_0 nI \qquad (1)$$

∴ Magnetic flux linked with each turn

$$\phi = BA = \mu_0 nIA$$

∴ Total magnetic flux linked with solenoid

$$N\phi = (\mu_0 nIA)N$$

But, $\qquad N\phi = LI$

where, $L$ is coefficient of self-induction.

$$(\mu_0 nIA)N = LI$$

$$L = \mu_0 nAN = \mu_0 \left(\frac{N}{l}\right)AN$$

$$L = \frac{\mu_0 AN^2}{l} \qquad (1)$$

This is required expression.


27.Define the coefficient of mutual induction. A long solenoid of length / and radius is enclosed coaxially within another long solenoid of length l and radius $r_2$ ($r_2 > r_1$ and $\gg r_2$). Deduce the expression for the mutual inductance of this pair of Solenoids.  [Delhi 2009; Ail India 2008]

Ans.

The mutual inductance of two inductor is equal to magnetic flux linked with one inductor when unit current flows through another conductor. $\qquad (1)$

or

The mutual inductance of two inductors is equal to emf induced in one coil, when rate of change of current in other coil is unity.

SI unit of mutual inductance = Henry (H)

$$1H = 1V\text{-}s/A \qquad (1)$$

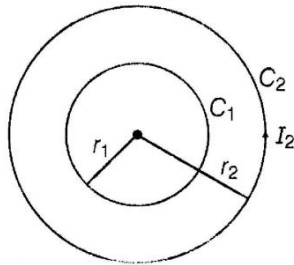**NOTE** Any one definition is sufficient.

Let current $I_2$ passes through the coil $C_2$.

Magnetic field at centre due to current loop $C_2$

$$B_2 = \frac{\mu_0 N_2 I_2}{2r_2}$$



where, $N_2$ = number of turns in coil $C_2$ **(1/2)**

$\therefore$ Total magnetic flux linked with coil $C_1$

$$\phi_1 = N_1 B_2 A_1 \qquad \textbf{(1/2)}$$

$$\phi_1 = N_1 \left( \frac{\mu_0 N_2 I_2}{2r_2} \right)(\pi r_1^2)$$
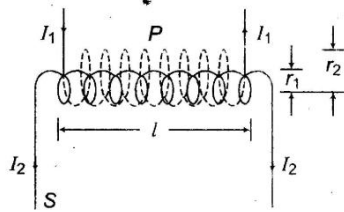
But, $\qquad \phi = \mu I_2$

$$\Rightarrow \quad MI_2 = \frac{\mu_0 N_1 N_2 I_2}{2r_2} \pi r_1^2$$

$$M = \frac{\mu_0 \pi N_1 N_2 r_1^2}{2 r_2} \qquad \textbf{(1)}$$

28. Deduce an expression for the mutual inductance of two long coaxial solenoids but having different radii and different number of turns. [All India 2009]

Ans.

. Let coaxial solenoid $P$ is wound over an another solenoid.



(1)

Let $l$ = length of both solenoid.

$r_1$ and $r_2$ = radii of $P$ and $S$

$A_2 = \pi r_2^2$  [area of secondary coil, $S$]

Magnetic induction in solenoid, $P$

$B_1 = \mu_0 n_1 I_1$          (1)

where, $n = \dfrac{N_1}{l}$ = number of turn per unit length.

$\therefore$ Total flux linked with solenoid $S$

$\phi_2 = B_1 A_2 N_2$

$\Rightarrow \quad \phi_2 = B_1 (\pi r_2^2) N_2$

$\qquad = (\mu_0 n_1 I_1) \pi r_2^2 N_2$

$\phi_2 = \left(\mu_0 \dfrac{N_1}{l} \cdot I_1\right) \pi r_2^2 N_2$

$\Rightarrow \quad \phi_2 = \dfrac{\mu_0 \pi I_1 N_1 N_2 r_2^2}{l}$          ...(i)

But $\quad \phi_2 = M I_1$

where, $M$ = coefficient of mutual induction

$\Rightarrow \quad M I_1 = \dfrac{\mu_0 \pi N_1 N_2 r_2^2}{l} I_1$

$\qquad M = \dfrac{\mu_0 \pi N_1 N_2 r_2^2}{l}$          (1)

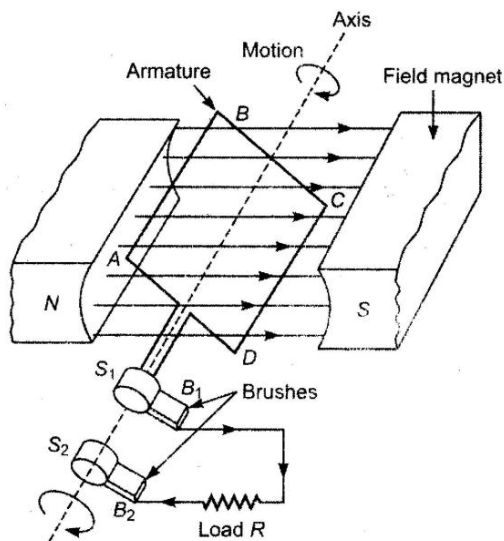This is required expression for coefficient of mutual induction.

## 5 Marks Questions

29.(i) Draw a labelled diagram of AC generator and state its working principle

(ii)How is magnetic flux linked with the armature coil changed in a generator ?

(iii)Derive the expression for maximum value of the induced emf and state the rule that gives the direction of the induced emf.

(iv)Show the variation of the emf generated versus time as the armature is rotated with respect to the direction of the magnetic fields.   [Delhi 2014 C]

Ans.

Whenever amount of magnetic flux linked with a coil changes, an emf induced in the coil. It lasts so long as the change in magnetic flux through the coil continues.
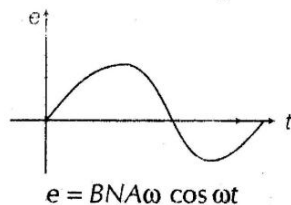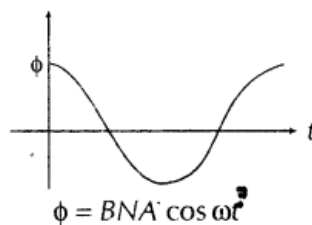
**(1)**



**Working** When a closed armature coil rotates in a uniform magnetic field with its axis perpendicular to the magnetic field, the magnetic flux linked with the loop changes and emf induces in the coil. Let initially angle between area vector of coil and magnetic field $B$ is $0°$. Thereafter, $AB$ comes downward and $CD$ upward then by Fleming's right hand rule induced current flows from $B$ to $A$.

During the next half revolution, when $CD$ comes downward end $AB$ upward then current flows from $C$ to $D$. During the first half rotation, current flows through $BAS_2B_2RB_1DC$ and during next half rotation along $CDB_1RB_2S_2AB$.

(a) **Variation of alternating emf with time**



$$e = BNA\omega \cos \omega t$$

(b) **Variation of magnetic flux with time**



$$\phi = BNA \cos \omega t$$

(ii) The choke coil is used to reduce the current. As, its power factor is zero, it reduces the current without wasting the power.

**(1)**

Thus, the direction of flow of current in resistance $R$ get changed alternatively after every half cycle.

Thus, AC is produced in coil. **(1)**

Let at any instant total magnetic flux linked with the armature coil is given G.

(where, $\theta = \omega t$ is the angle made by area vector of coil with magnetic field.)

$$\phi = NBA \cos\theta = NBA \cos\omega t$$

$$\therefore \quad \frac{d\phi}{dt} = -NBA\omega \sin\omega t$$

$$-\frac{d\phi}{dt} = NBA\omega \sin\omega t$$

By Faraday's law of EMI, $e = \dfrac{-d\phi}{dt}$

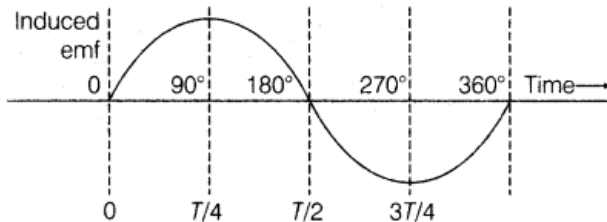Induced emf in coil is given by,

$$e = NBA\omega \sin\omega t$$

$$e = e_0 \sin \omega t$$

where, $e_0 = NBA\omega$

= peak value of induced emf



The mechanical energy spent in rotating the coil in magnetic field appears in the form of electrical energy. **(1)**

30. State the working of AC generator with the help of a labelled diagram. The coil of an AC generator having N turns, each of area A, is rotated with 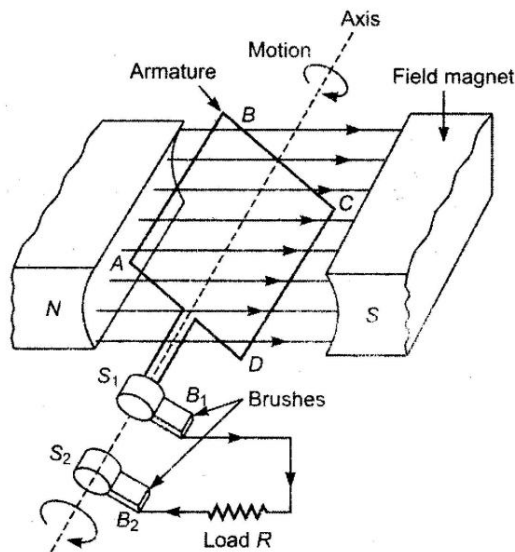a constant angular velocity to. Deduce the expression for the alternating emf generated in the coil. What is the source of energy generation in this device?

[Delhi 2010, All India 2008]

Ans.

Whenever amount of magnetic flux linked with a coil changes, an emf induced in the coil. It lasts so long as the change in magnetic flux through the coil continues.
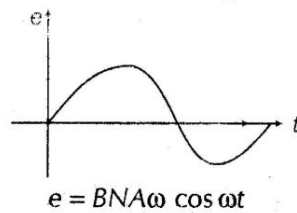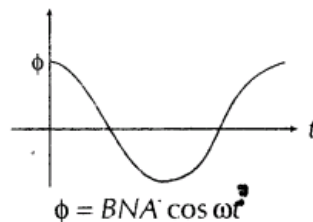
**(1)**



**Working** When a closed armature coil rotates in a uniform magnetic field with its axis perpendicular to the magnetic field, the magnetic flux linked with the loop changes and emf induces in the coil. Let initially angle between area vector of coil and magnetic field $B$ is $0°$. Thereafter, $AB$ comes downward and $CD$ upward then by Fleming's right hand rule induced current flows from $B$ to $A$.

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(a) **Variation of alternating emf with time**



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(ii) The choke coil is used to reduce the current. As, its power factor is zero, it reduces the current without wasting the power. **(1)**

Thus, the direction of flow of current in resistance $R$ get changed alternatively after every half cycle.

Thus, AC is produced in coil. **(1)**

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(where, $\theta = \omega t$ is the angle made by area vector of coil with magnetic field.)

$$\phi = NBA \cos\theta = NBA \cos\omega t$$

$$\therefore \quad \frac{d\phi}{dt} = -NBA\omega \sin\omega t$$

$$-\frac{d\phi}{dt} = NBA\omega \sin\omega t$$
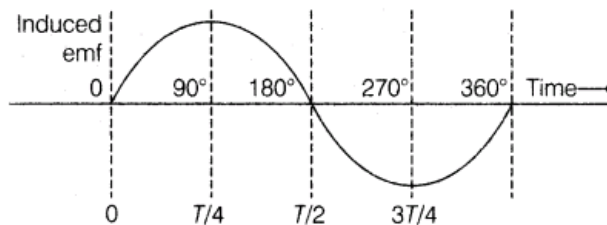
By Faraday's law of EMI, $e = \dfrac{-d\phi}{dt}$

Induced emf in coil is given by,

$$e = NBA\omega \sin\omega t$$

$$e = e_0 \sin \omega t$$

where, $e_0 = NBA\omega$
= peak value of induced emf



The mechanical energy spent in rotating the coil in magnetic field appears in the form of electrical energy. **(1)**

(d) Direction of induced emf can be determined using Fleming's right hand rule. **(1)**