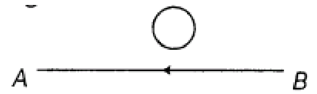
Electromagnetic Induction Laws

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.



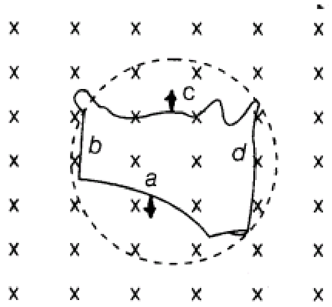
[All India 2014]

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]

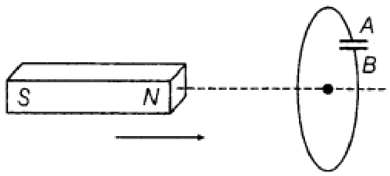
Ans.The glass bob will reach earlier on ground as acceleration due to gravity is independent of mass of the falling bodies. Being insulator, no induced current is developed in it due to the earth's magnetic field.

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:

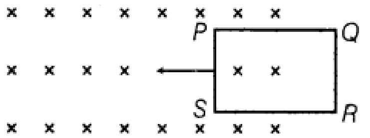
First law Whenever magnetic flux linked with a circuit changes, an emf is induced in it which lasts, so long as change in flux continuous. **(1/2)**

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

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

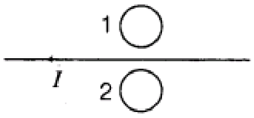
7.The closed loop PQRS of wire is moved into a uniform magnetic field at right angles to the plaue of the paper as shown in the figure. Predict the direction of the induced current in the loop.



[Foreign 2012]

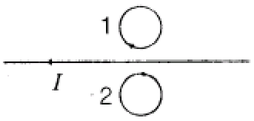
Ans.Since, magnetic flux increasing when the loop moves into uniform magnetic field. So the induced current should oppose this increase. Thus, flow will be from QPSRQ. i.e. anti-clockwise

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



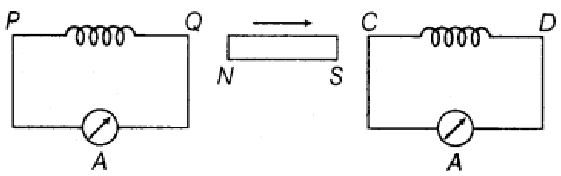
[Delhi 2012]

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]

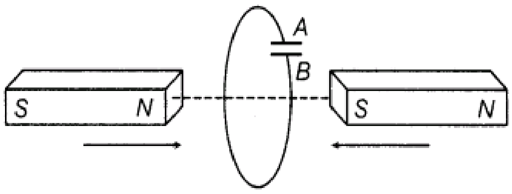
Ans.

> 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, $\omega = \frac{2\pi}{T}$

where, T = time period

∴ Charge in flux in one revolution

$$= BA = B(\pi L^2) \quad \textbf{(1)}$$

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

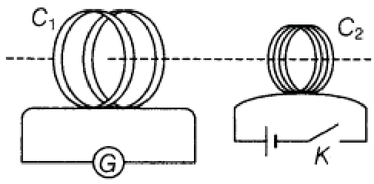
$$e = \frac{\Delta\phi}{\Delta T} = \frac{B\pi L^2}{T}$$

$$e = \frac{B\pi L^2}{\left(\frac{2\pi}{\omega}\right)} \quad \left[\because T = \frac{2\pi}{\omega}\right] \quad \textbf{(1/2)}$$

$$e = \frac{1}{2}B\omega L^2 \quad \textbf{(1/2)}$$

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.

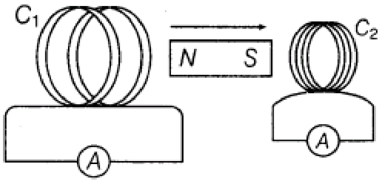
(*i*) Large deflection in the galvanometer can be obtained when change in magnetic flux is fast. So,

(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]

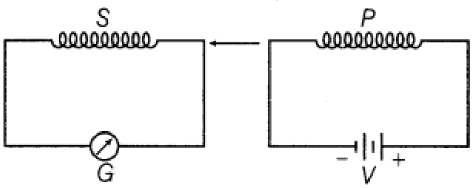
Ans. As N-pole of the magnet is moving away from the coil C1 therefore the coil will behave as South-pole and opposes the motion of the magnet. This implies the current in the coil is anti-clockwise. Also in coil C_2, it behaves as S-pole in order to repel the coming magnet. This implies current in the 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

$I \propto \frac{1}{R}$ (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]

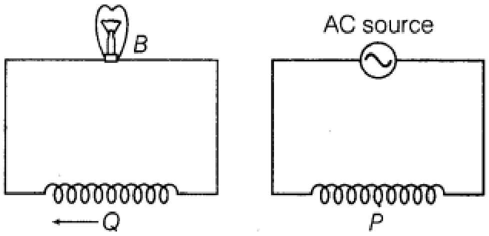
Ans.The coil P should be moved quickly towards or away from the coil 5.The laws involved here are Faraday's law of electromagnetic induction.

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

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.

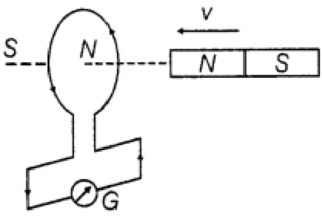
(*i*) Due to varying current in *P*, the flux linked with *P* change and hence *Q* changes, which in turn induces the emf in *Q* and bulb *B* lights. **(1)**

(*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.

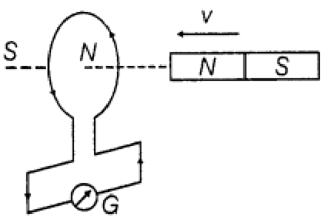
Lenz's law The induced emf of induced current is a circuit which always opposes the cause that produces it.



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.



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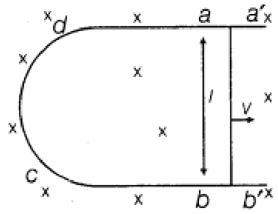
3 Marks Questions

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

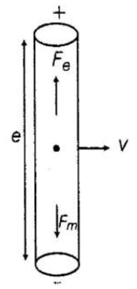
$d\phi = B \times$ change in area

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

$\therefore \quad \frac{d\phi}{dt} = Bvl$ **(1)**

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

(*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,

$$\mathbf{F}_e + \mathbf{F}_m = 0$$

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

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

$$|\mathrm{E}| = |Bv \sin 90|$$

$$\frac{dv}{dr} = Bu$$

$$\therefore \quad P_D = Bvl \quad \textbf{(1)}$$

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.

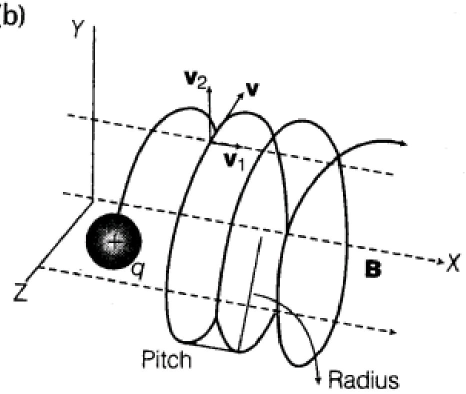
$$\therefore \quad qvB = \frac{mv^2}{r}$$

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

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

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

(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 5×10^{-4} T and the dip angle is 30°?

[All India 2009]

Ans.

Voltage difference between the ends of the wings of plane is developed because plane is intersecting the vertical component of earth's magnetic field due to which change in magnetic flux takes place.

(*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

$\because$ $\text{PD} = v\,(V)\,l$ **(1)**

$\therefore$ $\text{PD} = 500 \times (2.5 \times 10^{-4}) \times 25$

$\text{PD} = 3.125$ V **(1)**

22. 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 expressions for

(*i*) maximum emf induced in the coil.

(*ii*) power dissipation in the coil.

[Delhi 2008]

Ans.

To calculate the induced emf, we have to calculate change in magnetic flux. Here change in magnetic flux is taking place due to change in area swept because of rotation of the coil. So, find change in area and then change in magnetic flux, i.e. induced emf.

(*i*) Initially, area vector **A** of coil makes an angle θ with the direction of magnetic field. Let coil rotates by an angle θ with the magnetic field in time *t*.

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

∴ 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, $\omega = 2\pi f$

⇒ For N turn,

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

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

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

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

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

where, $\omega = 2\pi f$

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

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

$$e = e_0 \sin\omega t \qquad \text{...(iv)}$$

where, e_0 = maximum or peak value of emf induced in coil and given by

$$e_0 = 2\pi f NBA \qquad \textbf{(1)}$$

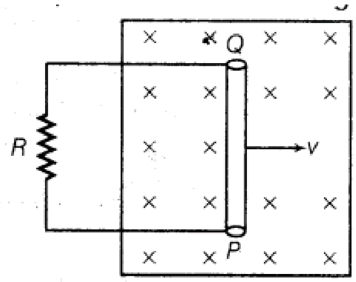
(*ii*) Power dissipated $= \dfrac{V_{rms}^2}{R} = \dfrac{e_{rms}^2}{R}$

where, R is the resistance.

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

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

23.A conducting rod PQ, of length /, 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.

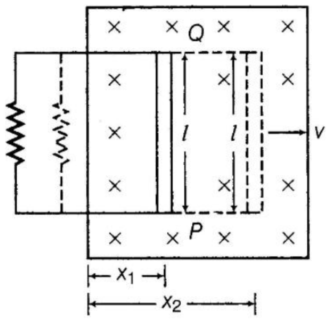
(ii)Find the force required to move the rod in the magnetic field.

(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.



$\therefore$ Area of loop inside the magnetic field,

$$A_1 = lx_1, A_2 = lx_2$$

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

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

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

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

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

$$\therefore \quad e = vBl$$ **(1)**

(*ii*) $\therefore$ 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.

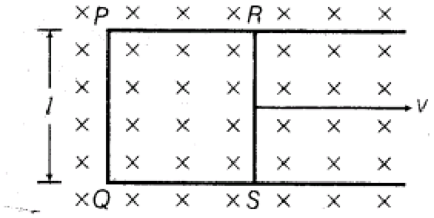
$$\therefore \quad F = IBl \sin 90°$$

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

$$F = \frac{vB^2l^2}{R}$$ **(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 / 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

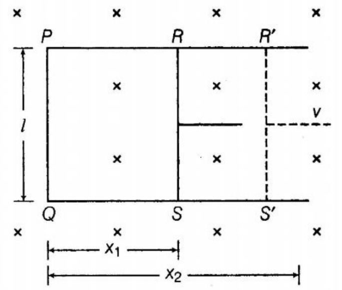
(a)the emf induced across the arm RS

(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,

$$V = vBl \quad \textbf{(1)}$$

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

∴ 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 $= \frac{vB^2l^2}{R}$ **(1)**

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

$$\therefore \quad P = \frac{v^2B^2l^2}{R}$$

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 dI/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:

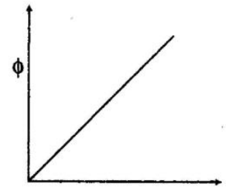
First law Whenever magnetic flux linked with a circuit changes, an emf is induced in it which lasts, so long as change in flux continuous. **(1/2)**

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

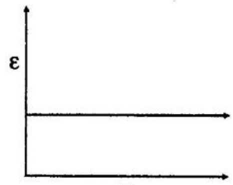
i.e. $e \propto \frac{(-)\,d\phi}{dt}$ or $e = -N\frac{d\phi}{dt}$

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*** $\frac{dI}{dt}$

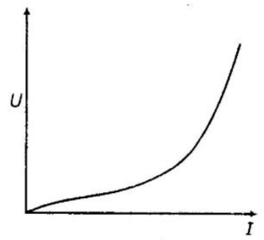


$\frac{dI}{dt}\rightarrow$

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

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

(c) Magnetic potential energy stored versus current



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

26.A metallic rod of length land resistance Ris 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 /, 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, $dA = \pi l^2$

$\therefore$ Change of magnetic flux.

$$d\phi = \mathbf{B} \cdot \mathbf{A} = BdA\cos 0° = B\pi l^2$$

Period of revolution T

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

(ii) Induced current in the rod,

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

(b) Force acting on the rod,

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

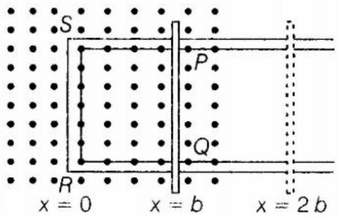
The external force required to rotate the rod opposes the Lorentz force acting on the rod/external force acts in the direction opposite to the Lorentz force

(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.

In this question, first of all, we have to understand the given limits carefully in which the magnetic flux exists. Induced emf induces when change in the flux takes place. In both forward and backward journey, change in flux takes place.

For statement of Faraday's law Refer to Ans 4. **(1)**

Case I When PQ moves forward.

(*i*) For $0 \le x < b$

Magnetic field B exists in the region.

$\therefore$ Area of loop $PQRS = lx$

$\therefore$ Magnetic flux linked with loop $PQRS$,

$$\phi = BA = Blx$$

$$\phi = Blx \quad \text{...(i)} \quad (b > x \ge 0)$$

(*ii*) For, $2b \ge x \ge b$

$$B = 0$$

$\therefore$ Flux linked with loop $PQRS$ is uniform and given by

$$\phi' = Blb \quad \text{...(ii)}$$

$$x = b$$ **(1/2)**

Forward journey

Thus, for $b > x \ge 0$

flux, $\phi = Blx$

$\Rightarrow \quad \phi \propto x$

For $\quad 2b \ge x \ge b$

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

Return journey

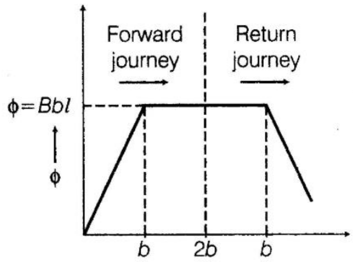
For $\quad b \le x \le 2b$,

$\phi = \text{constant} = Bbl$ **(1)**

For $\quad 0 \le x \le b$,

$\phi = Blx \quad$ (decreasing)

Graphical representation



(1/2)

Case II For $\quad b > x \ge 0, \; B = 0$

As, $\quad \phi = Blx$

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

Induced emf,

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

For $\quad 2b \ge x \ge b$,

As, $\phi' = Bbl$

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

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

Forward journey

For $b > x \geq 0$

$e = -vBl$

For $2b \geq x \geq b$

$e = 0$

Backward journey

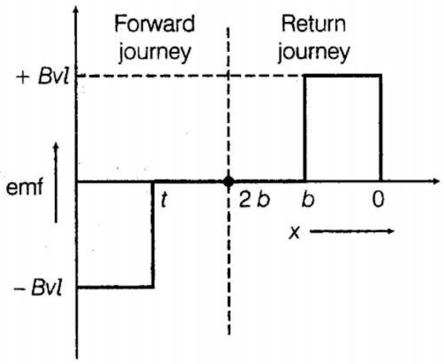
For $b > x \geq 0$

$e = vBl$

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

$e = 0$

Variation of induced emf



(1)