Very Short Answer Questions (PYQ)

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

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

Q. 2. When current in a coil changes with time, how is the back emf induced in the coil related to it? [CBSE (AI) 2008]

Ans. The back emf induced in the coil opposes the change in current.

Q. 3. State the law that gives the polarity of the induced emf. [CBSE (AI) 2009]

Ans. Lenz's Law: The polarity of induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produces it.

Q. 4. A long straight current carrying wire passes normally through the centre of circular loop. If the current through the wire increases, will there be an induced emf in the loop? Justify. [CBSE Delhi 2017]

Ans. No.

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

Q. 5. A light metal disc on the top of an electromagnet is thrown up as the current is switched on. Why? Give reason. [CBSE (AI) 2013]

Ans. A metal disc is placed on the top of a magnet, as the electric current flows through the coil, an induced current in the form of Eddies flows through the metal plate, the lower face attains the same polarity, and hence the metal disc is thrown up.

Q. 6. On what factors does the magnitude of the emf induced in the circuit due to magnetic flux depend? [CBSE (F) 2013]

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

$$|\omega| = \frac{\Delta\varphi}{\Delta t}$$

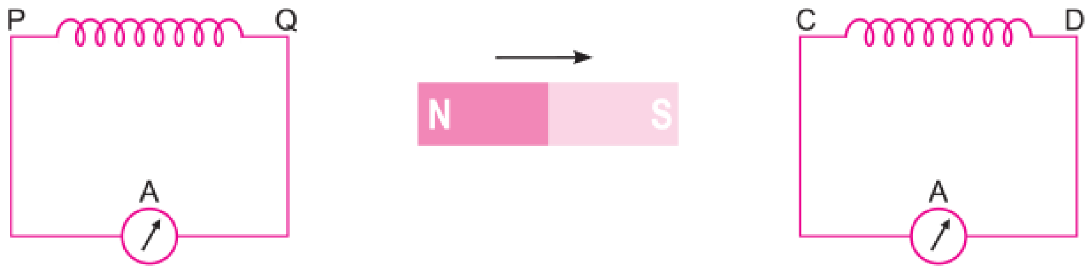
Q. 7. Give one example of use of eddy currents. [CBSE (F) 2016]

Ans. (i) Electromagnetic damping in certain galvanometers.

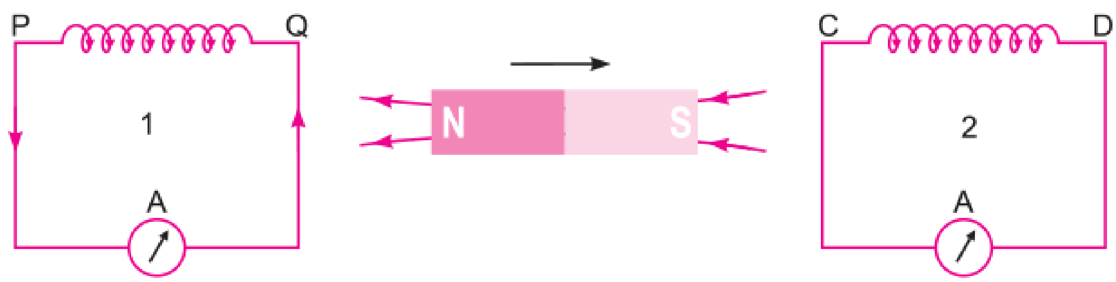
(ii) Magnetic braking in trains.

(iii) Induction furnace to produce high temperature. (Any one)

Q. 8. A bar magnet is moved in the direction indicated by the arrow between two coils PQ and CD. Predict the directions of induced current in each coil.
[CBSE (AI) 2012, 2017]

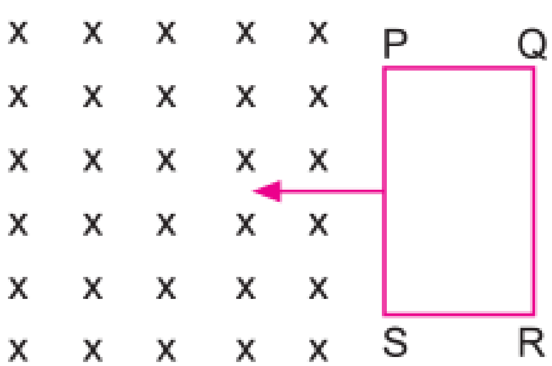


Ans.



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

Q. 9. The closed loop PQRS is moving into a uniform magnetic field acting at right angles to the plane of the paper as shown. State the direction of the induced current in the loop. [CBSE (AI) 2012]



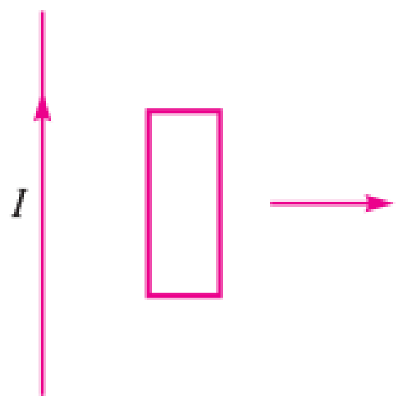
Ans. Due to the motion of coil, the magnetic flux linked with the coil increases. So by Lenz's law, the current induced in the coil will oppose this increase, hence tend to produce a field upward, so current induced in the coil will flow anticlockwise.

i.e., along PSRQP

Q. 10. A planar loop of rectangular shape is moved within the region of a uniform magnetic field acting perpendicular to its plane. What is the direction and magnitude of the current induced in it? [CBSE Ajmer 2015]

Ans. If planar loop moves within the region of uniform magnetic field, no current will be induced in the loop. Hence no direction.

Q. 11. A rectangular loop of wire is pulled to the right, away from the long straight wire through which a steady current I flows upwards. What is the direction of induced current in the loop? [CBSE (F) 2010]



Ans. Direction of induced current in loop is clockwise.

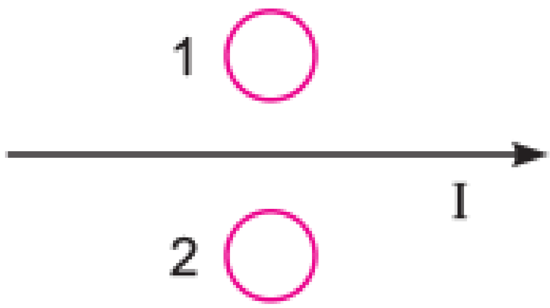
Reason: Induced current opposes the motion of loop away from wire; as similar currents attract, so in nearer side of loop the current will be upward, i.e., in loop, current is clockwise.

Q. 12. The motion of copper plate is damped when it is allowed to oscillate between the two poles of a magnet. What is the cause of this damping? [CBSE (AI) 2013]

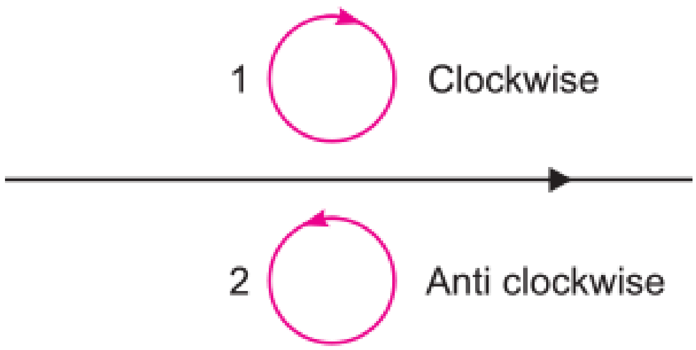
Ans. As the plate oscillate, the changing magnetic flux through the plate produces a strong eddy current in the direction, which opposes the cause.

Also, copper being diamagnetic substance, it gets magnetised in the opposite direction, so the plate motion gets damped.

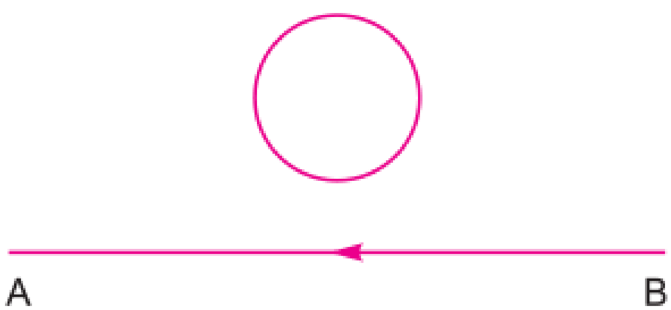
Q. 13. Predict the directions of induced currents in metal rings 1 and 2 lying in the same plane where current I in the wire is increasing steadily.
[CBSE Delhi 2012, (AI) 2017] [HOTS]



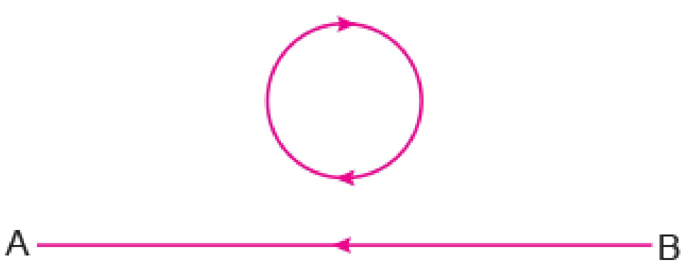
Ans.



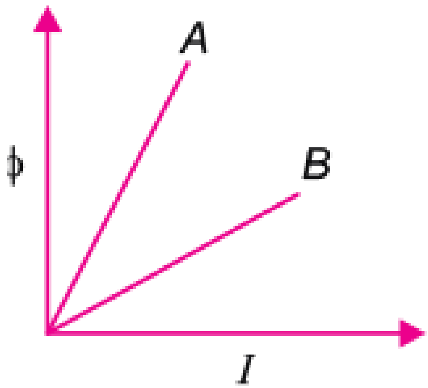
Q. 14. The electric current flowing in a wire in the direction from B to A is decreasing. Find out the direction of the induced current in the metallic loop kept above the wire as shown. [CBSE (AI) 2014]



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



Q. 15. A plot of magnetic flux (φ) versus current (I) is shown in the figure for two inductors A and B. Which of the two has larger value of self-inductance? [CBSE Delhi 2010]



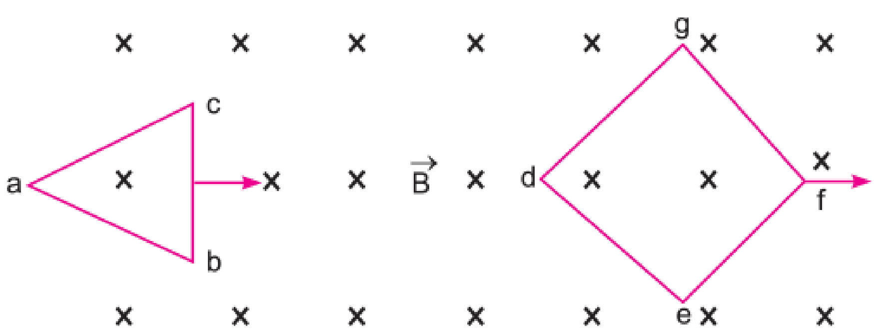
Ans.

$\varphi = \text{LI}$

For same current, $\varphi_A > \varphi_B$, so $L_A > L_B$

i.e., Inductor *A* has larger value of self-inductance.

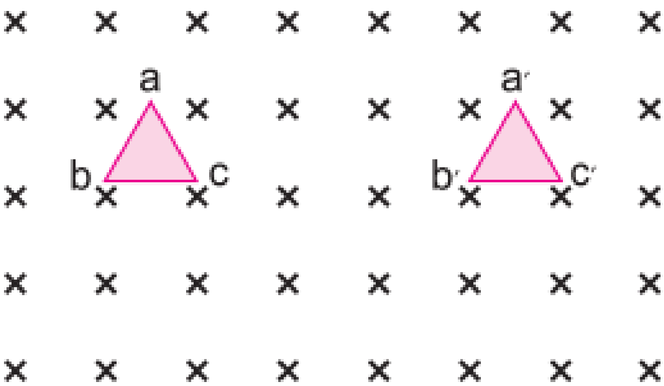
Q. 16. Two loops of different shapes are moved in the region of a uniform magnetic field pointing downward. The loops are moved in the directions shown by arrows. What is the direction of induced current in each loop? [CBSE (F) 2010] [HOTS]



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

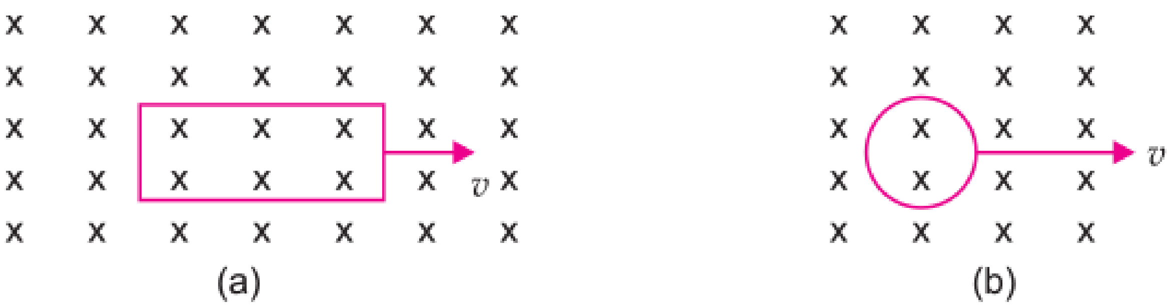
Loop defg is leaving the magnetic field; so flux linked with it tends to decrease, the induced current will be clockwise to produce magnetic field downward to oppose the decrease in magnetic flux.

Q. 17. A triangular loop of wire placed at abc is moved completely inside a magnetic field which is directed normal to the place of the loop away from the reader to a new position a′ b′ c′. What is the direction of the current induced in the loop? Give reason.
[CBSE (F) 2014] [HOTS]



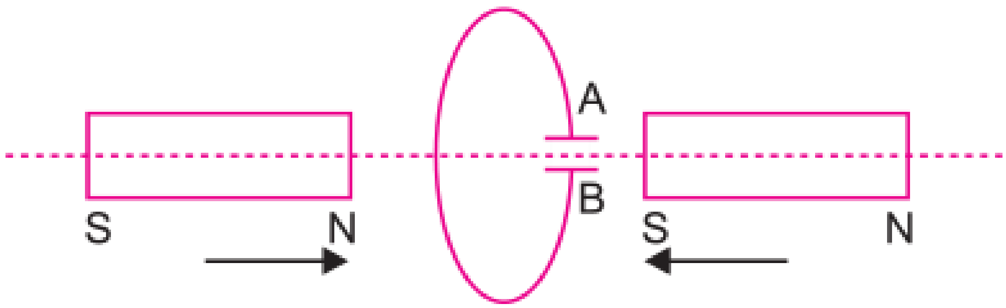
Ans. As there is no change in magnetic flux, so no current is induced in the loop.

Q. 18. A rectangular loop and a circular loop are moving out of a uniform magnetic field region to a field free region with a constant velocity. In which loop do you expect the induced emf to be a constant during the passage out of the field region? The field is normal to the loop. [CBSE (AI) 2010]



Ans. In rectangular coil the induced emf will remain constant because in this the case rate of change of area in the magnetic field region remains constant, while in circular coil the rate of change of area in the magnetic field region is not constant.

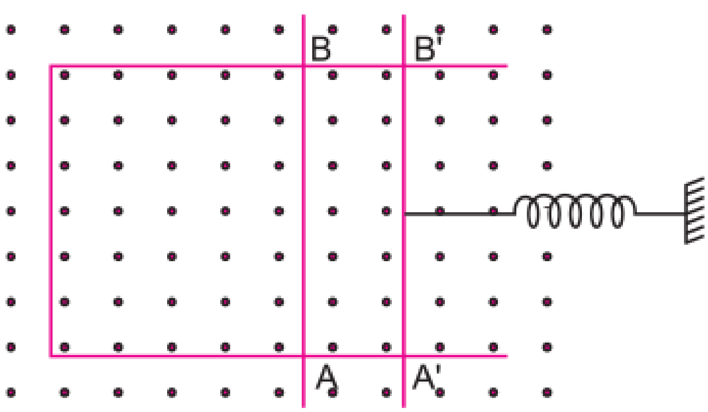
Q. 19. Predict the polarity of the capacitor C connected to coil, which is situated between two bar magnets moving as shown in figure. [CBSE Delhi 2011, (AI) 2017]



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

Very Short Answer Questions (OIQ)

Q. 1. A rectangular wire frame, shown below, is placed in a uniform magnetic field directed upward and normal to the plane of the paper. The part AB is connected to a spring. The spring is stretched and released when the wire AB has come to the position A′ B′ (t = 0) How would the induced emf vary with time? Neglect damping. [HOTS]



Ans. When the spring is stretched and released, the wire AB will execute simple harmonic (sinusoidal) motion, so induced emf will vary periodically. At t = 0, wire is at the extreme position

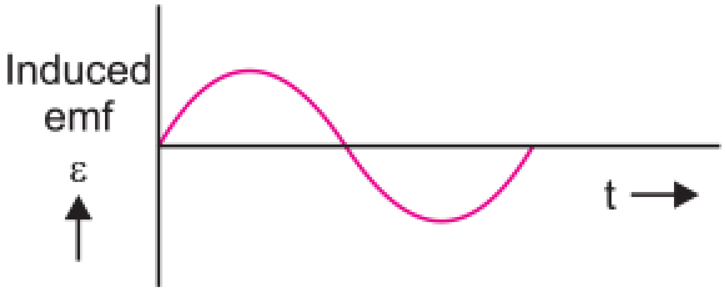
$v = 0$.

$v = A\omega \sin \omega t$

Induced emf $\varepsilon = Bvl$

$= BA\,\omega l \sin \omega t$

Where $A = BB' = AA'$ is the amplitude of motion and ω is angular frequency.



Q. 2. Write SI unit of magnetic flux. Is it a scalar or a vector quantity?

Ans. SI unit of magnetic flux is weber. It is a scalar quantity.

Q. 3. Show diagrammatically when is magnetic flux taken as

(i) Positive **(ii) Negative**

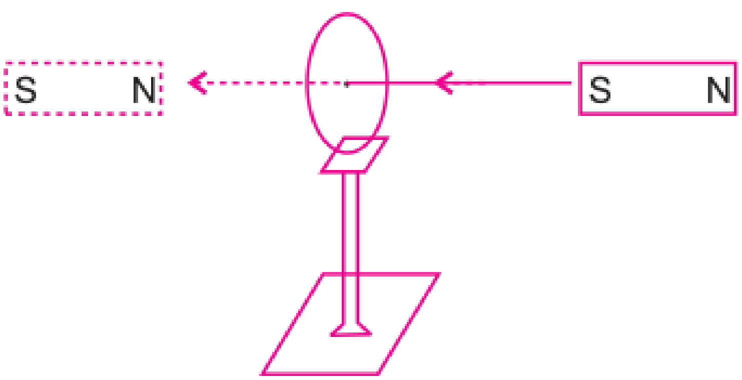
Ans. If the normal N to area A is in the same direction to B,

$f = \vec{B}.\vec{A}$ is positive.

If the normal N is in the opposite direction to B.

φ = cos 180° is negative.

Q. 4. Give the direction in which the induced current flows in the coil mounted on an insulating stand when a bar magnet is quickly moved along the axis of the coil from one side to the other as shown in the figure alongside.

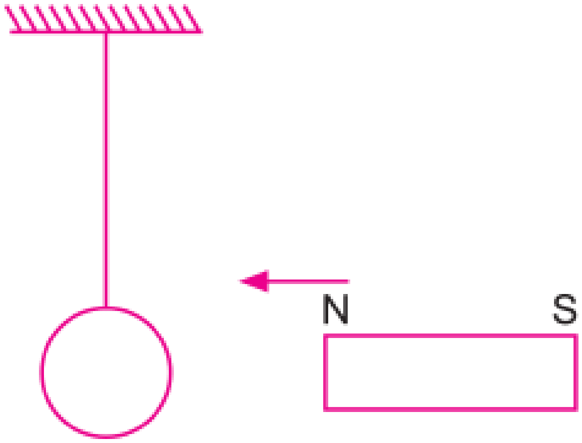


Ans. Current induced in the coil flows clockwise for an observer sitting on the magnet.

Q. 5. Why does a metallic piece become very hot when it is surrounded by a coil carrying high frequency alternating current?

Ans. Due to flow of high frequency alternating current in the coil, the magnetic flux linked with the metallic piece changes by a large amount, so heavy eddy currents are induced in the metallic piece. These currents cause metallic piece to get heated.

Q. 6. Give the direction in which induced current flows in the wire loop, when the magnet moves towards the loop as shown.



Ans. The current induced in the coil will oppose the approach of magnet, so this nearer face of the coil will act as North Pole; therefore on viewing from the magnet side the current in the coil will be anticlockwise.

Q. 7. A bar magnet falls from a height 'h' through a metal ring. Will its acceleration be equal to g? Give reason for your answer.

Ans. When magnet falls, the magnetic flux linked through the metal ring changes, so current is induced in the ring which (according to Lenz's law) opposes the approach of magnet, so its acceleration will be less than g.

Q. 8. Define 1 henry.

Ans. 1 henry is self-inductance of that coil in which 1 volt emf is produced when the rate of change of current in that coil is 1 A/s.

Q. 9. How does the self-inductance of an air coil change, when (i) The number of turns in the coil is decreased? (ii) An iron rod is introduced in the coil?

Ans. (i) Self-inductance of a coil $\propto N^2$.

When number of turns in coil is decreased, the self-inductance will decrease.

(ii) When an iron rod is introduced in the coil, the self-inductance of coil increases.

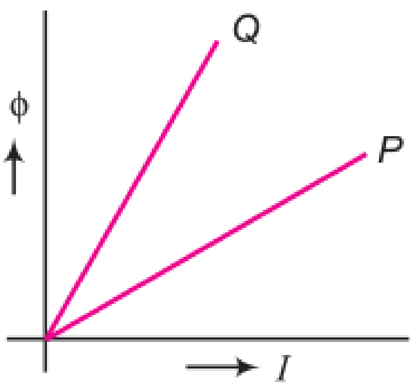
Q. 10. If the rate of change of current 2 ampere/second induces an emf of 40 mV in the solenoid, what is the self-inductance of this solenoid?

Ans.

$$\text{Induced emf } e = -L\frac{\Delta i}{\Delta t}$$

$$\therefore \quad L = \frac{e}{\left(\frac{\Delta i}{\Delta t}\right)}(\text{ numerically }) = \frac{40\times10^{-3}}{2} = 20\times10^{-3}H = 20 \text{ mH}$$

Q. 11. The given graph shows a plot of magnetic flux (φ) and the electric current (I) flowing through two inductors P and Q. Which of the two inductors has smaller value of self-inductance?

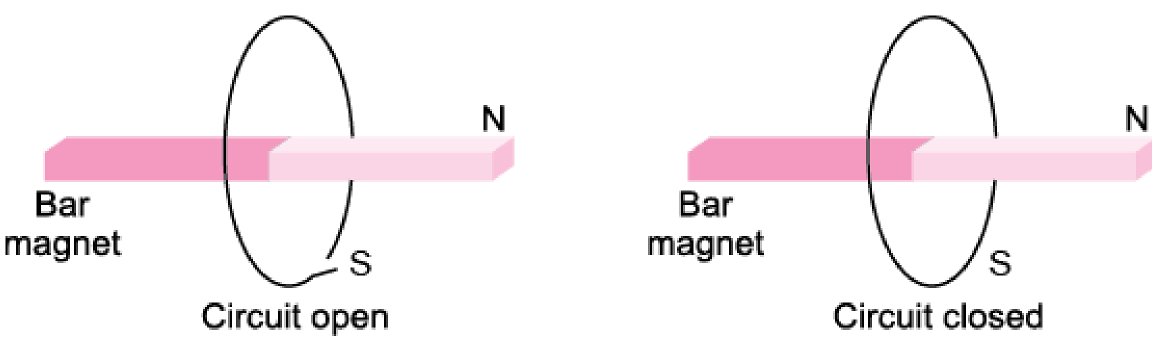


Ans.

$$\text{Inductor P, } \varphi = \text{LI} \Rightarrow L = \frac{\varphi}{I}$$

For $P, \frac{\varphi}{I}$ is lesser so, it has smaller value of Self inductance.

Q. 12. Consider a magnet surrounded by a wire with an on/off switch S (as shown in figure). If the switch is thrown from the off position (open circuit) to the on position (closed circuit), will a current flow in the circuit? Explain. [NCERT Exemplar]



Ans. No part of the wire is moving and so motional emf is zero. The magnet is stationary and hence the magnetic field does not change with time. This means no electromotive force is produced and hence no current will flow in the circuit.

Q. 13. A wire in the form of a tightly wound solenoid is connected to a DC source, and carries a current. If the coil is stretched so that there are gaps between successive elements of the spiral coil, will the current increase or decrease? Explain.
[NCERT Exemplar]

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

Q. 14. A solenoid is connected to a battery so that a steady current flows through it. If an iron core is inserted into the solenoid, will the current increase or decrease? Explain. [NCERT Exemplar]

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

Q. 15. If an LC circuit is considered analogous to a harmonically oscillating spring block system, which energy of the LC circuit would be analogous to potential energy and which one analogous to kinetic energy? [NCERT Exemplar]

Ans. Magnetic energy analogous to kinetic energy and electrical energy analogous to potential energy.

Q. 16. Consider a metal ring kept (supported by a cardboard) on top of a fixed solenoid carrying a current I (in figure). The centre of the ring coincides with the axis of the solenoid. If the current in the solenoid is switched off, what will happen to the ring?
[NCERT Exemplar]

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

Q. 17. Consider a metallic pipe with an inner radius of 1 cm. If a cylindrical bar magnet of radius 0.8 cm is dropped through the pipe, it takes more time to come down than it takes for a similar unmagnetised cylindrical iron bar dropped through the metallic pipe. Explain. [NCERT Exemplar]

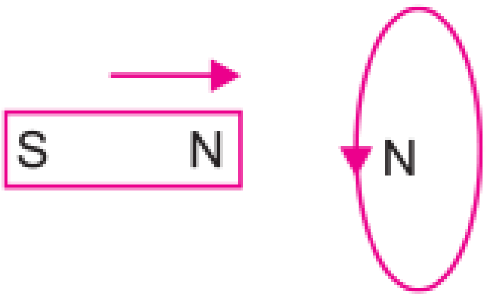
Ans. For the magnet, eddy currents are produced in the metallic pipe. These currents will oppose the motion of the magnet. Therefore magnet's downward acceleration will be less than the acceleration due to gravity g. On the other hand, an unmagnetised iron bar will not produce eddy currents and will fall an acceleration g. Thus the magnet will take more time.

Short Answer Questions – I (PYQ)

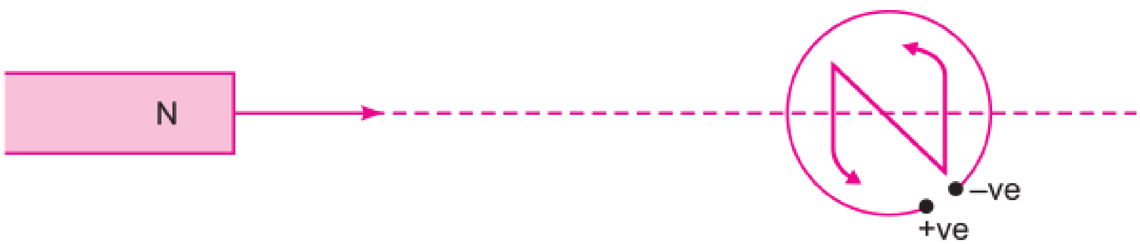
Q. 1. State Lenz's Law.

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

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



The direction of induced current in a circuit is such that it opposes the very cause which generates it. Yes, an emf will be induced at its ends. Justification: As the metallic rod falls down, the magnetic flux due to vertical component of Earth's magnetic field keeps on changing.



Q. 2. When a bar magnet is pushed towards (or away) from the coil connected to a galvanometer, the pointer in the galvanometer deflects. Identify the phenomenon causing this deflection and write the factors on which the amount and direction of the deflection depends. State the laws describing this phenomenon.

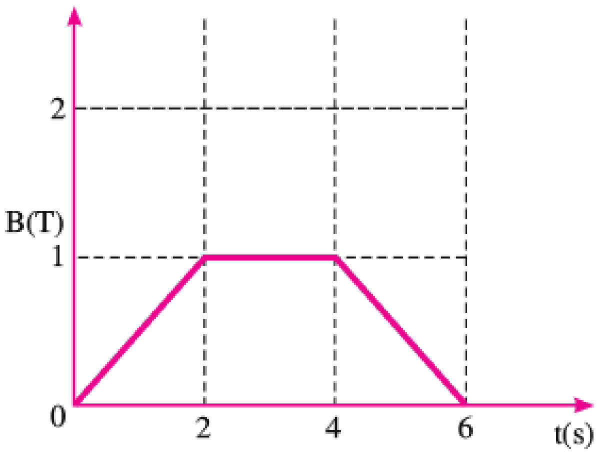
Ans. The phenomenon involved is electromagnetic induction (EMI). For the deflection amount depends upon the speed of movement of the magnet or rate of change of flux. Direction depends on the sense (towards, or away) of the movement of the magnet. Direction of deflection is according to Lenz' law.

The law describing the phenomenon is:

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

$$\varepsilon =- \frac{d\varphi_B}{dt}$$

Q. 3. The magnetic field through a circular loop of wire 12 cm in radius and 8.5 Ω resistance, changes with time as shown in the figure. The magnetic field is perpendicular to the plane of the loop. Calculate the induced current in the loop and plot it as a function of time. [CBSE (F) 2017]



Ans. We know,

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

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

For 0< t< 2

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

For 0< t< 2

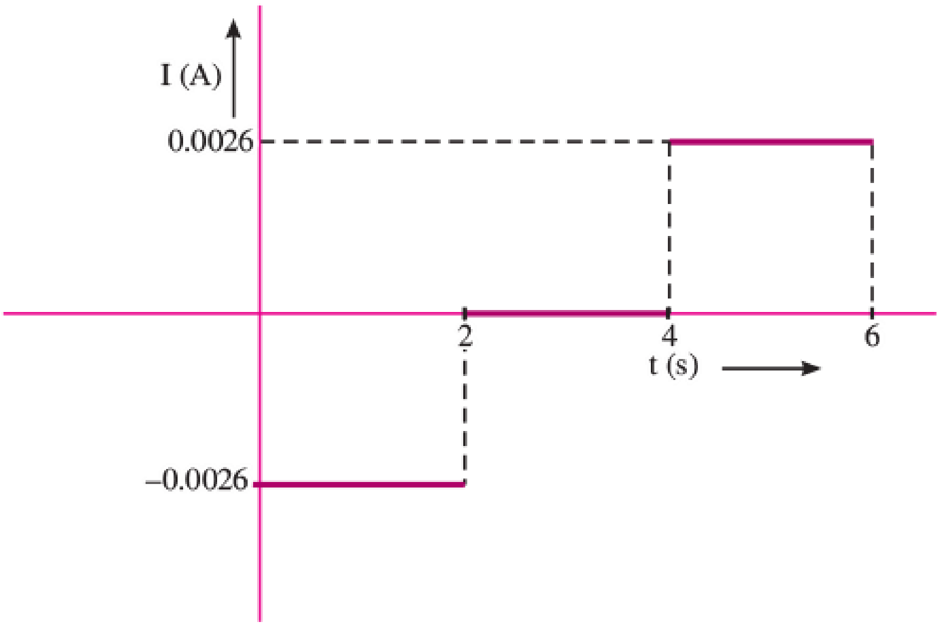
$$= \frac{-3.14(0.12)^2 ?1}{2 ?8.5} = 0.0026\ A$$

For, 2 < t < 4

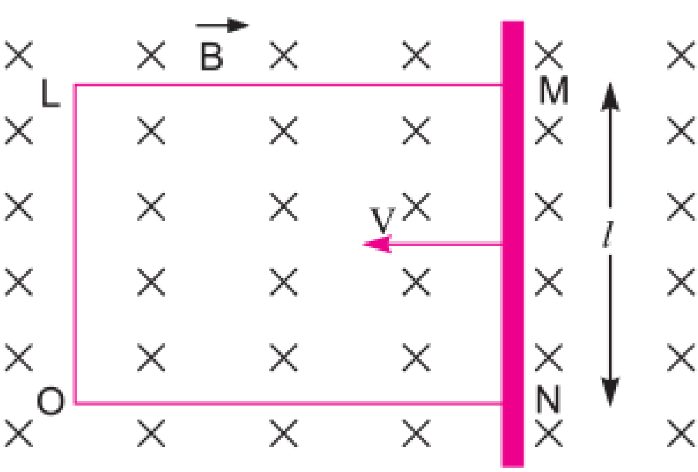
$\frac{dB}{dt} = 0 \Rightarrow I = 0$

For, $4 < t < 6$

$I = +0.0026$



Q. 4. A rectangular conductor LMNO is placed in a uniform magnetic field of 0.5 T. The field is directed perpendicular to the plane of the conductor. When the arm MN of length of 20 cm is moved towards left with a velocity of 10 ms^{-1}, calculate the emf induced in the arm. Given the resistance of the arm to be 5Ω (assuming that other arms are of negligible resistance), find the value of the current in the arm.
[CBSE (AI) 2013]



Ans. Induced emf in a moving rod in a magnetic field is given by

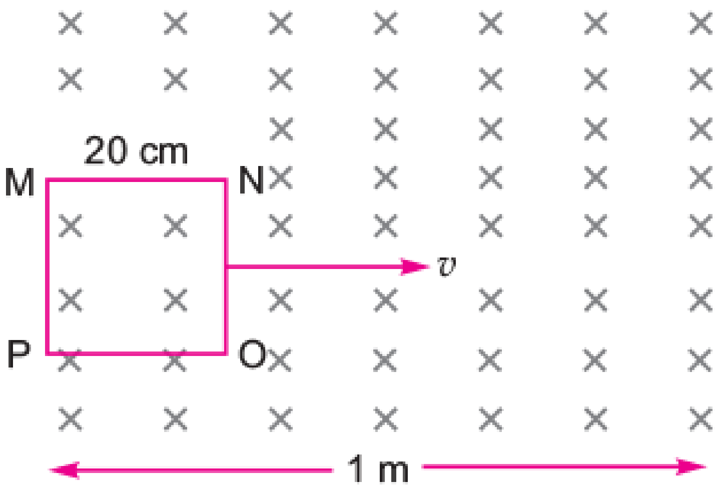
ε = – Blv

Since the rod is moving to the left so

ε = + Blv = 0.5 × 0.2 × 10 = 1 V

Current in the rod $I = \frac{\varepsilon}{R} = \frac{1}{5} = 0.2A$

Q. 5. A square loop MNOP of side 20 cm is placed horizontally in a uniform magnetic field acting vertically downwards as shown in the figure. The loop is pulled with a constant velocity of 20 cms^{-1} till it goes out of the field.



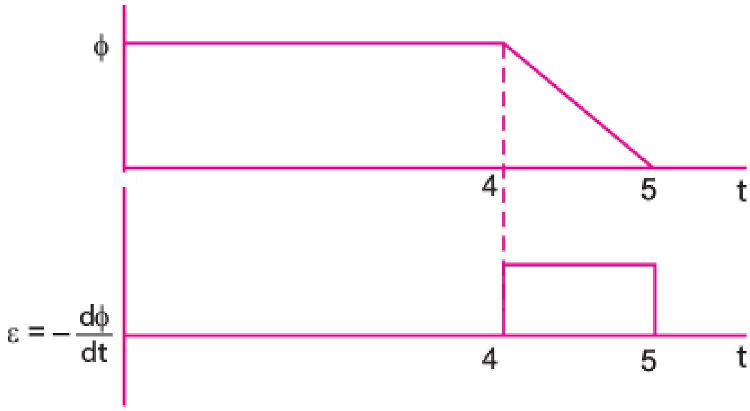
(i) Depict the direction of the induced current in the loop as it goes out of the field. For how long would the current in the loop persist?

(ii) Plot a graph showing the variation of magnetic flux and induced emf as a function of time. [CBSE Panchkula 2015]

Ans. (i) $t = \frac{d}{v} = \frac{20}{20} = 1s$

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

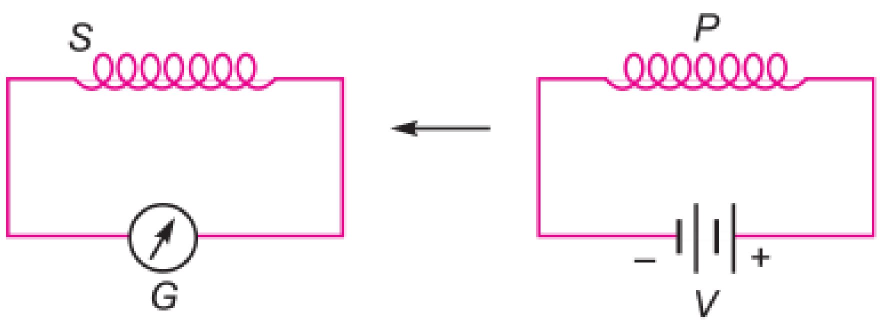
(ii)



Q. 6. (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?

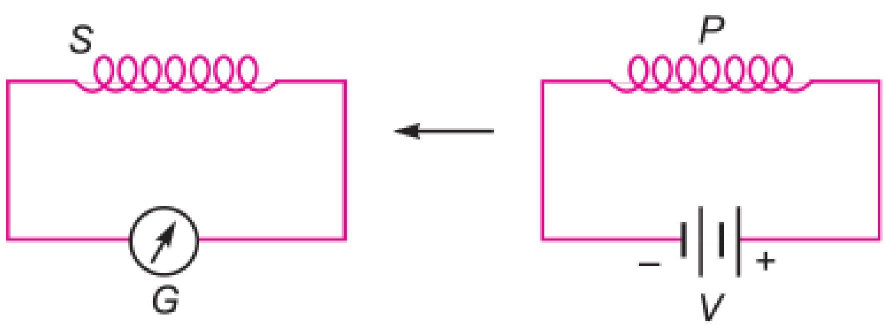
(ii) State the related law. [CBSE Delhi 2010]



Ans. (i) For larger deflection, coil P should be moved at a **faster rate.**

(ii) Faraday law: The induced emf is directly proportional to rate of change of magnetic flux linked with the circuit.

Q. 7. A current is induced in coil C1 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. [CBSE Delhi 2011]

Ans. (1) The deflection in galvanometer may be made large by

(i) Moving coil C_2 towards C_1 with high speed.

(ii) By placing a soft iron laminated core at the centre of coil C_1.

(2) The induced current can be demonstrated by connecting a torch bulb (in place of galvanometer) in Coil C_1. Due to induced current the bulb begins to glow.

Q. 8. Answer the following questions

(i) Define mutual inductance.

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

Ans. Change of flux for small change in current

$$d\varphi = \mathrm{MdI} = 1.5\ (20 - 0)\ \text{weber} = 30\ \text{weber}$$

Q. 9. A long solenoid with 15 turns per cm has a small loop of area 2.0 cm^2 placed inside the solenoid normal to its axis. If the current carried by the solenoid changes steadily from 2.0 A to 4.0 A in 0.1 s, what is the induced emf in the loop while the current is changing? [CBSE (F) 2016]

Ans.

Mutual inductance of solenoid coil system

$$M = \frac{\mu_0 N_1 N_2 A_2}{l}$$

Here $N_1 = 15$, $N_2 = 1$, $l = 1$ cm $= 10^{-2}$ m, $A_2 = 2.0$ cm^2 $= 2.0\times10^{-4}$ m^2

$$\therefore \qquad M = \frac{4\pi\times10^{-7}\times15\times1\times2.0\times10^{-4}}{10^{-2}} = 120\pi\times10^{-9}H$$

Induced emf, in the loop

$$\varepsilon_2 = M\frac{\Delta I}{\Delta t} \text{ (numerically)}$$

$$= 120\pi \times10-9 \ \frac{(4-2)}{0.1}$$

$$= 120\times3.14\times10^{-9}\times \frac{2}{0.1} = 7.5\times10^{-6}\ V = 7.5\ \mu V$$

Q. 10. A toroidal solenoid with air core has an average radius of 15 cm, area of cross-section 12 cm^2 and has 1200 turns. Calculate the self-inductance of the toroid. Assume the field to be uniform across the cross-section of the toroid. [CBSE (F) 2014]

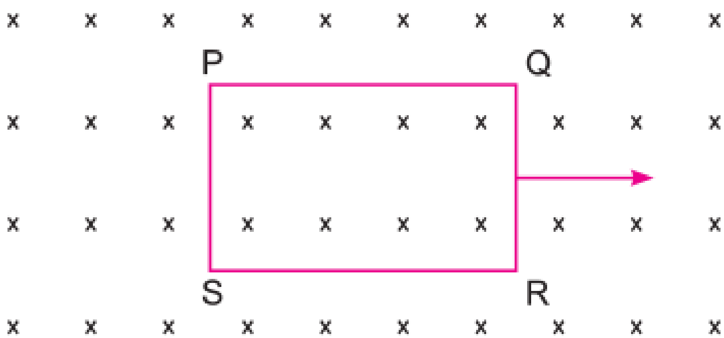
Ans.

Here, $r = 15$cm $= 0.15$ m, A$=$ 12 cm^2 $= 12\times10^{-4}$ m^2 and $N = 1200$

$$\text{Self inductance, } L = \frac{\mu_0 N^2 A}{l} = \frac{\mu_0 N^2 A}{2\pi r}$$

$$= \frac{4\pi\times10^{-7}\times(1200)^2\times12\times10^{-4}}{2\pi\times0.15} = 2.3\times10^{-3}H.$$

Q. 11. The closed loop (PQRS) of wire is moved out of a uniform magnetic field at right angles to the plane of the paper as shown in the figure. Predict the direction of the induced current in the loop. [CBSE (F) 2012]

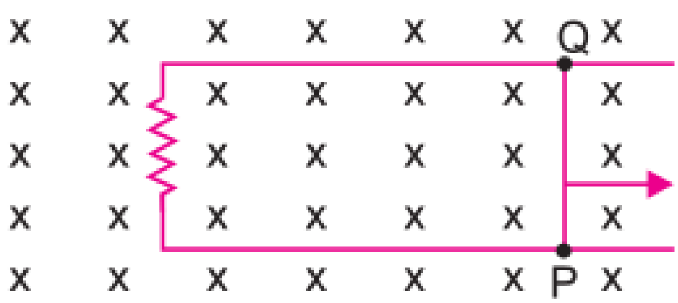


Ans. So far the loop remains in the magnetic field, there is no change in magnetic flux linked with the loop and so no current will be induced in it, but when the loop comes out of the magnetic field, the flux linked with it will decrease and so the current will be induced so as to oppose the decrease in magnetic flux, i.e., it will cause magnetic field downwards; so the direction of current will be clockwise.

Short Answer Questions – I (OIQ)

Q. 1. A 0.5 m long metal rod PQ completes the circuit as shown in the figure. The area of the circuit is perpendicular to the magnetic field of flux density 0.15 T. If the resistance of the total circuit is 3Ω calculate the force needed to move the rod in the direction as indicated with a constant speed of 2ms^{-1}.

Ans. Given: l = 0.5m, B = 0.15T, R = 3Ω, v = 2 ms^{-1}



emf., $\varepsilon = vBl$

Current, $I = \frac{\varepsilon}{R} \Rightarrow \frac{vBl}{R}$

Force needed to move the rod,

$$F = BIl = B \times \frac{vBl}{R} \times l = \frac{vB^2 l^2}{R}$$

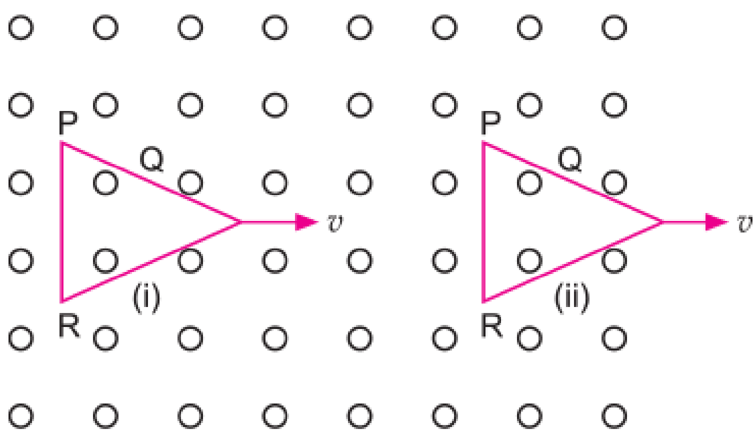
$$= \frac{2 \times (0.15)^2 \times (0.5)^2}{3} = 3.75 \times 10^{-3} N$$

Q. 2. If the self-inductance of an iron core inductor increases from 0·01 mH to 10 mH on introducing the iron core into it, what is the relative permeability of the core material used?

Ans.

$$\text{Relative permeability } \mu_r = \frac{L_{\text{medium}}}{L_{\text{air}}} = \frac{10 \text{ mH}}{0.01 \text{ mH}} = 100$$

Q. 3. Fig. shows two positions of a loop PQR in a perpendicular uniform magnetic field. In which position of the coil is there an induced emf?

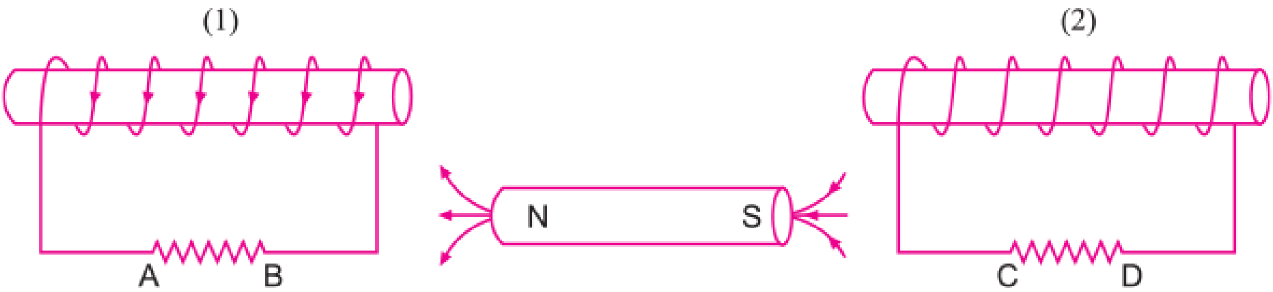


Ans. In position (i), the coil remains as such in magnetic field, so there is no magnetic flux change in the coil, hence no emf is induced.

In position (ii) the coil is coming out of the magnetic field, so the magnetic flux linked with it decreases and so an emf is induced in the coil.

Q. 4. In the figure given below, a bar magnet moving towards the right or left induces an emf in the coils (1) and (2). Find, giving reason, the directions of the

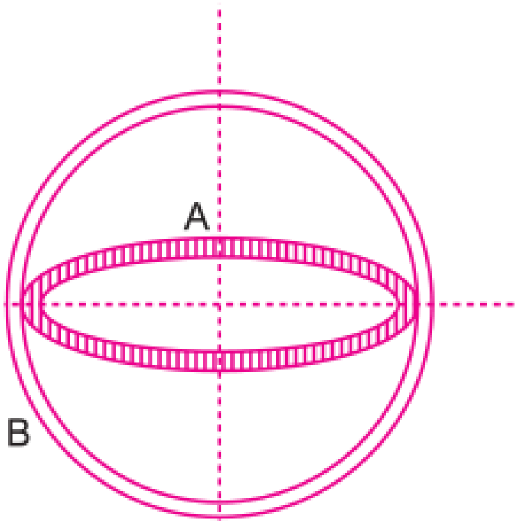
induced currents through the resistors AB and CD when the magnet is moving (a) towards the right, and (b) towards the left.



Ans. (a) When magnet moves towards the right, the nearer faces of coils, 1 and 2 act as south poles, so current induced in AB is from B to A and in coil 2 from C to D.

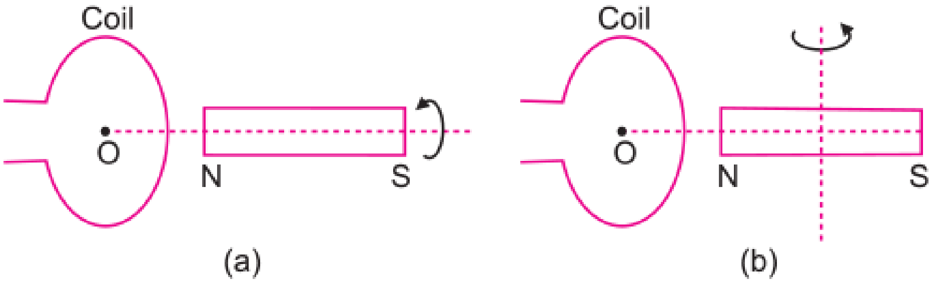
(b) When magnet moves towards left, the nearer faces of coils act as north poles, so current induced in coil, 1 will be from A to B and in coil 2 from D to C.

Q. 5. Two coils of wire A and B are placed mutually perpendicular as shown in figure. When current is changed in any one coil, will the current induce in another coil?



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

Q. 6. A cylindrical bar magnet is kept along the axis of a circular coil and near it as shown in fig. Will there be any induced emf at the terminals of the coil, when the magnet is rotated



(i) About its own axis and

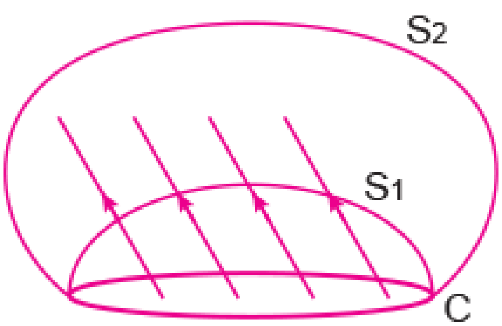
(ii) About an axis perpendicular to the length of the magnet?

Ans. (i) When the magnet is rotated about its own axis, then due to symmetry of magnet the magnetic flux linked with circular coil remains unchanged, hence no emf is induced at terminals of coil.

(ii) When the magnet is rotated about an axis perpendicular to the length, the positions of *N* and *S* poles of magnet changes continuously; so the magnetic flux linked with the coil changes continuously; hence the emf is induced at the terminals of the coil.

Q. 7. Consider a closed loop C in a magnetic field (see figure). The flux passing through the loop is defined by choosing a surface whose edge coincides with the loop and using the formula $\varphi = \overrightarrow{B_1}.d\,\overrightarrow{A_1} + \overrightarrow{B_2}.d\,\overrightarrow{A_2} + .$

Now if we chose two different surfaces S_1 and S_2 having C as their edge, would we get the same answer for flux. Justify your answer. [NCERT Exemplar]



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

Short Answer Questions –II (PYQ)

Q. 1. In an experimental arrangement of two coils C_1 and C_2 placed coaxially parallel to each other, find out the expression for the emf induced in the coil C_1 (of N1 turns) corresponding to the change of current I_2 in the coil C_2 (of N_2 turns). [CBSE Chennai 2015]

Ans.

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

$$N_1 \varphi_1 = MI_2 \qquad ...(i)$$

For current varying with time,

$$\frac{d(N_1 \varphi_1)}{dt} = \frac{d(MI_2)}{dt} \qquad ...(ii)$$

Since induced *emf* in coil C_1 is given by

$$\varepsilon_1 = -\frac{d(N_1 \varphi_1)}{dt}$$

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

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

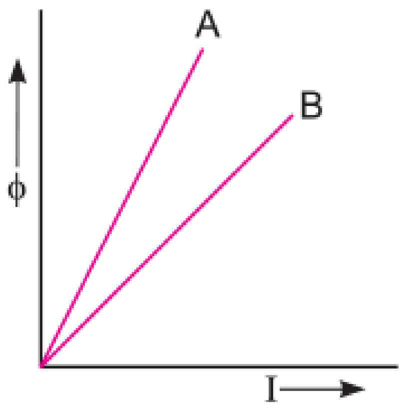
It shows that varying current in a coil induces emf in the neighbouring coil.

Q. 2. Answer the following questions

(1) How does the mutual inductance of a pair of coils change when

(i) Distance between the coils is increased and
(ii) Number of turns in the coils is increased? [CBSE (AI) 2013]

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



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

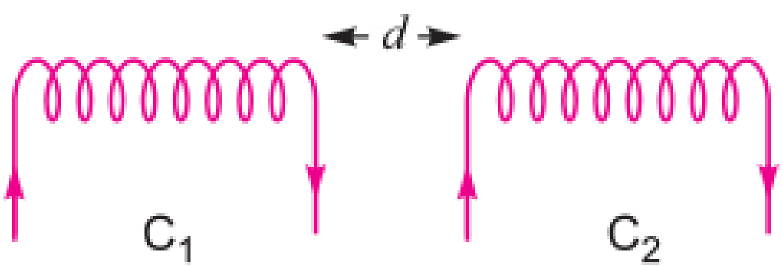
(i) Separation between the coils is increased?
(ii) The number of turns in each coil is increased?
(iii) A thin iron sheet is placed between the two coils, other factors remaining the same?

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

Ans. (1) (i) Mutual inductance decreases.

(ii) Mutual inductance increases.

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



It causes decrease in magnetic flux linked with the coil C_2. Hence induced emf in coil C_2 decreases by relation Hence mutual inductance decreases.

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

Q. 3. Define self-inductance of a coil. Show that magnetic energy required to build up the current I in a coil of self-inductance L is given by $\frac{1}{2}$ LI^2. [CBSE Delhi 2012]

OR

Define the term self-inductance of a solenoid. Obtain the expression for the magnetic energy stored in an inductor of self-inductance L to build up a current I

through it.
[CBSE (AI) 2014]

Ans. **Self-inductance** – Using formula φ = LI, if I = 1 **Ampere** then L = φ

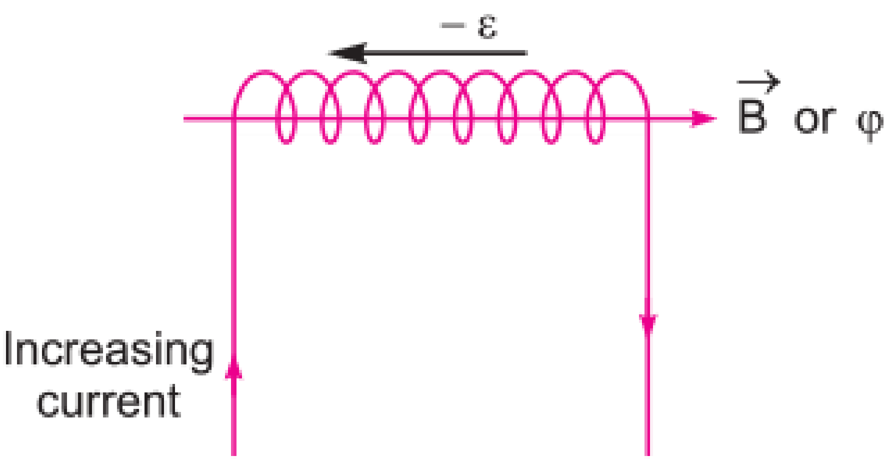
Self-inductance of the coil is equal to the magnitude of the magnetic flux linked with the coil, when a unit current flows through it.

Alternatively

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

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

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



Expression for magnetic energy

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

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

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

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

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

From work-energy theorem

$DU = LI\ dI$

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

Q. 4. Two identical loops, one of copper and the other of aluminium, are rotated with the same angular speed in the same magnetic field. Compare [CBSE (AI) 2010]

(i) The induced emf and

(ii) The current produced in the two coils. Justify your answer.

Ans. (i)

Induced emf, $\varepsilon = -\frac{d\varphi}{dt} = -\frac{d}{dt}(BA\ \cos\ \omega t)$

$$= BA\ \omega\ \sin\ \omega t$$

As B, A, ω are same for both loops, so induced emf is same in both loops.

(ii)

Current induced, $I = \frac{\varepsilon}{R} = \frac{\varepsilon}{\rho l/A} = \frac{\varepsilon A}{\rho l}$

As area A, length l and emf ε are same for both loops but resistivity ρ is less for copper, therefore current I induced is larger in copper loop.

Q. 5. A wheel with 8 metallic spokes each 50 cm long is rotated with a speed of 120 rev/min in a plane normal to the horizontal component of the Earth's magnetic field. The Earth's magnetic field at the plane is 0.4 G and the angle of dip is 60°. Calculate the emf induced between the axle and the rim of the wheel.

How will the value of emf be affected if the number of spokes were increased? [CBSE Delhi 2013]

Ans. If a rod of length 'l' rotates with angular speed ω in uniform magnetic field 'B'

$$\varepsilon = \frac{1}{2}Bl^2\,\omega$$

In case of earth's magnetic field $B_H = |B_e|\cos\delta$

and $B_V = |B_e|\sin\delta$

$$\therefore \qquad \varepsilon = \frac{1}{2}\,|B_e|\cos\delta . l^2\omega$$

$$= \frac{1}{2}\times 0.4\times 10^{-4}\cos 60^o \times (0.5)^2\times 2\pi\nu$$

$$= \frac{1}{2}\times 0.4\times 10^{-4}\times\frac{1}{2}\times(0.5)^2\times 2\pi\times\left(\frac{120\ \text{rev}}{60s}\right)$$

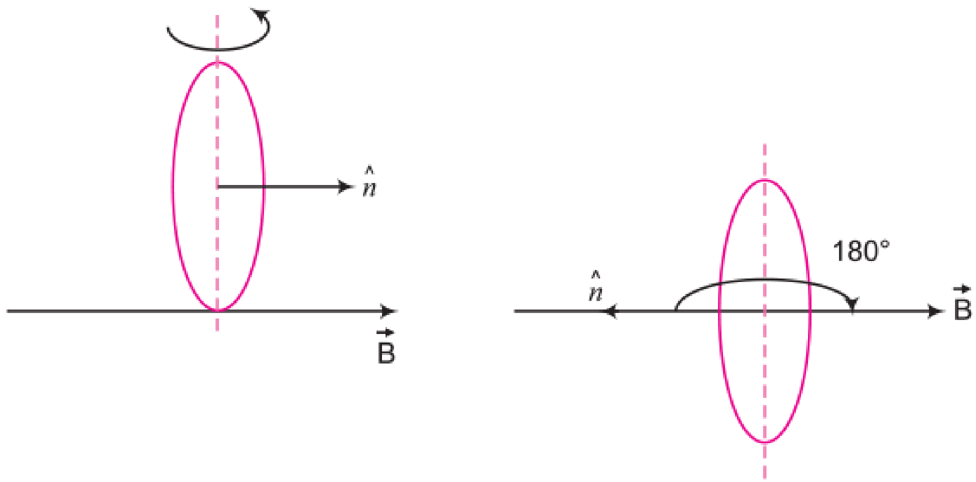
$$= 10^{-5}\times 0.25\times 2\times 3.14\times 2$$

$$\mathbf{= 3.14\times 10^{-5}\ volt}$$

Induced emf is independent of the number of spokes i.e., it remain same.

Q. 6. A circular coil of radius 10 cm, 500 turns and resistance 200Ω is placed with its plane perpendicular to the horizontal component of the Earth's magnetic field. It is rotated about its vertical diameter through 180° in 0.25 s. Estimate the magnitudes of the emf and current induced in the coil. (Horizontal component of the Earth's magnetic field at the place is 3.0×10^{-5} T) [CBSE (F) 2015]

Ans.



Initial magnetic flux, $\varphi_i = NBA$

$= 500 \times 3 \times 10^{-5} \times \pi\ (0.1)^2$

$= 15\ \pi \times 10^{-5}$ Wb

On turning by 180°.

Final flux, $\varphi_f = -\ NBA = -15\ \pi \times 10^{-5}$ Wb

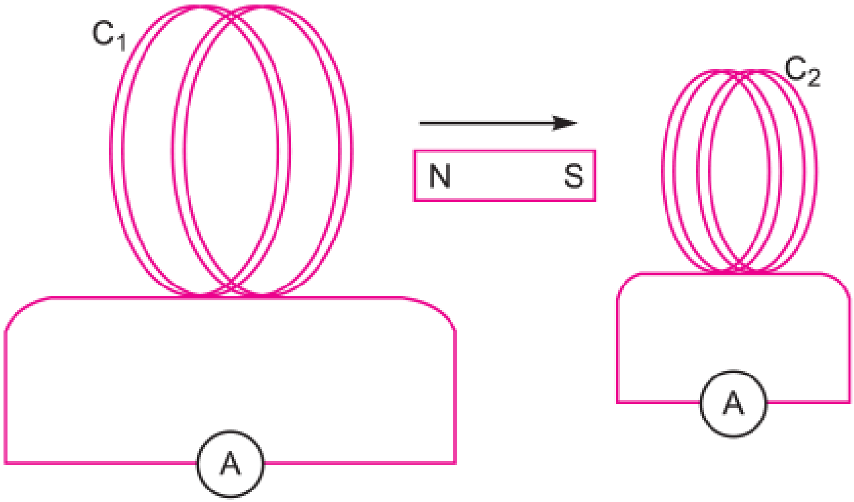
Magnitude of induced emf, $\varepsilon = -\frac{d\varphi}{dt}$

$= \frac{2 \times 15\pi\ \times 10^{-5}}{0.25} = 120\pi\ \times\ 10^{-5}$ volt

$= 376.8 \times 10^{-5} = 0.038$ volt

Induced current, $I = \frac{\varepsilon}{R} = \frac{0.038}{200} = 19 \times 10^{-5}\ A$

Q. 7. A magnet is quickly moved in the direction indicated by an arrow between two coils C_1 and C_2 as shown in the figure. What will be the direction of induced current in each coil as seen from the magnet? Justify your answer. [CBSE Delhi 2011]



Ans. According to Lenz's law, the direction of induced current is such that it opposes the relative motion between coil and magnet.

The near face of coil C_1 will become S-pole, so the direction of current in coil C_1 will be clockwise.

The near face of coil C_2 will also become S-pole to oppose the approach of magnet, so the current in coil C_2 will also be clockwise.

Q. 8. The currents flowing in the two coils of self-inductance L_1=16 mH and L_2=12 mH are increasing at the same rate. If the power supplied to the two coils are equal, find the ratio of [CBSE (F) 2014]

(i) Induced voltages
(ii) The currents and
(iii) The energies stored in the two coils at a given instant.

Ans. (i) Induced voltage (emf) in the coil,

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

$$\therefore \quad \frac{\varepsilon_1}{\varepsilon_2} = \frac{-L_1\frac{dI}{dt}}{-L_2\frac{dI}{dt}} = \frac{L_1}{L_2} = \frac{16\,\text{mH}}{12\,\text{mH}} = \frac{4}{3}$$

(ii) Power supplied, P= εI

Since power is same for both the coils

$$\therefore \ \varepsilon_1 I_1 = \varepsilon_2 I_2 = \frac{I_1}{I_2} = \frac{\varepsilon_2}{\varepsilon_1} = \frac{3}{4}$$

(iii) Energy stored in the coil is given by

$$U = \frac{1}{2}\mathrm{LI}^2$$

$$\therefore \frac{U_1}{U_2} = \frac{\frac{1}{2}L_1 I_1^2}{\frac{1}{2}L_2 I_2^2} = \frac{L_1}{L_2} \times \left(\frac{I_1}{I_2}\right)^2 = \frac{4}{3} \times \left(\frac{3}{4}\right)^2 = \frac{3}{4}$$

Q. 9. Figure shows a rectangular loop conducting PQRS in which the arm PQ is free to move. A uniform magnetic field acts in the direction perpendicular to the plane of the loop. Arm PQ is moved with a velocity v towards the arm RS. Assuming that the arms QR, RS and SP have negligible resistances and the moving arm PQ has the resistance r, obtain the expression for

(i) The current in the loop
(ii) The force and
(iii) The power required to move the arm PQ.

Ans. (i)

Current in the loop $PQRS$,

$$I = \frac{\varepsilon}{r}$$

Since $\varepsilon = \frac{d\varphi}{\mathrm{dt}}\mathrm{Blv}$ So, $I = \frac{\mathrm{Blv}}{r}$

(ii) The force required to keep the arm PQ in

Constant motion

$$F = \mathrm{BI}\ l = B\left(\frac{\mathrm{Blv}}{r}\right)l = \frac{B^2 l^2 v}{r}$$

(iii) Power required to move the arm PQ

$$P = F|v| = \left(\frac{B^2 l^2 v}{r}\right)|v| = \left(\frac{B^2 l^2 v^2}{r}\right)$$

Q. 10. Answer the following questions

A rod of length l is moved horizontally with a uniform velocity 'v' in a direction perpendicular to its length through a region in which a uniform magnetic field is

acting vertically downward. Derive the expression for the emf induced across the ends of the rod.

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

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

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

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

Using Lenz’s law

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

$\therefore \quad \varepsilon = Blv$

(ii) Suppose any arbitrary charge ‘q’ in the conductor of length ‘l’ moving inward in the field as shown in figure, the charge q also moves with velocity V in the magnetic field B

The Lorentz force on the charge ‘q’ is F = qvB and its direction is downwards.

So, work done in moving the charge ‘q’ along the conductor of length l

W = F.l

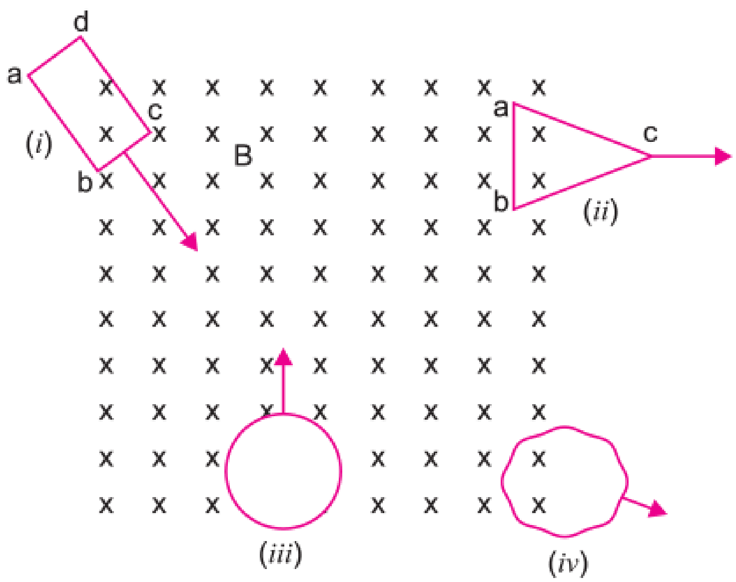
W = qvBl

Since emf is the work done per unit charge

$$\therefore \qquad \varepsilon = \frac{W}{q} = \text{Blv}$$

This equation gives emf induced across the rod.

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



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

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

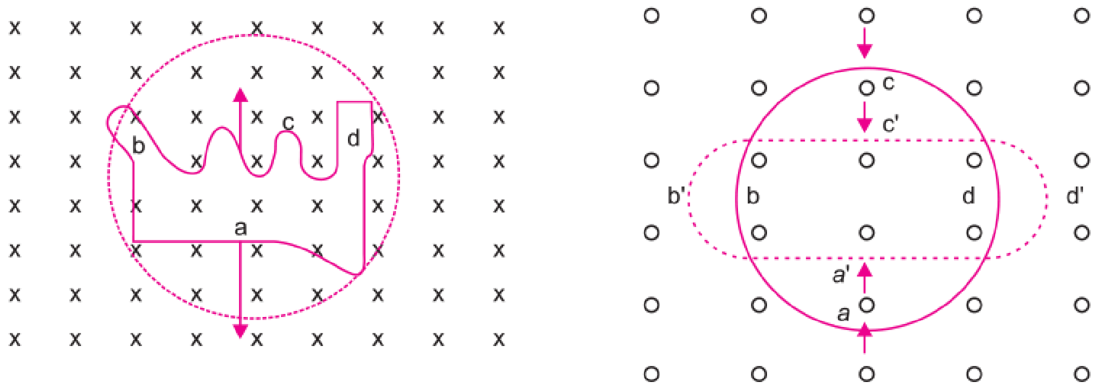
Thus in fig. (i) Current flows anticlockwise,

In fig. (ii) Current flows clockwise,

In fig. (iii) Current flows anticlockwise,

In fig. (iv) Current flows clockwise.

Q. 12. Use Lenz's law to determine the direction of induced current in the situation described by following figs. [CBSE (F) 2014]



(a) (b)

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

(ii) A circular loop being deformed into a narrow straight wire.

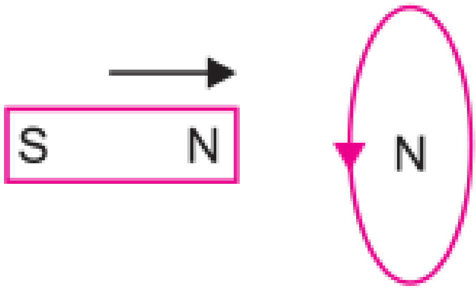
Ans. (i) For the given periphery the area of a circle is maximum. When a coil takes a circular shape, the magnetic flux linked with coil increases, so current induced in the coil will tend to decrease the flux and so will produce a magnetic field upward. As a result the current induced in the coil will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

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

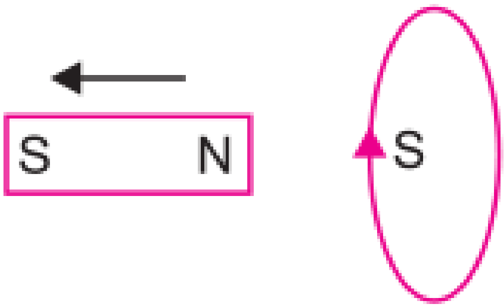
Q. 13. Show that Lenz's law is in accordance with the law of conservation of energy.
[CBSE (F) 2017]

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

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



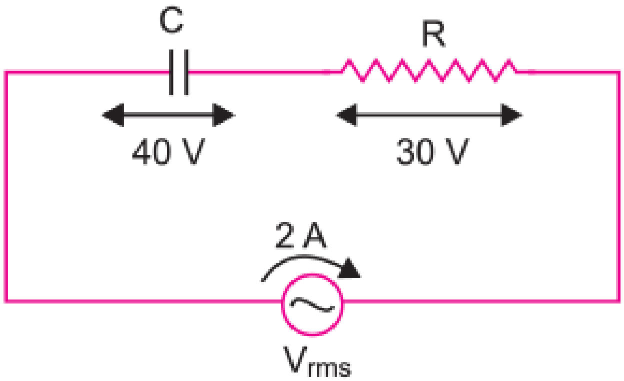
Similarly when North Pole of the magnet is moved away from the coil, the direction of current in the coil will be such as to attract the magnet. For this the nearer face of coil behaves as South Pole. This necessitates a clockwise current in the coil, when seen from the magnet side [fig. (b)].



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

Short Answer Questions –II (OIQ)

Q. 1. A bar magnet M is dropped so that it falls vertically through the coil C. The graph obtained for voltage produced across the coil versus time is showing in figure (b).



(i) Explain the shape of the graph.

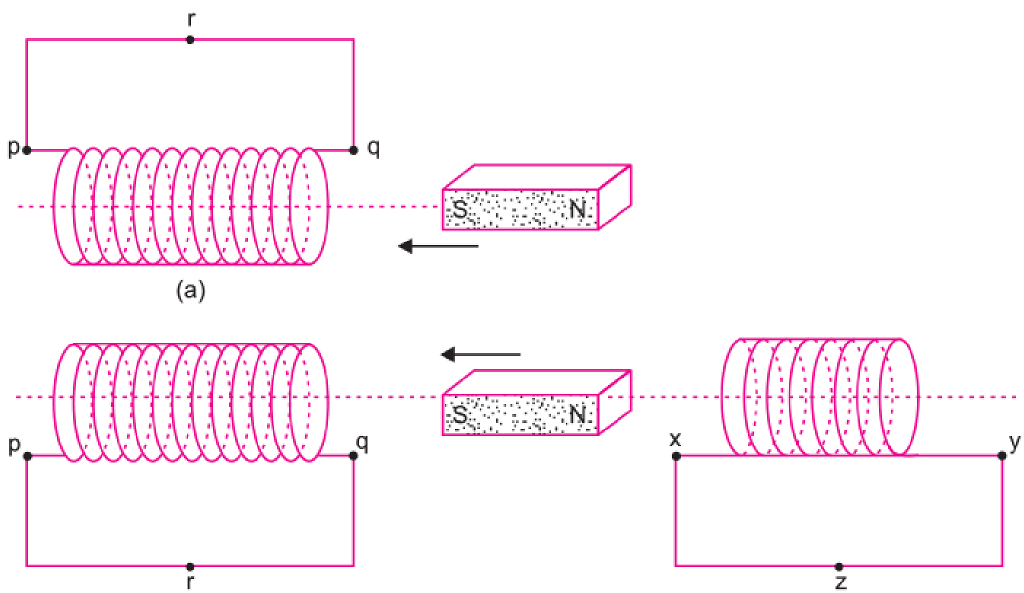
(ii) Why is the negative peak longer than the positive peak?

Ans. (i) When the bar magnet falls through the coil, the magnetic flux linked with the coil changes, so an emf (or pd) is developed across the coil.

Initially, the rate of increase of flux increases, becomes maximum and then it decreases, becomes zero. Now, magnetic flux begins to decrease, the rate of decrease increases becomes maximum and then it decreases and when the magnet is sufficiently far on the other side, the flux becomes zero and so pd induced becomes zero.

(ii) Negative peak is longer than Positive peak because magnet moves out of coil faster than it moves into the coil, so the rate of decrease of magnetic flux is faster than the rate of increase of flux.

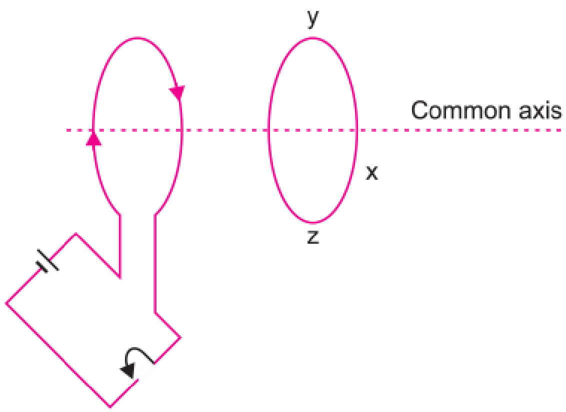
Q. 2. Predict the direction of induced current in the situations described in the following figs.



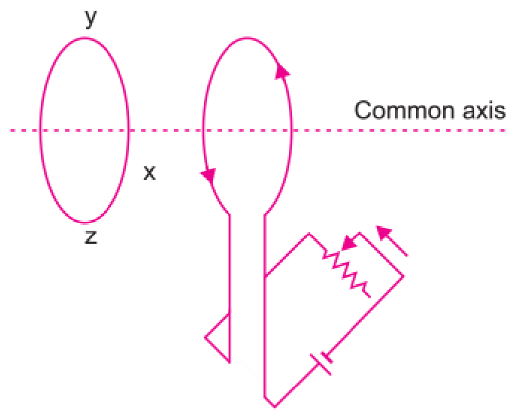
Ans. (a) The direction of current is along qrpq because the current induced in solenoid will oppose the approach of magnet, so from looking on magnet side, the current at nearer face should flow clockwise.

(b) In this case the current induced in coil pq will oppose the approach of magnet while coil xy will oppose the recession of magnet; so nearer faces of coils will act as S-poles. Accordingly the direction of current in coil pq will be along qrp and in coil xy it will be along yzx.

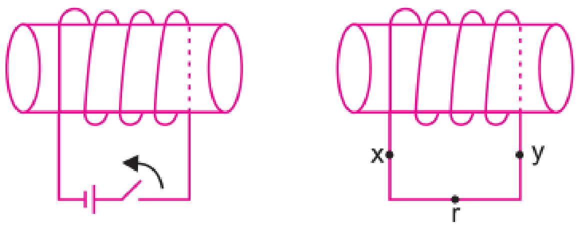
Q. 3. Predict the direction of induced current in the situations described in the following figs.



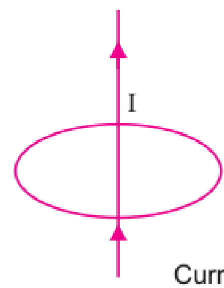
(a) Tapping key just closed



(b) Rheostat setting being changed



(c)
Tapping key just released



(d) Current (I) decreasing at a steady rate

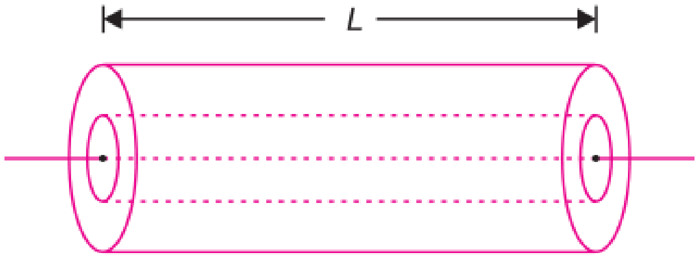
Ans. (a) When the tapping key is just closed, the current produced in the left loop flows clockwise, so magnetic field induced will flow along negative axis; the current induced in right coil will oppose the magnetic field produced, so current in right coil will flow anticlockwise, i.e., direction of current will be along yzx.

(b) The current in coil is anticlockwise. When rheostat setting is being changed, the resistance of the right circuit is decreasing, so current is increasing, the current induced in left loop will oppose the increase of current, so current induced in left coil will flow clockwise i.e., along zyx.

(c) Induced current in the right coil is along xry.

(d) No induced current because magnetic field lines lie in the plane of loop.

Q. 4. Figure shows two long coaxial solenoids, each of length 'L'. The outer solenoid has an area of cross-section A1 and number of turns/length n1 The corresponding values for the inner solenoid are A2 and n2 Write the expression for self-inductance L1, L2 of the two coils and their mutual inductance M. Hence show that M < $\sqrt{L_2}\, L_2$.



Ans. Self-inductance of a solenoid of length L

=μ0n[2]AL, where n is number of turns per metre.

$$L_1 = \mu_0 n_1^2 A_1 L$$

and $$L_2 = \mu_0 n_2^2 A_2 L$$

If I_1 is the current in outer solenoid, then magnetic field at axis, $B_1 = \mu_0 n_1 I_1$

Magnetic flux linked with the secondary coil

$$\varphi_2 = (n_2 L) B_1 A_2 = (n_2 L)((\mu_0 n_1 I_1) A_2 = \mu_0 n_1 n_2 \mathrm{LA}_2 I_1$$

$$M = \frac{\varphi_2}{I_1} = \mu_0 n_1 n_2 \mathrm{LA}_2 \qquad \dots (i)$$

Now, $L_1 L_2 = (\mu_0 n_1^2 A_1 L),(\mu_0 n_2^2 A_2 L)$

$$\sqrt{L_1 L_2} = \mu_0 n_1 n_2 L \sqrt{A_1 A_2} \qquad \dots (ii)$$

$$\frac{M}{\sqrt{L_1 L_2}} = \sqrt{\frac{A_2}{A_1}}$$

As $A_2 < A_1, A_2 < \sqrt{A_1 A_2}$

$\therefore\ M < \sqrt{L_1 L_2}$

Long Answer Questions

Q. 1. Answer the following questions

(i) What is induced emf? Write Faraday's law of electromagnetic induction. Express it mathematically.

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

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

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

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

(i) When the magnetic flux linked with a coil or circuit changes, an emf is induced in the coil. If coil is closed, the current is also induced. The emf and current last so long as the change in magnetic flux lasts. The magnitude of induced emf is proportional to the rate of change of magnetic flux linked with the circuit. Thus if $\Delta\varphi$ is the change in magnetic flux linked in time Δt then rate of change of flux is

$\frac{\Delta\varphi}{\Delta t}$,

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

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

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

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

$\varepsilon = -K\frac{\Delta\varphi}{\Delta t}$ where K is a constant of proportionality which depends on units chosen for φ, t and ε. In SI system the unit of flux φ is weber, unit of time t is second and unit of emf ε' is volt and $K=1$

$\therefore \quad \varepsilon = -\frac{\Delta\varphi}{\Delta t} \quad ...(i)$

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

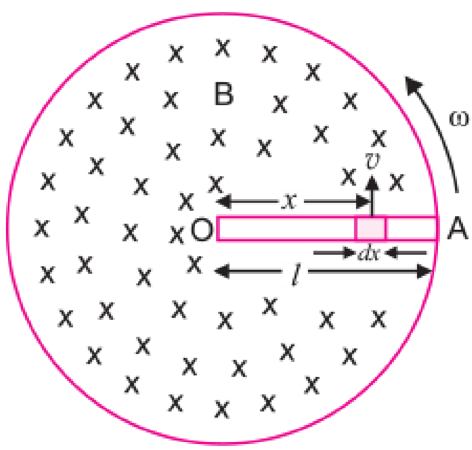
$\varepsilon = -N\frac{\Delta\varphi}{\Delta t} = -\frac{\Delta(N\varphi)}{\Delta t} ...(ii)$

Nφ is called the **effective magnetic flux or the number of flux linkages in the coil and may be denoted by φ**

(ii) Expression for Induced emf in a Rotating Rod

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

The emf induced across the ends of element



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

But $v = x\omega$

∴ $d\varepsilon = \mathrm{B}\, x\, \omega\, dx$

∴ The emf induced across the rod

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

$$= B\omega\left[\frac{x^2}{2}\right] = B\omega\left[\frac{l^2}{2} - 0\right] = \frac{1}{2}B\omega I^2$$

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

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

Q. 2. Answer the following questions

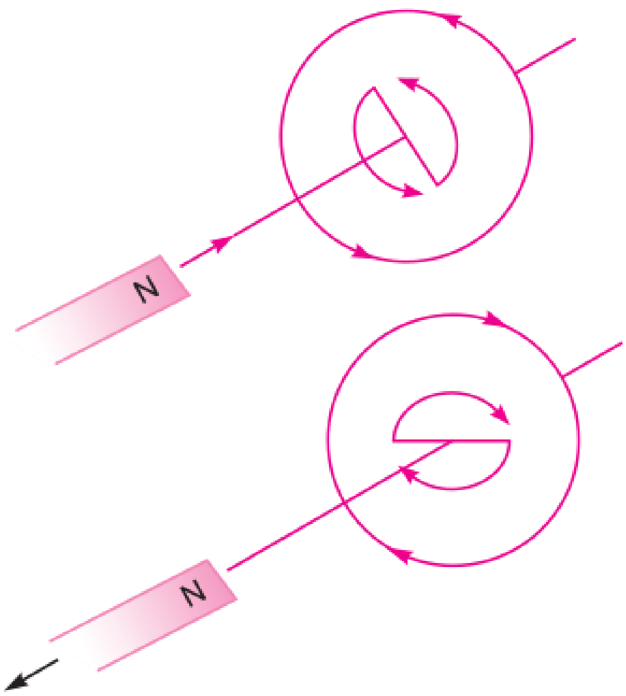
(1) Describe a simple experiment (or activity) to show that the polarity of emf induced in a coil is always such that it tends to produce an induced current which opposes the change of magnetic flux that produces it.

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

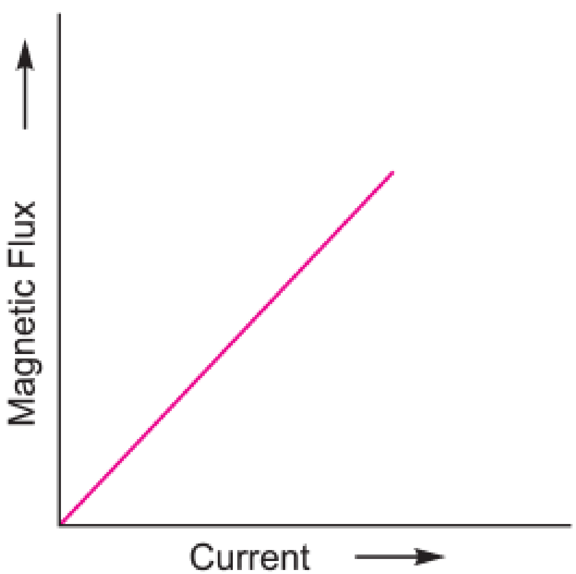
(i) Magnetic flux versus the current
(ii) Induced emf versus dI/dt
(iii) Magnetic potential energy stored versus the current. [CBSE Delhi 2014]

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

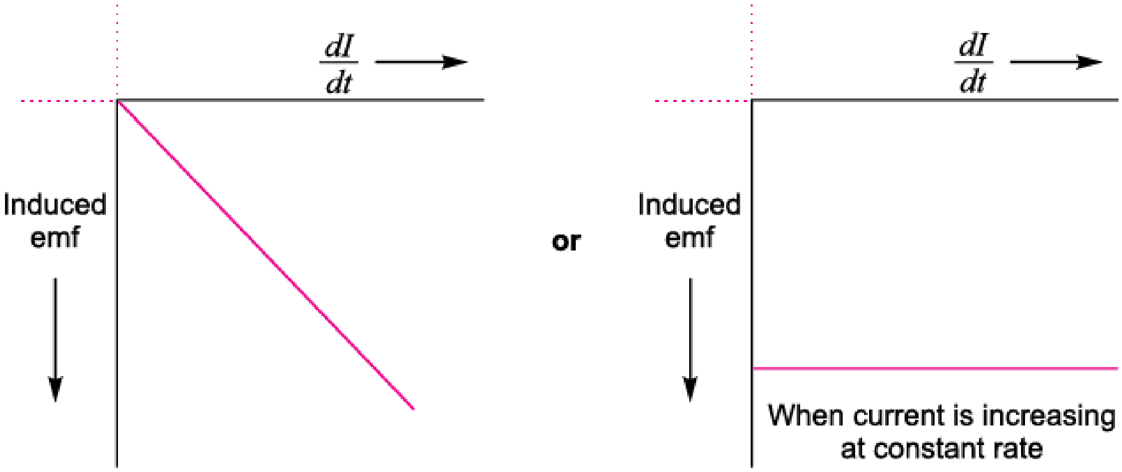
When a North Pole of a magnet is moved away from the coil, the current (I) flows in the clock-wise sense which corresponds to the generation of South Pole. The induced South Pole opposes the motion of the receding North Pole.



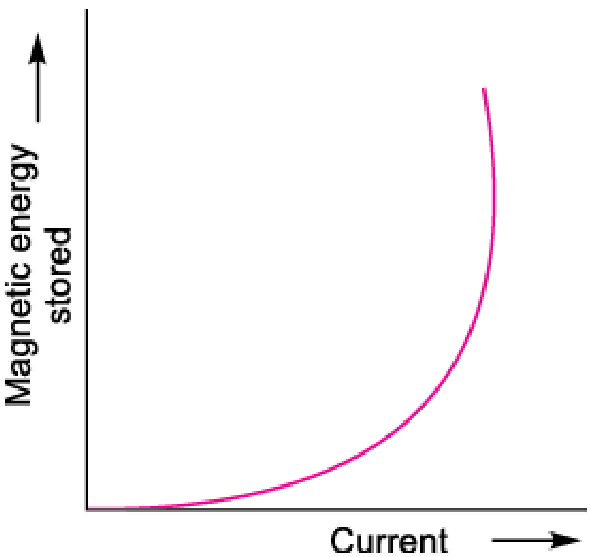
(ii) (i) Magnetic flux versus the current



(ii) Induced emf versus dI/dt



(iii) Magnetic energy stored



Q. 3. Derive an expression for (i) induced emf and (ii) induced current when a conductor of length l is moved with a uniform velocity, normal to a uniform magnetic field B. Assume the resistance of conductor to be R.

Ans. Expression for Induced emf: We know that if a charge q moves with velocity $\vec{V}$ in a magnetic field of strength $\vec{B}$, making an angle θ then magnetic Lorentz force

F = q vB sin θ

If $\vec{v}$ and $\vec{B}$ mutually perpendicular, then $\theta = 90^\circ$

$$F = qvB \sin 90^\circ = qvB$$

The direction of this force is perpendicular to both $\underset{V}{\rightarrow}$ and $\underset{B}{\rightarrow}$ and is given by Fleming's left hand rule.

Suppose a thin conducting rod PQ is placed on two parallel metallic rails CD and MN in a magnetic field of strength $\underset{B}{\rightarrow}$. The direction of magnetic field $\underset{B}{\rightarrow}$ is perpendicular to the plane of paper, downward. In fig $\underset{B}{\rightarrow}$ is represented by cross (×) marks. Suppose the rod is moving with velocity $\underset{V}{\rightarrow}$, perpendicular to its own length, towards the right. We know that metallic conductors contain free electrons, which can move within the metal. As charge on electron, q = – e therefore, each electron experiences a magnetic Lorentz force, F_m = evB, whose direction, according to Fleming's left hand rule, will be from P to Q Thus the electrons are displaced from end P towards end Q Consequently the end P of rod becomes positively charged and end Q negatively charged. Thus a potential difference is produced between the ends of the conductor. This is the **induced emf.**

Due to induced emf, an electric field is produced in the conducting rod. The strength of this electric field

$$E = \frac{V}{l} \qquad ...(i)$$

And its direction is from (+) to (–) charge, i.e., from P to Q.

The force on a free electron due to this electric field, $F_e = {}_eE$ ...(ii)

The direction of this force is from Q to P which is opposite to that of electric field. Thus the emf produced opposes the motion of electrons caused due to Lorentz force. This is in accordance with Lenz's law. As the number of electrons at end becomes more and more, the magnitude of electric force Fe goes on increasing, and a stage comes when electric force $\underset{Fe}{\rightarrow}$ and magnetic force $\underset{Fm}{\longrightarrow}$ become equal and opposite. In this situation the potential difference produced across the ends of rod becomes constant. In this condition

$F_e = F_m$

${}_eE = evB$ or $E = B_v$ ...(iii)

∴ The potential difference produced,

V = El = B v l Volt

Also the induced current $I = \frac{V}{R} = \frac{Bvl}{R}$ ampere

Q. 4. Derive expression for self-inductance of a long air-cored solenoid of length l, cross-sectional area A and having number of turns N. [CBSE Delhi 2012, 2009]

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

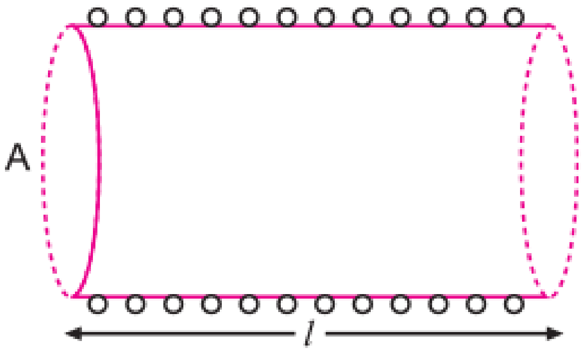
Consider a long air solenoid having ‘n’ number of turns per unit length. If current in solenoid is I, then magnetic field within the solenoid, $B = \mu_0 nI$ ...(i)

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

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

∴ $\Phi = (nl\, BA)$

Substituting the value of B from (i)



∴ $\Phi = (\mu_0 nI) A = \mu_0 n^2 AlI$ ...(ii)

∴ Self-inductance of air solenoid

$$L = \frac{\Phi}{I} = \mu_0 n^2 \text{ Al} \quad ...(iii)$$

If N is total number of turns in length l then

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

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

Remark: If solenoid contains a core of ferromagnetic substance of relative permeability μ_r then self inductance, $L = \frac{\mu_r \mu_0 N^2 A}{l}$.

Q. 5. Obtain the expression for the mutual inductance of two long co-axial solenoids S1 and S2 wound one over the other, each of length L and radii r_1 and r_2 and n_1 and n2 be number of turns per unit length, when a current I is set up in the outer solenoid S_2.
[CBSE Delhi 2017]

OR

(a) Define mutual inductance and write its SI units.

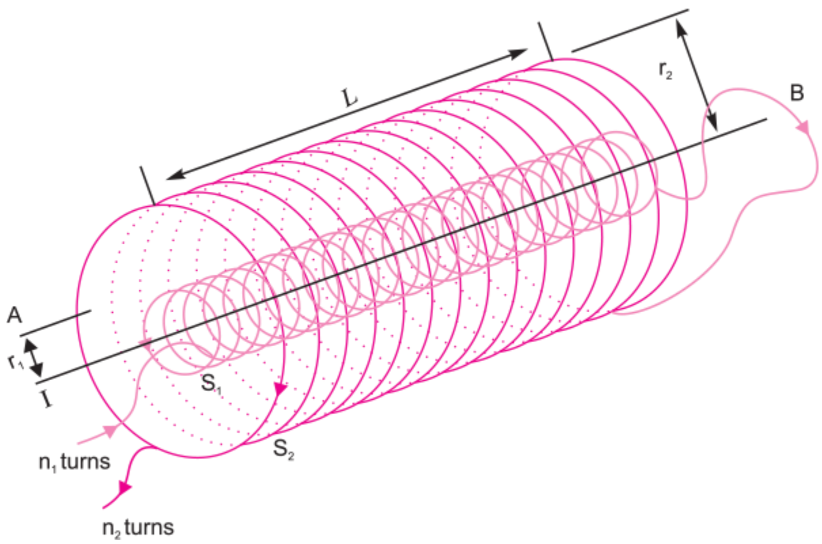
(b) Derive an expression for the mutual inductance of two long co-axial solenoids of same length wound one over the other.

(c) In an experiment, two coils C_1 and C_2 are placed close to each other. Find out the expression for the emf induced in the coil C_1 due to a change in the current through the coil C_2. [CBSE Delhi 2015]

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

The SI unit of mutual inductance is henry.

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



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

Imagine a time varying current I2 through S_2 which sets up a time varying magnetic flux φ1 through S_1.

∴ $\varphi 1 = M_{12}(I_2)$ ...(i)

Where, M_{12} = Coefficient of mutual inductance of solenoid S1 with respect to solenoid S_2

Magnetic field due to the current I_2 in S_2 is

∴ Magnetic flux through S_1 is

$\varphi_1 = B_2 A_1 N_1$

Where, $N_1 = n_1$ and L = length of the solenoid

$\varphi_1 = (\mu_0 n_2 I_2)(\pi r_1^2)(n_1 L)$ ...(ii)

$\varphi_1 = \mu_0 n_1 n_2 \pi r_1^2 \, \mathrm{LI_2}$)

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

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

Let us consider the reverse case.

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

$\therefore \varphi_2 = M_{21}(I_1)$ ...(*iv*)

where, M_{12}= Coefficient of mutual inductance of solenoid S_2 with respect to solenoid S_1 Magnetic flux due to S_1 is confined solely in S_1 as the solenoids are assumed to be very long. There is no magnetic field outside S_1 due to current I in S_1.

The magnetic flux linked with S_2 is

$\therefore \quad \varphi_2 = B_1 A_1 N_2 = (\mu_0 n_1 I_1)(\pi r_1^2)(n_2 L)$

$\varphi_2 = \mu_0 n_1 n_2 I_2 \pi r_1^2 \, \mathrm{LI_1}$ ...(*v*)

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

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

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

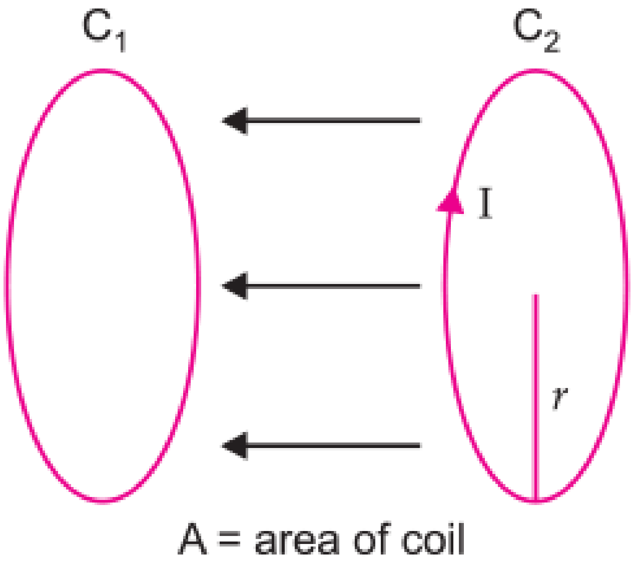
$M_{12} = M_{21} = M <= \mu_0 n_1 n_2 \pi r_1^2 L$

We can write the above equation as

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

$M = \frac{\mu_0 N_1 N_2 \pi r^2}{L}$

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



Flux linked with C_1 = flux of C_2

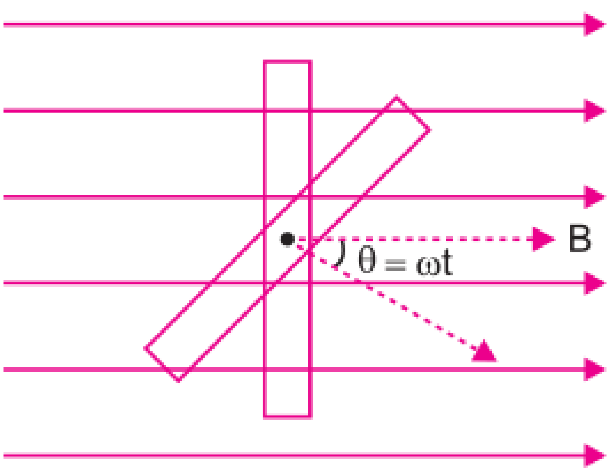
$$\varphi_{12} = B.A = \frac{\mu_0 I}{2r}.A$$

$$\text{emf in } C_1 = \frac{d\varphi_{12}}{dt} = \frac{d}{dt}\frac{\mu_0 AI}{2r}$$

Q. 6. A coil of number of turns N, area A is rotated at a constant angular speed ω, in a uniform magnetic field B and connected to a resistor R. Deduce expression for

(i) Maximum emf induced in the coil.
(ii) Power dissipation in the coil.

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



θ = ωt

∴ At this instant magnetic flux linked with the coil φ = BA cos ωt

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

$$\varepsilon = -N\frac{d\varphi}{dt} = -N\frac{d}{dt}\left(\mathrm{BA}\cos\omega t\right)$$

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

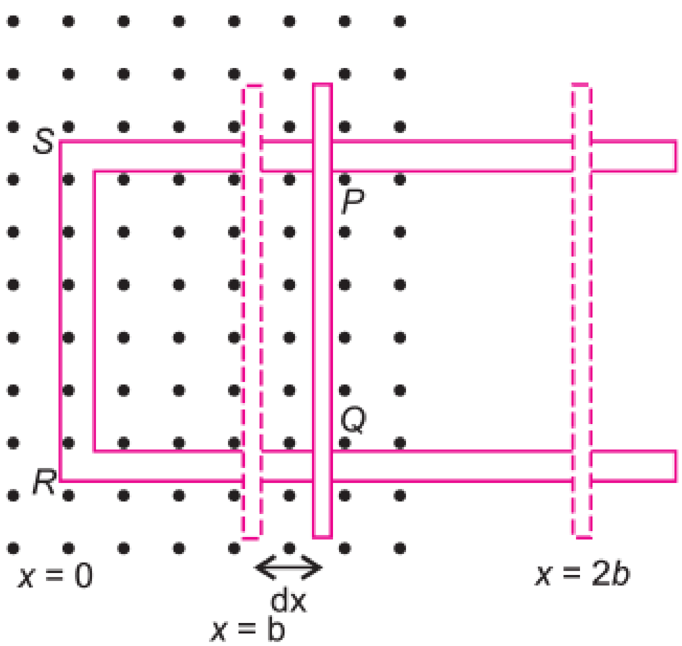
∴ For maximum value of emf ε,

sin ωt =1

∴ Maximum emf induced, ε_{max} = NBA ω

Q. 7. 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 variations of these quantities with distance 0 ≤ x ≤ 2b
[CBSE (AI) 2010, (North) 2016]



Ans. Refer to Point 3 of Basic Concepts.

Let length of conductor PQ =1

As x = 0, magnetic flux φ = 1

When PQ moves a small distance from x to x + dx then magnetic flux linked= BdA=Bldx
The magnetic field is from x = 0 to x = b, to so final magnetic flux

= ∑Bldx = Bl ∑dx =Blb (increasing)

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

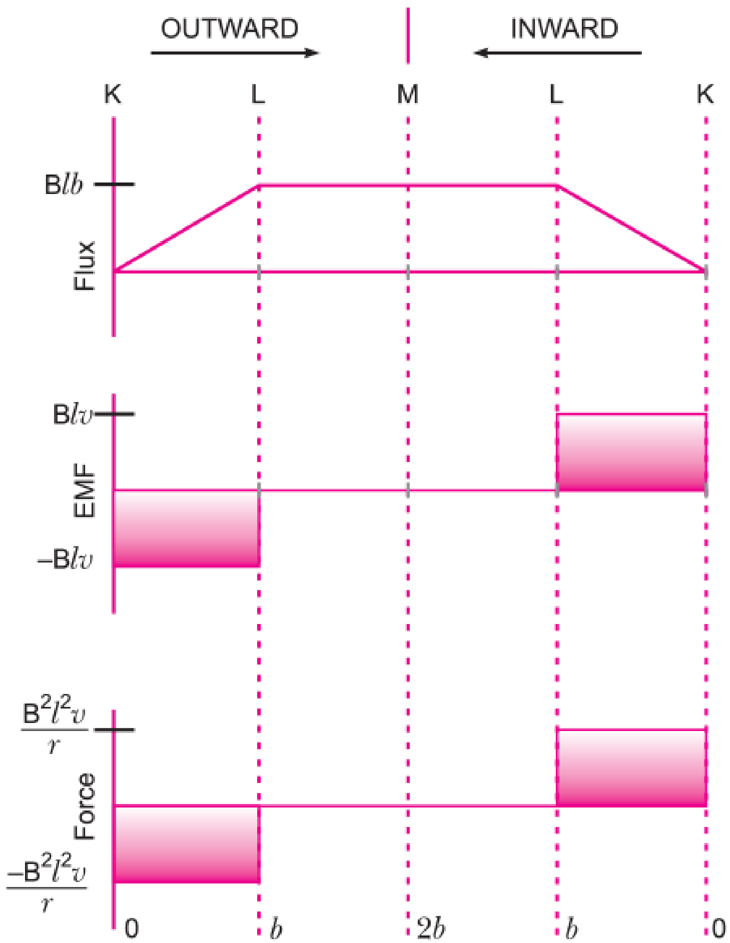
The magnetic flux from $x = b$ to $x = 2b$ is zero.

Induced emf, $\varepsilon = -\frac{d\varphi}{dt} = \frac{d}{dt}(Bldx) = -Bl\frac{dx}{dt} = -Blv$

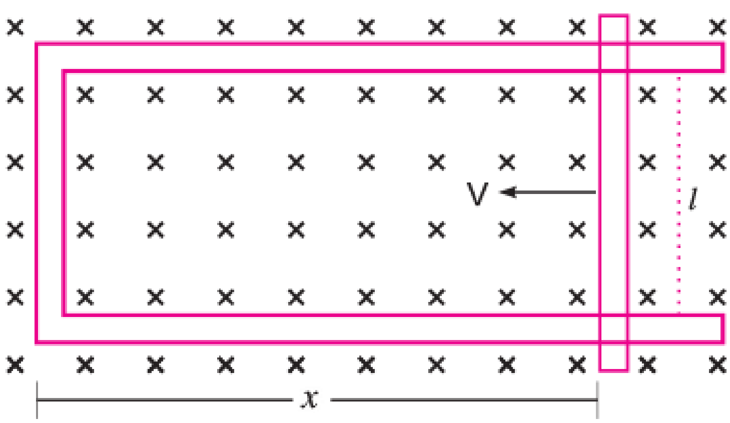
where $v = \frac{dx}{dt}$ velocity of arm PQ from $x = 0$ to $x = b$.

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

$$\varepsilon = Blv$$



Q. 8. What are eddy currents? How are they produced? In what sense eddy currents are considered undesirable in a transformer? How can they be minimised? Give two applications of eddy currents. [CBSE (AI) 2011, (F) 2015]



Ans. Eddy currents: When a thick metallic piece is placed in a time varying magnetic field, the magnetic flux linked with the plate changes, the induced currents are set up in the conductor; these currents are called **eddy currents.** These currents are sometimes so strong, that the metallic plate becomes red hot.

Due to heavy eddy currents produced in the core of a transformer, large amount of energy is wasted in the form of undesirable heat.

Minimisation of Eddy Currents: Eddy currents may be minimised by using **laminated core** of soft iron. The resistance of the laminated core increases and the eddy currents are reduced and wastage of energy is also reduced.

Application of Eddy Currents:

(i) Induction Furnace: In induction furnance, the metal to be heated is placed in a rapidly varying magnetic field produced by high frequency alternating current. Strong eddy currents are set up in the metal produce so much heat that the metal melts. This process is used in extracting a metal from its ore. The arrangement of heating the metal by means of strong induced currents is called the induction furnace.

(ii) Induction Motor: The eddy currents may be used to rotate the rotor. Its principle is: When a metallic cylinder (or rotor) is placed in a rotating magnetic field, eddy currents are produced in it. According to Lenz's law, these currents tend to reduce to relative motion between the cylinder and the field. The cylinder, therefore, begins to rotate in the direction of the field. This is the principle of induction motion.