Chapter 21

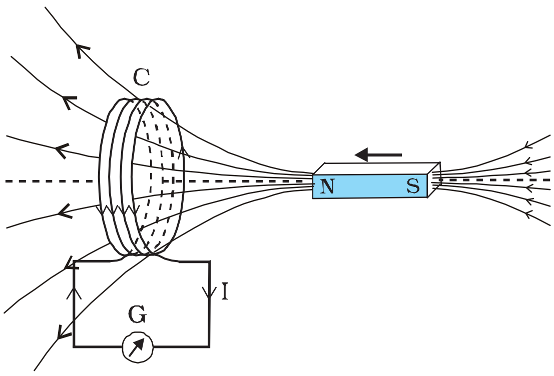
Electromagnetic Induction

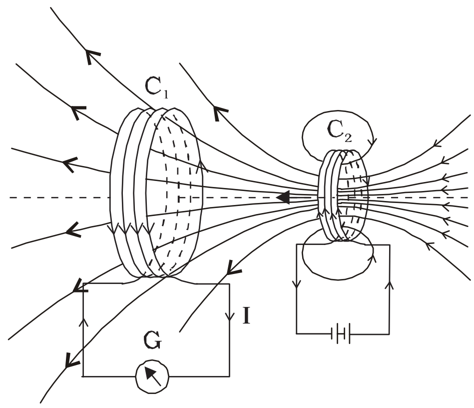
THE EXPERIMENTS OF FARADAY AND HENRY

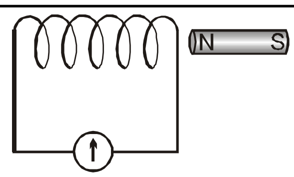
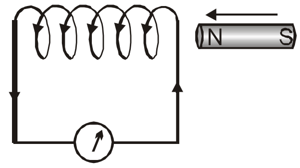
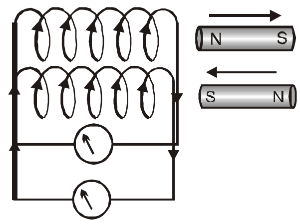
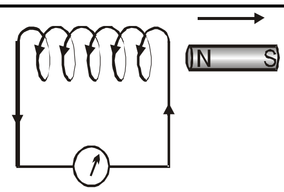
The discovery and understanding of electromagnetic induction are based on a long series of experiments carried out by Faraday and Henry. These experiments are illustrated by the following figures.

When the bar magnet is pushed towards the coil, the pointer in the galvanometer G deflects.

Current is induced in coil C_1 due to motion of the current carrying coil C_2





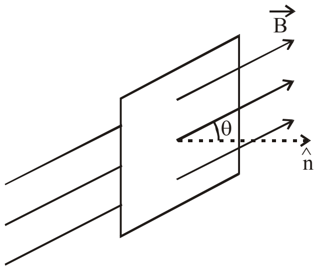
S. No.	Experiment	Observation	
1.	Place a magnet near a conducting loop with a galvanometer in the circuit.	No current flows through the galvanometer.	
2.	Move the magnet towards the loop.	The galvanometer register a current.	
3.	Reverse the direction of motion of the magnet.	The galvanometer deflection reverses.	
4.	Reverse the polarity of the magnet and move the magnet towards the loop.	The galvanometer deflection reverses.	
5.	Keep magnet fixed and move the coil towards the magnet.	The galvanometer register a current.	

6.	Increases the speed of the magnet.	The deflection in the galvanometer increases.
7.	Increase the strength of the magnet.	The deflection in the galvanometer increases.
8.	Increase the diameter of the coil.	The deflection in the galvanometer increases.
9.	Fix the speed of the magnet but repeat the experiment with the magnet closer to the coil.	The deflection in the galvanometer increases.
10.	Move the magnet at an angle to the plane of the coil.	Deflection decreases, it is maximum when the magnet moves perpendicular to the plane of the coil and is zero when the magnet moves parallel to the plane of the coil.
11.	Increase the number of turns of the coil.	Magnitude of current increases.

MAGNETIC FLUX

The number of magnetic lines of force crossing a surface is called magnetic flux linked with the surface.

It is represented by ϕ.



Magnetic flux $\phi = \vec{B}.\vec{A} = BA\cos\theta$

where B is strength of magnetic field, A is area of the surface and θ is the angle which normal to the area (unit area vector) makes with the direction of magnetic field.

The **S.I. unit** of magnetic flux is weber which is the amount of magnetic flux over an area of 1 m^2 held normal to a uniform magnetic field of one tesla.

The **c.g.s. unit** of ϕ is maxwell.

1 weber = 10^8 maxwell.

FARADAY'S LAW OF ELECTROMAGNETIC INDUCTION

Whenever the number of magnetic lines of force (flux) linked with any closed circuit change, an induced current flows through the circuit which lasts only so long as the change lasts. An increase in the number of lines of force produces an inverse current, while a decrease of such lines produces a direct current.

The induced emf is equal to the negative rate of change of magnetic flux.

i.e. $$e = \frac{-d\phi}{dt}$$

The -ve sign shows that the induced emf opposes the change in magnetic flux (Lenz's law).

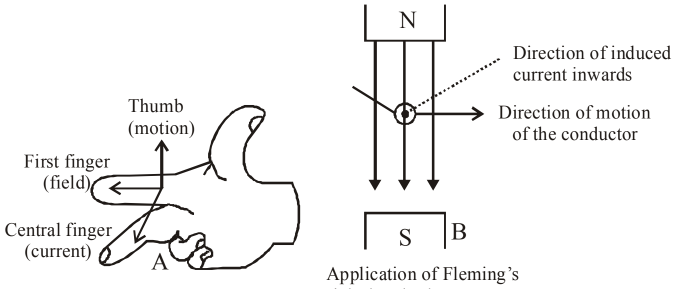
LENZ'S LAW

The direction of induced e.m.f. is given by Lenz's law. According to this law, *the direction of induced e.m.f. in a circuit is always such that it opposes the every cause which produces it.*

Thus, $$e = \frac{-d\phi}{dt}$$

Lenz's law is in accordance with the principle of conservation of energy. Infact, work done in moving the magnet w.r.t. the coil changes into electric energy producing induced current.

There is also another law for finding the direction of induced current. This is **Fleming's right hand rule**. According to this rule, if *we stretch the right-hand thumb and two nearby fingers perpendicular to one another such that the first finger points in the direction of magnetic field and the thumb in the direction of motion of the conductor, then the middle finger will point in the direction of the induced current.*



(a)

Application of Fleming's right-hand rule

(b)

Total flow of charge due to change of flux ($\Delta\phi$):

$$Q = N\Delta\phi / R = \frac{\text{(No. of turns} \times \text{change in magnetic flux)}}{\text{Resistance}}$$

METHODS OF INDUCING E.M.F.

As is known, e.m.f. is induced in a circuit only when amount of magnetic flux linked with the circuit changes. As $\phi = BA\cos\theta$, therefore **three methods of producing induced e.m.f. :**

(i) By changing B, (ii) By changing A and, (iii) By changing θ (orientation of the coil). When a conductor of length ℓ moves with a velocity v in a magnetic field of strength B so that magnetic flux linked with the circuit changes, the e.m.f. induced (ε) is given by

$$\varepsilon = B\ell v.$$

Induced e.m.f. and its direction

Case (i) **In conducting rod:** The induced e.m.f. is generated because of rotation of a conducting rod in a perpendicular magnetic field

$$e = -\frac{B\ell^2\omega}{2} \quad \text{also, } e = -BAf$$

where f = frequency of rotation and

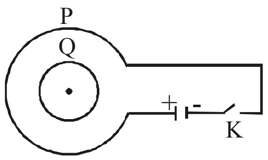
$A = \pi r^2$, where r is the radius of circle in which this rod moves, hence $r = \ell$. ω = angular velocity, ℓ = length of conducting rod.

Case (ii) **In disc:** Induced e.m.f generated in a disc rotating with a constant angular velocity in a perpendicular magnetic field

$$e = -BAf = -B\pi r^2 f = -\frac{Br^2\omega}{2}$$

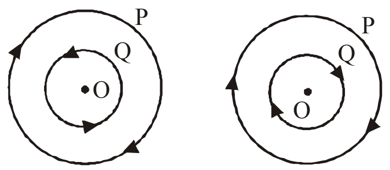
where A = area of disc = πr^2, r = radius of disc, ω = angular velocity of disc.

Case (iii) **In two coils:** When two coils are arranged as shown in the figure



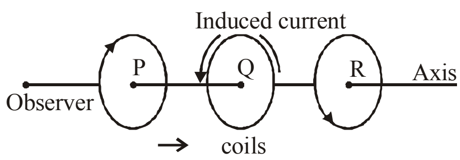
(a) if key K is closed then current in P will flow in clockwise direction and consequently induced current in Q will flow in anticlockwise direction. (see fig. a)

(b) when key K is opened then current in P falls from maximum to zero and consequently induced current in Q will flow in clockwise direction. (see fig. b)



(a) (b)

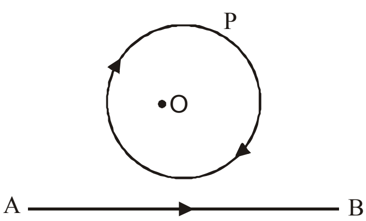
Case (iv) **In three coils arranged coaxially :** Three coils P, Q and R are arranged coaxially as shown in figure. Equal currents are flowing in coils P and R . Coils Q and R are fixed. Coil P is moved towards Q. The induced current in Q will be in anti-clockwise direction so that it may oppose the approach of P according to Lenz's law. As the face of P towards Q is a south pole hence plane of Q towards P will also be a south pole.



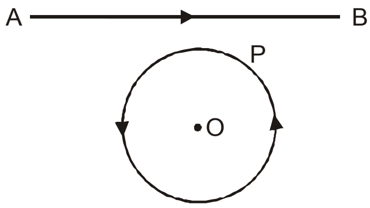
As there is no relative motion between Q and R, hence no current is induced in Q due to R.

Case (v) **Current increases in straight conductor :** When current in the straight conductor is increased then

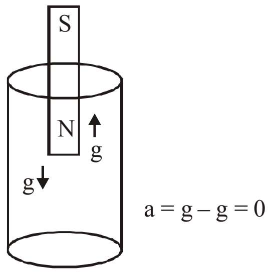
(a) the direction of induced current in the loop will be clockwise so that it may oppose the increase of magnetic flux in the loop in downward direction.



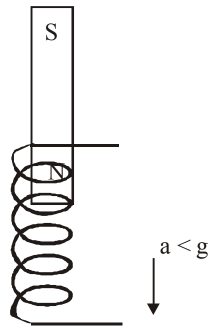
(b) the direction of induced current in the loop will be anti-clockwise so that it may oppose the increase of magnetic flux in the loop in upward direction.



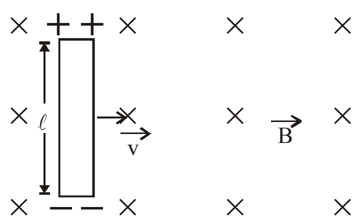
Case (vi) **Magnet dropped freely in long vertical copper tube:** The resistance of copper tube is quite negligible and hence maximum induced current are generated in it due to the motion of the magnet. Due to these induced current the motion of magnet is opposed to maximum. Consequently the acceleration of the magnet will be zero ($a = g - g = 0$).



Case (vii) **Magnet dropped freely into a long solenoid of copper wire:** The resistance of copper solenoid is much higher than that of copper tube. Hence the induced current in it, due to motion of magnet, will be much less than that in the tube. Consequently the opposition to the motion of magnet will be less and the magnet will fall with an acceleration (a) less than g. (i.e. $a < g$).



Case (viii) **Motional EMF:** Induced emf in a conducting rod moving perpendicular through a uniform magnetic field as shown



The induced emf produced across the rod

$$e = B\ell v = \int_0^{\ell} (\vec{v} \times \vec{B}).d\ell$$

This is also called motional emf and *it develops when a metal rod cuts magnetic lines of force.*

Special case : If the rod moves in the magnetic field making an angle θ with it, then induced emf $e = B_n v\ell = Bv\ell\sin\theta$.

COMMON DEFAULT

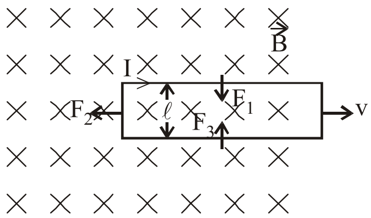
✘ ***Incorrect.*** When there is no change in magnetic flux no induced current is produced.

✔ ***Correct.*** Consider the case (viii) discussed above. There is no change in the magnetic flux throgh the rod, still induced emf is produced.

Case (ix) A straight conductor (slider) moving with velocity v on a U shaped wire placed in a uniform magnetic field.

The induced current produced is $I = \dfrac{B\ell v}{R}$

Case (x) When a rectangular loop perpendicular to the magnetic field is pulled out, then forces $\vec{F_1}$ and $\vec{F_3}$ being equal and opposite cancel out.

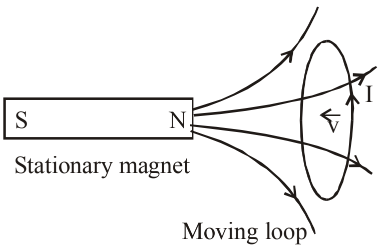


$$F_2 = BI\ell = B\left(\frac{B\ell v}{R}\right)\ell = \frac{B^2\ell^2 v}{R}$$

Power required to move the loop out

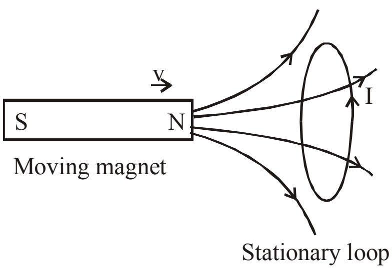
$$P = F_2 \times v = \frac{B^2\ell^2 v^2}{R}$$

Case (xi) The magnet is stationary and the loop is moving towards the magnet.



The induced emf or current I is shown which is in accordance to Lenz's law. In this case the magnetic force causes the charge to move. We know that if a charged particle is in motion in a field it experiences a magnetic force. This is because when charged particle moves it creates its own magnetic field which interacts with the existing magnetic field.

Case (xii) The magnet is moving towards the loop which is stationary.



The induced emf or current I is shown which is in accordance to Lenz's law. Here the varying magnetic field at the location of loop (due to the movement of magnet) creates an electric field.

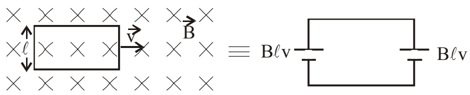
We should remember certain points regarding the induced electric field produced due to changing magnetic field.

- Induced electric field lines form closed loops (different from the electric field lines used to depict electric field produced due to charges)
- Induced electric field is non-conservative in nature (again a difference from the electric field produced by electric charges)

Mathematically, $e = \oint \vec{E}.\vec{dl} = -\dfrac{d\phi}{dt} \neq 0$

Note :

1. An emf is induced in a circuit where the magnetic flux is changing even if the circuit is open. But obviously no current will flow. If we close the circuit, the current will start flowing.
2. In a loop moving in a uniform magnetic field, when the loop remains in the field, the net emf induced is zero.

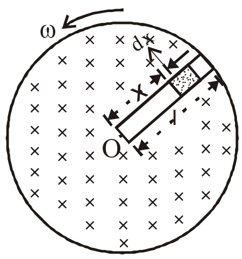


Example 1.

A copper rod of length ℓ is rotated about one end perpendicular to the uniform magnietic field B with constant angular velocity ω. What will be the induced e.m.f. between two ends ?

Solution :

Consider a small element of the rod of length dx at a distance x from the centre O.



Let v be the linear velocity of the element at right angles to the magnetic field B. The e.m.f. developed across the element is $de = Bv\,dx = B(\omega x)\,dx$ $(\because v = \omega x)$

The e.m.f. across the entire rod of length ℓ is given by

$$e = \int de = B\omega\int_0^\ell x\,dx = B\omega\left[\frac{x^2}{2}\right]_0^\ell$$

$$= B\omega(\ell^2/2) = \frac{1}{2}B\omega\ell^2$$

Example 2.

A conductor of length 10 cm is moved parallel to itself with a speed of 10 m/s at right angles to a uniform magnetic induction 10^{-4} Wb/m². *What is the induced e.m.f. in it?*

Solution :

Given : $\ell = 10 \text{ cm} = 0.1 \text{ m}, v = 10 \text{ m/s}$

$B = 10^{-4} \text{ Wb/m}^2$

e.m.f. induced in conductor

$$e = B\,\ell\,V = 10^{-4} \times 0.1 \times 10 = 10^{-4} \text{ V}$$

Example 3.

A metal rod of length 1 m is rotated about one of its ends in a plane right angles to a field of inductance 2.5 × 10^{-3} Wb/m². If it makes 1800 revolutions/min. Calculate induced e.m.f. between its ends.

Solution :

Given : $\ell = 1\text{m}, B = 5 \times 10^{-3} \text{ Wb/m}^2$

$$f = \frac{1800}{60} = 30 \text{ rotations/sec}$$

In one rotation, the moving rod of the metal traces a circle of radius $r = \ell$

$\therefore$ Area swept in one rotation = πr^2

$$\frac{d\phi}{dt} = \frac{d}{dt}(BA) = B.\frac{dA}{dt} = \frac{B\pi r^2}{T} = B\,f\,\pi\,r^2$$

$$= (5 \times 10^{-3}) \times 3.14 \times 30 \times 1 = 0.471 \text{ V}$$

$\therefore$ e.m.f. induced in a metal rod = 0.471 V

Example 4.

A coil having 100 turns and area 0.001 metre^2 is free to rotate about an axis. The coil is placed perpendicular to a magnetic field of 1.0 weber/metre^2. If the coil is rotate rapidly through an angle of 180°, how much charge will flow through the coil? The resistance of the coil is 10 ohm.

Solution :

The flux linked with the coil when the plane of the coil is perpendicular to the magnetic field is

$$\phi = nAB\cos\theta = nAB.$$

Change in flux on rotating the coil by 180° is

$$d\phi = nAB - (-nAB) = 2nAB$$

$$\therefore \text{ induced charge} = \frac{d\phi}{R}$$

$$= \frac{2nAB}{dt} = \frac{2 \times 100 \times 0.001 \times 1}{10}$$

$$= 0.01 \text{ coulomb}$$

Example 5.

Predict the direction of induced current in the situations described by the following fig. (1) to (5).

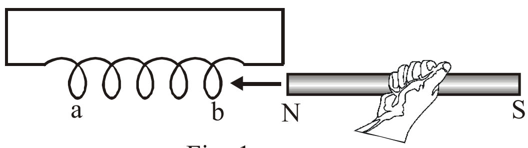


Fig -1

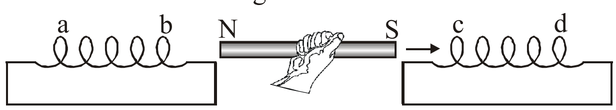


Fig.2

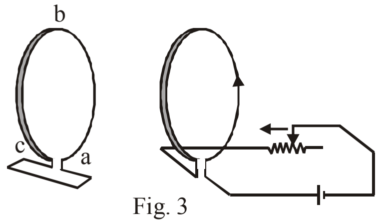


Fig. 3

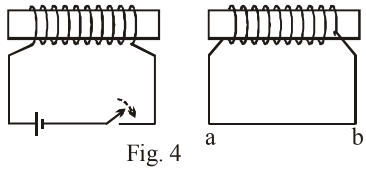


Fig. 4

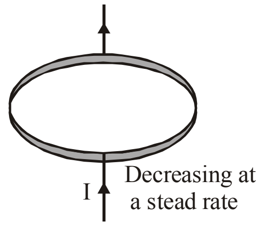


Fig.5

Solution :

Applying Lenz's law

Fig. (1) along $a \rightarrow b$

Fig. (2) along $b \rightarrow a$

Fig. (3) along $c \rightarrow a$

Fig. (4) along $a \rightarrow b$

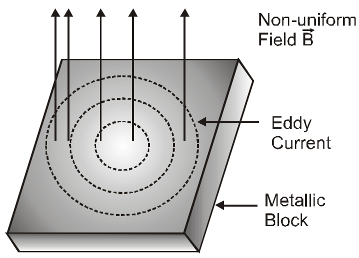
Fig. (5) no induced current since field lines lie in the plane of the loop.

EDDY CURRENTS

The induced circulating currents produced in a metal itself due to change in magnetic flux linked with the metal are called eddy currents. These currents were discovered by Foucault, so they are also known as Foucault Currents.

The direction of eddy currents is given by Lenz's law.

Eddy currents produced in a metallic block moving in a non-uniform magnetic field is shown in fig.



Applications of Eddy Current

Like friction, eddy currents are helpful in some fields and have to be increased, while in some other fields they are undesirable and have to be minimised.

(1) Dead beat galvanometer. (2) Energy meter.

(3) Speedometer. (4) Electric brakes.

(5) Single phase AC motor. (6) Induction furnace.

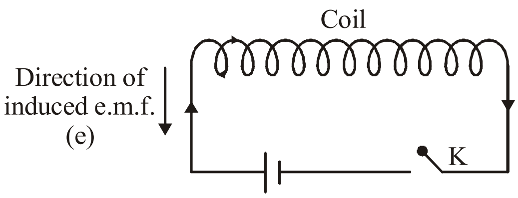
(7) Diathermy

Note : In a moving coil galvanometer, damping is necessary to avoid oscillation of display needle. This is brought into practice with the help of eddy currents. The winding of the coil of galvanometer is done on a metallic frame. When the coil rotates the magnetic flux linked with the metallic frame changes due to which eddy currents are developed which oppose the rotation of the coil. This is called **dead beat galvanometer.**

SELF INDUCTANCE AND MUTUAL INDUCTANCE

Self Inductance

The property of a coil by virtue of which the coil opposes any change in the strength of the current flowing through it, by inducing an e.m.f. in itself is called self inductance.



When a current I flows through a coil, the magnetic flux ϕ linked with the coil is $\phi = LI$, where *L is coefficient of self inductance* of the coil.

On differentiating, we get

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

If dI / dt = 1; L = – e.

Hence coefficient of *self inductance of a coil is equal to e.m.f. induced in the coil when rate of change of current through the same coil is unity.* Coefficient of self induction of a coil is also defined as the magnetic flux linked with a coil when 1 ampere current flows through the same coil.

The value of L depends on geometry of the coil and is given by

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

where ℓ is length of the coil (solenoid), N is total number of turns of solenoid and A is area of cross section of the solenoid.

The **S.I. unit** of L is henry. Coefficient of self induction of a coil is said to be one henry when a current change at the rate of 1 ampere/sec. in the coil induces an e.m.f. of one volt in the coil.

Keep in Memory

1. Energy stored in a coil (inductor) $= \frac{1}{2}\text{Li}^2$

   where L is the self-inductance and i current flowing through the inductor.

   The energy stored in the magnetic field of the coil.

   $$E = \frac{1}{2}Li^2 = \frac{1}{2}(\mu_0 n^2 A\ell)\left(\frac{B}{\mu_0 n}\right)^2$$

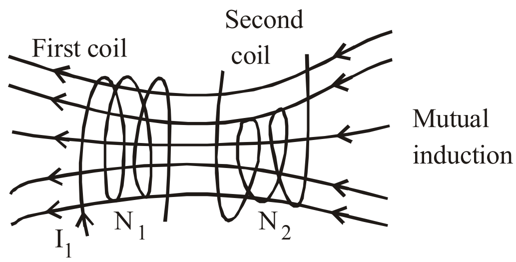
   $$= \left(\frac{B^2}{2\mu_0}\right)A\ell = \left(\frac{B^2}{2\mu_0}\right) \times \text{volume}$$

2. The self inductance is a measure of the coil to oppose the flow of current through it. The role of self-inductance in an electrical circuit is the same as that of the inertia in mechanics. Therefore it is called **electrical inertia**.

3. The magnetic energy density (energy stored per unit volume) in a solenoid $= \frac{B^2}{2\mu_0}$

Mutual Inductance

Mutual induction is the property of two coils by virtue of which each opposes any change in the strength of current flowing through the other by developing an induced e.m.f.



Coefficient of mutual inductance (M) of two coils is said to be one henry, when a current change at the rate of 1 ampere/sec. in one coil induces an e.m.f. of one volt in the other coil. The value of M depends on geometry of two coils, distance between two coils, relative placement of two coils etc.

The coefficient of mutual inductance of two long co-axial solenoids, each of length ℓ, area of across section A, wound on an air core is $M = \frac{\mu_0 N_1 N_2 A}{\ell}$] ...(1)

where N_1 and N_2 are total number of turns of the two solenoids.

The mutual inductance M is defined by the equation

$$N_2\phi_2 = MI_1$$

where I_1 is the current in coil 1, due to which flux ϕ_2 is linked with each turn of secondary coil.

Now we can calculate, e.m.f. e_2 induced in secondary by a changing current in first coil. From Faraday's law

$$e_2 = -\frac{d}{dt}(N_2\phi_2) = -M\frac{dI_1}{dt}$$

$$\text{If } \frac{dI_1}{dt} = 1 \Rightarrow e_2 = -M \qquad ...(2)$$

The two definitions for M defined by equations (1) and (2) are equivalent. We can express these two equations in words as :

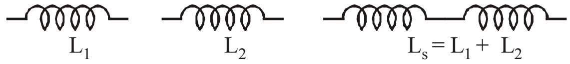
(i) M is numerically equal to the flux-linkage in one circuit, when unit current flows through the other. (we use this definition to calculate M)

(ii) M is numerically equal to the e.m.f. induced in one circuit, when the current changes in the other at the rate of one ampere in each second. (it is used to describe the mutual behavior of two circuits).

For a pair of coils, $M_{12} = M_{21} = \mu_0 N_1 N_2 A/\ell$, when wound on one another.

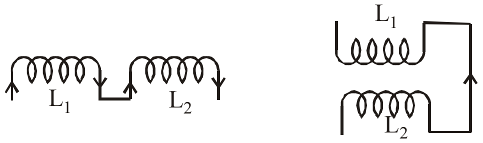
Keep in Memory

1. **Coefficient of self inductance of two coils in series** :



The effective self inductance is $L_s = L_1 + L_2$

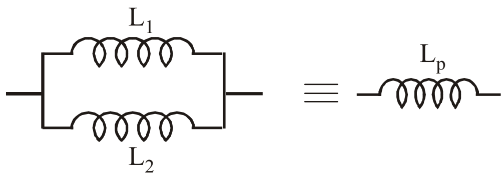
If M is the coefficient of mutual inductance between the two coils when they have flux linkage in the same sense,then $L = L_1 + L_2 + 2M$



And for flux linkage in opposite direction

$$L = L_1 + L_2 - 2M$$

2. **Coefficient of self inductance of two coils in parallel :**



$$\frac{1}{L_p} = \frac{1}{L_1} + \frac{1}{L_2}$$

(i) The coefficient of coupling between two coils having self inductance L_1 & L_2 and coefficient of mutual inductance M is

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

(ii) Generally the value of K is less than 1.

(iii) If K is 1, then the coupling of two coils is tight while if K < 1, then coupling is loose.

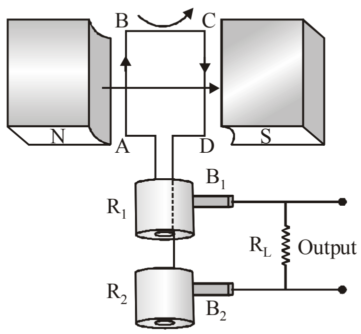
- Inductance is pure geometrical factor,and is independent of current or applied e.m.f.
- If the angle between the axis of two closely placed coil is θ then $M \propto \cos\theta$.

AC GENERATOR/DYNAMO/ALTERNATOR

An electrical machine used to convert mechanical energy into electrical energy is known as AC generator/alternator or dynamo.

Principle : It works on the principle of electromagnetic induction, i.e., when a coil is rotated in uniform magnetic field, an induced emf is produced in it.

Working :



When the armature coil ABCD rotates in the magnetic field provided by the strong field magnet, it cuts the magnetic lines of force. Thus the magnetic flux linked with the coil changes and hence induced emf is set up in the coil. The direction of the induced emf or the current in the coil is determined by the Fleming's right hand rule.

The current flows out through the brush B_1 in one direction of half of the revolution and through the brush B_2 in the next half revolution in the reverse direction. This process is repeated. Therefore, emf produced is of alternating nature.

$$e = -\frac{Nd\phi}{dt} = NBA\omega \sin\omega t = e_0 \sin\omega t \text{ , where } e_0 = NBA\omega$$

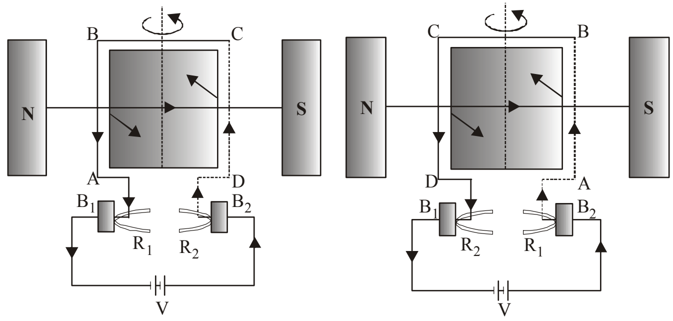
$$I = \frac{e}{R} = \frac{e_0}{R}\sin\omega t = I_0 \sin\omega t \text{ , } R \to \text{resistance of the circuit}$$

DC MOTOR

A D.C. motor converts direct current energy from a battery into mechanical energy of rotation.

Principle : It is based on the fact that when a coil carrying current is held in a magnetic field, it experiences a torque, which rotates the coil.

Working :



The battery sends current through the armature coil in the direction shown in fig. Applying Fleming's left hand rule, CD experiences a force directed inwards and perpendicular to the plane of the coil. Similarly, AB experiences a force directed outwards and perpendicular to the plane of the coil. These two forces being equal, unlike and parallel form a couple. The couple rotates the armature coil in the anticlockwise direction. After the coil has rotated through 180°, the direction of the current in AB and CD is reversed, fig. Now CD experiences an outward force and AB experiences an inward force. The armature coil thus continues rotating in the same i.e., anticlockwise direction.

Efficiency of the d.c. motor : Since the current I is being supplied to the armature coil by the external source of e.m.f. V, therefore,

Input electric power = VI

According to Joule's law of heating,

Power lost in the form of heat in the coil = $I^2 R$

If we assume that there is no other loss of power, then

Power converted into external work

i.e., Output mechanical power = $VI - I^2 R = (V - IR) I = EI$

$\therefore$ Efficiency of the d.c. motor

$$\eta = \frac{\text{Output mechanical power}}{\text{Input electric power}}$$

or $$\eta = \frac{EI}{VI} = \frac{E}{V} = \frac{\textit{Back e.m.f.}}{\textit{Applied e.m.f.}}$$

Uses of D.C Motor

1. The D.C. motors are used in D.C. fans (exhaust, ceiling or table) for cooling and ventilation.
2. They are used for pumping water.
3. Big D.C. motors are used for running tram-cars and even trains.

Example 6.

Two coils are wound on the same iron rod so that the flux generated by one also passes through the other. The primary has 100 loops and secondary has 200 loops. When a current of 2 A flows through the primary the flux in it is 25 x 10^{-4} Wb. Determine value of M between the coils.

Solution :

$$|e_s| = N_s \frac{d\phi_s}{dt} \text{ and } |e_s| = M\frac{di_p}{dt};$$

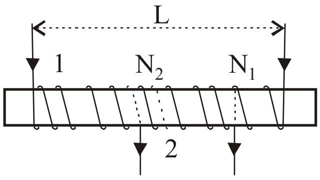
$$\therefore N_s \frac{d\phi_s}{dt} = M\frac{di_p}{dt} \qquad \text{or}$$

$$M = N_s \frac{d\phi_s}{di_p} = \frac{200(2.5\times10^{-4} - 0)}{(2-0)}$$

$$= 2.5\times10^{-2} = 25 \text{ mH}$$

Example 7.

A long solenoid of length L, cross section A having N_1 turns has wound about its centre is small coil of N_2 turns as shown in fig. Then find the mutual inductance of two circuits.



Solution :

Magnetic flux at the centre of solenoid $B_1 = \mu_0(N_1/L)i_1$

Magnetic flux through each turn of the coil of area A,

$$\phi_1 = B_1A = \frac{\mu_0 N_1 i_1}{L}\times A$$

Magnetic flux linked with the coil of turns N_2,

$$\phi_2 = \phi_1 \times N_2 = \frac{\mu_0 N_1 N_2 i_1 A}{L}$$

According to the definition of mutual inductance $\phi_2 = Mi_1$

$$\therefore Mi_1 = \frac{\mu_0 N_1 N_2 i_1}{L}A \text{ or } M = \frac{\mu_0 N_1 N_2 A}{L}$$

Example 8.

A small coil of radius r is placed at the centre of a large coil of radius R, where R >>r. The two coils are coplanar. The mutual induction between the coils is proportional to

(a) r/R (b) r^2/R

(c) r^2/R^2 (d) r/R^2

Solution : (b)

Let I be the current flows in the large coil.

$$\therefore \text{ Mag. field at the centre of coil } B = \frac{\mu_0 I}{2R}$$

Mag. flux linked with smaller coil

$$\phi = \pi r^2 B = \pi r^2\left(\frac{\mu_0 I}{2R}\right)$$

$$\text{But } \phi = MI \qquad \therefore M = \frac{\phi}{I} = \frac{\pi r^2 \mu_0}{2R} \text{ or } M \propto r^2/R$$

Example 9.

The mutual inductance of a pair of coils is 0.75 H. If current in the primary coil changes from 0.5 A to zero in 0.01 s find average induced e.m.f. in secondary coil.

Solution :

$$\text{Given : } M = 0.75 \text{ H and } \frac{dI}{dt} = \frac{0.5-0}{0.01} = 50 \text{ A/s}$$

$\therefore$ Average induced e.m.f. in secondary coil,

$$e = M\frac{dI}{dt} = 0.75\times50 = 37.5 \text{ V}$$

Example 10.

Find the self inductance of a coil in which an e.m.f. of 10 V is induced when the current in the circuit changes uniformly from 1 A to 0.5 A in 0.2 sec.

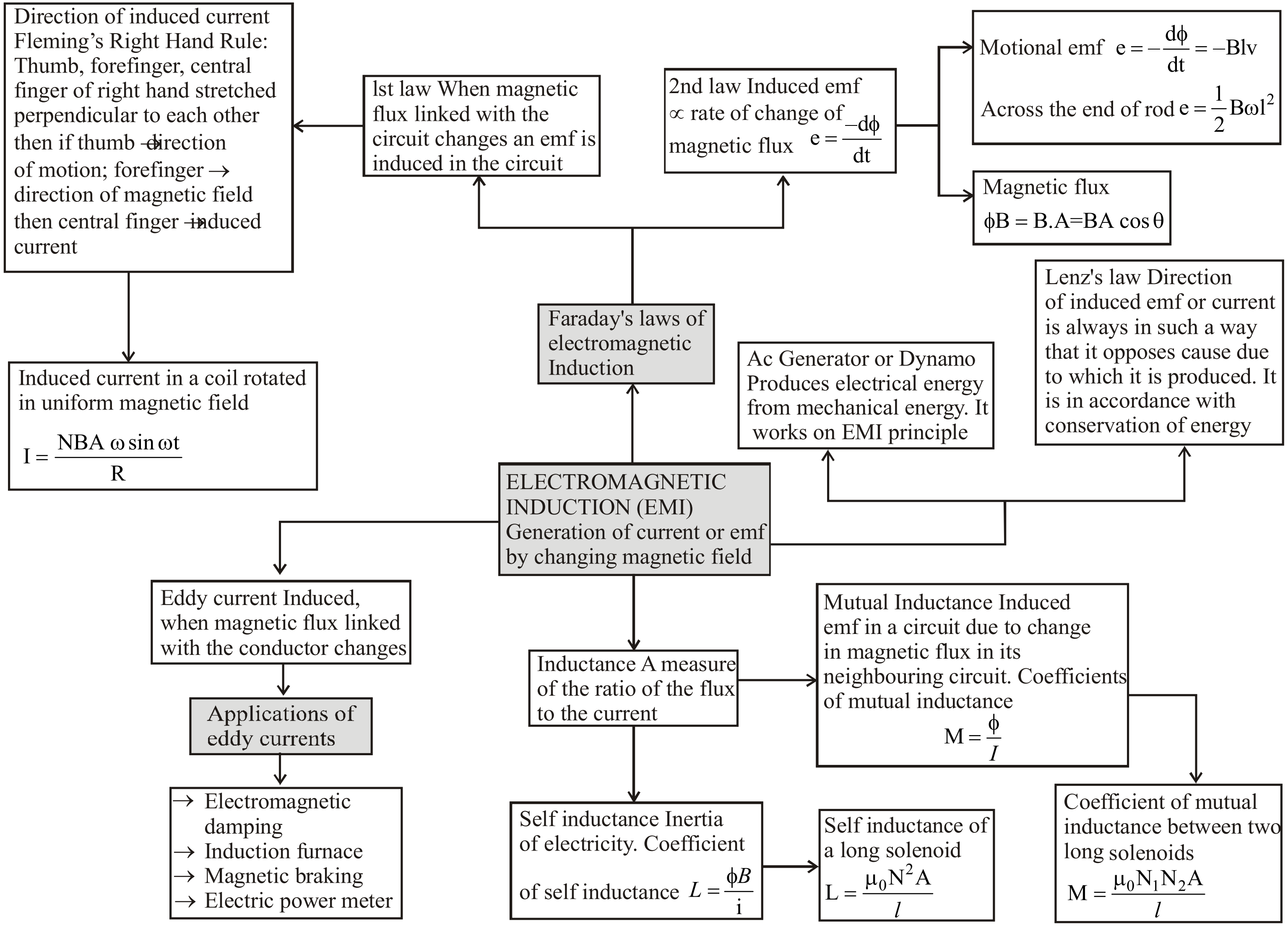
Solution :

$$\text{Given : } e = 10 \text{ V and } \frac{dI}{dt} = \frac{1-0.5}{0.2} = \frac{0.5}{0.2} = 2.5 \text{ A/s}$$

$$\text{Self inductance of coil } L = \frac{e}{dI/dt} = \frac{10}{2.5} = 4 \text{ H}$$

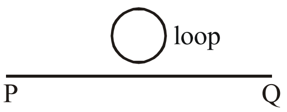
$$\left[\because e = L\frac{dI}{dt} \text{ (Considering Magnitude only)}\right]$$

CONCEPT MAP


ELECTROMAGNETIC INDUCTION (EMI) Generation of current or emf by changing magnetic field
Faraday's laws of electromagnetic Induction
Ist law When magnetic flux linked with the circuit changes an emf is induced in the circuit
2nd law Induced emf ∝ rate of change of magnetic flux $e = \frac{-d\phi}{dt}$
Motional emf $e = -\frac{d\phi}{dt} = -Blv$
Across the end of rod $e = \frac{1}{2}B\omega l^2$
Magnetic flux $\phi B = B.A = BA \cos\theta$
Direction of induced current Fleming's Right Hand Rule: Thumb, forefinger, central finger of right hand stretched perpendicular to each other then if thumb → direction of motion; forefinger → direction of magnetic field then central finger → induced current
Induced current in a coil rotated in uniform magnetic field $I = \frac{NBA\,\omega \sin \omega t}{R}$
Ac Generator or Dynamo Produces electrical energy from mechanical energy. It works on EMI principle
Lenz's law Direction of induced emf or current is always in such a way that it opposes cause due to which it is produced. It is in accordance with conservation of energy
Eddy current Induced, when magnetic flux linked with the conductor changes
Applications of eddy currents
→ Electromagnetic damping
→ Induction furnace
→ Magnetic braking
→ Electric power meter
Inductance A measure of the ratio of the flux to the current
Mutual Inductance Induced emf in a circuit due to change in magnetic flux in its neighbouring circuit. Coefficients of mutual inductance $M = \frac{\phi}{I}$
Coefficient of mutual inductance between two long solenoids $M = \frac{\mu_0 N_1 N_2 A}{l}$
Self inductance Inertia of electricity. Coefficient of self inductance $L = \frac{\phi B}{i}$
Self inductance of a long solenoid $L = \frac{\mu_0 N^2 A}{l}$

EXERCISE - 1
Conceptual Questions

1. Eddy currents are produced when
   (a) a metal is kept in varying magnetic field
   (b) a metal is kept in steady magnetic field
   (c) a circular coil is placed in a magnetic field
   (d) through a circular coil, current is passed
2. An inductor may store energy in
   (a) its electric field
   (b) its coils
   (c) its magnetic field
   (d) both in electric and magnetic fields
3. If N is the number of turns in a coil, the value of self inductance varies as
   (a) N^0 (b) N (c) N^2 (d) N^{-2}
4. A coil having an area A_0 is placed in a magnetic field which changes from B_0 to $4\,B_0$ in time interval t. The e.m.f. induced in the coil will be
   (a) $3A_0 B_0 / t$ (b) $4A_0 B_0 / t$
   (c) $3B_0 / A_0 t$ (d) $4A_0 / B_0 t$
5. An electron moves along the line PQ which lies in the same plane as a circular loop of conducting wire as shown in figure. What will be the direction of the induced current in the loop ?
   (a) Anticlockwise
   (b) Clockwise
   (c) Alternating
   (d) No current will be induced

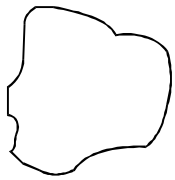


6. Induced emf in the coil depends upon
   (a) conductivity of coil
   (b) amount of flux
   (c) rate of change of linked flux
   (d) resistance of coil
7. Two identical coaxial circular loops carry current i each circulating in the clockwise direction. If the loops are approaching each other, then
   (a) current in each loop increases
   (b) current in each loop remains the same
   (c) current in each loop decreases
   (d) current in one-loop increases and in the other it decreases
8. The mutual inductance of a pair of coils, each of N turns, is M henry. If a current of I ampere in one of the coils is brought to zero in t second, the emf induced per turn in the other coil, in volt, will be
   (a) $\frac{MI}{t}$ (b) $\frac{NMI}{t}$ (c) $\frac{MN}{It}$ (d) $\frac{MI}{Nt}$
9. A rectangular coil of single turn, having area A, rotates in a uniform magnetic field B with an angular velocity ω about an axis perpendicular to the field. If initially the plane of the coil is perpendicular to the field, then the average induced emf when it has rotated through 90° is
   (a) $\frac{\omega BA}{\pi}$ (b) $\frac{\omega BA}{2\pi}$ (c) $\frac{\omega BA}{4\pi}$ (d) $\frac{2\omega BA}{\pi}$
10. According to Faraday's law of electromagnetic induction
    (a) electric field is produced by time varying magnetic flux.
    (b) magnetic field is produced by time varying electric flux.
    (c) magnetic field is associated with a moving charge.
    (d) None of these
11. Two solenoids of same cross-sectional area have their lengths and number of turns in ratio of 1 : 2. The ratio of self-inductance of two solenoids is
    (a) 1 : 1 (b) 1 : 2 (c) 2 : 1 (d) 1 : 4
12. The back e.m.f. in a d.c. motor is maximum, when
    (a) the motor has picked up max speed
    (b) the motor has just started moving
    (c) the speed of motor is still on the increase
    (d) the motor has just been switched off
13. The mutual inductance between two coils depends on
    (a) medium between the coils
    (b) separation between the two coils
    (c) orientation of the two coils
    (d) All of the above
14. If coefficient of self induction of a coil is 1 H, an e.m.f. of 1V is induced, if
    (a) current flowing is 1A
    (b) current variation rate is 1 As^{-1}
    (c) current of 1A flows for one sec.
    (d) None of these
15. Which of the following units denotes the dimension $\frac{ML^2}{Q^2}$, where Q denotes the electric charge?
    (a) Wb/m^2 (b) henry (H)
    (c) H/m^2 (d) weber (Wb)
16. In an AC generator, a coil with N turns, all of the same area A and total resistance R, rotates with frequency ω in a magnetic field B. The maximum value of emf generated in the coil is
    (a) N.A.B.R.ω (b) N.A.B.
    (c) N.A.B.R. (d) N.A.B.ω
17. A metal rod moves at a constant velocity in a direction perpendicular to its length. A constant uniform magnetic field exists in space in a direction perpendicular to the rod as well its velocity. Select correct statements (s) from the following.
    (a) The entire rod is at the same potential
    (b) There is an electric field in the rod
    (c) The electric potential is highest at the centre
    (d) The electric potential is lowest at its centre and increases towards its ends

18. A small square loop of wire of side ℓ is placed inside a large square loop of side L (L >> ℓ). The loop are coplanar and their centres coincide. The mutual inductance of the system is proportional is

(a) $\frac{\ell}{L}$ (b) $\frac{\ell^2}{L}$ (c) $\frac{L}{\ell}$ (d) $\frac{L^2}{\ell}$

19. As a result of change in the magnetic flux linked to the closed loop shown in the figure, an e.m.f. V volt is induced in the loop.



The work done (in joule) in taking a charge Q coulomb once along the loop is

(a) QV (b) 2QV (c) QV/2 (d) zero

20. A wire loop is rotated in a uniform magnetic field about an axis perpendicular to the field. The direction of the current induced in the loop reverses once each

(a) quarter revolution (b) half revolution
(c) full revolution (d) two revolutions

21. If the number of turns per unit length of a coil of solenoid is doubled, the self-inductance of the solenoid will

(a) remain unchanged (b) be halved
(c) be doubled (d) become four times

22. The total charge induced in a conducting loop when it is moved in a magnetic field depend on

(a) the rate of change of magnetic flux
(b) initial magnetic flux only
(c) the total change in magnetic flux
(d) final magnetic flux only

23. Lenz's law is consequence of the law of conservation of

(a) energy (b) momentum
(c) charge (d) mass

24. If rotational velocity of a dynamo armature is doubled, then induced e.m.f. will become

(a) half (b) two times
(c) four times (d) unchanged

25. Choke coil works on the principle of

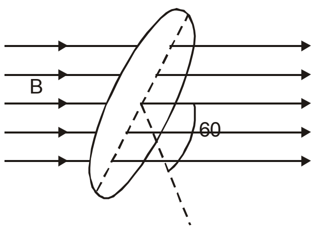
(a) transient current (b) self induction
(c) mutual induction (d) wattless current

EXERCISE - 2
Applied Questions

1. A current i = 2 sin (πt/3) amp is flowing in an inductor of 2 henry. The amount of work done in increasing the current from 1.0 amp to 2.0 amp is

(a) 1 J (b) 2 J (c) 3 J (d) 4 J

2. Fig shown below represents an area A = 0.5 m^2 situated in a uniform magnetic field B = 2.0 weber/m^2 and making an angle of 60º with respect to magnetic field.



The value of the magnetic flux through the area would be equal to

(a) 2.0 weber (b) $\sqrt{3}$ weber
(c) $\sqrt{3}/2$ weber (d) 0.5 weber

3. In a coil of area 10 cm^2 and 10 turns with magnetic field directed perpendicular to the plane and is changing at the rate of 10^8 Gauss/second. The resistance of the coil is 20Ω. The current in the coil will be

(a) 0.5 A (b) 5 A
(c) 50 A (d) 5 × 10^8 A

4. A generator has an e.m.f. of 440 Volt and internal resistance of 4000 hm. Its terminals are connected to a load of 4000 ohm. The voltage across the load is

(a) 220 volt (b) 440 volt
(c) 200 volt (d) 400 volt

5. When the current in a coil changes from 2 amp. to 4 amp. in 0.05 sec., an e.m.f. of 8 volt is induced in the coil. The coefficient of self inductance of the coil is

(a) 0.1 henry (b) 0.2 henry
(c) 0.4 henry (d) 0.8 henry

6. A copper disc of radius 0.1 m rotated about its centre with 10 revolutions per second in a uniform magnetic field of 0.1 tesla with its plane perpendicular to the field. The e.m.f. induced across the radius of disc is

(a) $\frac{\pi}{10}$ volt (b) $\frac{2\pi}{10}$ volt
(c) $\pi \times 10^{-2}$ volt (d) $2\pi \times 10^{-2}$ volt

7. A coil has 200 turns and area of 70 cm^2. The magnetic field perpendicular to the plane of the coil is 0.3 Wb/m^2 and take 0.1 sec to rotate through 180º. The value of the induced e.m.f. will be

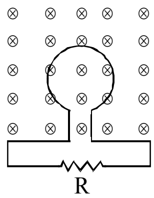
(a) 8.4 V (b) 84 V
(c) 42 V (d) 4.2 V

8. If a current increases from zero to one ampere in 0.1 second in a coil of 5 mH, then the magnitude of the induced e.m.f. will be
(a) 0.005 volt (b) 0.5 volt
(c) 0.05 volt (d) 5 volt

9. A 100 millihenry coil carries a current of 1 ampere. Energy stored in its magnetic field is
(a) 0.5 J (b) 1 J (c) 0.05 J (d) 0.1 J

10. The armature of a dc motor has 20W resistance. It draws a current of 1.5 A when run by a 220 V dc supply. The value of the back emf induced in it is
(a) 150 V (b) 170 V (c) 180 V (d) 190 V

11. In the figure the flux through the loop perpendicular to the plane of the coil and directed into the paper is varying according to the relation $\phi = 6t^2 + 7t + 1$ where ϕ is in milliweber and t is in second. The magnitude of the emf induced in the loop at t = 2 s and the direction of induce current through R are



(a) 39 mV; right to left
(b) 39 mV; left to right
(c) 31 mV; right to left
(d) 31 mV; left to right

12. A coil having 500 square loops each of side 10 cm is placed normal to a magnetic field which increases at the rate of 1 Wb/m^2. The induced e.m.f. is
(a) 0.1 V (b) 5.0 V (c) 0.5 V (d) 1.0 V

13. A circular coil and a bar magnet placed nearby are made to move in the same direction. If the coil covers a distance of 1 m in 0.5. sec and the magnet a distance of 2 m in 1 sec, the induced e.m.f. produced in the coil is
(a) zero (b) 0.5 V (c) 1 V (d) 2V.

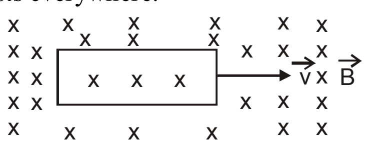
14. Magnetic flux ϕ in weber in a closed circuit of resistance 10Ω varies with time ϕ (sec) as $f = 6t^2 - 5t + 1$. The magnitude of induced current at t = 0.25s is
(a) 0.2 A (b) 0.6 A (c) 1.2 A (d) 0.8 A

15. The current in a coil of L = 40 mH is to be increased uniformly from 1A to 11A in 4 milli sec. The induced e.m.f. will be
(a) 100 V (b) 0.4 V (c) 440 V (d) 40 V

16. The self inductance of the motor of an electric fan is 10 H. In order to impart maximum power at 50 Hz, it should be connected to a capacitance of
(a) 8 μF (b) 4 μF (c) 2 μF (d) 1 μF

17. The flux linked with a coil at any instant 't' is given by $\phi = 10t^2 - 50t + 250$. The induced emf at t = 3s is
(a) –190 V (b) –10 V (c) 10 V (d) 190 V

18. A conducting square loop of side L and resistance R moves in its plane with a uniform velocity v perpendicular to one of its side. A magnetic induction B constant in time and space, pointing perpendicular and into the plane of the loop exists everywhere.



The current induced in the loop is
(a) $\frac{B\ell v}{R}$ clockwise (b) $\frac{B\ell v}{R}$ anticlockwise
(c) $\frac{2B\ell v}{R}$ anticlockwise (d) zero

19. The two rails of a railway track, insulated from each other and the ground, are connected to millivoltmeter. What is the reading of the millivoltmeter when a train passes at a speed of 180 km/hr along the track, given that the vertical component of earth's magnetic field is 0.2×10^{-4} wb/m^2 and rails are separated by 1 metre
(a) 10^{-2} volt (b) 10mV
(c) 1 volt (d) 1mV

20. A long solenoid having 200 turns per cm carries a current of 1.5 amp. At the centre of it is placed a coil of 100 turns of cross-sectional area 3.14×10^{-4} m^2 having its axis parallel to the field produced by the solenoid. When the direction of current in the solenoid is reversed within 0.05 sec, the induced e.m.f. in the coil is
(a) 0.48 V (b) 0.048 V
(c) 0.0048 V (d) 48 V

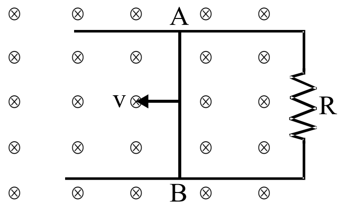
21. Two coils have a mutual inductance 0.005H. The current changes in first coil according to equation $I = I_0 \sin \omega t$ where $I_0 = 10A$ and $\omega = 100\pi$ radian/sec. The max. value of e.m.f. in second coil is
(a) 2π (b) 5π
(c) π (d) 4π

22. A metal conductor of length 1 m rotates vertically about one of its ends at angular velocity 5 radians per second. If the horizontal component of earth's magnetic field is 0.2×10^{-4}T, then the e.m.f. developed between the two ends of the conductor is
(a) 5mV (b) 50 μV
(c) 5 μV (d) 50mV

23. Two identical induction coils each of inductance L are jointed in series are placed very close to each other such that the winding direction of one is exactly opposite to that of the other, what is the net inductance?
(a) L^2 (b) 2 L
(c) L/2 (d) zero

24. A thin circular ring of area A is held perpendicular to a uniform magnetic field of induction B. A small cut is made in the ring and a galvanometer is connected across the ends such that the total resistance of the circuit is R. When the ring is suddenly squeezed to zero area, the charge flowing through the galvanometer is
(a) $\frac{BR}{A}$ (b) $\frac{AB}{R}$
(c) ABR (d) $\frac{B^2A}{R^2}$

25. Consider the situation shown. The wire AB is sliding on fixed rails with a constant velocity. If the wire AB is replaced by semi-circular wire, the magnitude of induced e.m.f. will



(a) increase
(b) decrease
(c) remain the same
(d) increase or decrease depending on whether the semi-circle buldges towards the resistance or away from it.

26. A coil is wound on a frame of rectangular cross-section. If all the linear dimensions of the frame are increased by a factor 2 and the number of turns per unit length of the coil remains the same, self-inductance of the coil increases by a factor of

(a) 4 (b) 8 (c) 12 (d) 16

27. A horizontal telegraph wire 0.5 km long running east and west in a part of a circuit whose resistance is 2.5 Ω. The wire falls to $g = 10.0\ m/s^2$ and $B = 2 \times 10^{-5}$ weber/m^2, then the current induced in the circuit is

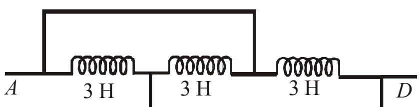
(a) 0.7 amp (b) 0.04 amp
(c) 0.02 amp (d) 0.01 amp

28. A conductor of length 0.4 m is moving with a speed of 7 m/s perpendicular to a magnetic field of intensity 0.9 Wb/m^2. The induced e.m.f. across the conductor is

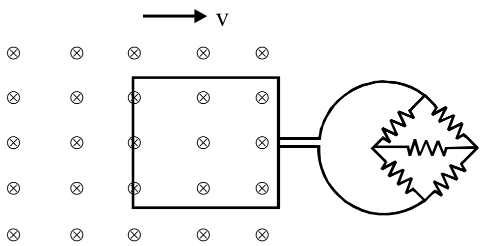
(a) 1.26 V (b) 2.52 V (c) 5.04 V (d) 25.2 V

29. The inductance between A and D is

(a) 3.66 H
(b) 9 H
(c) 0.66 H
(d) 1 H



30. A square metal loop of side 10 cm and resistance 1 Ω is moved with a constant velocity partly inside a uniform magnetic field of 2 Wbm^{-2}, directed into the paper, as shown in the figure. The loop is connected to a network of five resistors each of value 3Ω. If a steady current of 1 mA flows in the loop, then the speed of the loop is

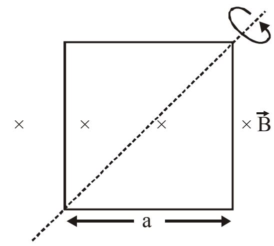


(a) 0.5 cms^{-1} (b) 1 cms^{-1}
(c) 2 cms^{-1} (d) 4 cms^{-1}

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

(a) remains stationary
(b) is attracted by loop A
(c) is repelled by loop A
(d) rotates about is CM with CM fixed

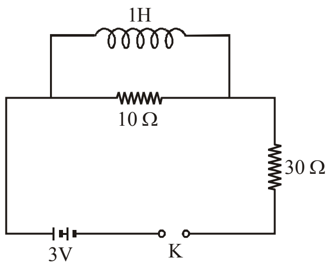
32. A square loop of side a is rotating about its diagonal with angular velocity ω in a perpendicular magnetic field $\vec{B}$. It has 10 turns. The emf induced is



(a) $B a^2 \sin \omega t$ (b) $B a^2 \cos \omega t$
(c) $5\sqrt{2}\ B a^2$ (d) $10\ B a^2 \sin \omega t$

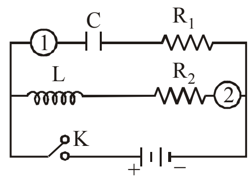
33. In fig., final value of current in 10Ω resistor, when plug of key K is inserted is

(a) $\frac{3}{10}$ A
(b) $\frac{3}{20}$ A
(c) $\frac{3}{11}$ A
(d) zero



34. In a circuit given in figure 1 and 2 are ammeters. Just after key K is pressed to complete the circuit, the reading is

(a) zero in both 1 and 2
(b) maximum in both 1 and 2
(c) zero in 1 and maximum in 2
(d) maximum in 1 and zero in 2



35. A solenoid has 2000 turns wound over a length of 0.3 m. Its cross-sectional area is $1.2 \times 10^{-3}\ m^2$. Around its central section a coil of 300 turns is wound. If an initial current of 2 A flowing in the solenoid is reversed in 0.25 s, the emf induced in the coil will be

(a) 2.4×10^{-4} V (b) 2.4×10^{-2} V
(c) 4.8×10^{-4} V (d) 4.8×10^{-2} V

36. Two coaxial solenoids are made by winding thin insulated wire over a pipe of cross-sectional area A = 10 cm^2 and length = 20 cm. If one of the solenoid has 300 turns and the other 400 turns, their mutual inductance is ($\mu_0 = 4\pi \times 10^{-7}\ Tm A^{-1}$)

(a) $2.4\pi \times 10^{-5}$ H (b) $4.8\pi \times 10^{-4}$ H
(c) $4.8\pi \times 10^{-5}$ H (d) $2.4\pi \times 10^{-4}$ H

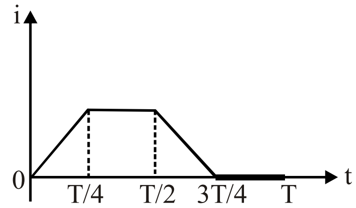
37. A varying current in a coil change from 10A to zero in 0.5 sec. If the average e.m.f induced in the coil is 220V, the self-inductance of the coil is
(a) 5 H (b) 6 H (c) 11 H (d) 12 H

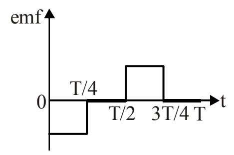
38. In an inductor of self-inductance L = 2 mH, current changes with time according to relation $i = t^2e^{-t}$. At what time emf is zero?
(a) 4s (b) 3s (c) 2s (d) 1s

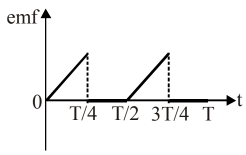
39. The magnetic flux through a circuit of resistance R changes by an amount $\Delta\phi$ in a time Δt. Then the total quantity of electric charge Q that passes any point in the circuit during the time Δt is represented by
(a) $Q = R.\frac{\Delta\phi}{\Delta t}$ (b) $Q = \frac{1}{R}.\frac{\Delta\phi}{\Delta t}$
(c) $Q = \frac{\Delta\phi}{R}$ (d) $Q = \frac{\Delta\phi}{\Delta t}$

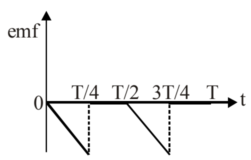
40. A conducting circular loop is placed in a uniform magnetic field, $B = 0.025\ T$ with its plane perpendicular to the loop. The radius of the loop is made to shrink at a constant rate of 1 mm s^{-1}. The induced e.m.f. when the radius is 2 cm, is
(a) $2\pi\mu V$ (b) $\pi\mu V$
(c) $\frac{\pi}{2}\mu V$ (d) $2\mu V$

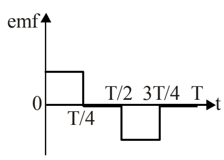
41. The current i in a coil varies with time as shown in the figure. The variation of induced emf with time would be



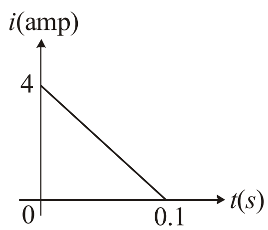
(a) 

(b) 

(c) 

(d) 

42. In a coil of resistance 10 Ω, the induced current developed by changing magnetic flux through it, is shown in figure as a function of time. The magnitude of change in flux through the coil in weber is



(a) 8 (b) 2 (c) 6 (d) 4

43. A coil of resistance 400Ω is placed in a magnetic field. If the magnetic flux ϕ (wb) linked with the coil varies with time t (sec) as $\phi = 50t^2 + 4$. The current in the coil at $t = 2$ sec is
(a) 0.5 A (b) 0.1 A (c) 2 A (d) 1 A

44. A coil of self-inductance L is connected in series with a bulb B and an AC source. Brightness of the bulb decreases when
(a) number of turns in the coil is reduced
(b) a capacitance of reactance $X_C = X_L$ is included in the same circuit
(c) an iron rod is inserted in the coil
(d) frequency of the AC source is decreased

45. A magnetic field of 2×10^{-2} T acts at right angles to a coil of area 100 cm^2, with 50 turns. The average e.m.f. induced in the coil is 0.1 V, when it is removed from the field in t sec. The value of t is
(a) 10 s (b) 0.1 s
(c) 0.01 s (d) 1 s

46. A rectangular coil of 20 turns and area of cross-section 25 sq. cm has a resistance of 100Ω. If a magnetic field which is perpendicular to the plane of coil changes at a rate of 1000 tesla per second, the current in the coil is
(a) 1 A (b) 50 A
(c) 0.5 A (d) 5 A

DIRECTIONS for Qs. (47 to 50) : Each question contains STATEMENT-1 and STATEMENT-2. Choose the correct answer (ONLY ONE option is correct) from the following.

(a) Statement -1 is false, Statement-2 is true
(b) Statement -2 is true, Statement-2 is true; Statement -2 is a correct explanation for Statement-1
(c) Statement -1 is true, Statement-2 is true; Statement -2 is not a correct explanation for Statement-1
(d) Statement -2 is true, Statement-2 is false

47. **Statement 1 :** An induced emf appears in any coil in which the current is changing.
Statement 2 : Self induction phenomenon obeys Faraday's law of induction.

48. **Statement 1 :** Lenz's law violates the principle of conservation of energy.
Statement 2 : Induced emf always opposes the change in magnetic flux responsible for its production.

49. **Statement 1 :** When number of turns in a coil is doubled, coefficient of self-inductance of the coil becomes 4 times.
Statement 2 : This is because $L \propto N^2$.

50. **Statement 1 :** An induced current has a direction such that the magnetic field due to the current opposes the change in the magnetic flux that induces the current.
Statement 2 : Above statement is in accordance with conservation of energy.

EXERCISE - 3
Exemplar & Past Years NEET/AIPMT Questions

Exemplar Questions

1. A square of side L metres lies in the xy-plane in a region, where the magnetic field is given by $B = B_0(2\hat{i} + 3\hat{j} + 4\hat{k})$ T, where B_0 is constant. The magnitude of flux passing through the square is

(a) $2B_0L^2$Wb (b) $3B_0L^2$Wb

(c) $4B_0L^2$Wb (d) $\sqrt{29}B_0L^2$Wb

2. A loop, made of straight edges has six corners at A (0, 0, 0), B (L, 0, 0), C(L, L, 0), D (0, L, 0), E(0, L, L) and F (0, 0, L). A magnetic field $B = B_0(\hat{i} + \hat{k})$ T is present in the region. The flux passing through the loop ABCDEFA (in that order) is

(a) B_0L^2 Wb (b) $2B_0L^2$Wb

(c) $\sqrt{2}B_0L^2$ Wb (d) $4B_0L^2$Wb

3. A cylindrical bar magnet is rotated about its axis. A wire is connected from the axis and is made to touch the cylindrical surface through a contact. Then,

(a) a direct current flows in the ammeter A

(b) no current flows through the ammeter A

(c) an alternating sinusoidal current flows through the ammeter A with a time period $T = \frac{2\pi}{\omega}$

(d) a time varying non-sinusoidal current flows through the ammeter A.

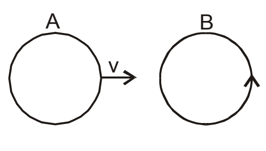
4. There are two coils A and B as shown in figure a current starts flowing in B as shown, when A is moved towards B and stops when A stops moving. The current in A is counter clockwise. B is kept stationary when A moves. We can infer that

(a) there is a constant current in the clockwise direction in A

(b) there is a varying current in A

(c) there is no current in A

(d) there is a constant current in the counter clockwise direction in A



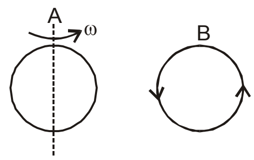
5. Same as problem 4 except the coil A is made to rotate about a vertical axis (figure). No current flows in B if A is at rest. The current in coil A, when the current in B (at t = 0) is counter-clockwise and the coil A is as shown at this instant, t = 0, is

(a) constant current clockwise

(b) varying current clockwise

(c) varying current counter clockwise

(d) constant current counter clockwise



6. The self inductance L of a solenoid of length *l* and area of cross-section A, with a fixed number of turns N increases as

(a) *l* and A increase

(b) *l* decreases and A increases

(c) *l* increases and A decreases

(d) both *l* and A decrease

NEET/AIPMT (2013-2017) Questions

7. A wire loop is rotated in a magnetic field. The frequency of change of direction of the induced e.m.f. is ***[2013]***

(a) twice per revolution

(b) four times per revolution

(c) six times per revolution

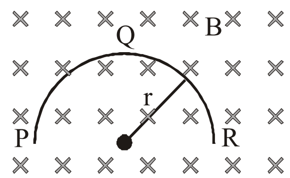
(d) once per revolution

8. A current of 2.5 A flows through a coil of inductance 5 H. The magnetic flux linked with the coil is ***[NEET Kar. 2013]***

(a) 2 Wb (b) 0.5 Wb

(c) 12.5 Wb (d) Zero

9. A thin semicircular conducting ring (PQR) of radius 'r' is falling with its plane vertical in a horizontal magnetic field B, as shown in figure. The potential difference developed across the ring when its speed is v, is : ***[2014]***



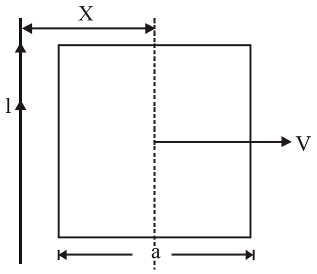
(a) Zero

(b) $Bv\pi r^2/2$ and P is at higher potnetial

(c) πrBv and R is at higher potnetial

(d) 2rBv and R is at higher potential

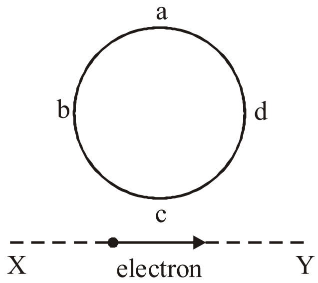
10. A conducting square frame of side 'a' and a long staight wire carrying current I are located in the same plane as shown in the figure. The frame moves to the right with a constant velocity 'V'. The emf induced in the frame will be proportional to ***[2015]***



(a) $\dfrac{1}{(2x-a)^2}$ (b) $\dfrac{1}{(2x+a)^2}$

(c) $\dfrac{1}{(2x-a)(2x+a)}$ (d) $\dfrac{1}{x^2}$

11. An electron moves on a straight line path XY as shown. The abcd is a coil adjacent to the path of electron. What will be the direction of current if any, induced in the coil? ***[2015 RS]***



(a) adcb

(b) The current will reverse its direction as the electron goes past the coil

(c) No current induced

(d) abcd

12. A long solenoid of diameter 0.1 m has 2×10^4 turns per meter. At the centre of the solenoid, a coil of 100 turns and radius 0.01 m is placed with its axis coinciding with the solenoid axis. The current in the solenoid reduces at a constant rate to 0A from 4 A in 0.05 s. If the resistance of the coil is $10\pi^2\Omega$. the total charge flowing through the coil during this time is :- ***[2017]***

(a) 16 μC (b) 32 μC

(c) 16 $\pi\mu$C (d) 32 $\pi\mu$C

Hints & Solutions

EXERCISE - 1

1. (a) 2. (c) 3. (c)

4. (a) Induced e.m.f. $\varepsilon = \frac{d\phi}{dt} = \frac{dBA}{dt} = A_0\frac{dB}{dt}$

$$= A_0\left(\frac{4B_0 - B_0}{t}\right) = 3A_0B_0/t$$

5. (a) 6. (c) 7. (c)

8. (a) $E = \frac{d}{dt}(NMI) \Rightarrow E = NM\frac{dI}{dt} \Rightarrow E = \frac{NMI}{t}$

emf induced per unit turn $= \frac{E}{N} = \frac{MI}{t}$

9. (d) Initially flux, $\phi = BA\cos 0 = BA$

After rotating through an angle 90°.
Flux through the coil is zero.

So, $\Delta\phi = BA$

Angular speed = w, so, time period $= \frac{2\pi}{\omega} = T$

$\frac{T}{4}$ is time taken to rotate 90°.

So, $\frac{\Delta\phi}{\Delta t} = \frac{BA}{T/4} = \frac{2BA\omega}{\pi}$

10. (a) Farady's law states that time varying magnetic flux can induce an e.m.f.

11. (b) From $L = \frac{\mu_0 N^2 A}{l} \alpha \frac{N^2}{l}$

we get, $\frac{L_1}{L_2} = \frac{(1/2)^2}{1/2} = \frac{1}{2}$

12. (a) The back e.m.f. in a motor is induced e.m.f., which is maximum, when speed of rotation of the coil is maximum.

13. (d) Mutual inductance between two coils depends on all the three factors given here.

14. (b) From e = LdI / dt, dI / dt $= \frac{e}{L} = \frac{1}{1} = 1As^{-1}$

15. (b) Mutual inductance $= \frac{\phi}{I} = \frac{BA}{I}$

$$[\text{Henry}] = \frac{[MT^{-1}Q^{-1}L^2]}{[QT^{-1}]} = ML^2Q^{-2}$$

16. (d) $e = -\frac{d\phi}{dt} = -\frac{d(N\vec{B}.\vec{A})}{dt}$

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

$$\Rightarrow e_{max} = NBA\omega$$

17. (b) Due to shifting of electrons, one end of the rod becomes positive and the other end negative. This developes a electric field in the rod.

18. (b)

19. (a) $V = \frac{W}{Q} \Rightarrow W = QV$

20. (b) It is because after every 1/2 revolution the current becomes zero and mode of change in flux changes thereafter (If before the current becomes zero, the mode of flux change was from left to right then after the current becomes zero the mode of flux change becomes right to left).

21. (d) Self inductance of a solenoid $= \frac{\mu n^2 A}{\ell}$

So, self induction $\propto n^2$

So, inductance becomes 4 times when n is doubled.

22. (c) $q = \int idt = \frac{1}{R}\int edt = \frac{1}{R}\int\left(\frac{-d\phi}{dt}\right)dt = \frac{1}{R}\int d\phi$

(taking only magnitude of e)

Hence, total charge induced in the conducting loop depends upon the total change in magnetic flux.

23. (a)

24. (b) $e \propto \omega$

25. (b)

EXERCISE - 2

1. (c)

2. (d) $\phi = BA\cos\theta = 2.0\times0.5\times\cos 60^\circ = \frac{2.0\times0.5}{2} = 0.5$ weber.

3. (b) $\varepsilon = \frac{d\phi}{dt} = nA\frac{dB}{dt}$

$\therefore\ \varepsilon = 10\times(10\times10^{-4})(10^4)$ (10^8 Gauss/sec=10^4 T/s)

$= 100$ V.

$I = (\varepsilon/R) = (100/20) = 5$amp.

4. (d) Total resistance of the circuit $= 4000 + 400 = 4400$ W

Current flowing $i = \frac{V}{R} = \frac{440}{4400} = 0.1$ amp.

Voltage across load $= R\,i = 4000\times0.1 = 400$ volt.

5. (b) $\varepsilon = M\frac{di}{dt}$ or $8 = M\left[\frac{(4-2)}{0.05}\right]$

$\therefore\ M = \frac{8\times0.05}{2} = 0.2$ henry

6. (c) e.m.f. induced $=\frac{1}{2}BR^2\omega=\frac{1}{2}BR^2(2\pi n)$

$=\frac{1}{2}\times(0.1)\times(0.1)^2\times 2\pi\times 10 = (0.1)^2\ \pi$ volts

7. (a) Change in flux = 2 B A N

$\therefore$ Induced e.m.f. $=\frac{2\times 0.3\times 200\times 70\times 10^{-4}}{0.1}$

8. (c) $\varepsilon=(5\times 10^{-3})(1/0.1)=0.05\,V$.

9. (c) Energy stored U is given by

$U=\frac{1}{2}Li^2=\frac{1}{2}\times(100\times 10^{-3})\ (1)^2=0.05\,J.$

10. (d)

11. (d) $\phi=6t^2+7t+1 \Rightarrow \frac{d\phi}{dt}=12t+7$

At time, t = 2 sec.

$\frac{d\phi}{dt}=24+7=31$ volt

Direction of current is from left to right according to Flemmings right hand rule.

12. (b) $e=\frac{d\phi}{dt}=\frac{d}{dt}(NBA)=NA\frac{dB}{dt}=500\times 10^{-2}\times 1=5.0\,V$

13. (a) Vel. of coil $=\frac{1}{0.5}=2\,m/s$

velocity of magnet $=\frac{2}{1}=2\,m/s.$

As they are made to move in the same direction, their relative velocity is zero. Therefore, induced e.m.f. = 0.

14. (a) $e=\frac{-d\phi}{dt}=\frac{-d}{dt}\left(6t^2-5t+1\right)=-12t+5$

e = – 12 (0.25) + 5 = 2 volt

$i=\frac{e}{R}=\frac{2}{10}=0.2A.$

15. (a) $e=\frac{LdI}{dt}=\frac{40\times 10^{-3}(11-1)}{4\times 10^{-3}}=100V$

16. (d) For maximum power, $X_L=X_C$, which yields

$C=\frac{1}{(2\pi n)^2L}=\frac{1}{4\pi^2\times 50\times 50\times 10}$

$\therefore\ C=0.1\times 10^{-5}F=1\mu F$

17. (b) $\phi=10t^2-50t+250$

$e=-\frac{d\phi}{dt}=-(20t-50)$

$e_{t=3}=-10\ V$

18. (d) Since the magnetic field is uniform the flux f through the square loop at any time t is constant, because

f = B × A = B × L^2 = constant

$\therefore\ \varepsilon=-\frac{d\phi}{dt}=$ zero

19. (d) $\varepsilon=Blv=(0.2\times 10^{-4})(1)(180\times 5/18)=10^{-3}\ V=1\ mV$

20. (b) $B=\mu_0 ni=(4\pi\times 10^{-7})\ (200\times 10^{-2})\times 1.5$

$= 3.8\times 10^{-2}\ Wb/m^2$

Magnetic flux through each turn of the coil

$\phi = BA = (3.8\times 10^{-2})(3.14\times 10^{-4}) = 1.2\times 10^{-5}$ weber

When the current in the solenoid is reversed, the change in magnetic flux

$=2\times(1.2\times 10^{-5})=2.4\times 10^{-5}$ weber

Induced e.m.f. $=N\frac{d\phi}{dt}=100\times\frac{2.4\times 10^{-5}}{0.05}=0.048\,V.$

21. (b) $\varepsilon=\frac{M}{dt}dI=0.005\times I_0\cos\omega t\times\omega$

and $\varepsilon_{max}=0.005\times I_0\times\ \omega\ =5\pi$

22. (b) l = 1m, w = 5 rad/s, $B=0.2\times 10^{-4}T$

$\varepsilon=\frac{B\omega\ell}{2}=\frac{0.2\times 10^{-4}\times 5\times 1}{2}=50\mu V$

23. (d) When two inductance coil are joined in series, such that the winding of one is exactly opposite to each other the emf produced in the two coils are out of phase such that they cancel out.

24. (b) The individual emf produced in the coil $e=\frac{-d\phi}{dt}$

$\therefore$ The current induced will be $i=\frac{|e|}{R}\Rightarrow i=\frac{1}{R}\frac{d\phi}{dt}$

But $i=\frac{dq}{dt}\ \Rightarrow\frac{dq}{dt}=\frac{1}{R}\frac{d\phi}{dt}\Rightarrow\int dq=\frac{1}{R}\int d\phi\Rightarrow q=\frac{BA}{R}$

25. (c) E.m.f. will remain same because change in area per unit time will be same in both cases.

26. (b) Self inductance $=\mu_0 n^2AL=\mu_0 n^2(\ell\times b)\times L$

n = Total number of turns/length

L = Length of inductor

l = Length of rectangular cross section

b = breadth of rectangular cross-section

So, when all linear dimensions are increased by a factor of 2. The new self inductance becomes L' = 8L.

27. (c) $i=\frac{\varepsilon}{R}=\frac{1}{R}\frac{d\phi}{dt}$

Here df = B × A $=(2\times 10^{-5})\times(0.5\times 10^{+3}\times 5)$

dt = time taken by the wire to fall at ground

$= (2h/g)^{1/2} = (10/10)^{1/2} = 1\text{sec}.$

$\therefore \quad i = \frac{1}{2.5}\left[\frac{(2\times10^{-5})\times(0.5\times10^{3}\times5)}{1}\right] = 0.02$ amp.

28. (b) Length of conductor (l) = 0.4 m; Speed (v) = 7 m/s and magnetic field (B) = 0.9 Wb/ m^2. Induced e.m.f. (ε) = Blv cos q = 0.9 × 0.4 × 7 × cos 0º = 2.52 V.

29. (d) The given circuit clearly shows that the inductors are in parallel we have, $\frac{1}{L} = \frac{1}{3} + \frac{1}{3} + \frac{1}{3}$ or L= 1H

30. (c) $\varepsilon = B\ell v = 2\times10^{-1}\times v = 0.2$ v

$I = \frac{\varepsilon}{R} = 10^{-3} \Rightarrow \frac{0.2v}{4} = 10^{-3}$

[Since effective resistance R of bridge is $R = \frac{6\times6}{6+6} = 3\Omega$

so total resistance = 1 + 3 = 4Ω]

$\Rightarrow v = 2\text{ cm s}^{-1}$

31. (c) An opposite current induced in B in accordance to Lenz's law. So the two loops repel each other.

32. (d) $\phi = n\,BA\cos\theta = 10\,B\,a^2\cos\omega t$

$e = -\frac{d\phi}{dt} = -\frac{d}{dt}\left(10\,B\,a^2\cos\omega t\right) = 10\,B\,a^2\sin\omega t\,(\omega).$

33. (d) As resistance of 1 H coil is zero, the entire current flows through the coil. Current through 10Ω resistance is zero.

34. (c) Capacitor is a dc blocking element and hence no current flow in (1).

An inductor offers a zero resistance path to flow of dc and hence maximum current flows through (2).

35. (b) $n = \frac{N}{\ell} = \frac{2000}{0.3} = \frac{20000}{3}$

$\xi = \frac{d}{dt}(NBA) = NA\frac{dB}{dt}$

Since $B = \mu_0 nI$

$\Rightarrow \quad \xi = (\mu NAn)\frac{dt}{dt} \quad \Rightarrow \quad \xi = 0.024\,V$

36. (d) $M = \frac{\mu_0 N_1 N_2 A}{\ell} = \frac{4\pi\times10^{-7}\times300\times400\times100\times10^{-4}}{0.2}$

$= 2.4\pi\times10^{-4}\,H$

37. (c) Initial current (I_1) = 10 A; Final current (I_2)= 0; Time (t) = 0.5 sec

and induced e.m.f. (e) = 220 V.

$-L\frac{dI}{dt} = -L\frac{(I_2 - I_1)}{t} = -L\frac{(0-10)}{0.5} = 20L$

or $L = \frac{220}{20} = 11$ H

(where L = Self inductance of coil)

38. (c) L = 2mH, $i = t^2e^{-t}$

$E = -L\frac{di}{dt} = -L[-t^2e^{-t} + 2te^{-t}]$

when E = 0

$-e^{-t}t^2 + 2te^{-t} = 0$

$2t\,e^{-t} = e^{-t}t^2$

t = 2 sec.

39. (c) $\frac{\Delta\phi}{\Delta t} = \varepsilon = iR \Rightarrow \Delta\phi = (i\Delta t)R = QR \Rightarrow Q = \frac{\Delta\phi}{R}$

40. (b) Magnetic flux linked with the loop is $\phi = B\pi r^2$

$|e| = \frac{d\phi}{dt} = B\pi\cdot 2r\frac{dr}{dt}$

When r = 2 cm, $\frac{dr}{dt} = 1\text{ mm }s^{-1}$

$e = 0.025\times\pi\times2\times2\times10^{-2}\times10^{-3}$

$= 0.100\times\pi\times10^{-5} = \pi\times10^{-6}\,V = \pi\mu V$

41. (a) $e = -L\frac{di}{dt}$

During 0 to $\frac{T}{4}, \frac{di}{dt}$ = const.

$\therefore$ e = – ve

During $\frac{T}{4}$ to $\frac{T}{2}, \frac{di}{dt} = 0$

$\therefore$ e = 0

During $\frac{T}{2}$ to $\frac{3T}{4}, \frac{di}{dt}$ = const.

$\therefore$ e = +ve

Thus graph given in option (a) represents the variation of induced emf with time.

42. (b) The charge through the coil = area of current-time ($i - t$) graph

$q = \frac{1}{2}\times0.1\times4 = 0.2\,C$

$q = \frac{\Delta\phi}{R} \quad \because$ Change in flux $(\Delta\phi) = q\times R$

$q = 0.2 = \frac{\Delta\phi}{10}$

$\Delta\phi$ = 2 weber

43. (a) According, to Faraday's law of induction

Induced e.m.f. $\varepsilon = -\frac{d\phi}{dt} = -(100t)$

Induced current i at t = 2 sec.

$= \left|\frac{\varepsilon}{R}\right| = +\frac{100 \times 2}{400} = +0.5\,\text{Amp}$

44. (c) By inserting iron rod in the coil,

$L \uparrow z \uparrow I \downarrow$ so brightness $\downarrow$

45. (b) $e = \frac{-(\phi_2 - \phi_1)}{t} = \frac{-(0 - NBA)}{t} = \frac{NBA}{t}$

$t = \frac{NBA}{e} = \frac{50 \times 2 \times 10^{-2} \times 10^{-2}}{0.1} = 0.1\,s$

46. (c) $i = \frac{e}{R} = \frac{\frac{nAdB}{dt}}{R}$

$= \frac{20 \times (25 \times 10^{-4}) \times 1000}{100} = 0.5\text{A}$

47. (b)
48. (a) Lenz's law (that the direction of induced emf is always such as to oppose the change that cause it) is direct consequence of the law of conservation of energy.
49. (b) 50. (b)

EXERCISE - 3

Exemplar Questions

1. (c) As we know that, the magnetic flux linked with uniform surface of area A in uniform magnetic field is

$\phi = B.A$

The direction of A is perpendicular to the plane of square and square line in x-y plane in a region.

$A = L^2 k$

As given that, $B = B_0\left(2\hat{i} + 3\hat{j} + 4\hat{k}\right)$

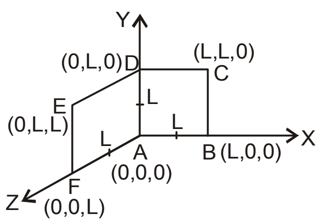
So, $\phi = B.A = B_0\left(2\hat{i} + 3\hat{j} + 4\hat{k}\right).L^2\hat{k}$

$= 4B_0L^2\,\text{Wb}$

2. (b) The loop can be considered in two planes, Plane of ABCDA lies x-y plane whose area vector $A_1 = |A|\hat{k}$, $A_1 = L^2\hat{k}$

whereas plane of ADEFA lies in y-z plane whose area vector $A_2 = |A|\hat{i}$, $A_2 = L^2\hat{i}$.

Then the magnetic flux linked with uniform surface of area A in uniform magnetic field is



$\phi = B.A$

$A = A_1 + A_2 = \left(L^2\hat{k} + L^2\hat{i}\right)$

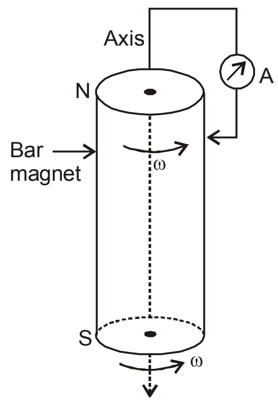
and $B = B_0\left(\hat{i} + \hat{k}\right)$

Now, $\phi = B.A = B_0\left(\hat{i} + \hat{k}\right)\cdot\left(L^2\hat{k} + L^2\hat{i}\right)$

$= 2\,B_0L^2\,\text{Wb}$

3. (b) Induced current flow only when circuit is complete and there is a variation about circuit this problem is associated with the phenomenon of electromagnetic induction.

If there is a symmetry in magnetic field of cylindrical bar magnet is rotated about its axis, no change in flux linked with the circuit takes place, consequently no emf induces and hence, no current flows in the ammeter (A).



4. (d) When the coil A stops moving the current in B b ecome ze ro, it possible only if the current in A is constant. If the current in A would be variable, there must be an induced emf (current) in B even if the A stops moving. So there is a constant current in same direction or counter clockwise direction in A as in B by lenz's law.

5. (a) By Lenz's law, at (t = 0) the current in B is counter-clockwise and the coil A is considered above to it. The counterclockwise flow of the current in B is equivalent to north pole of magnet and magnetic field lines are emanating upward to coil A.

When coil A start rotating at t = 0, the current in A is constant along clockwise direction by Lenz's rule. As flux changes across coil A by rotating it near the N-pole formed by flowing current in B, in anticlockwise.

6. (b) The self-inductance of a long solenoid of cross-sectional area A and length l, having n turns per unit length, filled the inside of the solenoid with a material of relative permeability is given by

$L = \mu_r\mu_0 n^2 Al$

$\therefore$ $n = N/l$

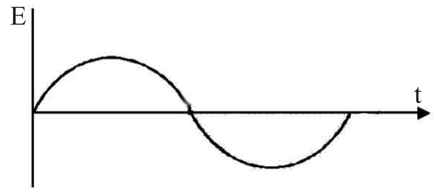
$L = \mu_r\mu_0\left[\frac{N^2.A}{l.l}\right].l$

$L = \mu_r\mu_0\,[N^2A/l]$ $\left(L \propto A, L \propto \frac{1}{l}\right)$

As μ_r and N are constant here so, to increase L for a coil, area A must be increased and l must be decreased.

NEET/AIPMT (2013-2017) Questions

7. (a) This is the case of periodic EMI



From graph, it is clear that direction is changing once in $\frac{1}{2}$ cycle.

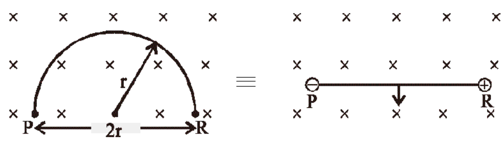
8. (c) Given: current I = 2.5 A
Inductance, L = 5H
Magnatic flux, ϕ = ?
We know, $\phi = LI \Rightarrow 5 \times 2.5$ Wb = 12.5 Wb

9. (d) Rate of decreasing of area of semicircular ring

$$= \frac{dA}{dt} = (2r)V$$

From Faraday's law of electromagnetic induction

$$e = -\frac{d\theta}{dt} = -B\frac{dA}{dt} = -B(2rV)$$



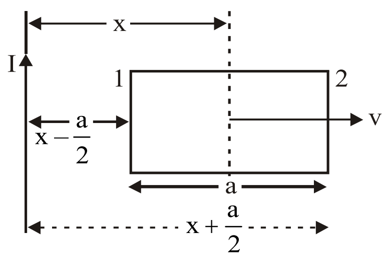
As induced current in ring produces magnetic field in upward direction hence R is at higher potential.

10. (c) Emf induced in side 1 of frame $e_1 = B_1 V\ell$

$$B_1 = \frac{\mu_o I}{2\pi\,(x - a/2)}$$

Emf induced in side 2 of frame $e_2 = B_2 V\ell$

$$B_2 = \frac{\mu_o I}{2\pi\,(x + a/2)}$$



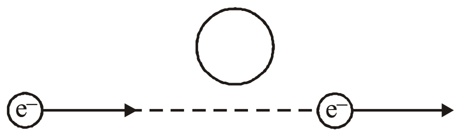
Emf induced in square frame

$$e = B_1 V\ell - B_2 V\ell$$

$$= \frac{\mu_0 I}{2\pi\,(x - a/2)}\ell v - \frac{\mu_0 I}{2\pi\,(x + a/2)}\ell v$$

$$\text{or, } e \propto \frac{1}{(2x - a)(2x + a)}$$

11. (b) Current will be induced,
when e^- comes closer the induced current will be anticlockwise
when e^- comes farther induced current will be clockwise



12. (b) Given, no. of turns N = 100
radius, r = 0.01 m
resistance, $R = 10\pi^2\,\Omega$, $n = 2 \times 10^4$
As we know,

$$\varepsilon = -N\frac{d\phi}{dt}$$

$$\frac{\varepsilon}{R} = -\frac{N}{R}\frac{d\phi}{dt}$$

$$\Delta I = -\frac{N}{R}\frac{d\phi}{dt}$$

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

$$\Delta q = -\left[\frac{N}{R}\left(\frac{\Delta\phi}{\Delta t}\right)\right]\Delta t$$

'–' ve sign shows that induced emf opposes the change of flux.

$$\Delta q = \left[\mu_0 n N\pi r^2\left(\frac{\Delta i}{\Delta t}\right)\right]\frac{1}{R}\Delta t = \frac{\mu_0 n N\pi r^2 \Delta i}{R}$$

$$\Delta q = \frac{4\pi \times 10^{-7} \times 100 \times 4 \times \pi \times (0.01)^2 \times 2 \times 10^4}{10\pi^2}$$

$$\Delta q = 32\mu C$$