ELECTROMAGNETIC INDUCTION

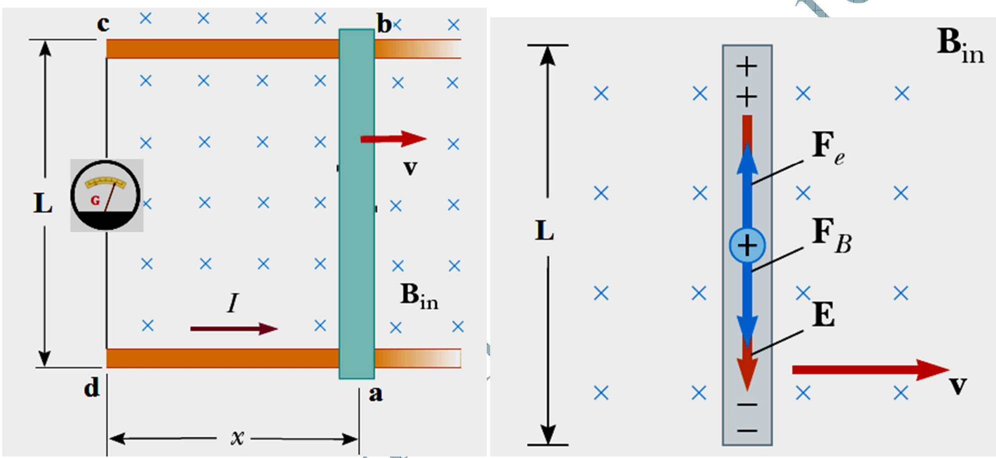
Q # 1. What do you know about electromagnetic induction?

Ans. When a conductor that is moved through a magnetic field, the electric current flow through the circuit. The emf produced in the conductor is called induced emf, and the current generated is called induced current. This phenomenon is known as electromagnetic induction.

Q # 2. Define the term motional emf. Also derive its expression.

Ans. The emf induced by the motion of a conductor across the magnetic field is called motional emf.

Consider a conducting rod of length L placed on two parallel metal rails separated by a distance L. A galvanometer is connected between the ends c and d of rails. This forms complete conducting loop abcd. A uniform magnetic field B is applied directed into the paper.



Initially, when the rod is stationary, galvanometer indicates no current in the loop. If the rod is pulled to the right with constant velocity **v**, the galvanometer indicates current flowing through the loop.

Obviously, the current is induced due to the motion of the conducting rod across the magnetic field. The rod is acting as a source of emf $\varepsilon = V_b - V_a = \Delta V$.

When the rod moves, a charge q within the rod also moves with same velocity v in the magnetic field B and experience a force that is given by:

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

The magnitude of force is

$$F = q\, v\, B \sin\theta$$

Since the angle between v and B is 90^{o}, so

$$F = q\, v\, B$$

Applying the right hand rule, we see that **F** is directed from a to b of the rod. Under the action of this force, the positive charge carriers inside rod accumulate on side b of the rod, due to which deficiency of positive charges occurs at side a of rod and equivalent negative charge appear on this side. This results in establishment of electric field $\mathbf{E_o}$ inside the rod from b to a.

The system quickly reaches an equilibrium state in which these two forces on the charge are balanced. If $\mathbf{E_o}$ is the electric intensity in this state then:

$$q E_o = q v B$$

$$\Rightarrow E_o = v B \quad ---------- \quad (1)$$

As the electric field intensity is the negative gradient of electric potential, therefore

$$E_o = -\frac{\Delta V}{L} \quad ---------- \quad (2)$$

Where L is the length of the conductor and ΔV is the potential difference, which is equal to induced emf due to motion of conductor in magnetic field. Comparing equation (1) and (2), we get:

$$-\frac{\Delta V}{L} = v B$$

$$\Rightarrow \Delta V = - v BL$$

Therefore, the magnitude of the motional emf is given as:

$$\varepsilon = \Delta V = - v BL$$

If the angle between ‘v’ and ‘B’ is θ, then

$$\varepsilon = \Delta V = - v BL \sin\theta$$

This is the expression of motional emf.

Q # 3. State and prove the Faraday’s law of electromagnetic induction.

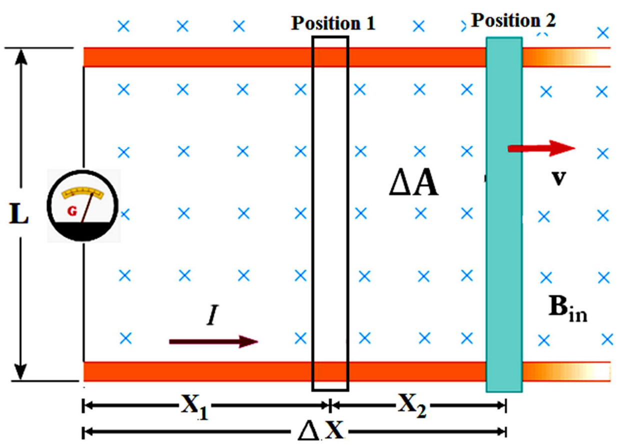
Ans.

Statement

The average emf induced in a conducting coil of N loop is equal to the negative of the rate at which the magnetic flux through the coil is changing with time.

Proof

Consider a conducting rod of length L placed on two parallel metal rails separated by a distance L. A galvanometer is connected between the ends c and d of rails. This forms complete conducting loop abcd. A uniform magnetic field B is applied directed into the paper.



Let the conducting rod L moves from position 1 to position 2 in small interval of time Δt. The distance traveled by the rod in time Δt is $x_2 - x_1 = \Delta x$. The motional emf induced in a rod mobbing perpendicular to magnetic field is $\varepsilon = -vBL$

Since the rod is moving with constant velocity **v**, therefore

$$v = \frac{\Delta x}{\Delta t}$$

The expression of motional emf becomes:

$$\varepsilon = -vBL = -\left(\frac{\Delta x}{\Delta t}\right)BL = -\frac{\Delta x.B.L}{\Delta t} \quad \text{----------} \quad (1)$$

As the rod moves through the distance Δx, the increase in the area of the loop is given by:

$$\Delta A = \Delta x .\, L$$

This increases the flux through the loop by

$$\Delta\phi = \Delta x.L.B$$

Thus equation (1) becomes:

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

If there is a coil of N loops instead of a single loop, then induced emf will become N times, i.e.,

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

The minus sign indicates that the direction of induced emf is such that it opposes the change in flux. This expression tells that the emf induced in a conducting coil of N loop is equal to the negative of the rate at which the magnetic flux through the coil is changing with time.

Q # 4. State and explain the Lenz's law.

Ans.

Statement

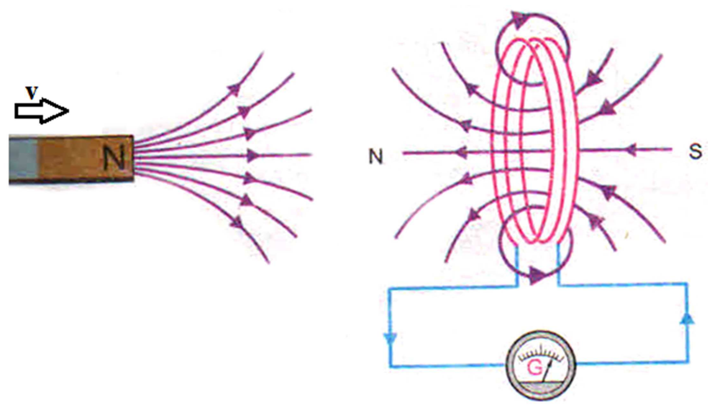
The direction of the induced current is always so as to oppose the change which causes the current.

Explanation

The mathematical expression of the Faraday's law of electromagnetic induction is:

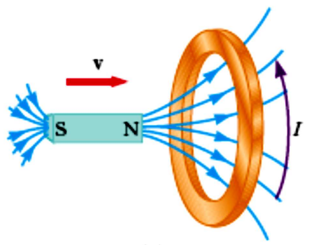
$$\varepsilon = -N\frac{\Delta\phi}{\Delta t}$$

The minus sign in the expression is very important. It has to do with the direction of induced emf.



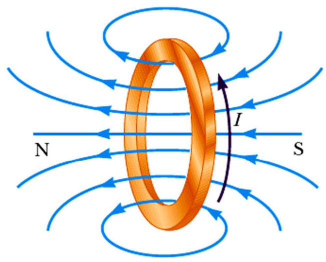
Consider a coil in which the current is induce by the movement of a bar magnet.

a) When the magnet is moved toward the stationary conducting loop, a current is induced in the direction shown. The magnetic field lines shown are those due to the bar magnet.



(a)

b) This induced current produces its own magnetic field directed to the left that counteracts the increasing external flux. The magnetic field lines shown are those due to the induced current in the ring.

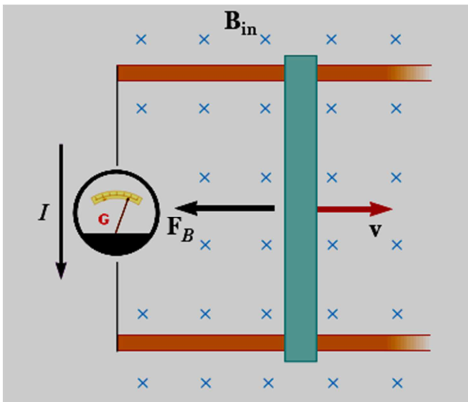


(b)

According to Lenz's law, the push of the magnet is the "change" that produces the induced current and current acts to oppose the push.

Q # 5. Describe the Lenz's law as a statement of Law of conservation of energy.

Ans. Consider a conducting rod of length L placed on two parallel metal rails separated by a distance L. A galvanometer is connected between the ends of rails. This forms complete conducting loop. A uniform magnetic field B is applied directed into the paper.



(a)

- When the rod moves towards right, emf is induced in it and current flows through loop in anti-clockwise direction.
- Since the current carrying current is moving in magnetic field, it experiences a magnetic force F having magnitude $F_m = ILB\sin 90^0 = ILB$.

By the right hand rule, the direction of magnetic force F_m is opposite to that of **v**, so it tends to stop the rod.

An external dragging force equal to F_m in magnitude but opposite in direction must be applied to keep the rod moving with constant velocity.

The dragging force provides the energy for the induce current to flow. This energy is the source of induced current. Thus electromagnetic induction is exactly according to low of conservation of energy.

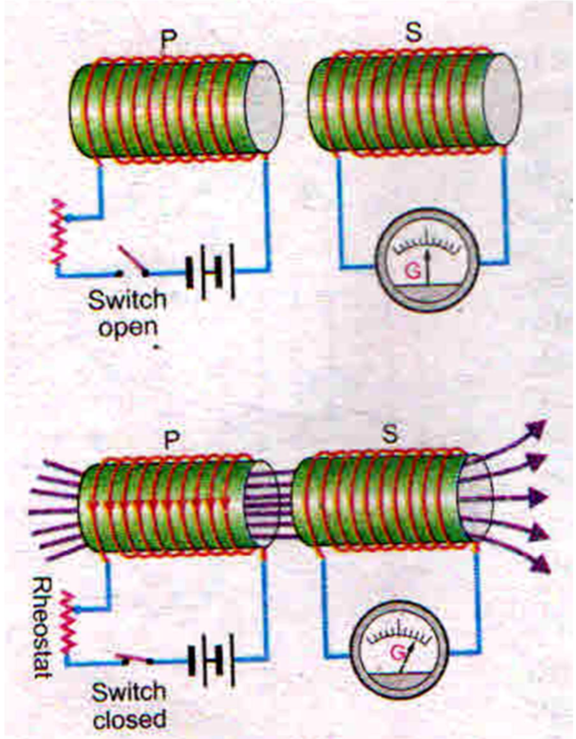
Q # 5. What do you know about mutual induction? Derive the expression of mutual induction.

The phenomenon in which the changing current in one coil induces an emf in another coil is called the mutual induction.

It is denoted by the symbol M and the SI unit of the mutual inductance is VsA^{-1}, which is called henry.

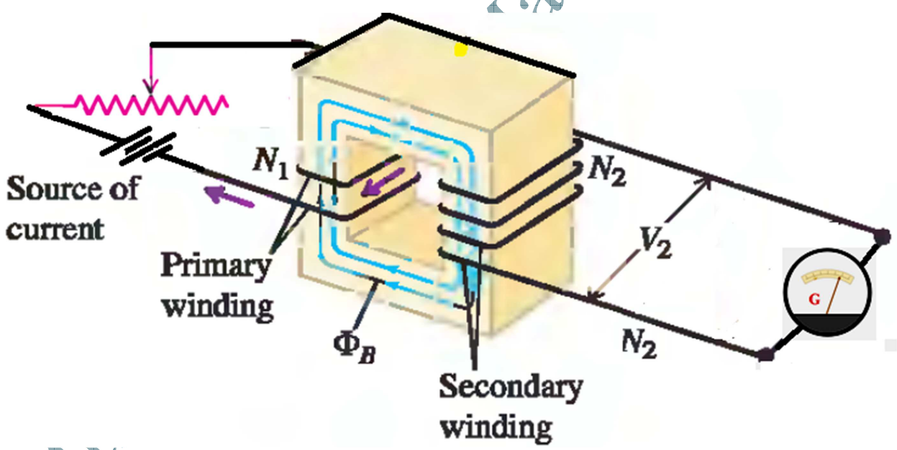
Derivation

Consider two coils placed close to each other. One coil is connected with a current source is called "primary" and the other one connected to the galvanometer is called the "secondary". If the current in the primary is changed by varying the resistance of the rheostat, the magnetic flux in the surrounding regions changes. Since the secondary coil is magnetically linked with primary, the changing flux in primary also changes flux through secondary.



According to Faraday's law, the emf induced in secondary is directly proportional to the rate of change of flux through it and is given by the expression:

$$\varepsilon_S = -N_S \frac{\Delta\phi_S}{\Delta t} \quad \text{----------} \quad (1)$$



As the flux through secondary coil $N_S\phi_S$ is directly proportional to the current I_P in primary coil, therefore

$$N_S\phi_S \propto I_P$$

$$\Rightarrow N_S\phi_S = M\, I_P$$

Where M is the constant of proportionality and is called the mutual inductance of two coils.

The equation (1) becomes:

$$\varepsilon_S = -N_S \frac{\Delta\phi_S}{\Delta t} = -\frac{\Delta(N_S\phi_S)}{\Delta t} = -\frac{\Delta(MI_P)}{\Delta t} = -M\frac{\Delta I_P}{\Delta t}$$

$$\varepsilon_S = -M\frac{\Delta I_P}{\Delta t} \quad \text{----------} \quad (2)$$

The negative sign indicates the fact that the induced emf is in such a direction that it opposes the change of current in the primary coil. The equation (2) can be written as:

$$M = -\frac{\varepsilon_S}{\left(\frac{\Delta I_P}{\Delta t}\right)}$$

This is expression of mutual induction which may also be described as the ratio of average emf induced in the secondary coil to the time rate of change of current in the primary.

Q # 6. What do you know about self induction? Derive the expression of self induction.

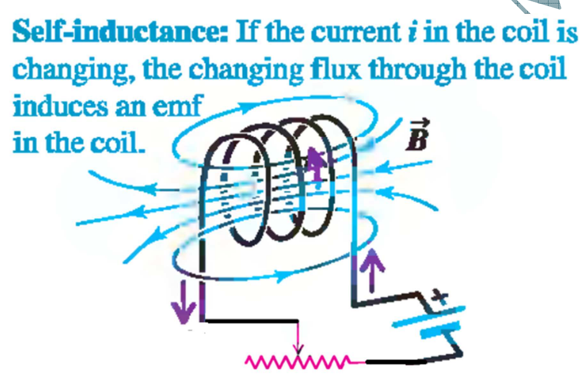
Ans. Self Induction

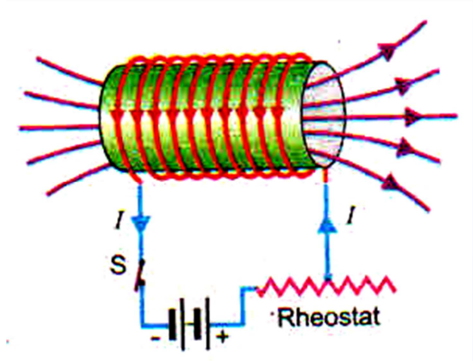
The phenomenon in which the changing current in a coil induces an emf in itself is called the self induction.

It is denoted by the symbol L and the SI unit of the self inductance is VsA^{-1}, which is called henry.

Derivation

Consider the circuit shown in the figure. A coil is connected in series with a battery and a rheostat. Magnetic flux is produced through the coil due to the current it. If the current is changed by varying the rheostat quickly, magnetic flux through the coil changes that causes an induced emf in the coil. Such an emf is called self induced emf.





According to Faraday's law, the emf induced in a coil is directly proportional to the rate of change of flux through it and is given by the expression:

$$\varepsilon_L = -N\frac{\Delta\phi}{\Delta t} \text{ ---------- } (1)$$

If the flux through one loop of the coil is ϕ, then the total flux through the coil of N loops would be $N\phi$. As ϕ is proportional to magnetic field which is in turn proportional to the current I, therefore:

$$N\phi \propto I$$

$$\Rightarrow N\phi = L\,I$$

Where L is the constant of proportionality and is called the self inductance of the coil.

The equation (1) becomes:

$$\varepsilon_L = -N\frac{\Delta\phi}{\Delta t} = -\frac{\Delta(N\phi)}{\Delta t} = -\frac{\Delta(LI)}{\Delta t} = -L\frac{\Delta I}{\Delta t}$$

$$\varepsilon_L = -L\frac{\Delta I}{\Delta t} \quad \text{----------} \quad (2)$$

The negative sign indicates the fact that the self induced emf must oppose the change that produced it. That's why the self induced emf is sometimes called back emf. The equation (2) can be written as:

$$L = -\frac{\varepsilon_L}{\left(\frac{\Delta I}{\Delta t}\right)}$$

This is expression of self induction which may also be described as the ratio of induced emf to the time rate of change of current in the coil.

Q # 7. Find out the expression of energy stored in the magnetic field of current carrying inductor.

Ans. Energy can be stored in the electric field between the plates of capacitor. In a similar manner, energy can be stored in the magnetic field of an inductor.

Consider a coil connected to a battery and a switch in series. When the switch is turned on voltage V is applied across the ends of the coil and current through it rises from zero to its maximum value I. Due to change of current, an emf is induced, which is opposite to that of battery. Work is done by the battery top move charges against the induced emf.

Work done by the battery in moving a small charged Δq is:

$$W = \Delta q\varepsilon_L \quad \text{----------} \quad (1)$$

Where ε_L is the magnitude of induced emf, given by:

$$\varepsilon_L = L\frac{\Delta I}{\Delta t}$$

Putting the value of ε_L in equation (1), we get:

$$W = \Delta qL\frac{\Delta I}{\Delta t} = \frac{\Delta q}{\Delta t}L\Delta I \quad \text{----------} \quad (2)$$

Total work done in establishing the current from 0 to I is found by inserting for $\frac{\Delta q}{\Delta t}$, the average current, and the value of ΔI.

Average Current = $\frac{\Delta q}{\Delta t} = \frac{0+I}{2} = \frac{1}{2}I$

Change in current $\Delta I = I - 0 = I$

The equation (2) will become:

$$W = \left(\frac{1}{2}I\right)L(I)$$

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

This work is stored as potential energy in the inductor. Hence the energy stored in an inductor is:

$$U_m = \frac{1}{2}LI^2 \qquad \text{----------} \quad (3)$$

This equation can be expressed in terms of the magnetic field strength **B** of a solenoid.

If the flux through one loop of the coil isΦ, then the total flux through the coil of N loops would be $N\Phi$. As the magnetic flux $\Phi = BA$ is proportional to magnetic field which is in turn proportional to the current I, therefore:

$$N\Phi \propto I$$

$$N\Phi = LI$$

$$L = \frac{N\Phi}{I} = \frac{NBA}{I} \qquad \text{----------} \quad (4)$$

The magnetic field strength inside solenoid is $B = \mu_0 nI$. Therefore the equation (4) becomes:

$$L = \frac{N\mu_0 nIA}{I} = N\mu_0 nA$$

If l is the length of solenoid, then putting $N = nl$ in the above equation, we get:

$$L = (nl)\mu_0 nA$$

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

Thus the equation (3) becomes:

$$U_m = \frac{1}{2}(\mu_0 n^2 Al)I^2$$

Since for a solenoid is $B = \mu_0 nI \Longrightarrow I = \frac{B}{\mu_0 n}$. Substituting for I, the above equation becomes:

$$U_m = \frac{1}{2}(\mu_0 n^2 Al)\left(\frac{B}{\mu_0 n}\right)^2 = \frac{1}{2}(\mu_0 n^2 Al)\frac{B^2}{\mu_0^2\ n^2}$$

$$U_m = \frac{1}{2}\frac{B^2}{\mu_0}(Al) \qquad \text{----------} \quad (5)$$

Now the energy density can be defined as the energy stored per unit volume insider the solenoid, so dividing equation (5) by volume (Al), we get energy density:

$$u_m = \frac{1}{2}\frac{B^2}{\mu_0}$$

Q # 8. What do you know about alternating current generator? Also describe its principle, construction and working.

A current generator is a device that converts mechanical energy into electrical energy.

Principle

The principle of an electric generator is based on Faraday's law of electromagnetic induction. When a coil is rotated in a magnetic field by some mechanical means, magnetic flux through the coil changes, and consequently an emf is induced in the coil.

Construction

A rectangular loop of wire of area A be placed in uniform magnetic field **B**. the loop is rotated about an axis through its center with constant angular velocity ω. One end of the loop is attached to a metal ring R and the other end to the ring R'. These rings, called slip rings are concentric with the axis of the loop and rotate with it. Rings RR' slide against stationary carbon brushes to which external circuit is connected.

Working

To calculate the induced emf in the loop, consider its position while it is moving in anticlockwise. The vertical side ab of the loop is moving with velocity **v** in the magnetic field **B**. if the angle between **v** and **B** is θ, the motional emf induced in the side ab has the magnitude,

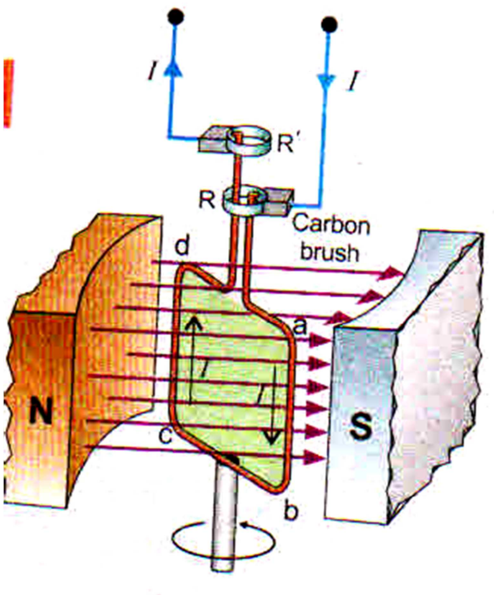
$$\varepsilon_{ab} = vBL \sin\theta$$

The same amount of emf is induced in the side cd. Therefore,

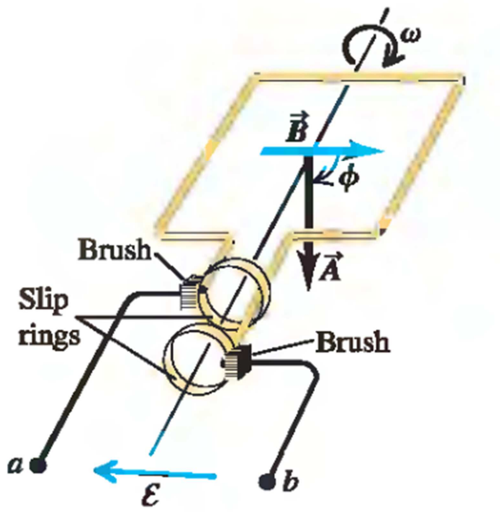
$$\varepsilon_{cd} = vBL \sin\theta$$

The net contribution to emf by the side ab and da is zero because the orce acting on the charges inside bc and da is not along the wire. Thus

$$\varepsilon_{bc} = \varepsilon_{da} = 0$$



(Front view)



The total emf is the loop is

$$\varepsilon = \varepsilon_{ab} + \varepsilon_{cd}$$

$$\varepsilon = vBL \sin\theta + vBL \sin\theta$$

$$\varepsilon = 2vBL \sin\theta$$

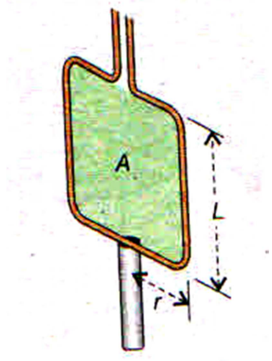
If the coil is replaced by a coil of N turns, the total emf in the coil will be:

$$\varepsilon = 2NvBL \sin\theta \qquad \text{---------} \quad (1)$$

The linear speed v of the vertical wire is related to the angular speed ω by the relation:

$$v = r\omega$$

Where r is the distance of the vertical wires from the center of the coil. Substituting this value in equation (1), we get:



$$\varepsilon = 2N(r\omega)BL \sin\theta$$

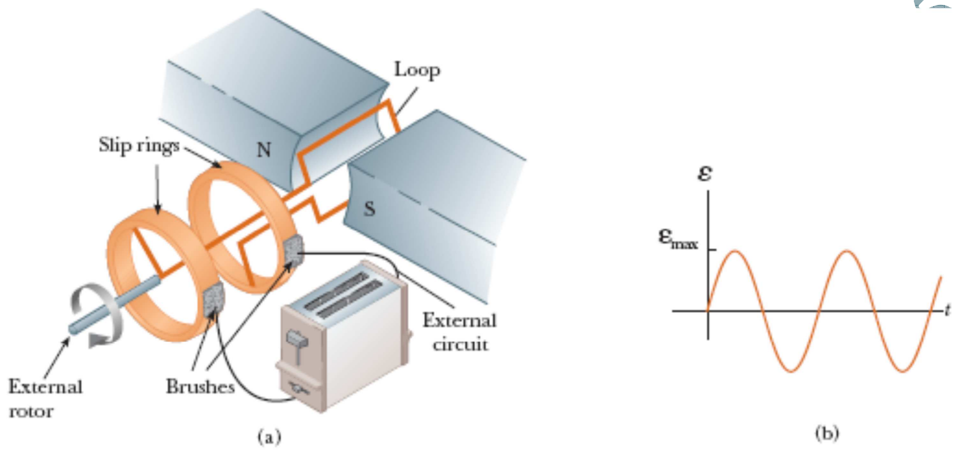
$$\Rightarrow \varepsilon = N\omega(2rL)B \sin\theta$$

$$\Rightarrow \varepsilon = N\omega AB \sin\theta \quad \text{---------} \quad (2)$$

Where $2rL = A =$ area of the coil

As the angular displacement $\theta = \omega t$, so the equation (2) becomes:

$$\varepsilon = N\omega AB \sin(\omega t) \quad \text{---------} \quad (3)$$



The equation (3) shows that the induced emf varies sinusoidally with time. It has the maximum value ε_0 when $\sin(\omega t)$ is equal to 1. Thus

$$\varepsilon_0 = N\omega AB$$

Thus the equation (3) can be written as:

$$\varepsilon = \varepsilon_0 \sin(\omega t)$$

If R is the resistance of the coil, then by Ohm's law, induced current in the coil will be:

$$I = \frac{\varepsilon}{R} = \frac{\varepsilon_0 \sin(\omega t)}{R} = \frac{\varepsilon_0}{R}\sin(\omega t)$$

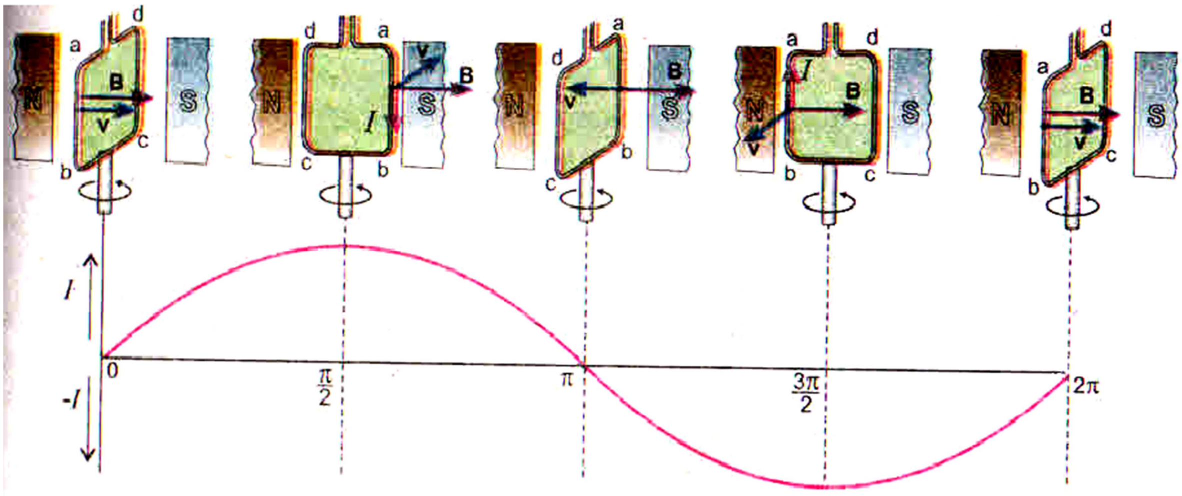
$$\Rightarrow I = I_0 \sin(\omega t)$$

Variation of Current as a Function of θ

- When the angle between v and B is $\theta = 0^0$, the current is zero.
- As θ increases, current also increases. At $\theta = 90^0$, the maximum current flows through the coil, directed along abcda.
- On further increase in θ, the current decreases. At $\theta = 180^0$, the current becomes zero.
- For $180^0 < \theta < 270^0$, current increases but in reverses the direction i.e., dcbad. At $\theta = 270^0$, the maximum current flows through the coil.

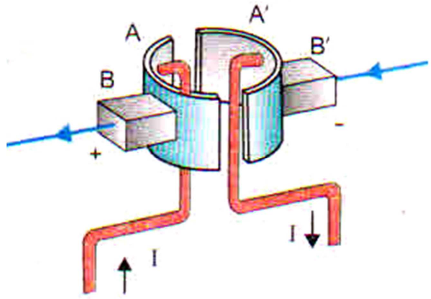
- At $\theta = 360^0$, one rotation is completed and the current decrease to zero. After one rotation, the cycle repeats itself.

The current alternates in direction once in one cycle. Therefore, such a current is called alternating current. It reverses its direction f times per second.

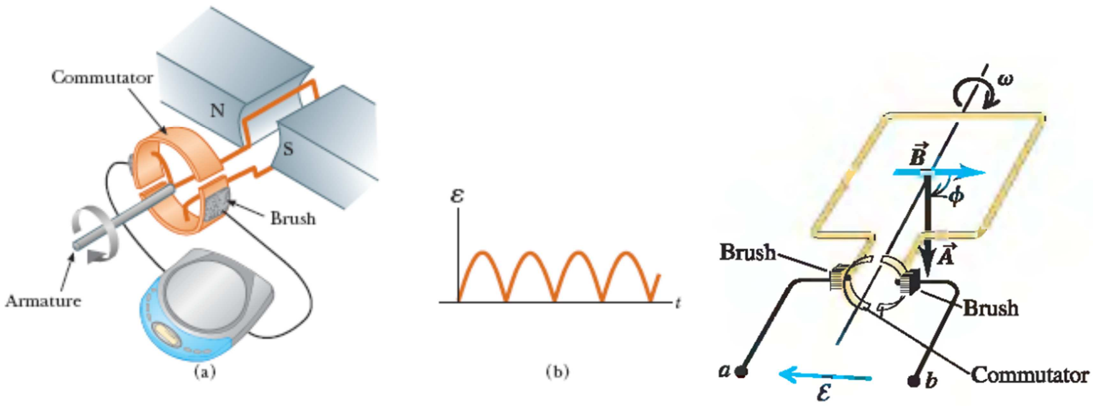


Q # 9. Write a note on DC Generator.

AC Generators are not suitable for many applications, for example to run a DC motor. In 1834, William Sturgeon invented a simple device called commutator that prevents the direction of current from changing.



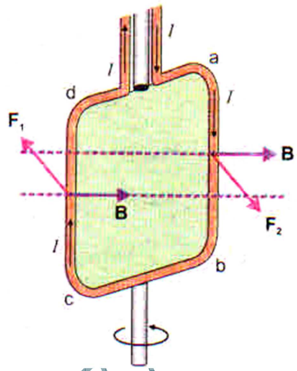
DC Generator is similar to the AC generator in construction with the difference that “slip rings” are replaced by “split rings”. The “split rings” are two halves of a ring that act as commutator.



When the current in the coil is zero and is about to change direction, the split rings also changes the contacts with the carbon brushes BB'. Therefore, the output from BB' remains in the same direction although the current is not constant in magnitude. The fluctuations of the output can be significantly reduced by using many coils rather than a single one.

Q # 10. Describe the back emf effects in generators.

Ans. A generator is a source of electricity production that converts the mechanical energy into electrical energy. For this purpose, a large turbine is turned by high pressure or waterfall. The shaft of the turbine is attached to the coil which rotates in the magnetic field.



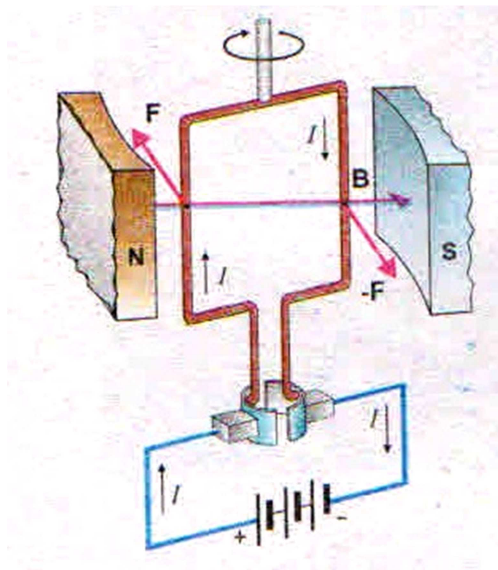
When the circuit is open, the generator does not supply electrical energy, and a very little force is needed to rotate the coil. As soon as the circuit is closed, a current is drawn through the coil. The magnetic field exerts force on the current carrying coil.

Force F_1 is acting on the left side of the coil whereas an equal but opposite force F_2 acts on the right side of the coil. These forces are such that they produce a counter torque that opposes the rotational motion of the coil. This effect is sometimes referred to as back motor effect in the generator.

Q # 11. Write a note on DC motor?

Ans. A motor is a device which converts electrical energy into mechanical energy. The basic principle of electric motor is that "a wire carrying current placed in magnetic field experience a force".

In construction a DC motor is similar to a DC generator, having a magnetic field, a commutator and an armature.



In DC motor, the brushes are connected to DC supply or battery. When the current flows through the armature coil, the force on the conductor produces a torque that rotates the armature. The amount to the torque depends upon the current, the strength to the magnetic field, the area of the coil ant the number of turns of the coil.

Q # 12. What do you know about back emf effect in motors? Also describe the relation between back emf and current.

Ans. When the coil motor rotates across the magnetic field by the applied potential difference V, an emf is induced in it. The induced emf is in such a direction that opposes the emf running motor. Due to this reason, the induced emf is called back emf of the motor. The magnitude of the back emf increases with the speed of motor.

Relation between Back Emf and Current

Since V and ε are opposite in polarity, the net emf in the circuit is $V-\varepsilon$. If R is the resistance of the coil and I the current drawn by the motor, then by Ohm's law:

$$I = \frac{V-\varepsilon}{R} \Rightarrow V = \varepsilon + IR$$

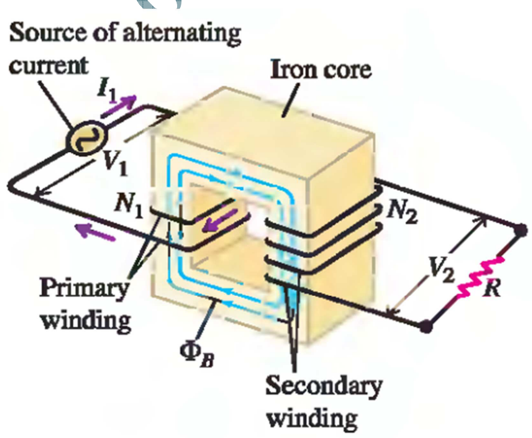
- When the motor is just started, back emf is almost zero and hence a large current passes through the coil.
- As the motor speeds up, the back emf increases and current becomes smaller and smaller. However, the current is sufficient to provide the torque on the coil drive the load and overcome losses due to friction.
- If the motor is overloaded, it slows down. Consequently, the back emf decreases and allows motor to draw more current.
- If the motor is overloaded beyond its limits, the current could be so high that it may burn out the motor.

Q # 13. What is transformer? Describe its construction, principle and working.

A transformer is an electrical device used to change a given alternating emf into a larger or smaller alternating emf.

Principle

The transformer works on the principle of mutual induction between two coils. The transformer consists of two coils of copper electrically insulated from each other, wound on the same iron core. The coil to which AC power is supplied is called primary and that from which power is delivered to the circuit is called secondary.



Working

Suppose that an alternating emf is applied to the primary. if at some instant t, the flux is changing at the rate of $\frac{\Delta\phi}{\Delta t}$, then there will back emf induced in the primary, which will oppose the applied voltage. The instantaneous value of the self induced emf is given by:

$$\text{Self induced emf} = -N_P\left[\frac{\Delta\phi}{\Delta t}\right]$$

Where N_P is the number of turns in the primary. If the resistance of the coil is negligible then the back emf is equal and opposite to applied voltage V_P.

$$V_P = -back\ emf = N_P\left[\frac{\Delta\phi}{\Delta t}\right] \qquad \text{---------} \qquad (1)$$

Assuming that the two coils are tightly coupled and the flux through the primary also passes through the secondary. Therefore, the rate of change of flux through secondary will be $\frac{\Delta\phi}{\Delta t}$ and the magnitude of induced emf across the secondary is given by:

$$V_S = N_S \left[\frac{\Delta \phi}{\Delta t} \right] \qquad \text{---------} \quad (2)$$

Where N_S is the number of turns in the secondary.

Dividing equation (1) and (2), we get:

$$\frac{V_P}{V_S} = \frac{N_P}{N_S} \qquad \text{---------} \quad (3)$$

Q # 14. Differentiate among step-up transformer and step-down transformer.

Step-up Transformer

A transformer in which voltage across secondary is greater than the primary voltage is called step up transformer. For the case of a step up transformer $V_S > V_P$, then according to the equation (3) we have: $N_S > N_P$.

Step-Down Transformer

A transformer in which voltage across secondary is less than the primary voltage is called step up transformer. For the case of a step down transformer $V_S < V_P$, then according to the equation (3) we have: $N_S < N_P$.

Q # 15. What is the difference between an ideal transformer and an actual transformer?

Ans. Electrical power in a transformer is transformed from its primary to the secondary coil by means of changing flux. For an ideal case the power input to the primary is nearly equal to the power output from secondary i.e.,

Power Input =Power Output

$$V_P I_P = V_S I_S$$

But in actual transformer, the output is always less than input due to power losses. There are two main causes of power losses, namely eddy currents and magnetic hysteresis.

Due to power losses, a transformer is far from being an ideal. The efficiency of the transformer is defined as:

$$E = \frac{Output\ \ Power}{Input\ \ Power} \times 100$$

Q # 16. Describe the different causes of power loss.

There are two main causes of power loss, which are given below

Eddy Current

The induced currents that are set up in the core of transformer in the direction perpendicular to the flux are known as eddy currents. It results in power dissipation and heating of the core material.

Hysteresis Losses

Hysteresis losses are the energy expended to magnetize and demagnetize the core material in each cycle of AC.

Q # 16. How the efficiency of the transformer can be improved?

Following step should be executed in order to improve the efficiency of transformer:

- Core should be assembled from the laminated sheet of a material whose hysteresis loop area is very small.
- The insulation between lamination sheets should be perfect so as to stop the flow of eddy currents.
- The resistance of the primary and secondary coils should be kept minimum.

EXERCISE SHORT QUESTIONS

Q # 1. Does the inducted emf in circuit depend on the resistance of the circuit? Does the induced current depend on the resistance of the circuit?

Ans. The expression for induced emf is given by

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

The relation shows that the induced emf in a coil only depend upon the rate of change of magnetic flux and number of turns but does not depend upon the resistance of the coil.

As the induced current flowing through a coil is given by:

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

this expression shows that the value of current depends upon the resistance of the coil. The smaller the value of the resistance of the coil, greater will he the value of current.

Q # 2. A square loop of wire is moving through a uniform magnetic field. The normal to the loop is oriented parallel to the magnetic field. Is a emf induced in the loop? Give a reason for your answer.

Ans. The induce emf in a wire is given by:

$$\varepsilon = vBL\sin\theta$$

Where θ the angle between "v" and "B".

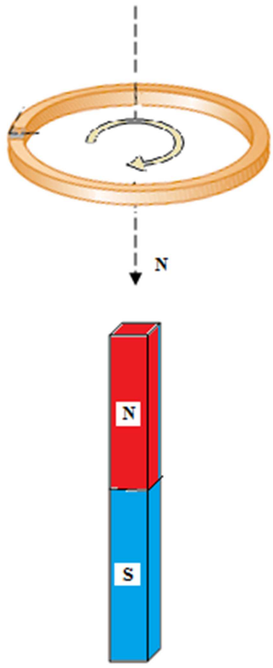
When normal to the loop is parallel to the field, the velocity vector "v" of side of loop is also parallel to field "B", so $\theta = 0$. Therefore,

$$\varepsilon = vBL\sin 0$$

$$\Longrightarrow \varepsilon = vBL(0)$$

$$\Longrightarrow \varepsilon = 0$$

Thus, emf induced in the loop is zero.

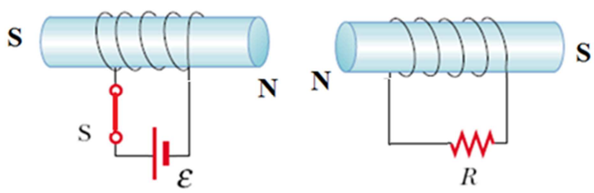


Q # 3. A light metallic ring is released from above into a vertical bar magnet as shown in the figure. Viewed from above, does the current flow clockwise or anti-clockwise in the ring?

Ans. According to Lenz's law, the direction of the induced current is opposite to the cause which produces it. So, the side of the ring facing north pole of magnet must be north pole of the induced magnetic field.

When viewed from above, the current in the ring is clockwise.

Q # 4. What is the direction of the current through resistor R as shown in the figure? As the switch S is (a) closed (b) open.



Ans. When switch S is closed, then the current in the primary coil increases from zero to maximum. During this time interval, magnetic flux through the secondary coil increases from zero to maximum and induced current produce in it. According to Lenz's law, the current through the secondary should flow in anti-clockwise direction. And current through resistor will be from left to right.

(b) However, if the switch is opened, the induced current through secondary should flow in clockwise direction. So the current through resistor R will flow from right to left.

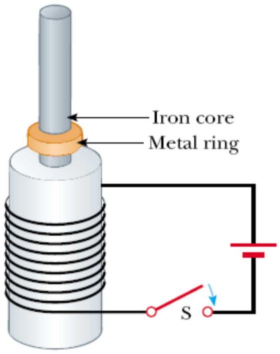
Q # 5. Does the induced emf always act to decrease the magnetic flux through a circuit?

Ans. The induced emf always opposes the cause that produces it.

- If the magnetic flux through the circuit through the circuit is increasing, then induced emf acts to decrease the magnetic flux.
- If the magnetic flux through the circuit through the circuit is decreasing, then induced emf acts to increase the magnetic flux.

Hence, the induced emf does not always act to decrease the magnetic flux through the circuit.

Q # 6. When the switch in the circuit is closed, a current is established in the coil and the metal ring jumps upward. Why? Describe what would happen to the ring if the battery polarity were reversed?



Ans. When the switch in the circuit is closed, the current is set up in the coil which establish magnetic field in it.

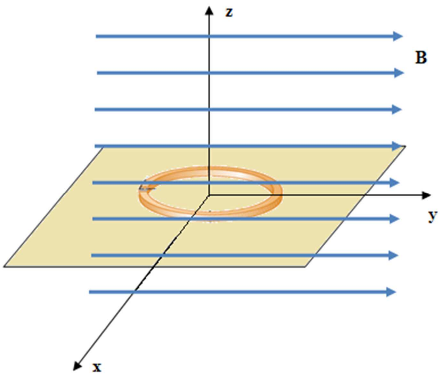
This result in change of magnetic flux through the metallic ring and hence an induced emf is produced in it.

The induced magnetic field in the ring opposes the magnetic field of the coil (according to Lenz's law). Therefore the ring experience a force of repulsion and jumps up.

The same event occurs even if the polarity of the battery is reversed.

Q # 7. Figure shows a coil of wire in the xy-plane with a magnetic field directed along the y-axis. Around which of the three coordinate axes should the coil be rotated in order to generate an emf and a current in the coil?

Ans.



- The coil must be rotated along x-axis to get change of magnetic flux and an induced current through it.
- If the coil is rotated about y-axis, the flux passing through the coil zero because plane of the coil remains parallel to magnetic field B all the times.
- If the coil is rotated about z-axis then no change of magnetic flux takes place through coil.

Hence if the coil is rotated about x-axis, then there is a change of magnetic flux passing through a coil. So only in this case, an emf is induced in the coil.

Q # 8. How would you position a flat loop of wire in a changing magnetic field so that there is no emf induced in the loop?

Ans. If the plane of loop of wire is placed parallel to changing magnetic field i.e., $\theta = 0$, then no flux through it will change. Hence no emf will be induced through the loop as:

$$\varepsilon = \omega AB \sin\theta$$

$$\varepsilon = \omega AB \sin 0 = \omega AB(0)$$

$$\varepsilon = 0$$

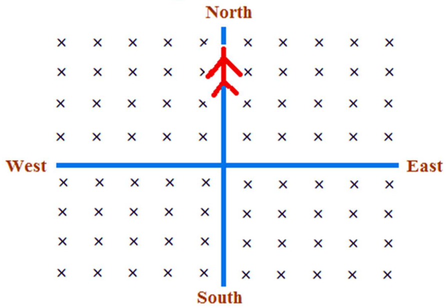
Q # 9. In a certain region, the earth's magnetic field point vertically down. When a plane flies due north, which wing tip is positively charged?

Ans. The magnetic force on electrons in the wing is given by:

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

When the plane flies due north in the earth magnetic field directed vertically downward, then electrons will experience force in east direction.

Thus west wingtip of the plane is positively charged.



Q # 10. Show that $\boldsymbol{\varepsilon}$ and $\frac{\Delta\varphi}{\Delta t}$ have the same units.

Ans. As we know that:

- $\varepsilon = \frac{W}{q}$

$$\Rightarrow unit\ of\ \varepsilon = \frac{unit\ of\ Work}{unit\ of\ charge} = \frac{joule}{coulomb} = volt \quad ---------- \quad (1)$$

- $\frac{\Delta\boldsymbol{\varphi}}{\Delta \boldsymbol{t}} = \frac{B\Delta\boldsymbol{A}}{\Delta \boldsymbol{t}}$

$$\Rightarrow unit\ of\ \frac{\Delta\boldsymbol{\varphi}}{\Delta \boldsymbol{t}} = \frac{(unit\ of\ B)(unit\ of\ \Delta A)}{unit\ of\ \Delta\boldsymbol{t}} = \frac{(NA^{-1}m^{-1})(m^2)}{s}$$

$$\Rightarrow unit\ of\ \frac{\Delta\boldsymbol{\varphi}}{\Delta \boldsymbol{t}} = \frac{N \times m}{A \times s}$$

As $N \times m = J\ (joule)$ and $A \times s = C\ (coulomb)$

$$\Rightarrow unit\ of\ \frac{\Delta\varphi}{\Delta t} = \frac{joule}{coulomb} = volt \quad ---------- \quad (2)$$

Hence from (1) and (2), it is proved that both $\boldsymbol{\varepsilon}$ and $\frac{\Delta\varphi}{\Delta t}$ have the same units.

Q # 11. When an electric motor, such as an electric drill, is being used, does it also act as a generator? If so what is the consequences of this?

Ans. When an electric motor is running, its armature is rotating in a magnetic field. A torque acts on the armature and at the same time, magnetic flux is changing through the armature which produces an induced emf. The induced emf opposes the rotation of armature. This means that motor also acts as generator when it is running.

consequences

- When the motor is just started, back emf is almost zero and hence a large current passes through the coil.
- As the motor speeds up, the back emf increases and current becomes smaller and smaller. However, the current is sufficient to provide the torque on the coil drive the load and overcome losses due to friction.
- If the motor is overloaded, it slows down. Consequently, the back emf decreases and allows motor to draw more current.
- If the motor is overloaded beyond its limits, the current could be so high that it may burn out the motor.

Q # 12. Can a DC motor be turned into a DC generator? What changes are required to be done?

Ans. Yes, a DC motor be turned into a DC generator.

In order to convert DC motor into a DC generator, two changes are to be done:

- The magnetic field must be supplied by the permanent magnet and not by electromagnet.
- An arrangement to rotate the coil armature should be provided.

Q # 13. Is it possible to change both the area of the loop and the magnetic field passing through the loop and still not have an induced emf in the loop?

Ans. If both area of the loop A and magnetic field strength B are changed such that change is magnetic flux is zero i.e., $\Delta\phi = 0$. Then by Faraday's law:

$$\varepsilon = -\frac{\Delta\phi}{\Delta t} = 0$$

Hence no induced emf in the loop will be produced.

Q # 14. Can an electric motor be used to drive an electric generator with output from the generator being used to operate the motor?

Ans. No it is not possible. Because if it is possible, it will be a self operating system without getting energy from some external source and this is against the law of conservation of energy.

Q # 15. A suspended magnet is oscillating freely in a horizontal plane. The oscillations are strongly damped when a metal plate is placed under the magnet. Explain why this occurs?

Ans. the oscillating magnet produces change of magnetic flux close to it. The metal plate placed below it experiences the change of magnetic flux. As the result, eddy current are produced inside metal. According to Lenz's law, these eddy current oppose the cause which produce it. So, the oscillations of magnet are strongly damped.

Q # 16. Four unmarked wires emerge from a transformer. What steps would you take to determine the turn ratio?

Ans. By checking continuity of the coils, the coils are separated as primary and secondary coils. An alternating voltage of known value V_P is connected to one coil (primary coil), the output voltage V_S across the ends of the other coil (secondary coil) is measured. The turn ratio of the coil is determined by using relation:

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

Q # 17. (a) Can a step-up transformer increase the power level?

(b) In a transformer, there is no transfer of charge from the primary to the secondary. How is, then the power transferred?

Ans.

(a). In case of an ideal transformer, the power output is equal to the power input. In actual transformer, due of dissipation of energy in the coil, the output power is always less than input power. Therefore, a step-up transformer can't increase power level.

(b). The two coils of transformer are magnetically linked i.e., the change of flux through one coil is linked with the other coil.

Q # 18. When the primary of a transformer is connected to AC mains, the current in it

(a) Is very small if the secondary circuit is open, but

(b) Increases when the secondary circuit is closed. Explain these facts.

Ans. (a). If the secondary circuit is open, then output power will be zero. Because output power is always slightly smaller than the output power, therefore a very small value of current is being drawn by a primary coil of transformer form AC mains.

(b). When the secondary circuit is closed, the output power will be increased. As we know that output power is equal to input power, therefore the transformer will draw large current from the AC mains to increase the primary power. Hence, greater current is needed in primary to equalize power in secondary coil.

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