

Chapter = 15

Electromagnetic Induction

Introduction

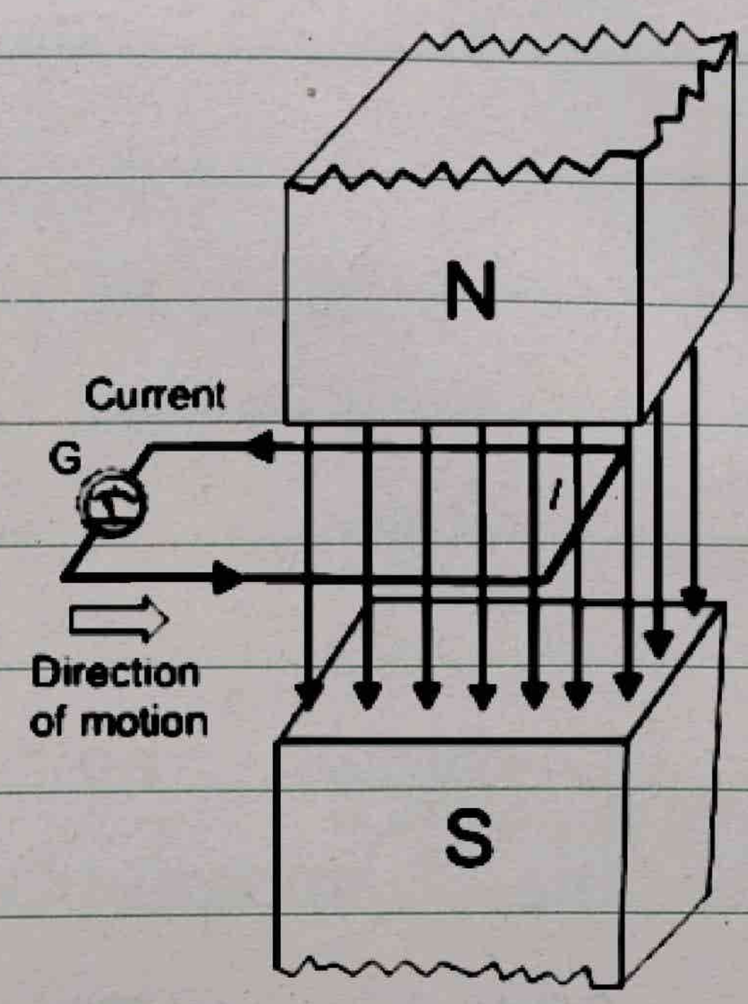
Oersted discovered that current produces magnetic field. Soon after that in 1831 Michael Faraday in England and Joseph Henry in USA observed that an emf is produced in a conductor when it is moved across a magnetic field. This is called induced emf. The current due to this emf is called induced current. This phenomenon is called electromagnetic induction.

15.1 Induced EMF and Induced current

Consider the fig. in which a straight wire of length "l" is placed in a magnetic fied of a permanent magnet. The wire is connected to a sensitive galvanometer to form a closed path or loop.

When the loop is at rest

galvanometer shows no current. If we move the wire from left to right, the lenght "l" of the wire is dragged acr. oss the magnetic field and a current flows through the loop. When we stop moving the loop, current also stops.



Now if the loop is moved in the opposite direction (from right to left), the current also flows in opposite direction. This is shown by the deflection of galvanometer in opposite direction.

The induced current I depends upon the
i) ; Speed of movement of the coil.
ii) ; Resistance "R" of the loop.

If we changerg the resistance of the loop keeping the speed same, then the product of I and R remains constant.

IR = constant.
IR = induced emf.

This induced emf produces indued "I".

This induced current "I" can be increased by,

i) : Using a strong magnetic field.
ii) : Increasing the speed of the loop.
iii) : Taking a coil of large number of turns.

Now, hold the loop stationary and move the magnet. Some results are produced i.e, induced emf and induced current are produced.

Result:

Relative motion of the loop and the magnet produces induced emf.

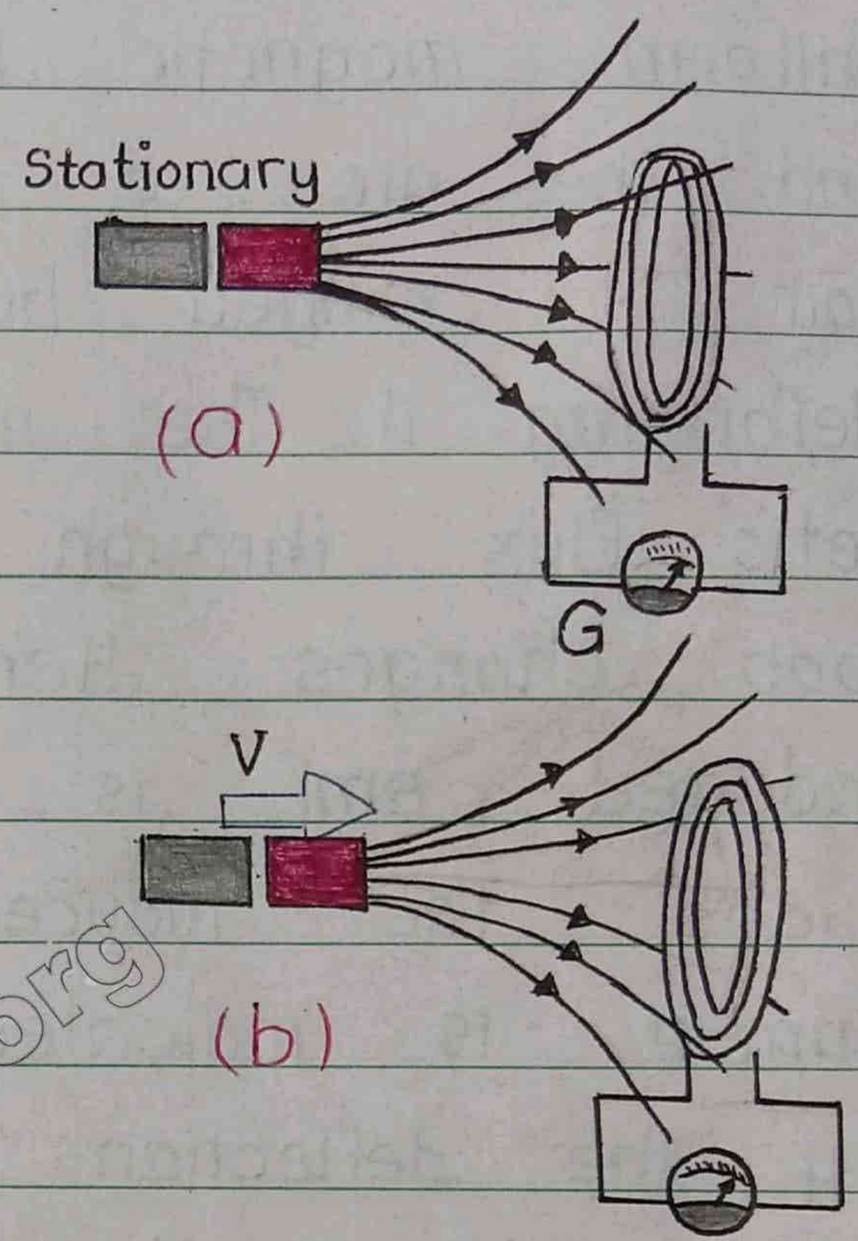
Conclusion:

Relative motion of the loop and the magnet changes the magnetic flux through the loop. The change of magnetic flux produces induced emf in the loop. Greater the rate of change of magnetic flux, larger is the induced emf.

Different methods to produce induced EMF

1) Magnet in motion coil at rest:

Consider a bar magnet and coil to which galvanometer is connected. When there is no relative motion between the magnet and the coil, galvanometer shows no current as shown in fig(a).



(a)

(b)

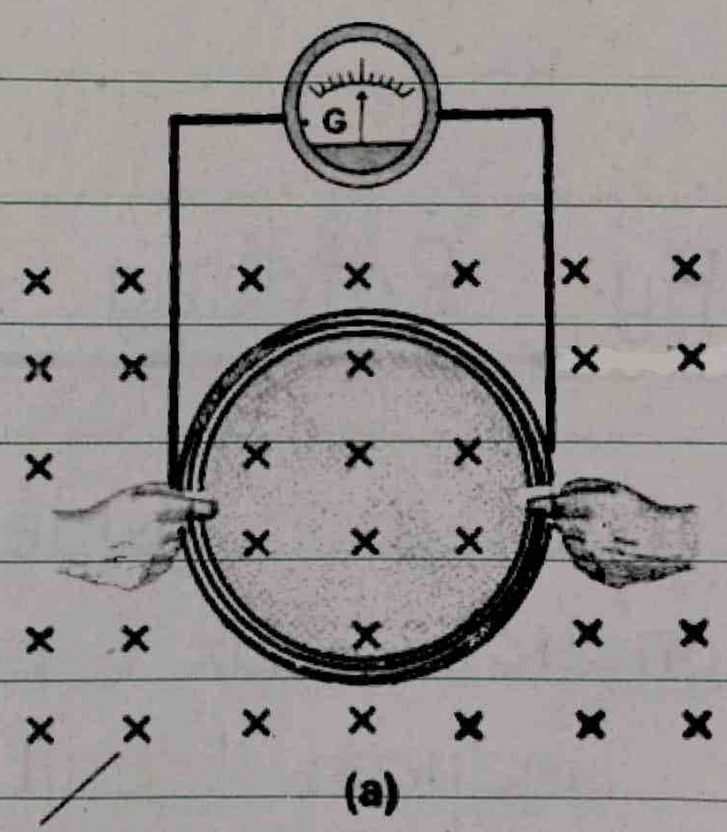
Now the magnet is moved towards the coil, the galvanometer shows a current fig (b).

Reason:

In moving the magnet, the magnetic flux through the coil changes. This changing magnetic flux produces can induced emf.

2) Magnet at rest, coil in motion:

Current is also produced if the magnet is stationary and the coil is moved towards or away from the magnet.

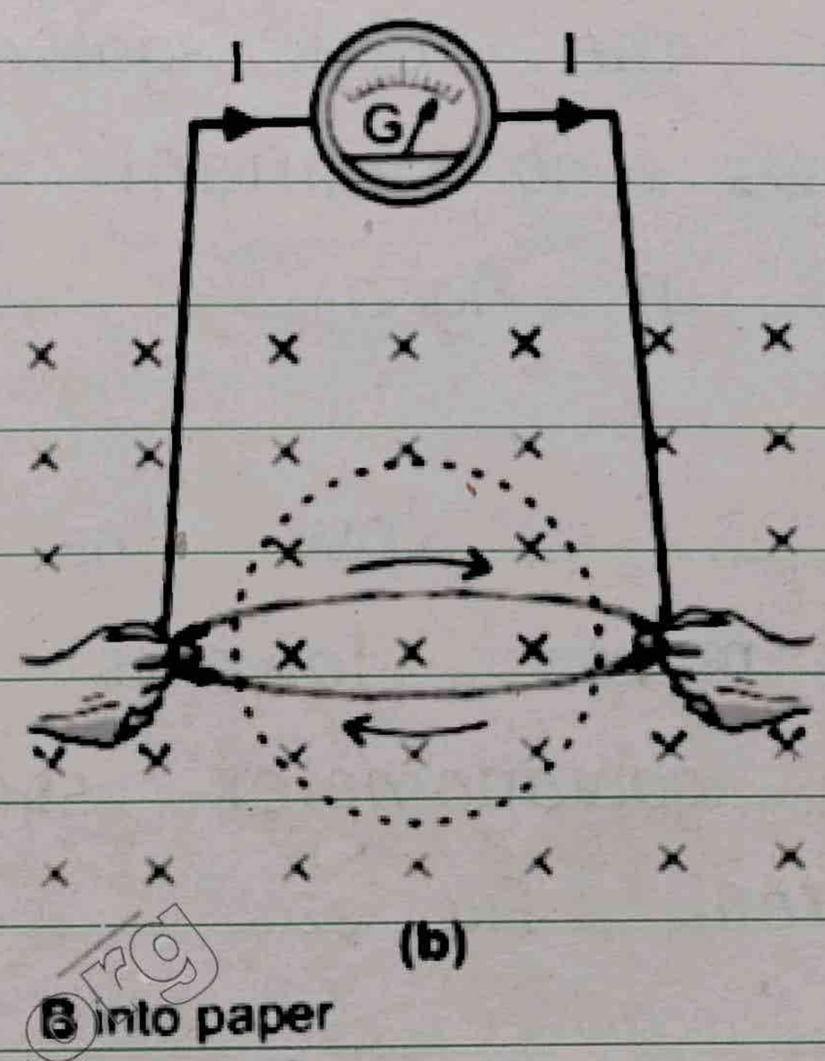


(a)

B into paper

3) By changing the Area of the coil:

When the coil is placed in a uniform magnetic field and the area of the coil is changed by deforming it. The magnetic flux through the loop changes. Hence induced emf is produced. The induced current is indicated by the deflection of galvanometer.



When the area is being reduced, the direction of induced current is in one direction. By increasing the area of the loop the direction of induced current is reversed. When we stop chaging the area of the coil galvanometer shows no deflection.

4) By Rotating the coil:

When the coil is rotated inside an external magnetic field magnetic flux passing through it changes and induced emf is produced. This causes

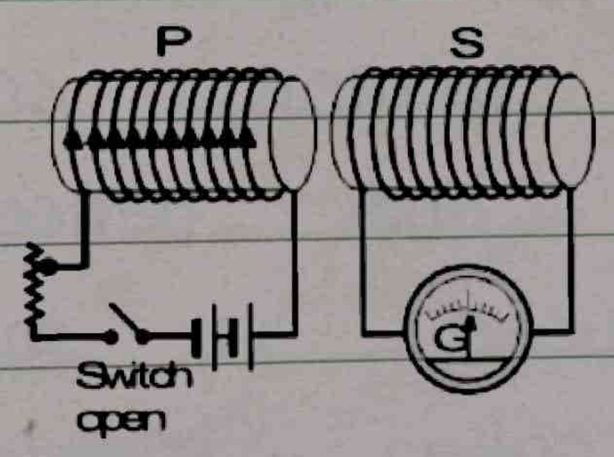
an induced current shown by the galvanometer.

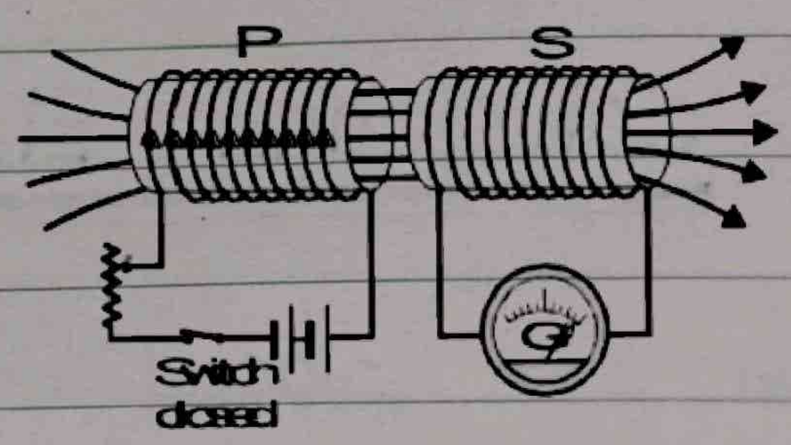
∵ This method of producing emf is used in electric generators.

5) By changing current in Mutual inductance:

Fig shows two coils placed side by side. The coil through which current is changed is called "Primary coil" P. The other coil across which emf is produced is called "Secondary coil" S. A sensitive galvanometer is connected to the secondary coil.

When switch of the primary coil circuit is closed current passing through the coil rises from zero to maximum value. Due to which magnetic flux passing through the coil changes. This change of magnetic flux





also takes place in the secondary coil. Due to this change of magnetic flux an induced emf is produced in the secondary coil which is shown by the deflection of the galvano-meter.

For steady current passing through the primary coil, no induced emf is produced in the secondary coil and the galvano-meter shows zero, No deflection.

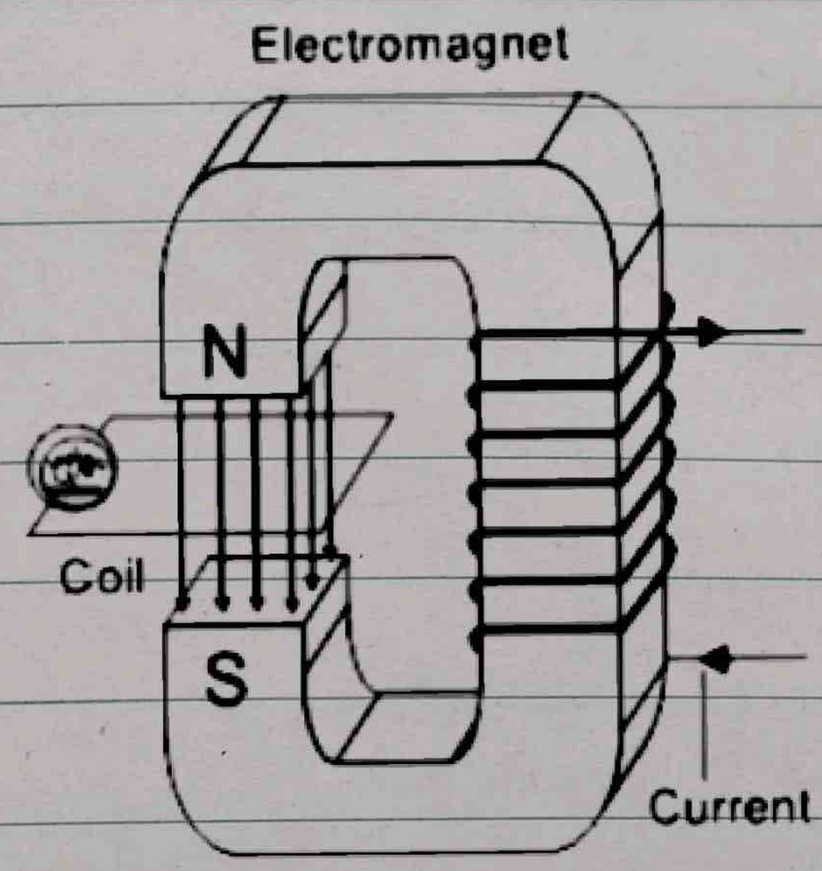
When the switch in the primary coil is turned "OFF". then current decreases (changes) from maximum to zero. During this changing current, galvanometer shows opposite current for a moment.

Current in the primary can be changed with the helf of the Rheostat in the primary coil. As a result induced emf and hence induced current can be produced in the secondary coil. This process is called "Mutual Induction."

6) Coil and Electromagnet:

Fig shows a coil is placed in the magnetic field of an

of an electromagnet. Both the coil and the electromagnet are stationary. The magnetic flux passing through the coil is changed by changing the current in the magnet. Hence induced emf is produced in the coil. Note that in this case both the coil and magnet are at rest.



15.2 : Motional EMF

Definition

"The emf induced by the motion of the conductor across the magnetic field is called motional emf." It is denoted by "ε".

$$\varepsilon = VBL = VBL \sin\theta$$

Derivation of Formula:

Consider a conducting rod (a,b) of length "L" and it can slide on two parallel metal rails as shown in fig. A galvanometer is connected between the ends c and d of the rails, this forms a conducting loop abcd. A uniform

magnetic field $\vec{B}$ into the page is applied due to which magnetic flux passes through the loop abcd.

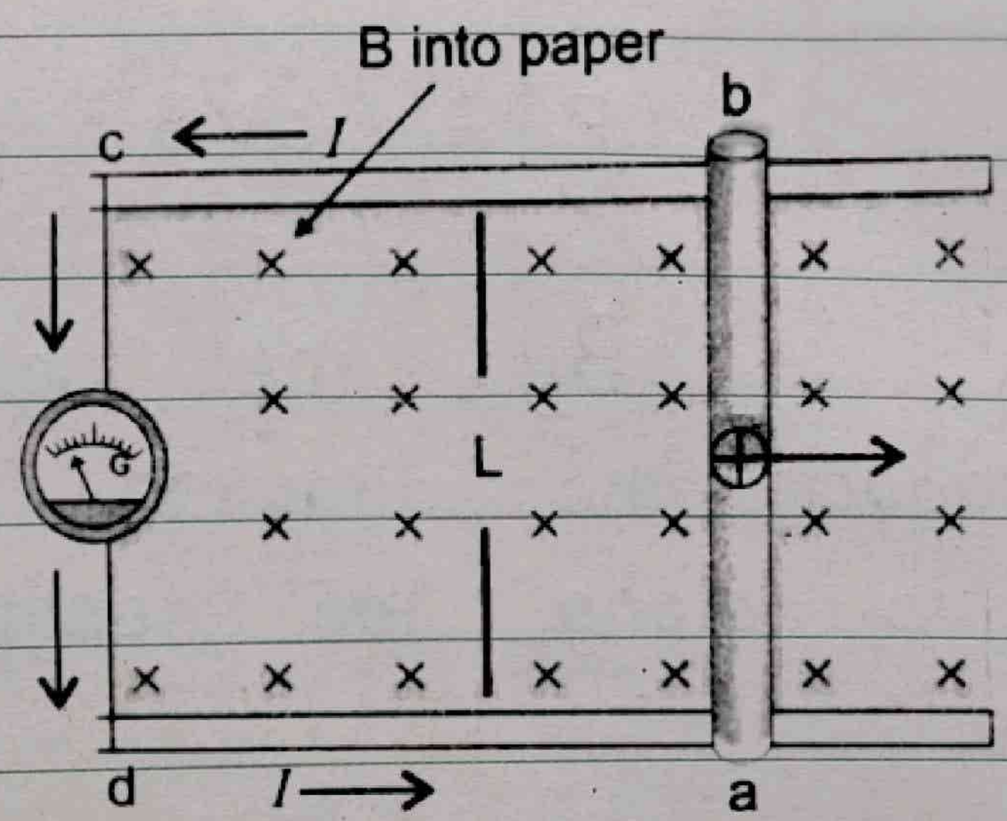


Fig.

When the rod is at rest, galvanometer shows no deflection, so no current is flowing through the loop. Now consider the rod is moved towards right with constant velocity $\vec{v}$. The galvanometer shows a current flowing through the loop. Thus the moving rod acts like a source of emf $\mathcal{E}$.

$$\mathcal{E} = V_b - V_a = \Delta V$$

When the rod moves a charge "q" also moves with in the rod with the same velocity $\vec{v}$ in the magnetic field $\vec{B}$ and experiences a force $\vec{F}$.

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

Magnitude,

$$F = qvB\sin\theta = qVB\sin(90) = qVB(1)$$

$$F = qVB \longrightarrow (1)$$

By the right hand rule of cross product the direction of $\vec{F}$ on $\vec{q}$ is from a to b along the length of the rod.

As,

$$F = qE \longrightarrow (2)$$

E is the electric field with in the rod from a to b. Comparing equation (1), (2)

$$\cancel{q}E = \cancel{q}VB$$

$$\boxed{E = vB} \longrightarrow (3)$$

As,

Electric intensity = − Gradient of electric Potential

$$E = -\frac{\Delta V}{L} \qquad \because \Delta V = \varepsilon$$

$$\boxed{E = -\frac{\varepsilon}{L}} \longrightarrow (4)$$

Comparing eq- (3), (4)

$$-\frac{\varepsilon}{L} = vB$$

$$\varepsilon = -vBL \longrightarrow (5)$$

This is the magnitude of motion emf.

If the angle between $\vec{v}$ and $\vec{B}$ is θ. then

$$\boxed{\varepsilon = vBL\sin\theta} \longrightarrow (6)$$

If $v = 0$, $\varepsilon = 0$

It means that no motional emf. is produced in the stationary rod.

Due to induced emf positive charges would flow along the path abcda, therefore, the induced current is anticlock wise.

15.3 Faraday's Law and Induced EMF

Statement:

"The average emf induced in a conducting coil of N loop is equal to the negative of the rate of change of magnetic flux with respect to time, in the coil."

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

The $-ve$ sign shows that the direction of the induced emf is such that it opposes the change in flux.

Proof:

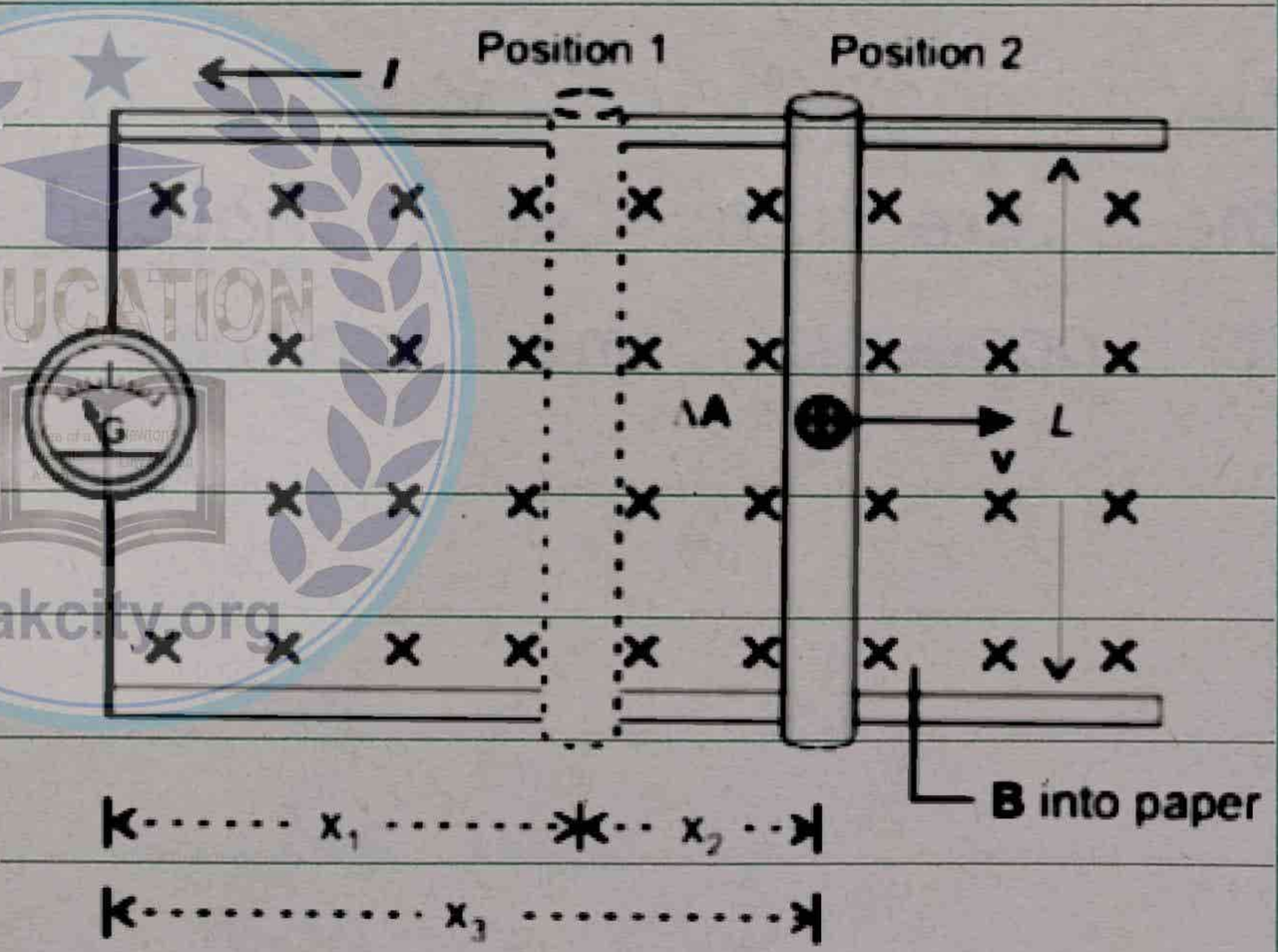
We know that motional emf

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

The motional emf and all other types of induced emf be expressed in terms of magnetic flux as explained below.

Experiment:

Consider the experiment shown in fig. The conducting rod "L" moves from position (1) to position (2) in a time Δt.



$$\boxed{\Delta X = X_2 - X_1}$$

Distance travelled by the rod in time Δt.

$$\frac{\Delta X}{\Delta t} = v = \text{velocity of the conductor.}$$

As,

$$\varepsilon = -vBL$$

$$\varepsilon = -\left(\frac{\Delta x}{\Delta t}\right) BL$$

$$\varepsilon = -\frac{B(\Delta x . L)}{\Delta t}$$

$$\varepsilon = -\frac{B\Delta A}{\Delta t}$$

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

$(\Delta x . L) = \Delta A =$ Increase in Area of the loop.

$B\Delta A = \Delta\phi =$ change in flux.

If the coil has N loops

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

This is called Faraday's Law of electromagnetic induction. The (—) sign show that the direction of induced emf is such that it opposes the change in flux.

15.4 Lenz's Law and Direction of Induced EMF

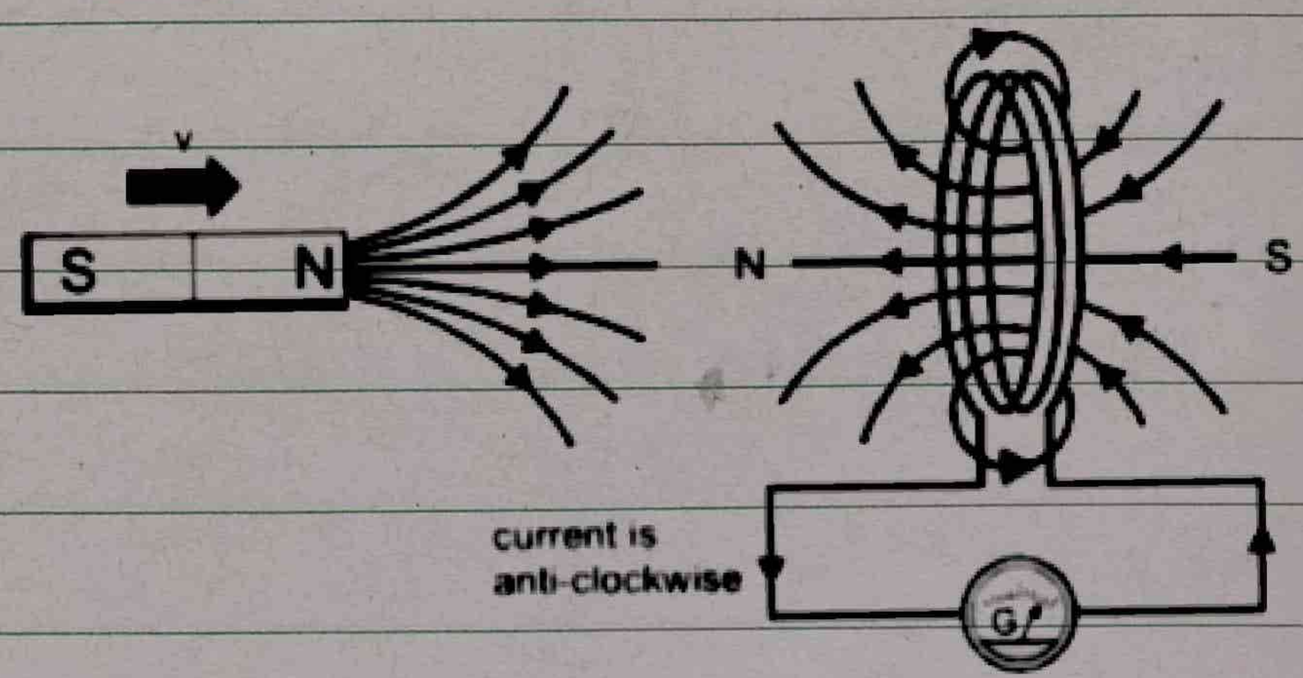
Statement:

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

This law was given by Russian Physicist Heinrich. Lenz in 1834. He discovered that the polarity of an induced emf always leads to an induced current that opposes the change inducing the emf through the magnetic field of the induced current.

Explanation:

We apply the Lenz's Law to the coil in which current is induced by the movement of a bar maget. We know that a current carrying coil produces a magnetic field similar to that of a bar magnet.

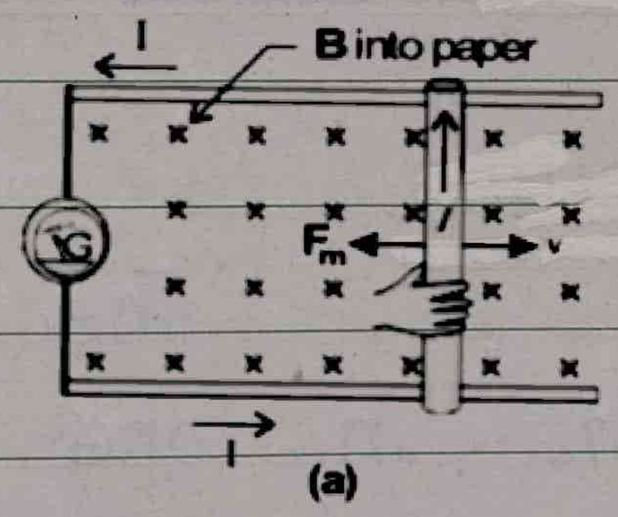


One face

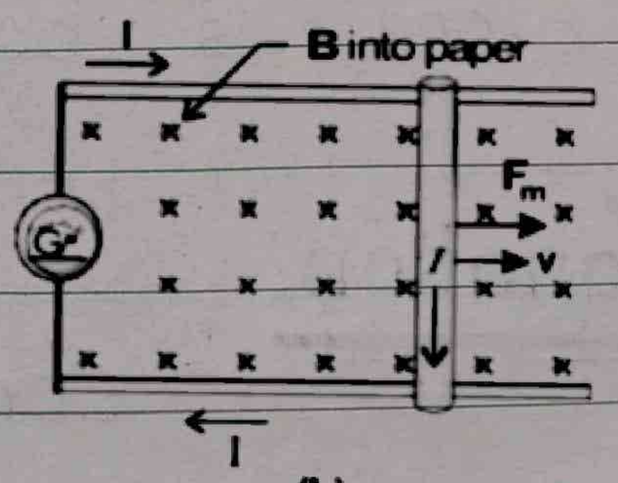
of the coil acts as the north pole while the other one as the south pole. Then the induced current in the coil flows in such a manner that the face of the coil towards the magnet becomes the north pole and so it repells the north pole of the bar magnet.

According to the Lenz's Law the "Push" of the magnent is the chage that produces the induced current, and the current acts to oppose the push. On the other hand if we pull the magnet away from the coil, the induced current will oppose the "Pull" by creating a south pole on the face of the coil towards the bar magnet.

The statement of Lenz's Law is the law of conservation of energy, which can be applied to those circuits, which have induced currents.



(a)



(b)

Consider the experimental set up shown in fig

When the rod moves towards

right. emf is induced in it and an induced current flows through the loop in the anti-clockwise direction. Since the current carring rod is moving in the magnetic field, it experiences a magnetic force "F" having the magnitude.

$$F = ILB \sin(90) = ILB$$

By right hand rule the direction of "F_m" is opposite to that of v, so it tries to stop the rod fig. An external pulling froce equal to "F_m" in magnitude but opposite in direction must be applied to keep the rod moving with constant velocity. This pulling froce gives the energy for the induced current to flow.

15.5 Mutual Induction

Definition:

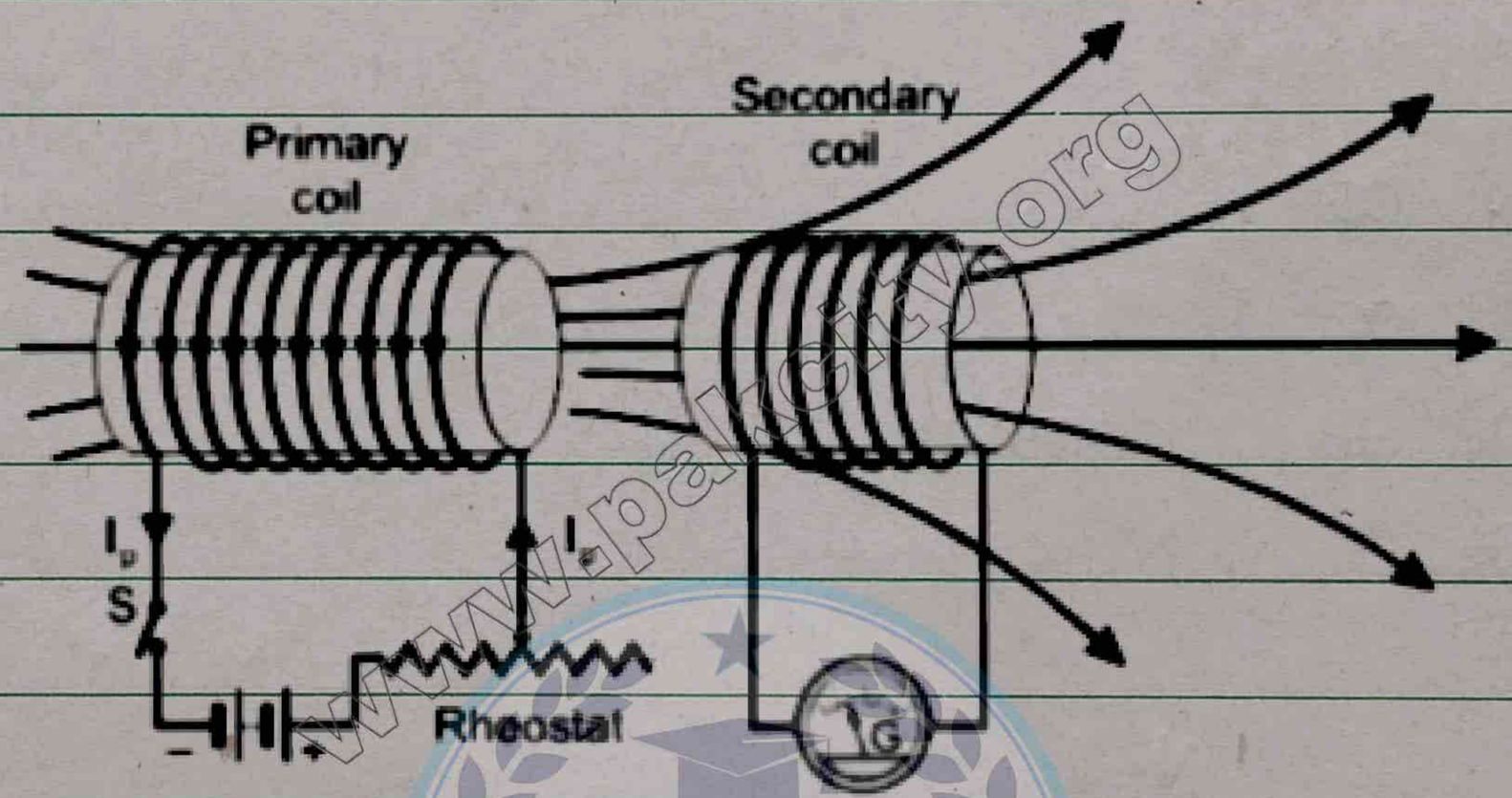
"The process in which a changing current in one coil induces an emf in another coil is called the mutual induction."

Explanation:

Consider two coils placed very

close to each other. The coil which is connected to a battery and rheostat is called "Primary coil". By changing the position of variable contact of rheostat, the current is changed in the primary coil.

This change of current produces change of magnetic flux which is also taking place in the "secondary coil."



This produces an induced emf in the secondary coil. This is indicated by the deflection of galvanometer. According to the Faraday's Law of electromagnetic induction the induced voltage across the secondary coil is directly proportional to the rate of change of magnetic flux passing through secondary coil $\frac{\Delta\phi}{\Delta t}$.

So, induced emf across the secondary coil is

$$\mathcal{E}_s = -N_s \frac{\Delta \Phi_s}{\Delta t}$$

N_s = Number of turns of secondary coil.
Φ_s = magnetic flux through one turn of secondary coil.

As,

Flux = BA

Flux $\propto$ B and B $\propto I_p$

So,

Flux $\propto I_p$

$N_s \Phi_s \propto I_p$

$N_s \Phi_s$ = constant $\times I_p$

$N_s \Phi_s = M \times I_p$

$\because$ M = Mutual inductance.

$$M = \frac{N_s \Phi_s}{I_p}$$

→ M depends upon

i) : Number of turns of the coil,
ii) : their area of crossection,
iii) : their closeness.
iv) : nature of the material of the core upon which the coils are wound.

Using Faraday's Law, the induced emf

across the secondary coil.

$$\mathcal{E}_s = -N_s \frac{\Delta \Phi_s}{\Delta t} = -\frac{N_s \Delta \Phi_s}{\Delta t}$$

$$\mathcal{E}_s = -\frac{\Delta (N_s \Phi_s)}{\Delta t} = -\frac{\Delta (M I_p)}{\Delta t}$$

$$\mathcal{E}_s = -M \frac{\Delta I_p}{\Delta t}$$

$$\boxed{\mathcal{E}_s \propto -\frac{\Delta I_p}{\Delta t}}$$

This shows that the induced emf in the secondary coil is directly proportional to the rate of change of current in the primary coil.

The negative sign shows that the induced emf is such that it opposes the cause which produces it. Ignoring the -ve sign.

$$\mathcal{E}_s = M \frac{\Delta I_p}{\Delta t}$$

$$\boxed{M = \frac{\mathcal{E}_s}{\left(\frac{\Delta I_p}{\Delta t}\right)}}$$

Definition of M:

Mutual inductance is the ratio of emf across the secondary coil to the rate of change of current in the

primary coil.

Unit:

Unit of Mutual Inductance is Henry "H"

$$M = \frac{\varepsilon_s}{\frac{\Delta I_p}{\Delta t}}$$

$$1H = \frac{\text{Volt}}{\frac{\text{Amp}}{\text{sec}}} = VA^{-1}S$$

Henry:

One henry is the mutual inductance of the pair of coils in which a rate of change of current of one ampere per second in the primary produces an induced emf of one volt in the secondary.

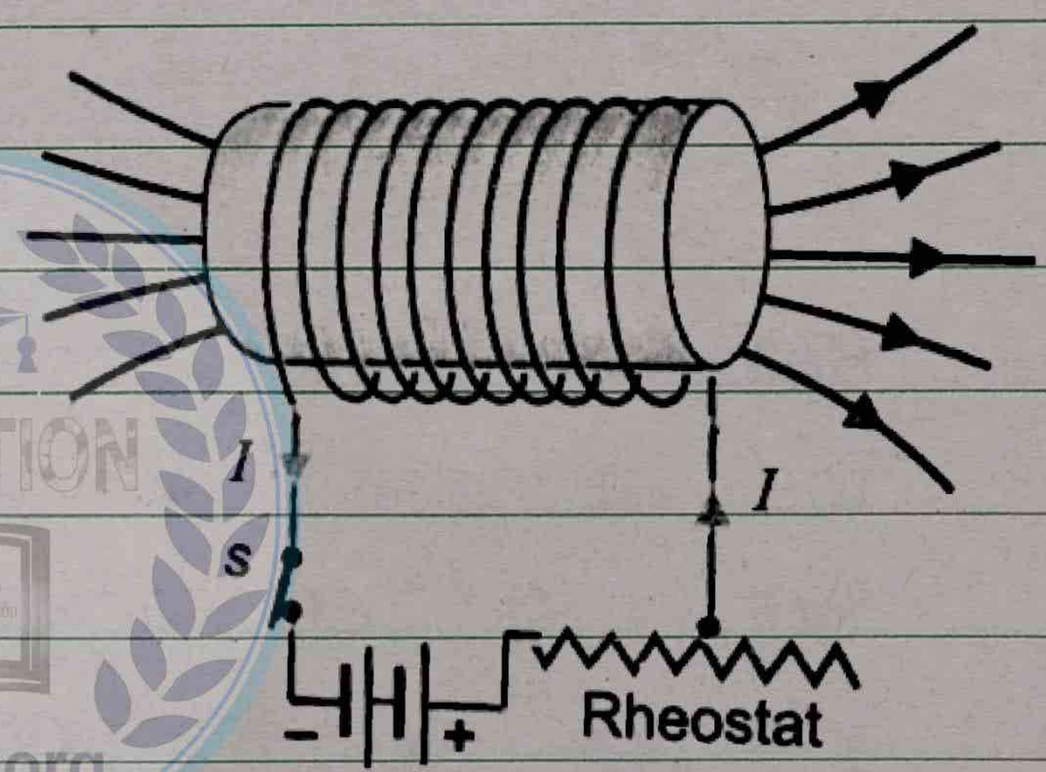
15.6 Self Induction

Definition:

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

Explanation:

Consider the circuit as shown in fig. A coil is connected in series with a battery and a rheostat. Magnetic flux is produced in the coil due to current in it.



The current is changed by changing the position of variable contact of the rheostat So the magnetic flux passing through the coil changes. Hence an emf is induced in the coil itself according to the Faraday's Law. This is called Self_Induced emf.

This emf is small as compared to the applied voltage. But the sign of induced emf is opposite to that of the applied

voltage. So the resultant emf in the circuit is some what less than the applied voltage

Let,

ϕ = Flux through one loop of coil.

$N\phi$ = Total flux through N_loops of the coil.

Flux = BA and $B \propto I$

Flux $\propto I$

$N\phi \propto I$

$N\phi$ = constant $\times I$ $\qquad$ L = constant

$N\phi = LI$

L is called Self_Inductance of the coil.

$$L = \frac{N\phi}{I}$$

Self_inductance depends upon

i) : The number of turns in the coil.

ii) : Area of crossection of the coil.

iii) : Material of the core upon which coil is wound.

iv) : Using a ferromagnetic material (iron) for the core, the magnetic flux and hence the inductance can be increased.

Using Faraday's Law, emf induced in the coil is.

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

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

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

Or

$$\varepsilon_L \propto -\frac{\Delta I}{\Delta t}$$

So,

Self induced emf is directly proportional to the rate of change of current in the same coil.

$$\boxed{L = \frac{\varepsilon_L}{\left(\frac{\Delta I}{\Delta t}\right)}} \longrightarrow (1)$$

Definition of Self Inductance:

"Self Inductance is the ratio of the average emf to the rate of change of current in the coil itself."

Its unit:

The SI unit of self inductance is VsA^{-1} which is equal to one henry. Its unit is henry (H).

Back emf:

The negative sign (equation 1) shows that the self Induced emf must oppose the change that produces it. This is the reason that self induced emf is sometime called as back emf.

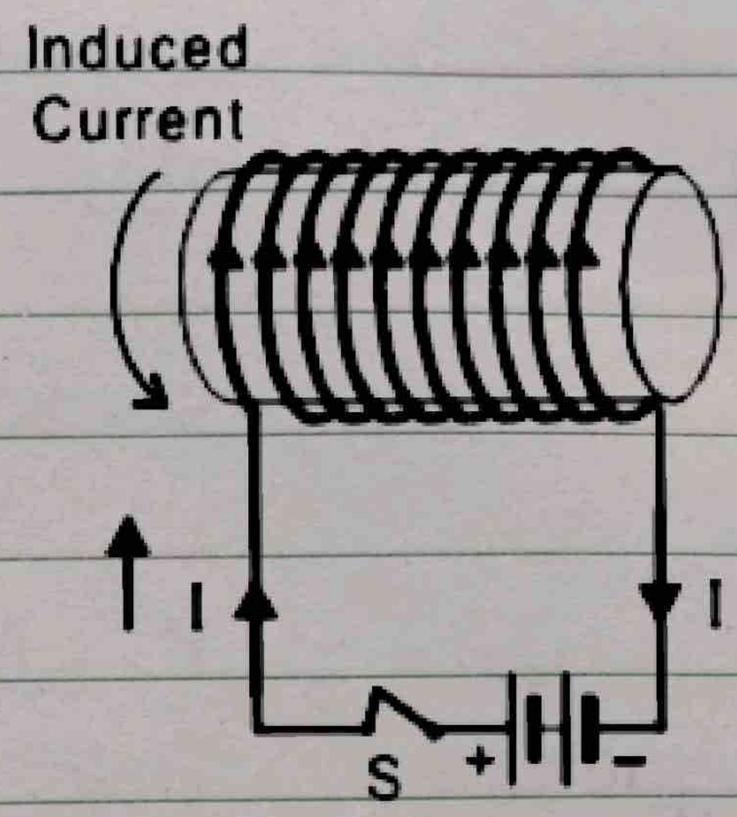
15.7 Energy stored in an Inductor

"Energy can be stored in electric field between the plates of the capacitor."
Similarly,
"Energy can be stored in the magnetic field of an inductor."

Explanation:

Consider a coil (inductor) is connected with a battery through a switch S. When the switch S is turned "ON", voltage "V" is applied across the ends of the coil and current rises from zero to its maximum valve. Due to change of current an emf is induced which is opposite to that of

battery. Work is done by the battery to move charge against the induced emf.



By definition

$$V = \frac{\Delta W}{\Delta q}$$

$$\varepsilon_L = \frac{\Delta W}{\Delta q}$$

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

$$\Delta W = \Delta q \cdot \varepsilon_L$$

$$\Delta W = \Delta q \cdot L\frac{\Delta I}{\Delta t}$$

$$\boxed{\Delta W = \frac{\Delta q}{\Delta t} \cdot L \cdot \Delta I} \longrightarrow (1)$$

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

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

Using above values in equation (1)

$$\Delta W = \frac{1}{2} I \cdot L \cdot I$$

$$\boxed{\Delta W = \frac{1}{2} L I^2}$$

This work done by the battery

against the action of induced emf is converted into energy stored in the coil.

$$\text{Energy stored} = U_m = \frac{1}{2} L I^2 \longrightarrow (2)$$

$U_m = \frac{1}{2} L I^2$ is the energy stored in the magnetic field of the current carrying coil.

Energy Stored U_m in terms of Magnetice field:

For a solenoid (coil) $\because B = \mu_o n I$

$$\text{Flux} = BA$$

$$\phi = \mu_o n I . A$$

But,

$$N\phi = LI$$

$$N(\mu_o n \cancel{I} . A) = L\cancel{I}$$

But, $\frac{N}{l} = n =$ Number of turns per unit length.

$$L = N . \mu_o n A$$

$N = nl$

So,

$$L = nl . \mu_o n A$$

$$\boxed{L = \mu_o n^2 (Al)} \longrightarrow (3)$$

Putting the value of "L" in eq.(2). we get

$$\boxed{U_m = \frac{1}{2} (\mu_o n^2 Al) I^2} \longrightarrow (4)$$

Since B for a solenoid is given by

$$B = \mu_0 n I, \quad I = \frac{B}{\mu_0 n}$$

These values put in equation (4).

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

Or,

$$\boxed{U_m = \frac{1}{2}\frac{B^2}{\mu_0}(Al)} \longrightarrow (5)$$

Where Al is the volume of solenoid.

Energy Density:

"Energy stored per unit volume is called energy density."

$$\text{Energy density} = \frac{U_m}{Al} = \frac{U_m}{\text{volume}} = \frac{\text{Energy}}{\text{volume}}$$

$$\text{Energy density} = \frac{1}{2}\frac{B^2}{\mu_0}$$

Unit:

Unit of energy density is $Joule.m^{-3}$.

15·8 Alternatig Current Generator

Definition:

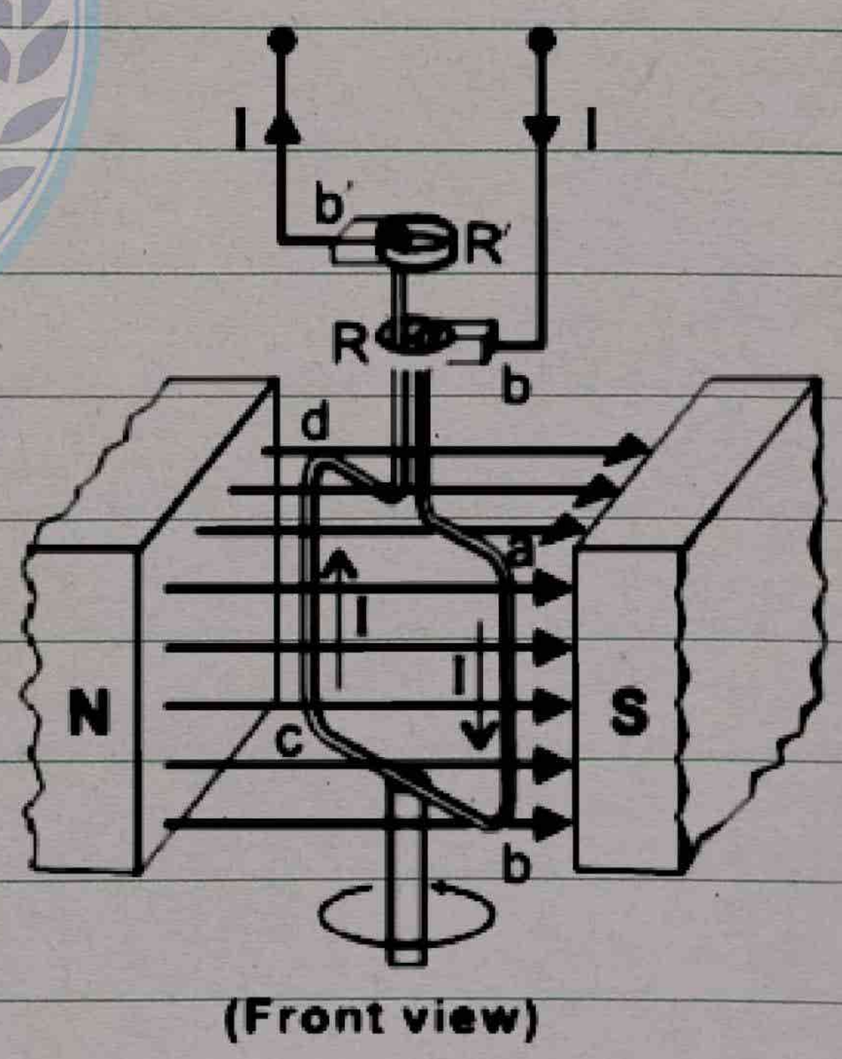
"A current generator is a device which converts mechanical energy into electrical energy."

Principle:

Current generator is based upon 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, as a result an emf is induced in the coil.

Construction and working:

A rectangular loop of wire is placed in a uniform magnetic field $\vec{B}$ as shown in fig. The loop is rotated about z_axis through its centre at constant angular velocity "ω". One end of the loop is attached to a metal ring R'. These rings are called slip



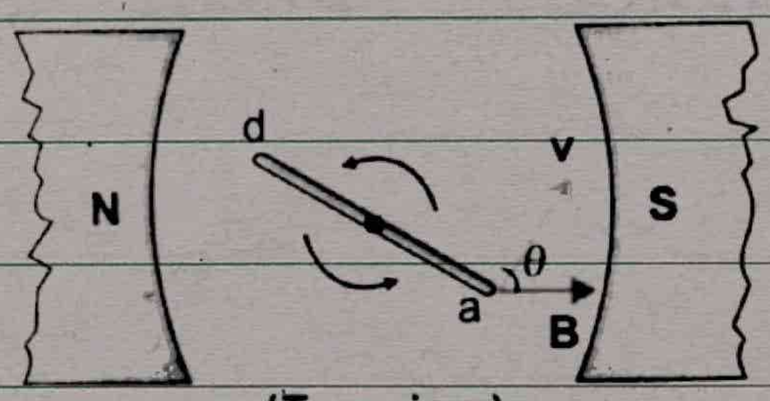
(Front view)

rings. They have their centres at the axis of rotation of the loop and rotate along with it.

Ring R, R′ slide (slip) against stationary carbon brushes B, B′. The brushes are connected.

Calculation of emf:

Consider the position of the coil as shown in fig. As it is rotating anticlockwise. The vertical side ab of the loop is moving with velocity "V" in the magnetic field "B". If angle between "V" and "B" is θ, than the motional emf in the side ab is.



(Top view)

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

$$\varepsilon_{bc} = vBL\sin(0) = 0$$

The direction of induced current in the wire is from top to bottom. It is found by the right hand rule of cross product $\vec{F} = q(\vec{v} \times \vec{B})$. Current flows in the direction of

Force $\vec{F}$ which acts on $+q$.

Same amount of emf is induced in the side cd but opposite direction i.e. from bottom to top.

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

$$\varepsilon_{ad} = vBL\sin(0) = 0$$

The net emf by the sides bc and da is zero, because the force acting on the charges inside bc and da is not along the wire.

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

Since both emf's in the sides ab and cd send current in the same direction in the loop. so the net emf in the loop is

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

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

$$\boxed{\varepsilon = 2vBL\sin\theta}$$

If there are "N" turns in the loop.

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

The linear speed "V" of the vertical wire is related to its angular speed ω as.

$$V = r\omega$$

So,

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

$$\varepsilon = B(2r \times L)N\omega . \sin\theta$$

$$\varepsilon = BAN\omega \sin\theta \longrightarrow (1)$$

$2r \times L = A$
Area of loop

Or,

$$\boxed{\varepsilon = BAN\omega \sin \omega t} \longrightarrow (2)$$

$\omega = \frac{\theta}{t}$
$\theta = \omega t$

This equation shows that the induced emf varies sinusoidally with time t. ε has maximum value $= \varepsilon_0$ when $\sin\theta = \sin\omega t = 1$

$$\varepsilon_0 = BAN\omega \longrightarrow (3)$$

Or,

$$\boxed{\varepsilon = \varepsilon_0 \sin \omega t} \longrightarrow (4)$$

Induced current in the coil is

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

$$I = I_0 \sin \omega t$$

$\because \omega = \frac{\theta}{t}$
$\theta = \omega t$

As,

$\varepsilon = \varepsilon_0 \sin 2\pi f t$ or $\varepsilon = \varepsilon_0 \sin\theta$ $\quad \theta = 2\pi f t$

$I = I \sin 2\pi f t$ or $I = I_0 \sin\theta \longrightarrow (5)$

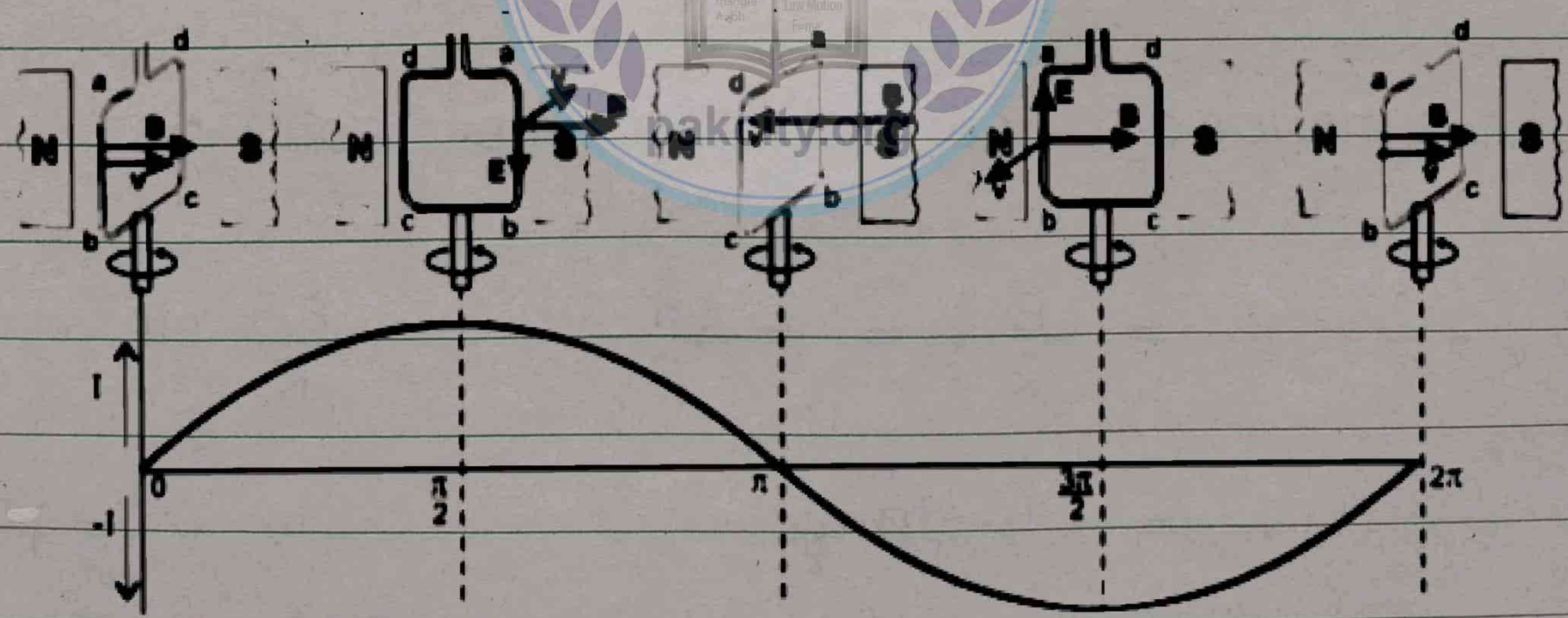
Current I depends upon $\theta = 2\pi Ft$

Current Verses Different Positions of one Loop of coil:

Fig shows the graph of current corresponding to different positions of one loop the coil. As θ increases from $0°$, current also increases.

1): When the angle between V and B is $\theta = 0°$ the plane of the loop is perpendicular to B, current is zero.

2): At $\theta = 90° = \frac{\pi}{2}$ rad, the plane of the loop is parallel to B. current is maximum directed along abcda.



On further increase in θ, current decreases.

3):

At $\theta = 180^\circ = \pi$ rad, The current becomes zero and the plane of the loop is again in perpendicular to "B".

4):

At $\theta = 270^\circ = \frac{3\pi}{2}$ red, current is maximum in the reverse direction as the loop is parallel to "B".

5):

At $\theta = 360^\circ = 2\pi$ red, one rotation is completed, the loop is perpendicular to "B" and the current decreases from -ve maximum value to zero.

After one rotation the cycle repeats itself.

Alternating Current:

The current alternates its direction once in one cycle therefore, such a current is called The alternating current which reverses in direction "f" per second.

Armature:

In an A.C generator, a number of coils are wound on iron cylinder. This cylinder is rotated in the magnetic field. This assembly of a number of coils is called Aamature.

Electromagnet :

The magnetic field is usually provided by an electromagnet. Armature is rotated by a fuel engnie or a turbine run by a water fall in some comercial generators, field magnet is rotated around stationary armature.

15.9 DC Generator

Definition:

"It is a device to produce direct current or direct emf."

It consists of commutator, magnet, armature and carbon brushes.

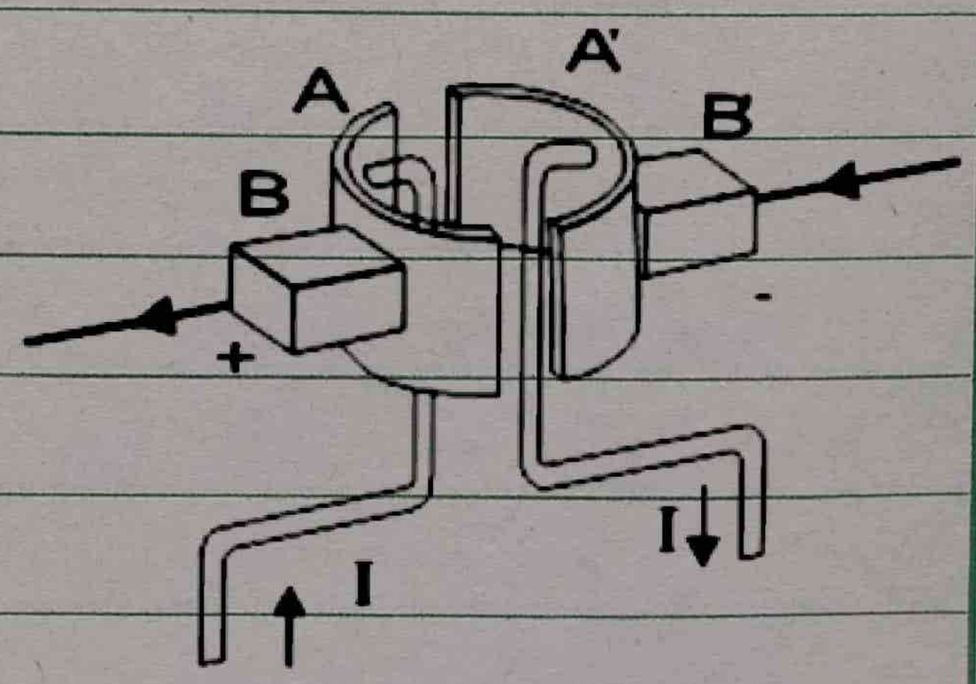
Commutator:

In 1834 Stugeron inventend a simple device called commutator that prevents the direction of current from changing.

Split Rings:

The construction of a DC Generator is similar as that of AC Generator. The only difference is that slip rings are replaced by split Rings. A, A'.

The split rings are two halves of a rings that act as a commutator. Fig shows the split rings A, A' attached to the two ends of the coil that rotates in the magnetic



field. When the current in the coil is zero and is about to change direction, the split rings A, A' interchange their contacts with the carbon brushes BB'

In this way electrical potential of one brush remains permanently positive and that of the other permanently negative.

Hence the output current from BB' remains in the same direction. Such a current is called DC. It is shown in fig. Although current is not constant in magnitude. The cure is shown in figure. It is similar to a sine curve with the lower half inverted.

The fluctuations of the out put can be significantly reduced by using many coil rather than a single coil.

Multiple coils are wound around a cylinderical core to form the armature. Each coil is attached to a seperate commutator. The out put of every coil is tapped only as it reaches its peak emf so that the out put current is almost constant.

15·10 Back Motor Effect in Generators

A generator is a source of electricity production.

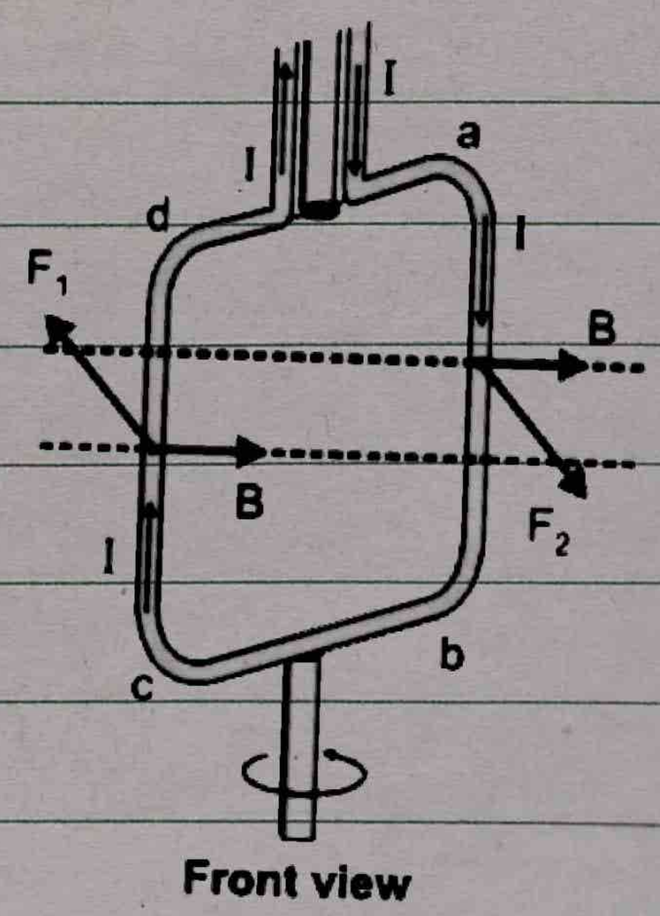
Turbine :

A large turbine is rotated by high pressure steam or waterfall. The shaft of the turbine is attached to the coil which rotates in a magnetic field. It converts the mechanical energy of the turbine to electrical energy. The generator supplies current to external circuit.

Load :

The devices in the circuit that consume electrical energy are known as the load. The greater the load the larger the current is supplied by the generator.

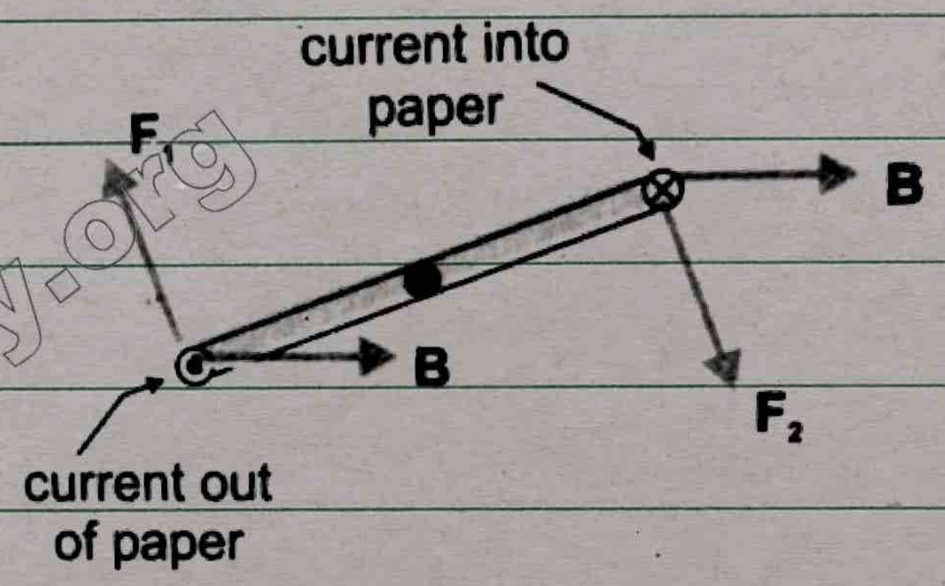
When the circuit is open the generator does not supply electrical energy and a very little force is needed to rotate the coil.



As soon as the circuit is closed, a current is drawn through the coil. The magnetic field exerts force on the current carrying coil.

Back Motor Effect:

Fig (b) shows the forces acting on the coil. Force F_1 is acting on the left side of the coil whereas on equal but opposite force F_2 acts on the right side of the coil. These forces are such that they produce a counter torque (opposing torque) that opposes the rotational motion of the coil. This effect is sometimes called as Back Motor Effect in the generators. When the large current is drawn from the generator, greater opposing torque is produced.



(b) Top view

Fig.

It means that move mechanical energy is required to keep the coil rotating with constant angular speed. This is in agreement with the law of conservation of energy.

15.11 DC Motor

Definition:

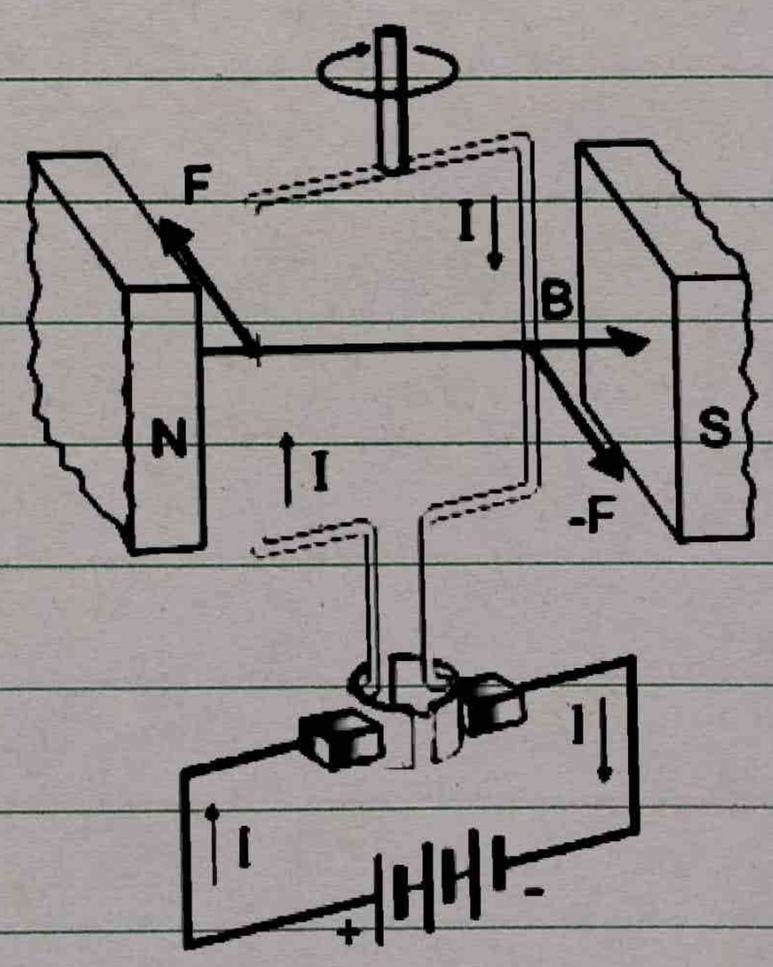
"It is a device which converts electrical energy into mechanical energy."

Principle:

When a current carrying wire is placed in a magnetic field, it experiences a force. This is the basic principle of an electric motor.

Construction and Working:

The construction of a dc motor is similar to a dc generator. A dc motor consists of a magnet, a commutator and an armature.



In the dc motor, the brushes are connected to DC supply or battery.

Armature Coil:

When the current flows through the armature coil, The force on the

conductors produces a toque that rotates the the armature. The amount of this toque depends upon the current, the strength of the magnetic field, the area of the coil and the number of turns of the coil. ($\tau = NIAB \cos\alpha$)

Commutator:

If the current in the coil were all the time in the same direction, the torque on it would be reversed after each half revolution. But at this moment, the commutator reverses the direction of the current that keeps the torque always in the same sense.

A little problem arises due to the use of commutator. That is the torque becomes zero each time the current changes its direction. This creates jerks in the smooth running of the armature. However the problem is solved by using more than one coil wrapped around a soft iron core. Hence a more steady torque is produced.

Field Coil:

The magnetic field in the motor is provided by a permanent magnet or an

electromagnet. The windings of the electromagnet are usually called field coils. The field coils may be in series or in parallel to the armatue coils.

15·12 Back EMF Effect in Motors

Motor:

"Motor is like a generator running in reverse."

Back EMF of the Motor:

When the coil of the motor rotates across the magnetic field, by the applied potential difference "V" an emf "ε" is induced in it. The induced emf is in opposite direction to the applied voltage "V". Due to this reason, induced emf is called Back EMF of the Motor.

The magnitude of the back emf increases with the increase of speed of motor.

Since V and ε are opposite in polarity,

$V - \varepsilon$ = net emf in the circuit.

If R is the resistance and I is the current drawn by the motor, then by ohm's law

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

$$IR = V - \varepsilon$$

$$V = \varepsilon + IR$$

When the motor is just started, back emf is almost zero ($\varepsilon = 0$). So large current passes through the coil.

As the motor speeds up, the back emf increases and the current becomes smaller and smaller. However, the current is sufficient to provide torque on the coil to drive the load and to overcome losses due to friction.

If the motor is overloaded, it slows down, consequently, the back emf decreases and allows the motor to draw more current. If the motor is overloaded beyond its limits, the current could be

so high that it may burn the motor out.

15.13 Transformer

Definition:

"A transformer is an electrical device to change a given alternating emf into a large or small alternating emf."

Principle:

It works on the principle of Mutual Induction between two coils.

Construction:

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 spplied is called primary coil and that from which power is delivered to the circuit is called secondary coil.

There is no electrical connection between the two coils but they are magnetically linked.

Working:

Suppose that an alternating emf is applied to the primary coil.

$\frac{\Delta\Phi}{\Delta t}$ = Rate of change of flux in the primary coil.

There will back emf induced in the primary which will oppose the applied voltage. The instantaneous value of the self-induced emf is

Self induced emf $= -N_p \frac{\Delta\phi}{\Delta t} =$ Back emf.

If the resistance of the coil is negligible, then the back emf is equal and opposite to applied voltage V_p.

$$V_p = -\text{Back emf} = -\left[N_p\left(\frac{\Delta\phi}{\Delta t}\right)\right]$$

$$\boxed{V_p = N_p \frac{\Delta\phi}{\Delta t}} \longrightarrow (1)$$

N_p = Number of turns primary

The changing flux due primary coil passes through the secondary coil.

$\frac{\Delta\phi}{\Delta t}$ = Rate of change of flux in the seconday coil.

Magnitude of induced emf in the secondary coil is.

$$V_s = N_s \frac{\Delta\phi}{\Delta t} \longrightarrow (2)$$

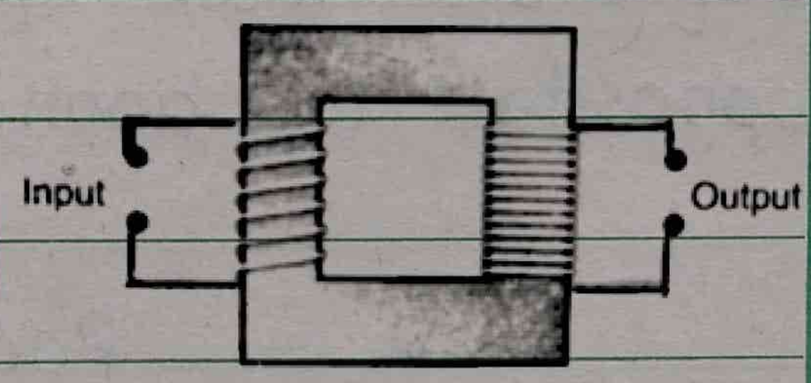
N_s = Number of turns in secondary coil.

Divide equation (2) by equation (1). we get.

$$\frac{V_s}{V_p} = \frac{N_s}{N_p} \longrightarrow (3)$$

1) Step up Transformer:

If $N_s > N_p$ then by equation (3) $V_s > V_p$. Such a transformer in which out put (secondary) voltage V_s is greater than the input (primary) voltage V_p is called a setp up transformer.

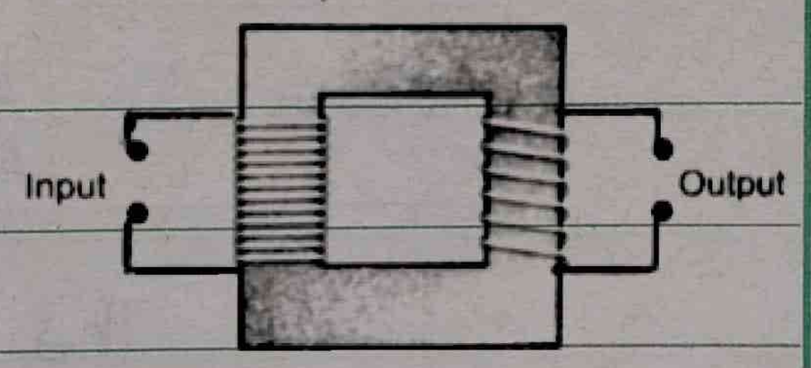


(a) Step up transformer

2) Step down Transformer:

If $N_s < N_p$, $V_s < V_p$

Such a transformer in which output (secondary) voltage V_s is less than the input (primary) voltage V_p is called a setp down tansformer.



(b) Step down transformer

Power of Transformer:

The transformer transfers electrical power from its primary to its secondary coil by means of changing magnetic flux.

For an ideal transformer.

power input = power output

$$V_p I_p = V_s I_s$$

$\because P = VI$

$$\boxed{\frac{V_s}{V_p} = \frac{I_p}{I_s}}$$

I_p and I_s are the currents in primary and secondary. The current are inversely proportional to their voltages.

$$\boxed{V \propto \frac{1}{I}}$$

Applications:

1): "A step up tansformer increases the voltage and decreases the current."

So, that the current can be transmitted over long distances without much power loss. This is the principle used in the electric supply networks.

Power loss by heating effect is I^2R and is reduced by decreasing the current.

Explanation :

Suppose R is the resistance of the transmission line. In order to minimize the power loss I^2R durring transmission, it is not possible to reduce R because it requires the use of thick copper wire which becomes highly uneconomical. The problem can be solved by decreasing "I"

At the generating power station the voltage is stepped up to several thousand volts, consequently the current is decreased significantly and power is transmitted to long distances with out much loss.

2): Step down transformer decrease the voltage to a safe value for consumer.

3): Inside a house transformer may be used to step down the voltage from 220v to 9v for running bell or operating a transistor radio.

4): Transformers with several secondaries are used in television and radio receivers where several different voltages are required.

Ideal Transformer:

In an ideal transformer the out put power is nearly equal to input power.

Actual Transformer:

In an actual transformer the output is always less than the input due to power loss. There are two main causes of power loss.

i) ; Eddy currents.

ii) ; Magnetic Hysteresis.

Soft IRON core:

In order to enhance the magnetic flux the primary and secondary coils of the transformer are wound on soft iron core. The flux generated by the coils also passes through the core.

i) Eddy Currents:

As magnetic flux changes through a solid conductor, induced currents are produced in closed paths in the body of the conductor. These induced currents are produced in a direction perpendicular to the flux and are known as eddy currents.

As a result power is dissipated and the core material is heated up.

How to minimize Power Loss:

In order to minimize the power loss due to the flow of eddy currents. the core is laminated with insulation in between the layers of laminations which stops the flow of eddy currents.

Hysterises:

Hysterises loss is the energy spent to magnetize and demagnetize the core material in each cycle of "AC".

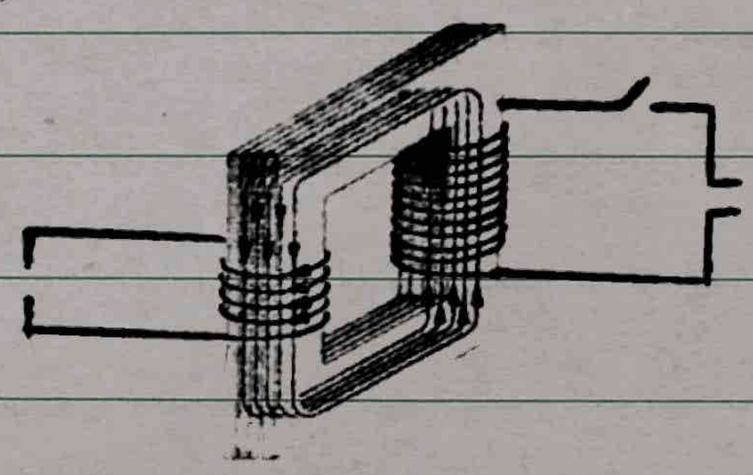


Fig.

Effeciency:

Due to the above mentioned power losses the out put power is always less than its input power. The effeciency of a transformer is defined as

$$E = \frac{\text{out put power}}{\text{in put power}} \times 100$$

∵ Effeciency of a real transformer is less than 100 %

To improve (increase) the effeciency.

i) : Resistance of the primary and secodary coils should be kept minimum.

ii) : The primary and secondary coils should be so wound in such away that flux coupling between them is maximum.

Chapter = 15

Questions

Question = 15.1

Answer:

Induced emf does not depend upon the resistance of the circuit. It depends upon the rate of charge of magnetic flux.

Induced emf $\propto$ Rate of Charge of magnetic flux.

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

$$\varepsilon = -N\frac{\Delta \phi}{\Delta t}$$ Faraday's Law.

Induced current $I = \frac{\varepsilon}{R}$ depends upon the resistance of the circuit.

Question = 15.2

Answer:

According to the given condition

of the question no magnetic flux charges through the squre loop of wire.

Charge in flux = 0

$\Delta\phi = 0$

According to the Faraday's law

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

$$\varepsilon = -N\frac{(0)}{\Delta t}$$

$$\varepsilon = 0$$

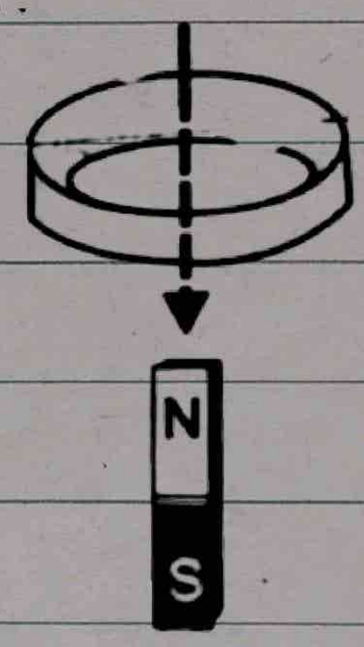
Hence

No emf is induced.

Question = 15.3

Answer :

When the ring is falling, there is a charge of magnetic flux across the ring and induced current is produced in the ring.



According to the Lenz's law the induced current in the current

ring should oppose the cause that produces it.

The magnetic field produced by the induced current in the ring will oppose the motion of the ring towards the bar-magnet.

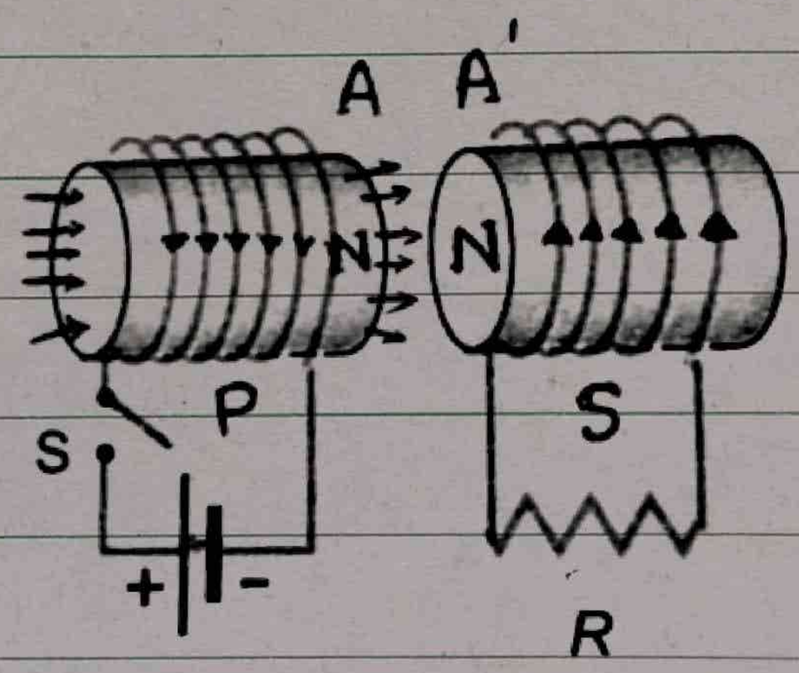
As viewed from above the current should be in the clockwise direction.

So a north-pole is formed on the face of the ring opposite to the N-pole of the bar magnet.

Question = 15.4

Answer:

(a) When the switch is closed, the current in the primary (P) increases from zero to maximum for a short interval of time. By the right hand rule to find the direction of magnetic field, the face A of the coil P becomes N-pole.



Induced current is produced in the secondary coil (S). By the Lenz's Law the direction of induced current should be such that it opposes the cause which produces it.

So, the face A' of the seconday coil S should also become a N-pole. So the direction of the current is shown in fig in the secondary coil. This current flows in the secondary coil for a short interval of time during which current in the primary coil changes from zero to maximum. When a steady current flows in the primary No current is produced in the secondary coil.

(b) When the switch S is oppened the current in the secondary coil is opposite to that shown in fig.

Question = 15.5

Answer:

No,

The induced emf does not always act to decrease the magnetic flux

throught a circuit.

In principle, the induced emf tries to oppose any change in the magnetic flux.

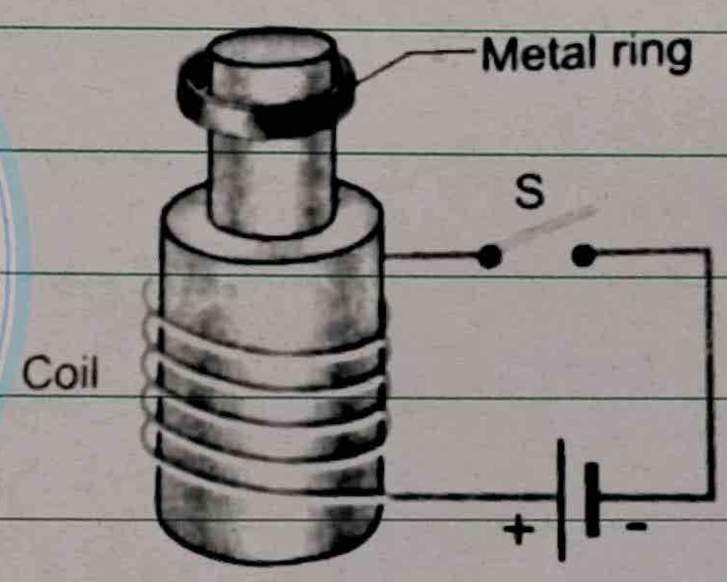
i) When the flux is increasing in a circuit, the induced emf acts to decrease it.

ii) When the flux is decreasing in a circuit, the induced emf acts to increase it.

Question = 15.6

Answer:

One closing the switch S, a magnetic field is produced in the coil and hence in the core.



This changing magnetic field produces an induced current in the metal ring which produces its own magnetic field. Both magnetic fields repel each other.

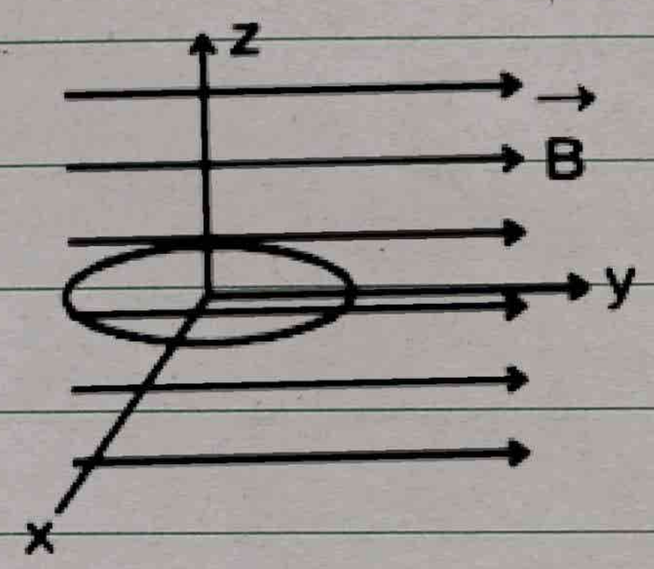
The ring is free to move so it

jumps up due to force of repulsion. This is in accordance with the Lenz's Law. If the polarity of the battery is reversed, the ring will jump again. The reason is same as above.

Question = 15.7

Answer:

The coil should rotate about x-axis. So that there is a change of magnetic flux and an induced current is produced in the coil.



Question = 15.8

Answer:

When the plane of the loop is parallel to the changing magnetic field, no magnetic flux passes through the loop. So the change of the flux is zero in the loop. Therefore, no induced emf is produced in it.

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

$$\varepsilon = -N \frac{0}{\Delta t} = -N(0)$$

$$\boxed{\varepsilon = 0}$$

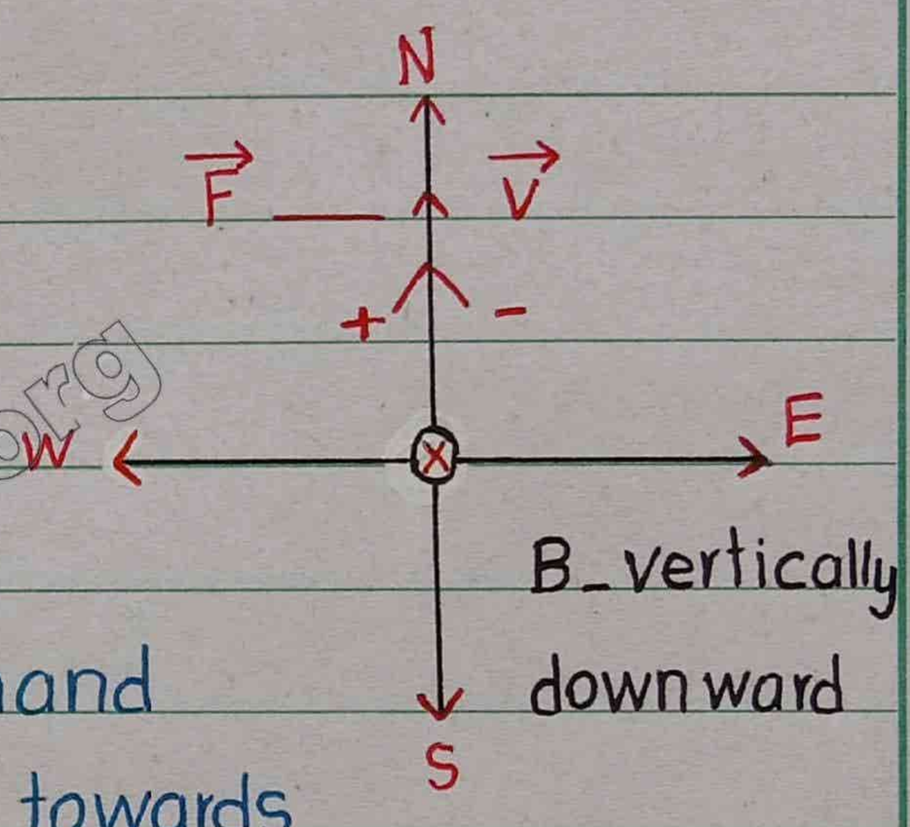
By Faraday's Law

Question = 15.9

Answer:

Magnetic force on a moving charge is

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



By using the right hand rule the direction of F is towards the west. So the west_wing tip is positively charged.

Question = 15.10

Answer:

As,

$$\varepsilon = \frac{\Delta W}{\Delta Q} \qquad \because W = \vec{F}.\vec{d}$$

$$J = N \times m$$

Unit of $\varepsilon = \frac{J}{C} = \frac{N \times m}{C} \longrightarrow (1)$

Unit of $\frac{\Delta \phi}{\Delta t} = \frac{\Delta(\vec{B}.\vec{A})}{\Delta t} = \frac{\text{Tesla} \times m^2}{S}$

Unit of $\frac{\Delta\phi}{\Delta t} = \frac{N}{A \times m} \times \frac{m^2}{S} = \frac{N \times m^2}{\frac{C}{S} \times m \times S}$ $\because$ Tesla $= \frac{N}{Am}$

$$\boxed{\frac{\Delta\phi}{\Delta t} = \frac{N \times m}{C}} \longrightarrow (2)$$

By eq (1) and (2) unit of ε and $\frac{\Delta\phi}{\Delta t}$ are equal.

Question = 15.11

Answer:

When an electric motor is used an induced emf is produced in the coil of the motor which is called "Back Emf". Hence the running electric motor behaves like a generator. The back emf opposes the external emf. Hence the current through the motor decreases.

Question = 15.12

Answer:

Yes,

A d.c motor can be converted into a d.c generator. The construction of a d.c motor and d.c generator is same.

To convert a d.c motor into d.c generator the armature coil of the motor is

rotated by some external means. Due to the rotation of the coil in the permanent magnet, the magnetic flux through the coil changes. Thus according to the Faraday's Law an emf is induced in the coil.

The induced current produced can be drawn to an external circuit from the carbon brushes which have connections with the split rings. Hence the mechanical energy is converted into electrical energy.

Question = 15.13

Answer:

By Faraday's Law

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

If change of flux is zero $\Delta\phi = 0$ induced emf is zero $\varepsilon = 0$.

As,

$$\Delta\phi = \Delta(\vec{B}.\vec{A}) = \Delta\vec{B}.\Delta\vec{A}$$

i); If ΔB is doubled and ΔA is halved then change in flux is zero $\Delta\phi = 0$ so $\varepsilon = 0$,

In general

"If B is increased at a certain rate and Area A is decreased at the same rate (and vice versa) then there is no change in magnetic flux $\Delta\phi = 0$ so, induced emf is also zero $\varepsilon = 0$."

Question = 15.14

Answer:

No,

It is the violation of Law of conservation of energy.

An electric generator connected with an electric motor forms sigle system. It requires external energy to run this system. With out providing external energy this system cannot work.

Question = 15.15

Answer:

Due to the oscillations of the magnet, the magnetic flux passing through the metallic plate changes.

This change of magnetic flux produces an induced emf and hence induced current or "eddy current" are produced in the metal plate.

The induced current produces its own magnetic field which always opposes the the motion of the magnet. This is according to the Lenz's Law. Hence the oscillatory motion of the bar magnet is damped.

Question = 15.16

Answer:

Two ends of the wire are the ends of the primary coil and the remaining two as the ends of the secondary coil.

i); First we use the ohmmeter to check the continuity of the pairs.

ii): We seperate them into two pairs, primary and secondary.

iii): The primary coil is connected to the known voltage V_P. Voltage across the secondary V_S in measured by the voltmeter. Then the ratio of the voltoges $\frac{V_S}{V_P}$ is equal to the turn ratio $\frac{N_S}{N_P}$.

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

Question = 15.17

Answer:

(a) A step-up transformer steps-up a.c voltages. It cannot step-up power, because it is against the Law of conservation of energy.

For an ideal transformer

Input power = Out put power

(b) Power is transferred from the primary to the secondary coil due to the

procss of "electromagnetic Induction."

Question = 15.18

Answer:

(a) When the secondary circuit is open then out put power will be zero. So the input power must be zero or very small. So a very small current flows in the primary.

(b) If the secondary circuit is closed and a load is applied across the secondary, then power is consumed in the secondary coil. It requires that same power must be supplied by the primary. Hence the current in the primary increases.

Chapter = 15

Examples

Example 15.1

Solution:

$L = 25\,cm$

$L = \frac{25}{100}\,m$

$L = 0.25\,m \quad = V = 0.5\,ms^{-1}$

$B = 0.25\,T$ $\qquad$ T = Tesla

$\theta = 90^\circ$

$\varepsilon = ?$

$\varepsilon = VBL\sin\theta$ $\qquad$ $\sin 90^\circ = 1$

$\varepsilon = VBL$

$\varepsilon = 0.5 \times 0.25 \times 0.25$

$$\varepsilon = 3.13 \times 10^{-2} \text{ volts.}$$

Example 15.2

Solution:

$$B = 0.6\ T$$

$$\frac{\Delta A}{\Delta t} = 0.8\ m^2 s^{-1}$$

$$N = 1$$

$$\varepsilon = ?$$

By Faraday's Law

$$\Phi = BA$$

$$\varepsilon = N \frac{\Delta \Phi}{\Delta t}$$

$$\varepsilon = N \frac{\Delta (BA)}{\Delta t}$$

$$\varepsilon = NB \frac{\Delta A}{\Delta t}$$

$$\varepsilon = 1 \times 0.6 \times 0.8$$

$$\varepsilon = 0.48 \text{ volts}$$

Example 15.3

Solution:

$\varepsilon_s = 5.6$ Volt

$\Delta I_p = 100A - 20A$

$\Delta I_p = 80A$

$\Delta t = 0.02s$

$M = ?$

$N_s = 100$

$\Delta\phi = ?$

$$\varepsilon_s = M \frac{\Delta I_p}{\Delta t}$$

$$5.6 = M \times \frac{80}{0.02}$$

$$M = \frac{5.6 \times 0.02}{80}$$

or

$$M = 1.4 \times 10 \, VsA^{-1}$$

$M = 1.4 \times 10^3$ Henry

By Faraday's law

$$\varepsilon_s = N_s \frac{\Delta \phi_s}{\Delta t}$$

$$\Delta \phi_s = \frac{\varepsilon_s \times \Delta t}{N_s}$$

$$\Delta \phi_s = \frac{5.6 \times 0.02}{200}$$

$$\boxed{\Delta \phi_s = 56 \times 10^{-4} \text{ Wb}}$$

Example 15.4

Solution:

$N = 1000$

$\Delta I = 5A - 0$

$\Delta I = 5A$

$\Delta t = 0.2 s$

$\varepsilon = 50$ volts

$L = ?$

$I = 6A$

$\phi = ?$

$$L = \frac{\varepsilon}{\Delta I / \Delta t}$$

$$L = \frac{50}{5/0.2}$$

$$L = \frac{50 \times 0.2}{5}$$

$L = 2$ Henry

$N\phi = LI$

$$\phi = \frac{LI}{N}$$

$$\phi = \frac{2 \times 6}{1000}$$

$$\boxed{\phi = 1.2 \times 10^{-2} \text{ Wb}}$$

Example 15.5

Solution:

$L = 10\ cm$

$L = \frac{10}{100}\ m$

$L = 0.10\ m$

$n = 40\ per\ cm$

$n = \frac{40}{cm}$

$n = \frac{40}{10^{-2}\ m}$

$n = \frac{4000}{m}$

$n = 4000\ per\ m$

$I = 5A$

$U_m = ?$ $\qquad 1cm = 10^{-2} m$

$A = 28\ cm^2$ $\qquad (1\ cm)^2 = (10^{-2}\ m)^2$

$A = 28 \times 10^{-4}\ m^2$ $\qquad 1cm^2 = 10^{-4} m^2$

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

$$L = 4\pi \times 10^{-7} \times (4000)^2 \times 28 \times 10^{-4} \times 0.10$$

$$L = 5.63 \times 10^{-3} \text{ Henry}$$

$$U_m = \frac{1}{2} L I^2$$

$$U_m = \frac{1}{2} \times 5.63 \times 10^{-3} \times (5)^2$$

$$\boxed{U_m = 7.04 \times 10^{-2} \text{ J}}$$

Example 15.6

Solution:

$f = 50$ Hz

$1 cm = 10^{-2} m$

$N = 200$

$1 cm = 10^{-4} m^2$

$A = 120 \text{ cm}^2$

$A = 120 \times 10^{-4} \text{ m}^2$

$\varepsilon_o = \varepsilon_{(max)} = 240$ volts

$B = ?$

$\omega = 2\pi f$

$\omega = 2 \times \frac{22}{7} \times 50$

$\omega = 314.3 \ rad s^{-1}$

$\varepsilon_o = BAN\omega$

$B = \frac{\varepsilon_o}{AN\omega}$

$B = \frac{240}{120 \times 10^{-4} \times 200 \times 314.3}$

$B = 0.32 \ T$

T = Tesla

Example 15.7

Solution:

$V = 24V$

$R = 2\,\Omega$

$\varepsilon = 22.5\,V$ Back emf

$I = ?$

(i) When motor just starts up

back emf

$\varepsilon = 0$

As

$V = \varepsilon + IR$

$V = 0 + IR$

$I = \frac{V}{R} = \frac{24}{2}$

$I = 12\,A$

(ii) When the motor runs at normal speed

$\varepsilon = 22.5\,V$

$V = \varepsilon + IR$

$V - \varepsilon = IR$

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

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

$$I = \frac{24 - 22.5}{2}$$

$$I = 0.75\,A$$

Example 15.8

Solution:

$$\frac{N_s}{N_p} = 50$$

$$I_p = 20A$$

$$V_p = 220 \text{ Volts}$$

$$V_s = ?$$

$$I_s = ?$$

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$\frac{V_s}{220} = 50$$

$$V_s = 220 \times 50$$

$$V_s = 11000 \text{ volts}$$

$$\frac{V_s}{V_p} = \frac{I_p}{I_s}$$

$$I_s = I_p \times \frac{V_p}{V_s}$$

$$I_s = 20 \times \frac{220}{11000}$$

$$I_s = 0.4 \text{ A}$$

Chapter = 15

Problems

Problem 15.1

Solution:

$\varepsilon_1 = 0.45\,V$ $\qquad$ $B_1 = 0.22\,T$

$\varepsilon_2 = 1.5\,V$ $\qquad$ $B_2 = ?$

Velocity v, Length L and angle θ remains same.

As

$$\varepsilon = VBL\sin\theta$$

$$\varepsilon_1 = VB_1L\sin\theta \longrightarrow (1)$$

$$\varepsilon_2 = VB_2L\sin\theta \longrightarrow (2)$$

Divide eq (1) and (2)

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{VB_1L\sin\theta}{VB_2L\sin\theta}$$

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{B_1}{B_2}$$

$$B_2 = B_1 \times \frac{\varepsilon_2}{\varepsilon_1}$$

$$B_2 = 0.22 \times \frac{1.5}{0.45}$$

$$\boxed{B_2 = 0.73\,T}$$

Problem 15.2

Solution:

$B = 0.5\ Wb\ m^{-2}$ (vertically downward)

$\varepsilon = ?$

$L = 5\,cm$

$L = \frac{5}{100}\ m$

$L = 0.05\ m$

$V = 100\ cm\ s^{-1}$

$V = 1\ m\ s^{-1}$

$\theta = 60^\circ$ with horizontal

$\theta = 90^\circ - 60^\circ$

$\theta = 30^\circ$ with $\vec{B}$ (vertical)

$\varepsilon = VBL\sin\theta$

$\varepsilon = 1 \times 0.5 \times 0.5 \times \sin 30^\circ$

$$\boxed{\varepsilon = 1.25 \times 10^{-2}\ V}$$

Problem 15.3

Solution:

$N = 10$

$A = 1.5 \times 10^{-3}\ m^2$

$B_i = 0.05\ T$

$B_f = 0.06T$

$\Delta B = B_f - B_i$

$\Delta B = 0.06T - 0.05T$

$\Delta B = 0.01T$

$\Delta t = 0.1S$

$\varepsilon = ?$

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

$$\varepsilon = N \frac{\Delta (BA)}{\Delta t}$$

$$\varepsilon = N \times \frac{A \Delta B}{\Delta t}$$

$$\varepsilon = 10 \times \frac{1.5 \times 10^{-3} \times 0.01}{0.1}$$

$$\boxed{\varepsilon = 1.5 \times 10^{-3} V}$$

Problem 15.4

Solution:

$N = 15$

$r = 2cm$

$r = \frac{2}{100} m$

$r = 0.02m$

Angle between the plane of the coil and $\vec{B} = 40^\circ$

Angle between the normal to the plane of coil $\vec{A}$ and $\vec{B}$

$\theta = 90^\circ - 40^\circ$

$\theta = 50^\circ$

$B_i = 0.2T$

$B_f = 0.5T$

$\Delta B = B_f - B_i$

$\Delta B = 0.5T - 0.2T$

$\Delta B = 0.3T$

$\Delta t = 0.2S$

$\varepsilon = ?$

$\varepsilon = N \frac{\Delta \phi}{\Delta t}$ $\quad (\phi = \vec{B} \cdot \vec{A}$

$\varepsilon = N \times \frac{\Delta (\vec{B} \cdot \vec{A})}{\Delta t}$

$\varepsilon = N \times \frac{\Delta \vec{B} \cdot \vec{A}}{\Delta t}$

$\varepsilon = N \times \frac{\Delta B \pi r^2 \cos\theta}{\Delta t}$

$\varepsilon = 15 \times \frac{0.3 \times 3.14 \times (0.02)^2 \cos 50^\circ}{0.2}$

$\boxed{\varepsilon = 1.82 \times 10^{-2} V}$

Problem 15.5

Solution:

$$\varepsilon = 0.8V$$

$$\frac{\Delta IP}{\Delta t} = 200\ As^{-1}$$

$$M = ?$$

$$\varepsilon = M \frac{\Delta IP}{\Delta t}$$

$$M = \frac{\varepsilon}{\Delta IP / \Delta t}$$

$$M = \frac{0.8}{200}$$

$$M = 4 \times 10^{-3}\ H$$

$$M = 4\ mH$$

$$M = 4 \text{ milli Henry.}$$

Problem 15.6

Solution:

$M = 0.75\ H$

$\Delta I_p = 10A - 0$

$\Delta I_p = 10A$

$\Delta t = 0.025s$

$\varepsilon_s = ?$

$\Delta \phi_s = ?$

$N_s = 500$

$$\varepsilon_s = M \frac{\Delta I_p}{\Delta t}$$

$$\varepsilon_s = 0.75 \times \frac{10}{0.025}$$

$\varepsilon_s = 300V$

By Faraday's Law

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

$$\varepsilon_s = N_s \frac{\Delta \phi_s}{\Delta t}$$

$$\Delta \phi_s = \frac{\varepsilon_s \times \Delta t}{N_s}$$

$$\Delta \phi_s = \frac{300 \times 0.025}{500}$$

$$\boxed{\Delta \phi_s = 1.5 \times 10^{-2}\ Wb}$$

Problem 15.7

Solution:

$N = 200$

$L = 2.5\ mH$

$L = 2.5 \times 10^{-3}\ H$

$\phi = ?$ (flux through one turn)

$I = 2A$

$\varepsilon = ?$

$$\frac{\Delta I}{\Delta t} = 20\ As^{-1}$$

Flux through N turns

$$N\phi = LI$$

$$\phi = \frac{LI}{N}$$

$$\phi = \frac{2.5 \times 10^{-3} \times 2}{200}$$

$$\phi = 1.92 \times 10^{-5}\ Wb$$

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

$$\varepsilon = 2.4 \times 10^{-3} \times (20)$$

$$\varepsilon = 48 \times 10^{-3}\ V$$

$$\boxed{\varepsilon = 48\ mV}$$

Problem 15.8

Solution:

$$L = 8cm$$

$L = \frac{8}{100} m$

$L = 0.08 m$

$A = 0.5 cm^2$

$A = 0.5 \times 10^{-4} m^2$

$N = 520$

$\mu_o = 4\pi \times 10^{-7} Wb A^{-1} m^{-1}$

$\Delta I = 1.5 A$

$\Delta t = 0.2 S$

$L = ?$

$\varepsilon = ?$

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

$n = \frac{520}{.08m}$

$n = 6500 m^{-1}$

$L = \mu_o n^2 (LA)$

$$L = 4\pi \times 10^{-7} \times (6500)^2 \times 0.08 \times .5 \times 10^{-4}$$

$$L = 2.12 \times 10^{-4}\ H$$

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

$$\varepsilon = 2.12 \times 10^{-4} \times \frac{1.5}{0.2}$$

$$\boxed{\varepsilon = 1.6 \times 10^{-3}\ V}$$

Problem 15.9

Solution:

$$I_i = 100\ mA$$

$$I_i = 100 \times 10^{-3}\ A$$

$$I_i = 0.1\ A$$

$$I_f = 200\ mA$$

$$I_f = 200 \times 10^{-3}\ A$$

$I_f = 0.2\ A$

$\Delta I = I_f - I_i$

$\Delta I = 0.2A - 0.1A$

$\Delta I = 0.1A$

$\Delta t = 0.005\ s$

$\varepsilon = 40\ mV$

$\varepsilon = 40 \times 10^{-3}\ V$

(a) $L = ?$

(b) $\Delta u_m = ?$

(a) $\varepsilon = L \dfrac{\Delta I}{\Delta t}$

$L = \dfrac{\varepsilon}{\Delta I / \Delta t}$

$L = \dfrac{40 \times 10^{-3}}{0.1 / 0.005}$

$$L = \frac{40 \times 10^{-3} \times 0.005}{0.1}$$

$$L = 2 \times 10^{-3}\ H$$

$$L = 2\ mH$$

As

(b) $$\Delta U_m = \frac{1}{2} L I^2$$

$$\Delta U_m = (U_m)_f - (U_m)_i$$

$$\Delta U_m = \frac{1}{2} L I_f^2 - \frac{1}{2} L I_i^2$$

$$\Delta U_m = \frac{1}{2} L (I_f - I_i)$$

$$\Delta U_m = \frac{1}{2} \times 2 \times 10^{-3} \left((0.2)^2 - (0.1)^2 \right)$$

$$\Delta U_m = 1 \times 10^{-3} (0.04 - 0.01)$$

$$\Delta U_m = 10^{-3} (0.03)$$

$$\boxed{\Delta U_m = 3 \times 10^{-5}\ J}$$

Problem 15.10

Solution:

$U_m = ?$

$B = 7 \times 10^{-5}\ T$

$A = 10 \times 10^{8}\ m^2$

$L = 750\ m$ (height)

$U_m = \frac{1}{2} \frac{B^2}{\mu_0} (AL)$

$U_m = \frac{1}{2} \times \frac{(7 \times 10^{-5})^2}{4\pi \times 10^{-7}} (10 \times 10^{8} \times 750)$

$U_m = 1.46 \times 10^{9}\ J$

Problem 15.11

Solution:

$A = 16cm \times 16cm$

$$A = \frac{16}{100} m \times \frac{16}{100} m$$

$$A = 0.16 \times 0.16 \, m^2$$

$$A = 2.56 \times 10^{-2} \, m^2$$

$N = 200$

$B = 0.05T$

$\varepsilon_0 = 12V$ Maximum or peak value

$\omega = ?$

$$\varepsilon_0 = BAN\omega$$

$$\omega = \frac{\varepsilon_0}{BAN}$$

$$\omega = \frac{12}{0.05 \times 2.56 \times 10^{-2} \times 200}$$

$$\boxed{\omega = 46.9 \, rad s^{-1}}$$

Problem 15.12

Solution:

$N = 360$

$\omega = 420$ rev per min

$\omega = 420 \ \frac{rev}{min}$

As

$1 \text{ rev} = 2\pi \text{ rad}$

$\omega = \frac{420 \times 2\pi \text{ rad}}{60s}$

$\omega = 43.98 \text{ rad } s^{-1}$

$B = 0.14 \text{ T}$

$\varepsilon_0 = 50 \text{ V}$ Peak or maximum value

$W = 5 \text{ cm}$

$W = 0.05 \text{ m}$ (Width)

$L = ?$ Length

$\varepsilon_0 = BAN\omega$

$$A = \frac{\varepsilon_0}{BN\omega}$$

$$A = \frac{50}{0.14 \times 360 \times 43.98}$$

$$A = 0.0226\ m^2$$

Area = Length x Width

$$A = LW$$

$$L = \frac{A}{W}$$

$$L = \frac{0.0226\ m^2}{5 \times 10^{-2}\ m}$$

$$L = 0.45\ m$$

$$L = .45 \times 10\ cm$$

$$\boxed{L = 45\ cm}$$

Problem 15.13

Solution:

$\varepsilon_0 = 5\,KV$

$\varepsilon_0 = 5 \times 10^3\,V$

$\varepsilon_0 = 5000\,V$

$f = 50\,Hz$ $\qquad A = 1\,m^2$

$B = ?$ $\qquad N = 200$

$\varepsilon_0 = BAN\omega$

$B = \dfrac{\varepsilon_0}{AN\omega}$ $\qquad \omega = 2\pi f$

$B = \dfrac{\varepsilon_0}{AN2\pi f}$

$B = \dfrac{5000}{1 \times 200 \times 2 \times \pi \times 50}$

$B = 0.079\,T$

$B = 0.8\,T$

Problem 15.14

Solution:

$\varepsilon_1 = 120V$

$\omega_1 = 1680 \text{ rev.min}^{-1}$

$\varepsilon_2 = ?$

$\omega_2 = 3360 \text{ rev min}^{-1}$

As

$$\varepsilon = BAN\omega$$

$$\varepsilon_1 = BAN\omega_1$$

$$\varepsilon_2 = BAN\omega_2$$

$$\frac{\varepsilon_2}{\varepsilon_1} = \frac{\cancel{BAN}\omega_2}{\cancel{BAN}\omega_1}$$

$$\varepsilon_2 = \frac{\omega^2}{\omega_1}$$

$$\varepsilon_2 = \frac{\omega_2}{\omega_1} \times \varepsilon_1$$

$$\varepsilon_2 = \frac{3360 \text{ rev min}^{-1}}{1680 \text{ rev min}^{-1}} \times 120V$$

$$\varepsilon_2 = 2 \times 120V$$

$$\boxed{\varepsilon_2 = 240V}$$

Problem 15.15

Solution:

$V = 240V$

$R = 0.5\ \Omega$

$I = 15A$

$\varepsilon = ?$ (Back emf)

$V = \varepsilon + IR$

$\varepsilon = V - IR$

$\varepsilon = 240 - 15 \times 0.5$

$\varepsilon = 240 - 7.5$

$$\boxed{\varepsilon = 232.5V}$$

Problem 15.16

Solution:

$r = 4\,cm$

$r = \frac{4}{100}\,m$

$r = 0.04\,m$

$R = 1.0\,m\,\Omega$

$R = 1 \times 10^{-3}\,\Omega$

$B_i = 0.2T$

$B_f = 0.4T$

$\Delta B = B_f - B_i$

$\Delta B = 0.4T - 0.2T$

$\Delta B = 0.2T$

$\Delta t = 5 \times 10^{-3}\,s$

$I = ?$

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

N = 1 turn

$$\varepsilon = N \frac{\Delta \Phi}{\Delta t}$$

$$\varepsilon = \frac{\Delta \Phi}{\Delta t}$$

$$\varepsilon = \frac{\Delta (BA)}{\Delta t}$$

$$\varepsilon = \frac{(\Delta B) A}{\Delta t}$$

$$\varepsilon = \frac{\Delta B \pi r^2}{\Delta t}$$

$$\varepsilon = \frac{0.2 \times (3.14) \times (0.04)^2}{5 \times 10^{-3}}$$

$$\varepsilon = 0.2 V$$

$$I = \frac{\varepsilon}{R} = \frac{0.2}{1 \times 10^{-3}}$$

$$I = 200 A$$

Problem 15.17

Solution:

$N = 10$

$A = 35\,cm^2$

$A = 35 \times 10^{-4}\,m^2$

$\Delta B = 0.5\,T - 0$

$\Delta B = 0.5\,T$

$\Delta t = 1.0\,s$

$\varepsilon = ?$

$$\varepsilon = \frac{N\,\Delta\Phi}{\Delta t} = N\,\frac{\Delta(BA)}{\Delta t}$$

$$\varepsilon = N\,\frac{\Delta BA}{\Delta t}$$

$$\varepsilon = 10 \times \frac{0.5 \times 35 \times 10^{-4}}{1}$$

$$\boxed{\varepsilon = 1.75 \times 10^{-2}\,V}$$

Problem 15.18

Solution:

$V_p = 240$

$V_s = 12\,V$

$P_s = 30\,W$ (Power at secondary)

$I_p = ?$

$\frac{N_s}{N_p} = ?$

Power at primary = Power at secondary

$P_p = P_s$

$V_p I_p = P_s$

$I_p = \frac{P_s}{V_p} = \frac{30W}{240V}$

$I_p = 0.125\,A$

Transformation ratio $= \frac{N_s}{N_p}$

$\frac{N_s}{N_p} = \frac{V_s}{V_p}$

$$\frac{N_s}{N_p} = \frac{12V}{240V}$$

$$\boxed{\frac{N_s}{N_p} = \frac{1}{20}}$$