PART – IV : ELECTROMAGNETIC INDUCTION AND ALTERNATING CURRENTS

CHAPTER 6 ELECTROMAGNETIC INDUCTION

Syllabus

- *Electromagnetic induction; Faraday's laws, induced emf and current; Lenz's Law.*
- *Eddy currents, Self and mutual induction.*

Revision Notes

Electric Field and Dipole

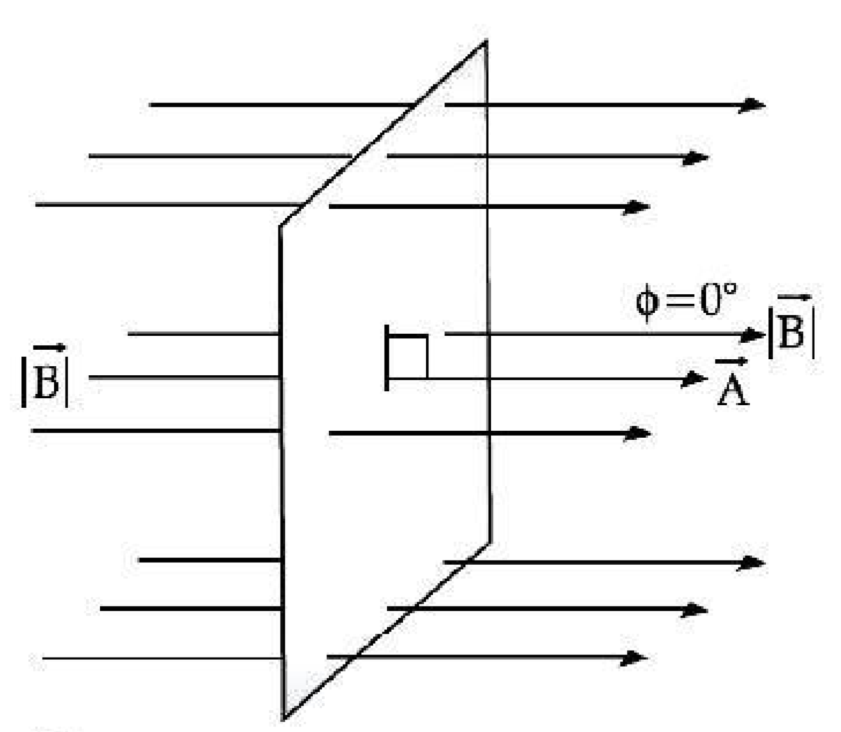
(a) Concept Notes

Electromagnetic induction

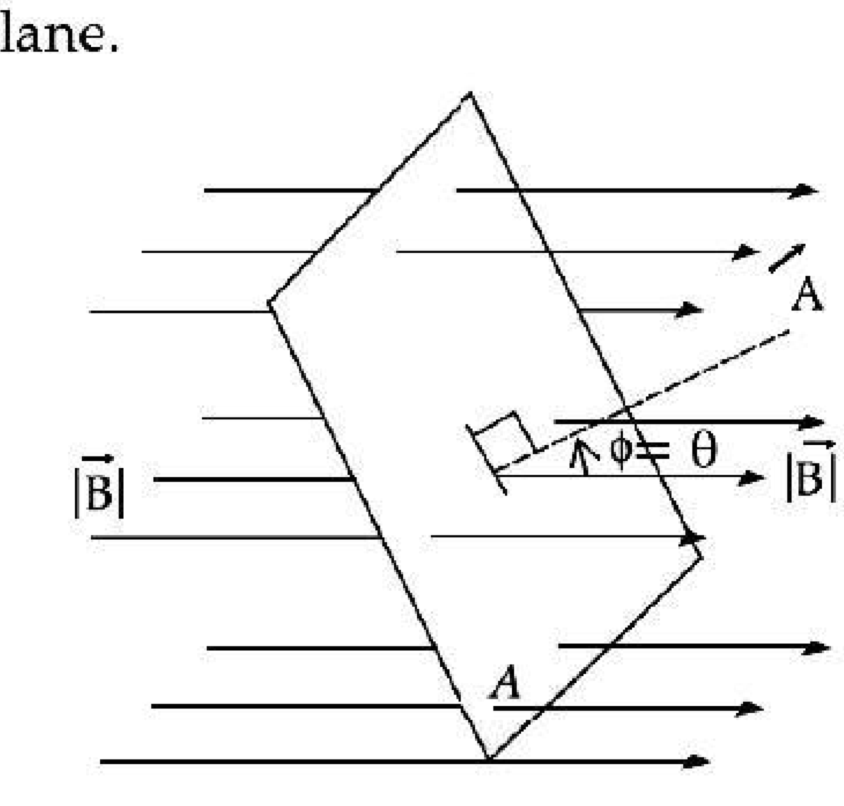
- Electromagnetic induction is the process of generating the electric current with a changing magnetic field.
- It takes place whenever a magnetic field is changing or electric conductors move relative to one another when they are in fluctuating magnetic field.
- The current produced by electromagnetic induction is more when the magnet or coil moves faster. When magnet or coil moves back and forth repeatedly, then alternating current is produced.

Magnetic flux:

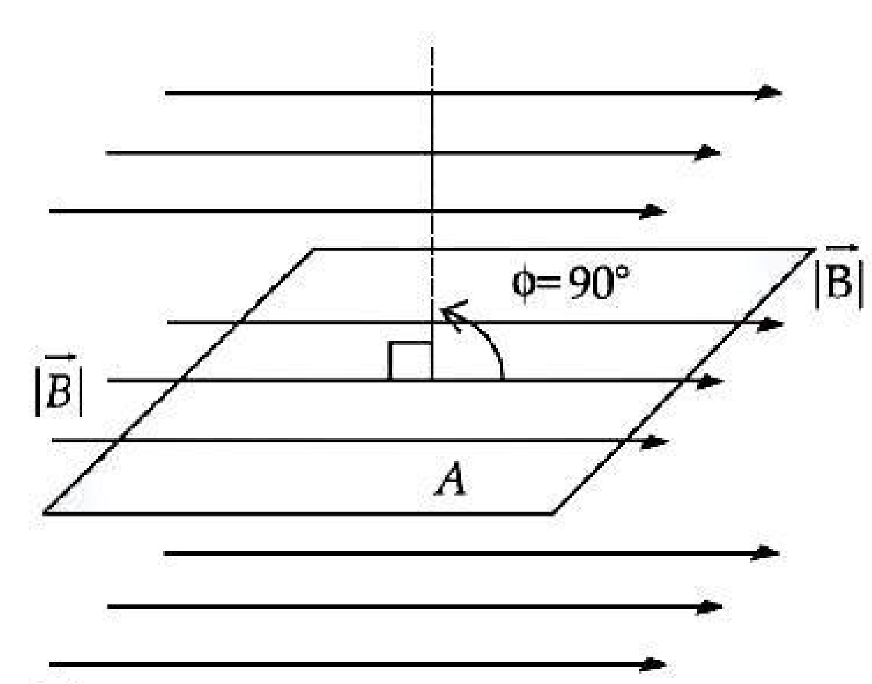
- Magnetic flux through an enclosed area is the number of magnetic field lines cutting through a surface area *A*, defined by unit area vector.
- The unit of magnetic flux is weber, where, 1 Wb = 1 T/m^2.
- Magnetic flux (ϕ_B) is related to number of field lines passing through a given area.
- If magnetic field is changing, the changing magnetic flux will be $\phi_B = NBA \cos\theta$, where θ is the angle between magnetic field and normal to the plane.



$\vec{B}$ parallel to A (ϕ= 0°)
magnetic flux ϕ_B = BA.



$\vec{B}$ at an angle ϕ with the perpendicular to A :
magnetic flux ϕ_B = BA cosθ



$\vec{B}$ perpendicular to A (ϕ=90°) :
magnetic flux ϕ_B = 0.

Electromagnetic Induction

Trace the Mind Map
- First Level
- Second Level
- Third Level

In 1831, Michael Faraday discovered electromagnetic induction and James Clerk Maxwell mathematically described it.

Faraday's law of electromagnetic induction

1. Whenever magnetic flux through an area bounded by a closed conducting loop changes, an emf is produced in the loop.
2. The emf is given by $E = -\,d\phi/dt$ where $\phi = \int \vec{B}.\vec{ds}$ is the magnetic flux through the area.

Mutual induction

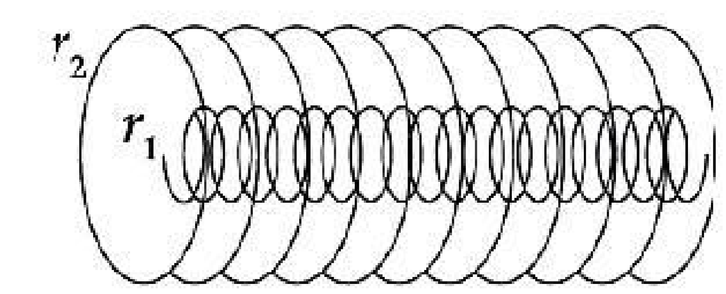
$\phi = Mi$

$\dfrac{d\phi}{dt} = -M\dfrac{di}{dt}$

$M_{12} = \mu_0\, n_1 n_2\, \pi r_1^2 l$

$M_{21} = \mu_0 n_1 n_2\, \pi r_2^2 l$

Emf induced in an AC generator, $E = NBA\omega \sin \omega t$



Lenz's law

The direction of the induced current is such that it opposes the change that has induced it.

Self induction

If we consider a solenoid of N turns, the flux through each turn, $\phi = \int \vec{B}.\vec{ds}$.
EMF induced between the ends of coil, $E = -N\dfrac{d}{dt}\int \vec{B}.\vec{ds}$

Self inductance of long solenoid

$L = \mu_0 n^2 \pi r^2 l$

n = Number of turns per unit length

ϕ = Flux = $(\mu_0 ni)\, \pi r^2$

r = Radius of each loop of solenoid

- **Growth of current in LR Circuit**

  $i = \dfrac{E}{R}(1 - e^{tR/L}) = i_0\,(1 - e^{-t/\tau})$

- **Decay of current**

  $i = i_0 e^{-t/\tau}$

- **Energy stored in an Inductor**

  $U = \dfrac{1}{2}Li^2$

Eddy current

It is induced when magnetic flux linked with the conductor changes.

Induced current

$I = \dfrac{E}{R} = -\dfrac{1}{R}\dfrac{d\phi}{dt}$

Induced EMF

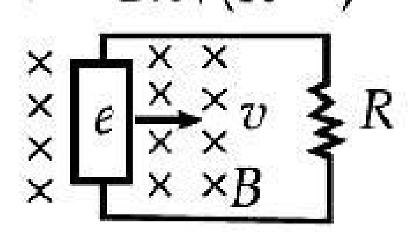
$E = \dfrac{-d\phi}{dt}$

Motional EMF

$E = \left|\dfrac{d\phi}{dt}\right| = \left|Bl\dfrac{dx}{dt}\right|$

$= Blv$

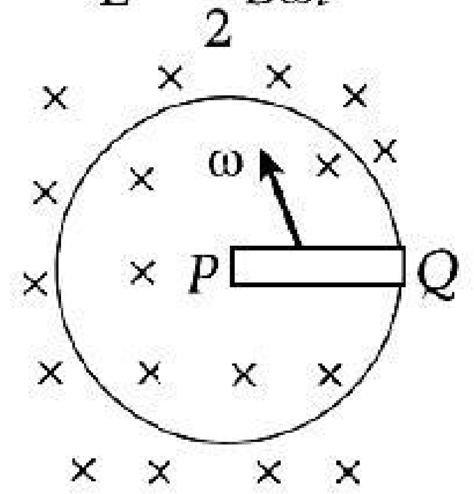
$i = Blv/(R+r)$



r = Resistance of rod moving with velocity v in uniform magnetic field $\vec{B}$

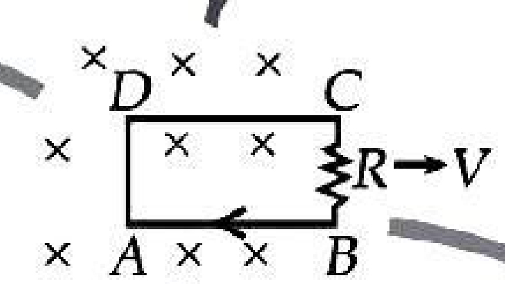
EMF induced in a rotating conductor

$E = \dfrac{1}{2}B\omega l^2$



Where l = Length of rod

Rectangular loop



EMF induced

$E = vBl$

$i = \dfrac{vBl}{R}$

Magnetic force on the loop

$F = B^2 l^2\, v/R$

= Force required to move the loop with constant velocity (v)

Thermal power developed in the loop is

$P = \dfrac{v^2 B^2 l^2}{R}$

Magnetic flux density

- The change in magnetic flux per unit change in area is called magnetic flux density.
- Magnetic flux is given by: $d\phi = \vec{B} \cdot d\vec{A}$

  For $\vec{B}$ parallel to $d\vec{A}$, we have

  $$d\phi = B(dA)\cos 0° = B(dA)$$

  Therefore, $$B = \frac{d\phi}{dA} \quad ....(i)$$

  i.e., **magnetic induction** is equal to the magnetic flux density. In other words, the magnetic field may be measured in terms of magnetic flux density. From equation (i), we find:

  Unit of $$B = \frac{\text{Unit of } d\phi}{\text{Unit of } dA}$$

  Or, $$T = \frac{\text{Wb}}{\text{m}^2}$$

  i.e., Tesla = weber per square metre.

Faraday's Laws of Electromagnetic Induction

- The induced emf in a closed loop due to a change in magnetic flux through the loop is known as Faraday's law.
- **Faraday's First Law** of Electromagnetic Induction states that whenever a conductor is placed in varying magnetic field, an emf is induced which is known as induced emf and if the conductor circuit is closed, current is also induced which is called alternating current.
- **Faraday's Second Law** of Electromagnetic Induction states that the induced emf is equal to the rate of change of flux linkage where flux linkage is the product of number of turns in the coil and flux associated with the coil.

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

  ϕ_B is magnetic flux through the circuit and is represented as $\phi_B = \int \vec{B} . d\vec{A}$

  With N loops of similar area in a circuit and ϕ_B being the flux through each loop, emf is induced in every loop. Writing the formula for Faraday's law as

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

  where, ε = Induced emf [V], N = Number of turns in the coil

  $\Delta\phi$ = Change in the magnetic flux [Wb], Δt = Change in time [s]

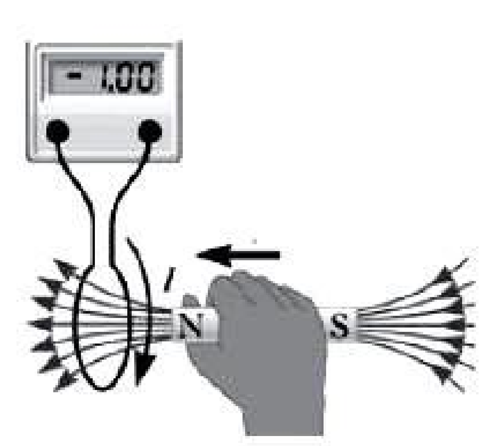
  The negative sign indicates that ε opposes its cause.
- If there is no change in magnetic flux, no emf is induced.

Induced emf and current

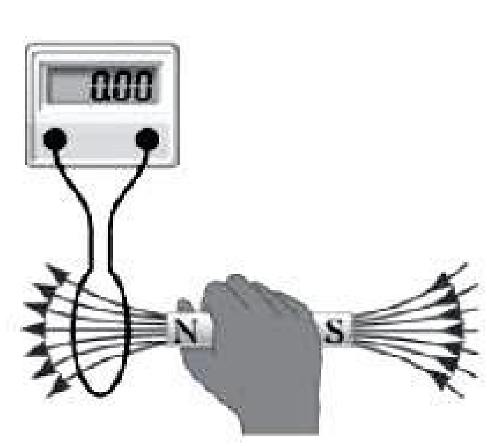
- A changing magnetic flux induces an electric field which induces a current in the circuit.
- A wire moving in the field induces a current which acts same as current provided by a battery.
- Changing magnetic flux and induced electric field are related to induced emf as per Faraday's law.
- The induced EMF in a conductor moving is related to the magnetic field as $E = B.l.v\sin\theta$

Induced current

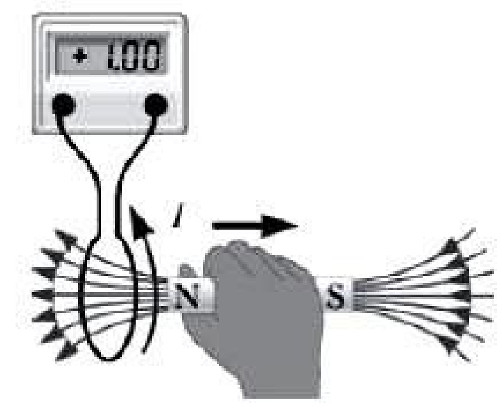
- When a conductor moves across flux lines, magnetic forces on the free electrons induce an electric current.
- When a magnet is moved towards a loop of wire connected to an ammeter, ammeter shows current induced in the loop.



- When a magnet is held stationary, there will be no induced current in the loop, even though the magnet is inside the loop.

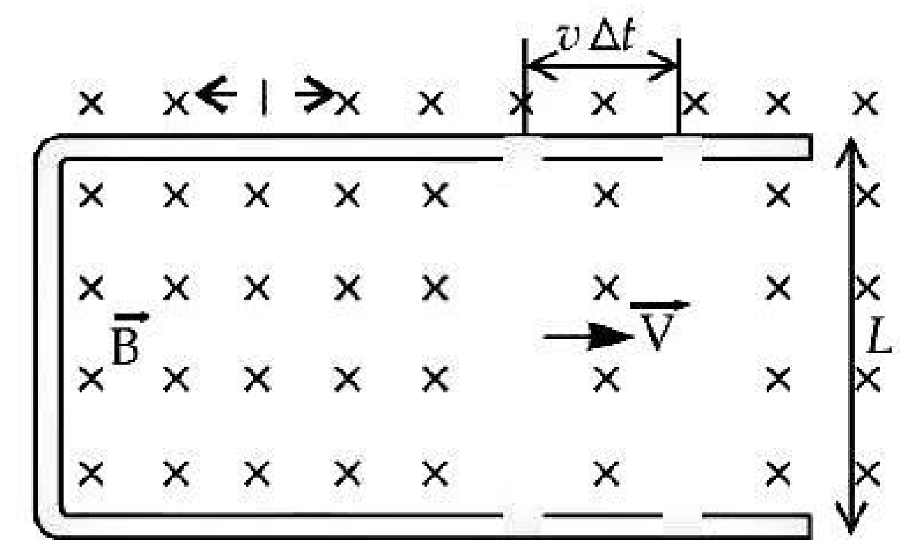


➢ When a magnet is moved away from the loop, the ammeter shows opposite current induced in the loop.



Motional emf

➢ The relationship between an induced emf ε in a wire or a conductor moving at a constant speed v through a magnetic field B is given by:



$$\phi_B = Blx$$

$$\varepsilon = \frac{-d\phi_B}{dt} = \frac{d}{dt}(Blx)$$

$$= -Bl\frac{dx}{dt}$$

$$= Blv \qquad \left(\frac{dx}{dt} = -v\right)$$

➢ An induced emf from Faraday's law is generated from a motional emf that opposes the change in flux.

➢ Magnetic and electric forces on charges in a rod moving perpendicular to magnetic field is given as:

At equilibrium

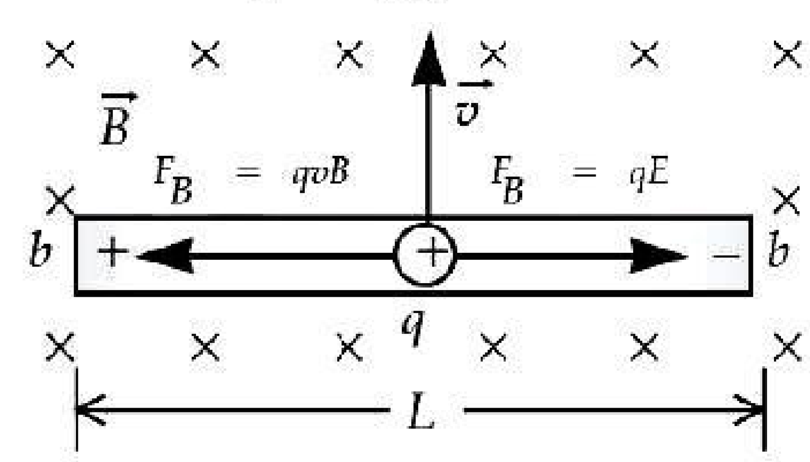
$$F_E = F_B$$

$$qE = qvB$$

$$E = vB$$

$$\frac{V}{l} = vB \qquad \left[\text{Here, } E = \frac{V}{l}\right]$$

$$V = Bvl$$



Lenz's law

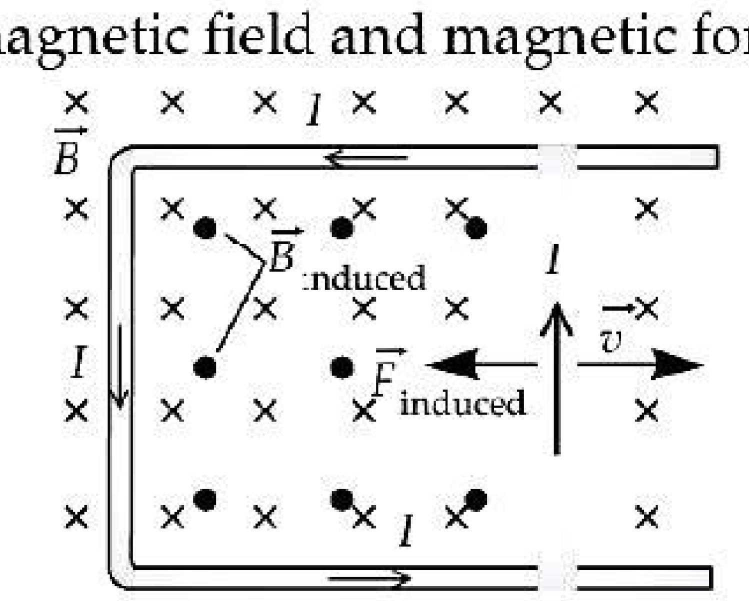
➢ Lenz's law is used to determine the direction of induced magnetic fields, currents and *emfs*.

➢ The direction of an induced emf always opposes the change in magnetic flux which causes the emf.

➢ It explains the negative sign in Faraday's flux rule, $\varepsilon = -\frac{d\phi_B}{dt}$ showing that the polarity of induced emf tends to produce a current that opposes the cause *i.e.* change in magnetic flux.

➢ As per conservation of energy, induced emf opposes its cause, making mechanical work to continue with the process which gets converted into electrical energy.

➢ Slide wire containing induced current, magnetic field and magnetic force:



Electric Generators and Back Emf

➢ Electric generator rotates a coil in a magnetic field inducing an emf which is given as a function of time

$$\varepsilon = NBA\,\omega\sin(\omega t).$$

where, A = Area of N-turn coil rotated at constant angular velocity ω in uniform magnetic field $\vec{B}$.

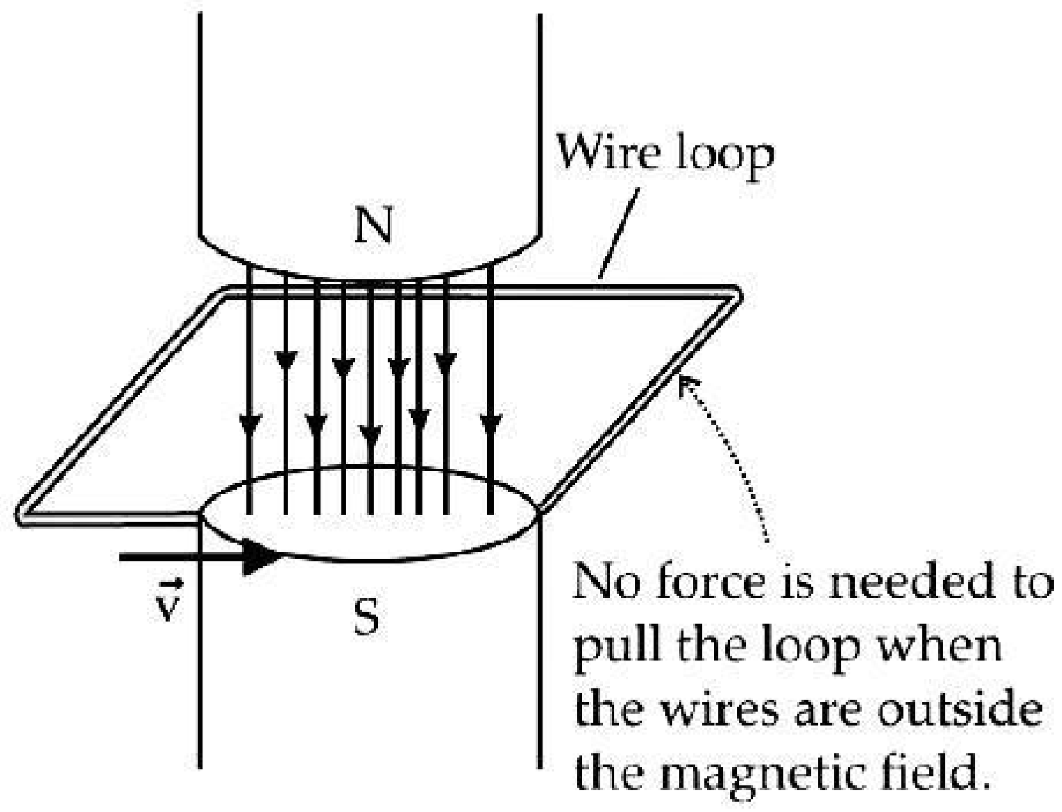
➢ The peak emf of a generator is, $\varepsilon_0 = NBA\omega$

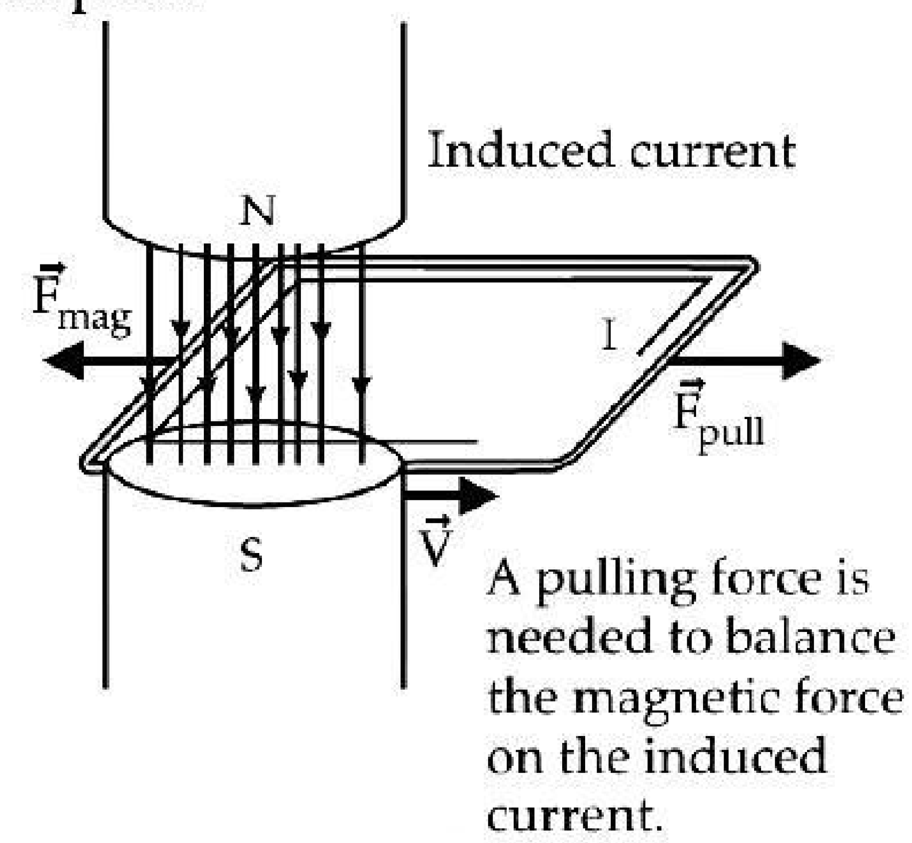
➢ Any rotating coil produces an induced emf. In motors, it is known as back emf as it opposes the emf input to the motor.

Eddy Currents, Self and Mutual Induction

Eddy Currents

- Current loops induced in moving conductors are called eddy currents. They can create significant drag, called as magnetic damping.
- Eddy currents give rise to magnetic fields that oppose any external change in the magnetic field.
- Eddy currents are induced electric currents that flow in a circular path:





- Eddy currents flowing in a material will generate their own secondary magnetic field that opposes the coil's primary magnetic field.

Mutual Induction

- The production of induced emf in a circuit, when the current in the neighbouring circuit changes is called **mutual induction.**

  When the circuit of the primary coil is closed or opened, deflection is produced in the galvanometer of the secondary coil. This is due to the mutual induction.
- The mutual induction between two coils depends on the following factors:
  - The number of turns of primary and secondary coils.
  - The shape, size or geometry of the two coils. *i.e.*, the area of cross-section and the length of the coils.

Coefficient of mutual induction:

- Suppose, the instantaneous current in the primary coil is I. Let the magnetic flux linked with the secondary coil be ϕ. It is found that the magnetic flux is proportional to the current. *i.e.*,

  $$\phi \propto I \quad \text{or} \quad \phi = MI \qquad \text{...(i)}$$

  where, M is the constant of proportionality. It is called coefficient of mutual induction.

  The induced emf ε in the secondary coil is given by

  $$\varepsilon = -\frac{d\phi}{dt} = -M\frac{dI}{dt} \qquad \text{...(ii)}$$

  The negative sign is in accordance with the Lenz's law *i.e.*, the induced emf in the secondary coil opposes the variation of current in the primary coil.

  Taking magnitude of induced emf the equation (ii), we find

  $$M = \frac{\varepsilon}{(dI/dt)}$$

  Therefore, $$\text{Unit of } M = \frac{\text{V}}{\text{As}^{-1}} = \text{VA}^{-1}\text{s}$$

  If n_1, n_2 be the number of turns per unit length in primary and secondary coils per unit length and r be their radius, then coefficient of mutual inductance is given as

  $$M = \mu_0 n_1 n_2 \pi r^2 l$$

Self-Induction:

- The production of induced emf in a circuit, when the current in the same circuit changes is known as **self-induction.**

  Suppose the instantaneous current in the circuit is I and if the magnetic flux linked with the solenoid is ϕ, then it is found that:

$$\phi \propto I \text{ or } \phi = LI \quad ...(i)$$

where, L is the constant of proportionality. It is called **coefficient of self-induction.**

The induced emf ε in the coil is given by

$$\varepsilon = -\frac{d\phi}{dt} = -L\frac{dI}{dt} \quad ...(ii)$$

The negative sign is in accordance with the Lenz's law *i.e.*, the induced emf opposes the variation of current in the coil.

Taking the magnitude of the induced emf from the equation (ii), we find:

$$L = \varepsilon / (dI/dt) \quad ...(iii)$$

Then, the coefficient of self-induction is the ratio of induced emf in the circuit to the rate of change of the current in the circuit.

Unit of L: The unit of self-induction is also called henry (symbol H).

From equation (ii), we find that if $dI/dt = 1 \text{ As}^{-1}$ and $\varepsilon = 1$ V,

then $L = 1 \text{ H} \Rightarrow 1 \text{ VA}^{-1}\text{s}$

- If a rod of length l moves perpendicular to a magnetic field B with a velocity v, then the induced emf produced across it, is given by

$$\varepsilon = vBl$$

In general, we have,

$$\varepsilon = Blv \sin\theta$$

- If a metallic rod of length l rotates about one of its ends in a plane perpendicular to the magnetic field, then the induced emf produced across its ends is given by

$$\varepsilon = \frac{B\omega l^2}{2} = \frac{B2\pi f l^2}{2} = BAf$$

Here, ω = angular velocity of rotation, $A = \pi l^2$ = area of circle and f = frequency of rotation.

- Inductance in the electrical circuit is equivalent to the inertia (mass) in mechanics.
- When a bar magnet is dropped into a coil, the electromagnetic induction in the coil opposes its motion, so the magnet falls with acceleration less than that due to gravity.
- The inductance of a coil depends on the following factors:
  - area of cross-section,
  - number of turns
  - permeability of the core.
- Unit of induction, $H = \frac{\text{Wb}}{\text{A}} = \frac{\text{Vs}}{\text{A}} = \Omega.\text{s}$
- The self inductance of a circular coil is given by:

$$L = \frac{\phi}{I} = \frac{BAN}{I} = \frac{\mu_0}{4\pi}.\frac{(2\pi NI)}{rI} \times AN \qquad \left[\because B = \frac{\mu_0}{4\pi}.\frac{2\pi NI}{r}\right]$$

$$L = \frac{\mu_0 N^2}{2r}A = \frac{\mu_0 N^2}{2r} \times \pi r^2$$

or

$$L = \frac{\mu_0 N^2 \pi r}{2}$$

- The self inductance of a solenoid of length l is given by

$$L = \frac{\phi}{I} = \frac{BAN}{I} = \left(\frac{\mu_0 NI}{l}\right)\frac{AN}{I} \qquad \left[\because B = \frac{\mu_0 NI}{l}\right]$$

or

$$L = \frac{\mu_0 N^2 A}{l} = \mu_0 n^2 Al = \mu_0 n^2 V \qquad \left[\because n = \frac{N}{l}\right]$$

Here, $n = N/l$ = Number of turns per unit length and $V = Al$ = Volume of the solenoid.

- If two coils of inductance L_1 and L_2 are coupled together, then their mutual inductance is given by

$$M = k\sqrt{L_1 L_2}$$

where, k is called the coupling constant.

- The value of k lies between 0 and 1.

For perfectly coupled coils, $k = 1$, it means that the magnetic flux of primary coil is completely linked with the secondary coil.

- Eddy currents do not cause sparking.
- If a current I is set up in a coil of inductance L, then the magnetic field energy stored in it is given by

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

Mnemonics

Concept: Induced emf in a conductor moving in a magnetic field:
Mnemonics: **I** eat **L**oaf and **B**oiled **V**egetables
Interpretation: **I**: Induce **e**at: **e**mf **L**oaf and: **L**ength of Conductor **B**oiled: **B** (magnetic field) **V**egetables: **V** (Velocity)

Know the Terms

- **Electric generator:** Device for converting mechanical work into electrical energy that induces an emf by rotating a coil in magnetic field
- **Induced electric field:** Field generated due to changing magnetic flux with time
- **Induced emf:** A short-lived voltage generated by a conductor or coil, moving in a magnetic field
- **Magnetic damping:** A process in which energy of motion is converted in to heat by way of electric eddy currents induced in a coil that passes between the poles of a magnet
- **Magnetic flux:** The number of magnetic field lines measured through a given area
- **Motional *emf*:** Voltage produced by the movement of conducting wire or a conductor in a magnetic field
- **Peak *emf*:** The maximum *emf* produced by a generator
- **Back emf:** The emf generated by a running motor due to coil that turns in a magnetic field which opposes the voltage that powers the motor
- **Inductor:** A device used to store electrical energy in the form of magnetic field when electric current flows
- EMF produced by an electric generator: $\varepsilon = NBA\omega\sin(\omega t)$

Know the Formulae

- Magnetic flux: $\phi_m = \int \vec{B}.\vec{dA}$
- Faraday's law: $\varepsilon = -N\frac{d\phi_m}{dt}$
- Motional induced emf: $\varepsilon = Blv$
- Motional emf around a circuit: $\varepsilon = \oint E.dl = -\frac{d\phi_m}{dt}$
- EMF produced by an electric generator $\varepsilon = NBA\sin\omega t$
- For Self Induction $\varepsilon = \frac{d\phi}{dt} = -L\frac{dI}{dt}$
- For Mutual Induction $\varepsilon = \frac{d\phi}{dt} = -M\frac{dI}{dt}$
- The inductance in series is given by $L_s = L_1 + L_2 + L_3 + ...$
- The inductance in parallel is given by $\frac{1}{L_p} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + ...$
- Mutual Inductance of two coils is given by

$$M = \frac{n_0 n_r N_P N_S A_P}{I_P} = \frac{n_0 n_r N_P N_S A_S}{I_P}$$

where, μ_0 is the permeability of free space ($4\pi \times 10^{-7}$).
μ_r is the relative permeability of the soft iron core.
N_S is number of turns in secondary coil.
N_P is number of turns in primary coil.
A_P is the cross-sectional area of primary coil in m^2.
A_S is the cross-sectional area of secondary will in m^2.
I is the coil current.

➢ For *A.C.* Generator $\varepsilon = \varepsilon_0 \sin\omega t$ or $\varepsilon = \varepsilon_0 \sin 2\pi\nu t$

STAND ALONE MCQs (1 Mark each)

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

(A) $2B_0L^2$ Wb **(B)** $3B_0L^2$ Wb
(C) $4B_0L^2$ Wb **(D)** $\sqrt{29}B_0L^2$ Wb

Ans. Option (C) is correct.

Explanation: Magnetic flux is defined as the total number of magnetic lines of force passing normally through an area placed in a magnetic field and is equal to the magnetic flux linked with that area.

Square lies in X-Y plane in $\vec{B}$ so $\vec{A} = L^2\hat{k}$

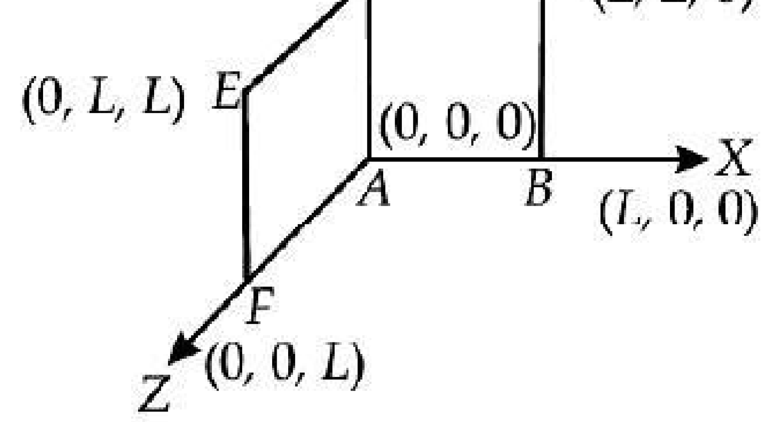
$$Q = B.A$$
$$= B_0(2\hat{i} + 3\hat{j} + 4\hat{k}).(L^2\hat{k})$$
$$= B_0[2\times\hat{i}\hat{k} + 3\times\hat{j}\hat{k} + 4\times\hat{k}.\hat{k}]$$
$$= B_0L^2[0 + 0 + 4]$$
$$= 4B_0L^2 Wb.$$

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

(A) B_0L^2 Wb. **(B)** $2B_0L^2$ Wb.
(C) $\sqrt{2}B_0L^2$ Wb. **(D)** $4B_0L^2$ Wb.

Ans. Option (B) is correct.

Explanation: The loop can be considered in two planes :



(i) Plane of ABCDA is in X-Y plane. So its vector $\vec{A}$ is in Z-direction. Hence,

$$A_1 = |A|\hat{k} = L^2\hat{k}$$

(ii) Plane of DEFAD is in Y-Z plane

So $A_2 = |A|\hat{i} = L^2\hat{i}$

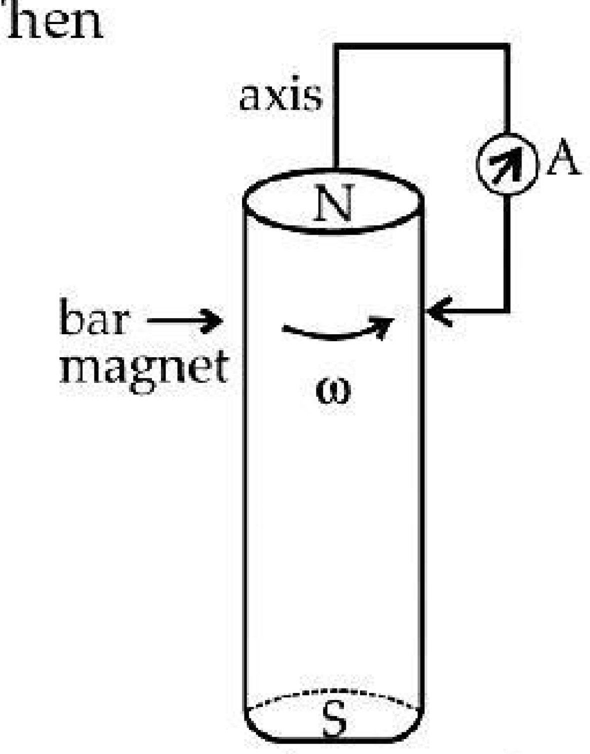
$\therefore \quad A = A_1 + A_2 = L^2(\hat{i} + \hat{k})$

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

So, $Q = B.A = B_0(\hat{i} + \hat{k}).L^2(\hat{i} + \hat{k}) = B_0L^2$
$[\hat{i}.\hat{i} + \hat{i}.\hat{k} + \hat{k}.\hat{i} + \hat{k}.\hat{k}]$

$= B_0L^2[1 + 0 + 0 + 1] \quad (\because \cos 90° = 0)$
$= 2B_0L^2 Wb$

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



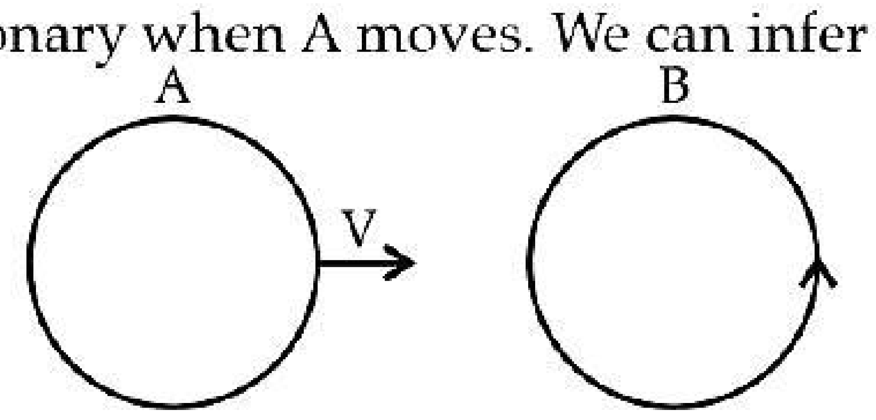
(A) a direct current flows in the ammeter A.
(B) no current flows through the ammeter A.
(C) an alternating sinusoidal current flows through the ammeter A with a time period $2\pi/\omega$.
(D) a time varying non-sinusoidal current flows through the ammeter A.

Ans. Option (B) is correct.

Explanation: The phenomenon of electromagnetic induction is used in this problem. Whenever the number of magnetic lines of force (magnetic flux) passing through a circuit changes (or a moving conductor cuts the magnetic flux), an emf is produced in the circuit (or emf induces across the ends of the conductor) is called induced emf. The induced emf persists only as long as there is a change or cutting of flux.

When cylindrical bar magnet is rotated about its axis, no change in flux linked with the circuit takes place, consequently no emf induces and hence, no current flows through the ammeter *A*. Hence the ammeter shows no deflection.

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

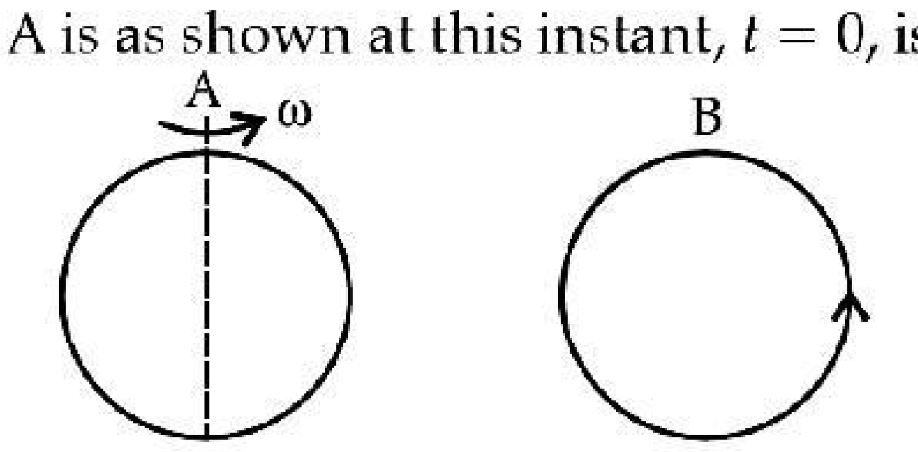


(A) there is a constant current in the clockwise direction in A.
(B) there is a varying current in A.
(C) there is no current in A.
(D) there is a constant current in the counter clockwise direction in A.

Ans. Option (D) is correct.

Explanation: When coil A moves towards coil B with constant velocity, so rate of change of magnetic flux due to coil B in coil A will be constant that gives constant current in coil A in same direction as in coil B by Lenz's law.

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



(A) constant current clockwise.
(B) varying current clockwise.
(C) varying current counter-clockwise.
(D) constant current counter-clockwise.

Ans. Option (A) is correct.

Explanation: In this case, the direction of the induced electromotive force/induced current is determined by the Lenz's law. According to the Lenz's law, the direction of induced emf or current in a circuit is such that it oppose *x* the cause that produces it. This law is based upon law of conservation of energy.
When the current in coil B (at $t = 0$) is counter-clockwise and the coil A is considered above it. The counter-clockwise flow of the current in coil B is equivalent to North Pole of magnet and magnetic field lines are eliminating upward to coil A. When coil A starts rotating at $t = 0$, the current in coil A is constant along clockwise direction by Lenz's rule.

Q. 6. The polarity of induced emf is defined by
(A) Ampere's circuital law.
(B) Biot-Savart law.
(C) Lenz's law.
(D) Fleming's right hand rule.

Ans. Option (C) is correct.

Explanation: According to Lenz's law, the direction of an induced e.m.f. always opposes the change in magnetic flux that causes the e.m.f.

Q. 7. Lenz's law is consequence of the law of conservation of
(A) Charge **(B)** mass
(C) energy **(D)** momentum

Ans. Option (C) is correct.

Explanation: Lenz's law is a consequence of the law of conservation of energy.
Lenz law says that induced current always tends to oppose the cause which produces it. So work is done against opposing force. This work is transformed into electrical energy. So it a consequence of law of conservation of energy.

Q. 8. The magnetic flux linked with a coil is given by an equation $\phi = 5t^2 + 2t + 3$.
The induced e.m.f. in the coil at the third second will be
(A) 32 units **(B)** 54 units
(C) 40 units **(D)** 65 units

Ans. Option (A) is correct.

Explanation: Induced e.m.f $= -d\phi/dt$
$= (5t^2 + 2t + 3) = -(10t + 2) = -32$

Q. 9. The self-inductance L of a solenoid of length l and area of cross-section A, with a fixed number of turns N increases as
(A) l and A increase.
(B) l decreases and A increases.
(C) l increases and A decreases.
(D) both l and A decrease.

Ans. Option (B) is correct.

Explanation: As we know that,

$$L = \mu_r \mu_0 \frac{N^2 A}{l}$$

As L is constant for a coil,

$$L \propto A \text{ and } L \propto \frac{1}{l}$$

As μ_r and N are constant here so, to increase L for a coil, area A must be increased and l must be decreased. So answer (B) is correct.
Important point: The self and mutual inductance of capacitance and resistance depend on the geometry of the devices as well as permittivity/permeability of the medium.

Q. 10. An iron-cored solenoid has self inductance 2.8H. When the core is removed, the self inductance becomes 2 mH. The relative permeability of the material of the core is
(A) 1400 **(B)** 1200
(C) 2800 **(D)** 2000

Ans. Option (A) is correct.

Explanation: $\mu_r = L/L_0 = 2.8/(2 \times 10^{-3}) = 1400$

Q. 11. In which of the following application, eddy current has no role to play?

(A) Electric power meters
(B) Induction furnace
(C) LED lights
(D) Magnetic brakes in trains

Ans. Option (C) is correct.

Explanation: LED is a *p-n* junction diode and emits light when forward biased.

Q. 12. Which one of the following statements is wrong?

(A) Eddy currents are produced in a steady magnetic field.
(B) Eddy current is used to produce braking force in moving trains.
(C) Eddy currents is minimized by using laminated core.
(D) Induction furnace uses eddy current to produce heat

Ans. Option (A) is correct.

Explanation: Eddy current is produced when a metal is kept in a time varying magnetic field.

Q. 12. If the back e.m.f. induced in a coil, when current changes from 1A to zero in one millisecond, is 5 volts, the self-inductance of the coil is

(A) 5 H **(B)** 1 H
(C) 5×10^{-3} H **(D)** 5×10^{3} H

Ans. Option (C) is correct.

Explanation: $e = -L \dfrac{di}{dt}$

$$5 = -L \times \frac{0-1}{10^{-3}}$$

$$\therefore \quad L = 5 \times 10^{-3} \text{H}$$

Q. 13. Magnetic field energy stored in a coil is

(A) Li^2 **(B)** $\frac{1}{2}Li$
(C) Li **(D)** $\frac{1}{2}Li^2$

Ans. Option (D) is correct.

Explanation: If current I flows through a coil of self-inductance L, then magnetic field energy stored in it is $\frac{1}{2}Li^2$

Q. 14. If two coils of self inductance L_1 and L_2 are coupled together, their mutual inductance becomes

(A) $M = k\sqrt{L_1L_2}$ **(B)** $M = k\sqrt{\frac{L_1}{L_2}}$
(C) $M = k\sqrt{L_1 + L_2}$ **(D)** None of the above

Ans. Option (A) is correct.

Explanation: If two coils of self inductance L_1 and L_2 are coupled together, their mutual inductance becomes $M = k\sqrt{L_1L_2}$ where k = coupling constant whose value lies between 0 and 1.

Q. 15. An inductor and a bulb are connected in series with a dc source. A soft iron core is then inserted in the inductor. What will happen to intensity of the bulb?

(A) Intensity of the bulb remains the same.
(B) Intensity of the bulb decreases.
(C) Intensity of the bulb increases.
(D) The bulb ceases to glow.

Ans. Option (B) is correct.

Explanation: When a soft iron core is inserted in the inductor, the magnetic flux increases. According to Lenz's law, it will be resisted by reducing the current. Since the current reduces, the intensity of the bulb decreases.

? ASSERTION AND REASON BASED MCQs (1 Mark each)

Directions : In the following questions, A statement of Assertion (A) is followed by a statement of Reason (R). Mark the correct choice as.

(A) Both A and R are true and R is the correct explanation of A
(B) Both A and R are true but R is NOT the correct explanation of A
(C) A is true but R is false
(D) A is false and R is true

Q. 1. Assertion(A): Faraday's laws of electromagnetic induction are consequences of law of conservation of energy.

Reason (R): The parameter LR in a L-R circuit has the dimension of time.

Ans. Option (C) is correct.

Explanation: In electromagnetic induction, magnetic energy, mechanical energy are converted into electrical energy. So, Faraday's laws of electromagnetic induction are direct consequences of law of conservation of energy. Hence assertion is true.

In a L-R circuit, L/R parameter has the dimension of time. Hence the reason is false.

Q. 2. Assertion (A): When two identical loops of copper and Aluminium are rotated with same speed in the same magnetic field, the induced e.m.f. will be same.

Reason (R): Resistance of the two loops are equal.

Ans. Option (C) is correct.

Explanation: Induced e.m.f. in a rotating loop in a magnetic field depends on the area of the loop, number of turns, speed of rotation and magnetic field strength. It does not depend on the material of the coil. So, when two identical loops of copper and aluminium are rotated with same speed in the same magnetic field, the induced e.m.f. will be same. So, the assertion is true.

Resistance of the two loops cannot be equal. Resistance of copper loop is less than that of the aluminium loop. So, the reason is false.

Q. 3. Assertion (A): Lenz's law does not violets the principle of conservation of energy.

Reason (R): Induce e.m.f. never opposes the change in magnetic flux that causes the e.m.f.

Ans. Option (C) is correct.

Explanation: Lenz's law is based on principle of conservation of energy. So, the assertion is true.

Induced e.m.f. always opposes the change in magnetic flux that causes the e.m.f. So, the reason is also false.

Q. 4. Assertion (A): If the number of turns of a coil is increased, it becomes more difficult to push a bar magnet towards the coil.

Reason (R): The difficulty faced is according to Lenz's law.

Ans. Option (A) is correct.

Explanation: As it is tried to push a bar magnet towards a coil, magnetic flux increases. According to Faraday's law induced e.m.f. is generated. As the number of turns increases, induced e.m.f. increases.

According to Lenz's law, Induced e.m.f. always opposes the change in magnetic flux that causes the induction of e.m.f. So, the induced e.m.f. will oppose the motion of the bar magnet towards the coil. As the number of turns increases, opposition increases. Hence both assertion and reason are true and the reason explains the assertion properly.

Q. 5. Assertion (A): When the magnetic flux changes around a metallic conductor, the eddy current is produced.

Reason (R): Electric potential determines the flow of charge.

Ans. Option (B) is correct.

Explanation: Change in flux induces emf in conductor which generates eddy current. So assertion is true.

Electric potential determines the flow of charge. So reason is also true. But reason is not the proper explanation of generation of eddy current.

Q. 6. Assertion (A): The cores of electromagnets are made of soft iron.

Reason (R): Coercivity of soft iron is small.

Ans. Option (A) is correct.

Explanation: The core of an electromagnet should be such that it gets magnetized easily. Also, it loses magnetism easily as soon as the magnetizing field is removed. Soft iron has this property. So, soft iron is used as the core electromagnet. So the assertion is true. Coercivity is a measure of the ability of a ferromagnetic substance to withstand external magnetic field without becoming demagnetized. For soft iron, it should be very low. Coercivity is low for soft iron. So, reason is also true. Also, reason properly explains the assertion.

Q. 7. Assertion (A): Mutual inductance becomes maximum when coils are wound on each other.

Reason (R): Mutual inductance is independent of orientation of coils.

Ans. Option (C) is correct.

Explanation: Mutual inductance depends on size, number of turns, relative position and relative orientation of the 2 coils. So, when coils are wound on each other, the mutual inductance will be maximum.

So, assertion is true, But the reason is false.

Q. 8. Assertion (A): Self inductance may be called the inertia of electricity.

Reason (R): Due to self inductance, opposing induced e.m.f. is generated in a coil as a result of change in current or magnetic flux linked with the coil.

Ans. Option (B) is correct.

Explanation: Inertia is defined as the tendency of an object to resists its change of state of motion. Induced e.m.f. in a coil is changed by the change in current or magnetic flux. The property by which a coil opposes these parameters to incur any change in induced e.m.f. is known as self-inductance. Hence, self inductance may be called the inertia of electricity. So, the assertion and reason both are true but reason cannot explain why so happens.

CASE-BASED MCQs

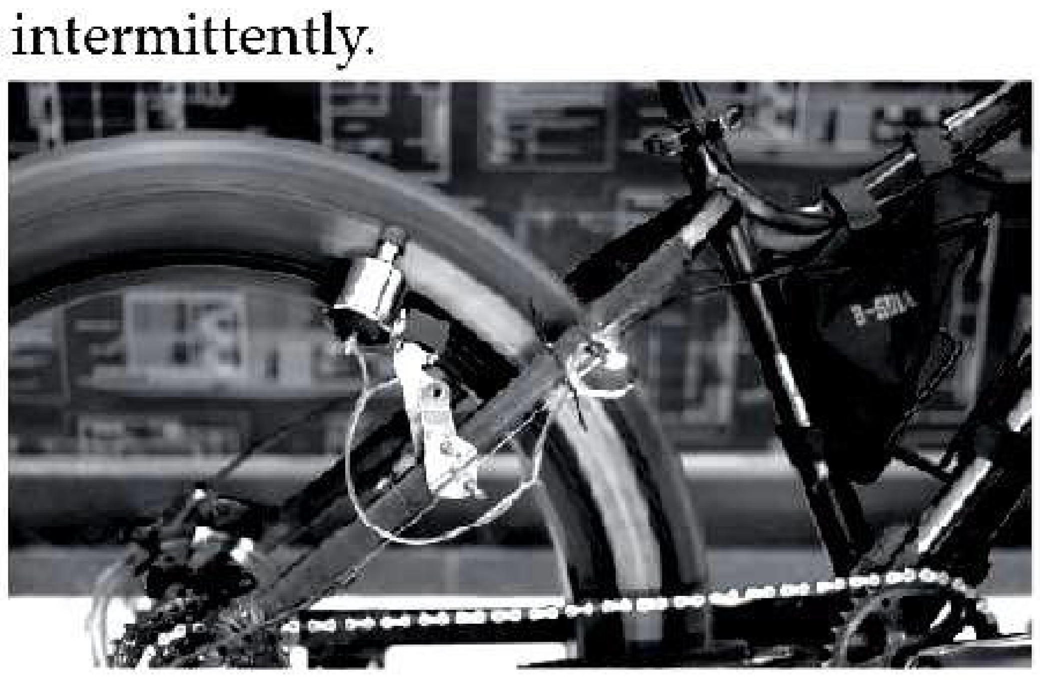
Attempt any 4 sub-parts out of 5. Each sub-part carries 1 mark.

I. Read the following text and answer the following questions on the basis of the same:

Bottle Dynamo: A bottle dynamo is a small generator to generate electricity to power the bicycle light.

Is is not a dynamo. Dynamo generates *DC* but a bottle dynamo generates *AC*. Newer models are now available with a rectifier. The available *DC* can power the light and small electronic gadgets. This is also known as sidewall generator since it operates using a roller placed on the sidewall of bicycle tyre. When the bicycle is in motion, the dynamo roller is engaged and electricity is generated as the tyre spins the roller. When engaged, a dynamo requires the bicycle rider to exert more effort to maintain a given speed than would otherwise be necessary when the dynamo is not present or disengaged.

Bottle dynamos can be completely disengaged during day time when cycle light is not in use. In wet conditions, the roller on a bottle dynamo can slip against the surface of the tyre, which interrupts the electricity generated. This cause the lights to go out intermittently.



Q. 1. Why bottle dynamo is not a dynamo ?

(A) It generates AC only

(B) It generates DC only

(C) It looks like a bottle

(D) It requires no fuel to operate

Ans. Option (A) is correct.

> *Explanation:* Dynamo generates DC. But bottle dynamo generates AC. So, it is not a dynamo in that sense. But, it generates electricity for bicycle light.

Q. 2. Can you recharge the battery of your mobile phone with the help of bottle dynamo ?

(A) Yes

(B) No

(C) Yes, when a rectifier is used

(D) Yes, when a transformer is used

Ans. Option (C) is correct.

> *Explanation:* Newer models of bottle generators are now available with a rectifier. DC available from such bottle generator can be used directly for charging mobile phone. Otherwise with the old models, a rectifier is to be attached to convert AC to DC.

Q. 3. Bottle generator generates electricity:

(A) when fuel is poured in the bottle.

(B) when cycle is in motion.

(C) when it is mounted properly.

(D) when wind blows.

Ans. Option (B) is correct.

> *Explanation:* Bottle generator is also known as sidewall generator since it operates using a roller placed on the sidewall of bicycle tyre. When the bicycle is in motion, the dynamo roller is engaged and electricity is generated as the tyre spins the roller.

Q. 4. Bulb of bicycle light glows:

(A) with AC supply only.

(B) with DC supply only.

(C) with both AC and DC supply.

(D) only when AC supply is rectified.

Ans. Option (C) is correct.

> *Explanation:* Normal lamps work with both AC and DC. So, bottle generators of older model or newer model can be directly used for bicycle lamp.

Q. 5. Which one of the following is not an advantages of newer model of bottle dynamo ?

(A) Works intermittently when it roller slips on tyre

(B) Small electronic gadgets can be charged

(C) Can be easily disengaged during day time

(D) Requires no fuel

Ans. Option (A) is correct.

> *Explanation:* In wet conditions, the roller on a bottle dynamo (old model or new model) can slip against the surface of the tyre, which interrupts the electricity generated. This causes the lights to go out intermittently. This is not an advantage.

II. Read the following text and answer the following questions on the basis of the same:

Electromagnetic damping: Take two hollow thin cylindrical pipes of equal internal diameters made of aluminium and *PVC*, respectively. Fix them vertically with clamps on retort stands. Take a small cylindrical magnet having diameter slightly smaller than the inner diameter of the pipes and drop it through each pipe in such a way that the magnet does not touch the sides of the pipes during its fall. You will observe that the magnet dropped through the *PVC* pipe takes the same time to come out of the pipe as it would take when dropped through the same height without the pipe.

Now instead of *PVC* pipe use an aluminium pipe. Note the time it takes to come out of the pipe in each case. You will see that the magnet takes much longer time in the case of aluminium pipe.

Why is it so ? It is due to the eddy currents that are generated in the aluminium pipe which oppose the change in magnetic flux, *i.e.*, the motion of the magnet. The retarding force due to the eddy currents inhibits the motion of the magnet. Such phenomena are referred to as electromagnetic damping.

Note that eddy currents are not generated in PVC pipe as its material is an insulator whereas aluminium is a conductor.

This effect was discovered by physicist Foucault (1819-1868).

Q. 1. Eddy current is generated in a:

(A) metallic pipe. **(B)** PVC pipe.

(C) glass pipe. **(D)** wooden pipe.

Ans. Option (A) is correct.

Explanation: Eddy currents are not generated in non-conductor/insulator. Eddy currents are generated in conductor/metal.

Q. 2. Eddy current was first observed by:

(A) Helmhotlz **(B)** Foucault

(C) D'Arsonval **(D)** Shock ley

Ans. Option (B) is correct.

Explanation: The generation of eddy current was discovered by physicist Foucault (1819-1869).

Q. 3. What is electromagnetic damping ?

(A) Generation of electromagnetic wave during the passage of a magnet through a metal pipe

(B) Change of the direction of propagation of electromagnetic wave due to a variable magnetic flux

(C) Change of the frequency of electromagnetic wave due to a variable magnetic flux

(D) To slow down the motion of a magnet moving through a metal pipe due to electromagnetically induced current.

Ans. Option (D) is correct.

Explanation: The retarding force due to the eddy currents inhibits the motion of the magnet in a metal pipe. This phenomena is known as electromagnetic damping.

Q. 4. To observe electromagnetic damping a magnet should be dropped through a metal pipe and:

(A) the magnet should not touch inner wall of the pipe.

(B) the magnet should touch the inner wall of the pipe.

(C) it does not matter whether the magnet touches the inner wall of the pipe or not.

(D) the magnet should be larger in size than the diameter of the pipe.

Ans. Option (A) is correct.

Explanation: To observe electromagnetic damping, a magnet should be dropped through a metal pipe and the magnet should not touch the inner wall of the pipe.

Q. 5. A piece of wood and a bar magnet of same dimension is dropped through an aluminium pipe. Which of the following statements is true ?

(A) The piece of wood will take more time to come out from the pipe.

(B) The bar magnet will take more time to come out from the pipe.

(C) Both will take same time to come out from the pipe.

(D) The time required will depend on the mass of the wooden piece and the mass of the bar magnet.

Ans. Option (B) is correct.

Explanation: When a piece of wood and a bar magnet of same dimension is dropped through an aluminium pipe, the bar magnet will take more time to come out from the pipe due to electromagnetic damping.

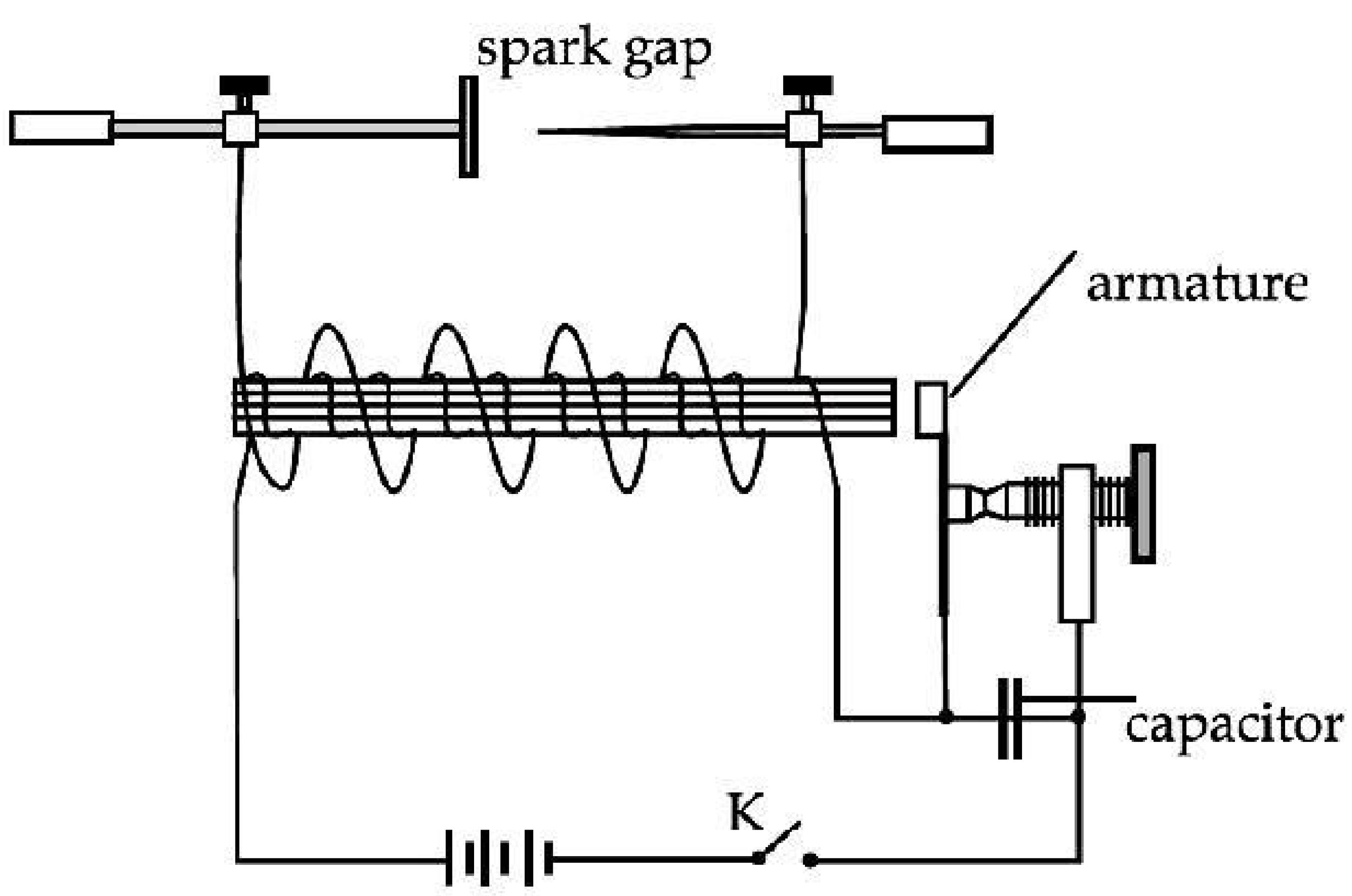
III. Read the following text and answer the following questions on the basis of the same:

Spark coil

The principle of electromagnetic induction was discovered by Michael Faraday in 1831. Induction coils were used widely in electrical experiments and for medical therapy during the last half of the 19th century, eventually leading to the development of radio in the 1890's.

The spark coil designed on the principle of electromagnetic induction was the heart of the earliest radio transmitters. Marconi used a spark coil designed by Heinrich Rhumkorff in his early experiments.

An **induction coil** or "spark coil" is a type of electrical transformer used to produce high-voltage pulses from a low-voltage (DC) supply. To create the flux changes necessary to induce voltage in the secondary coil, the direct current in the primary coil is repeatedly interrupted by a vibrating mechanical contact called interrupter.



The spark scoil consists of two coils of insulated wire wound around a common iron core. One coil, called the primary coil, is made from relatively few (tens or hundreds) turns of coarse wire. The other coil, the secondary coil typically consists of up to a million turns of fine wire (up to 40 gauge).

An electric current is passed through the primary, creating a magnetic field. Because of the common core, most of the primary's flux couples with the secondary. When the primary current is suddenly interrupted, the magnetic field rapidly collapses. This causes a high voltage pulse to be developed across the secondary terminals due to electromagnetic induction. Because of the large number of turns in the secondary coil, the secondary voltage pulse is typically many thousands of volts. This voltage is sufficient to create an electric spark, to jump across an air gap separating the secondary's output terminals. For this reason, this induction coils are also called spark coils.

To operate the coil continually, the DC supply current must be repeatedly connected and disconnected. To do that, a magnetically activated vibrating arm called an interrupter is used which rapidly connects and breaks the current flowing into the primary coil. The interrupter is mounted on the end of the coil next to the iron core. When the power is turned on, the produced magnetic field attracts the armature. When the armature has moved far enough, contacts in the primary circuit breaks and disconnects the primary current. Disconnecting the current causes the magnetic field to collapse and create the spark. A short time later the contacts reconnect, and the process repeats.

An arc which may form at the interrupter contacts is undesirable. To prevent this, a capacitor of 0.5 to 15 μF is connected across the primary coil.

Q. 1. The heart of the radio transmitters of Marconi was a

(A) spark coil.

(B) toroid.

(C) RF tuning coil.

(D) Van de Graff generator.

Ans. Option (A) is correct.

> ***Explanation:*** The spark coil designed on the principle of electromagnetic induction was the heart of the earliest radio transmitters. Marconi used a spark coil designed by Heinrich Rhumkorff in his early experiments.

Q. 2. Spark coil is a type of

(A) electrical generator.

(B) electrical transformer.

(C) static electricity generator.

(D) large capacitor.

Ans. Option (B) is correct.

> ***Explanation:*** A spark coil is a type of electrical transformer used to produce high-voltage pulses from a low-voltage (DC) supply. To create the flux changes necessary to induce voltage in the secondary coil, the direct current in the primary coil is repeatedly interrupted by a vibrating mechanical contact called interrupter.

Q. 3. Which of the following statements is correct?

(A) Spark coil consists of two coils of insulated wire. Primary coil, is made from relatively few turns of fine wire. The secondary coil consists of up to a million turns of coarse wire.

(B) Spark coil consists of two coils of insulated wire. Primary coil, is made from a (tens or million turns of coarse wire. The secondary coil consists of up to a few turns of fine wire.

(C) Spark coil consists of two coils of insulated wire. Primary coil, is made from relatively few turns of coarse wire. The secondary coil consists of up to a million turns of fine wire.

(D) Spark coil consists of two coils of insulated wire. Both primary and secondary coil, is made from a million turns of fine wire.

Ans. Option (C) is correct.

> ***Explanation:*** The spark coil consists of two coils of insulated wire wound around a common iron core. One coil, called the primary coil, is made from relatively few (tens or hundreds) turns of coarse wire. The other coil, the secondary coil typically consists of up to a million turns of fine wire (up to 40 gauge).

Q. 4. Why most of the primary's flux couples with the secondary in spark coil?

(A) Since the primary coil is wound on the secondary coil

(B) Since the primary coil is of thick wire

(C) Since the core is common

(D) None of the above

Ans. Option (C) is correct.

Explanation: The spark coil designed on the principle of electromagnetic induction was the heart of the earliest radio transmitters. Marconi used a spark coil designed by Heinrich Rhumkorff in his early experiments.

Q. 5. What is the function of interrupter in a spark coil?

(A) To rapidly connect and break the current flowing into the primary coil

(B) To rapidly connect and break the current flowing into the secondary coil

(C) to control the formation of spark

(D) None of the above

Ans. Option (A) is correct.

Explanation: To operate the coil continually, the DC supply current must be repeatedly connected and disconnected. To do that, a magnetically activated vibrating arm called an interrupter is used which rapidly connects and breaks the current flowing into the primary coil.