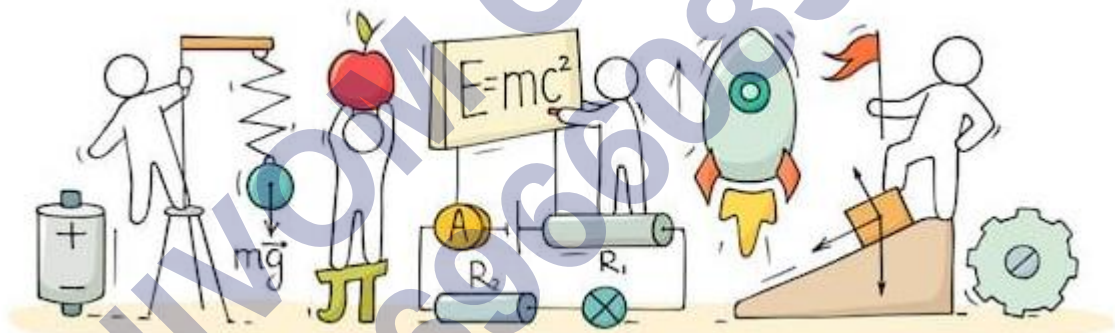# PHYSICS

CHAPTER 6: ELECTROMAGNETIC INDUCTION

ELECTROMAGNETIC INDUCTION

Electromagnetic induction:

Whenever the magnetic flux linked with an electric circuit changes, an emf is induced in the circuit. This phenomenon is called electromagnetic induction.

Faraday's Laws of Electromagnetic Induction:

- Whenever the magnetic flux linked with a circuit changes, an induced emf is produced in it.

- The induced emf lasts so long as the change in magnetic flux continues.

- The magnitude of induced emf is directly proportional to the rate of change in magnetic flux, i.e.,

$$E \propto \frac{d\varphi}{dt} \Rightarrow E = -\frac{d\varphi}{dt}$$

where constant of proportionality is one and negative sign indicates Lenz's law.

Here, flux = NBA cosθ, SI unit of φ = weber,

CGS unit of φ = maxwell, 1 weber = 10^8 maxwell,

Dimensional formula of magnetic flux

$$[\varphi] = [ML^{-2}T^{-2}A^{-2}]$$

Lenz's Law:

- The induced emf/ induced current direction is determined by this law.

- The direction of induced emf or current in a circuit, according to this law, is such that it opposes the source that generates it. The law of conservation of energy underpins this rule.

- When the N-pole of a bar magnet advances towards the coil, the flux associated with the loop increases, causing an emf. Induced current flows through the loop circuit since it is closed.

- Because the approaching north pole is the cause of this induced current, the induced current in the loop is directed in such a way that the front face of the loop behaves like the north pole. Therefore, induced current as seen by the observer O is an anticlockwise direction.

- The cause of generated emf in the coil can also be referred to as relative motion if the loop is free to move. As a result, the relative motion between the two objects works against the cause.

- The loop and the incoming magnet should be in opposition. As a result, the loop will begin to move in the direction of the magnet is moving.

- It is critical to keep in mind that whenever the reason of induced the new motion is always in the direction of the emf.

Eddy Current:
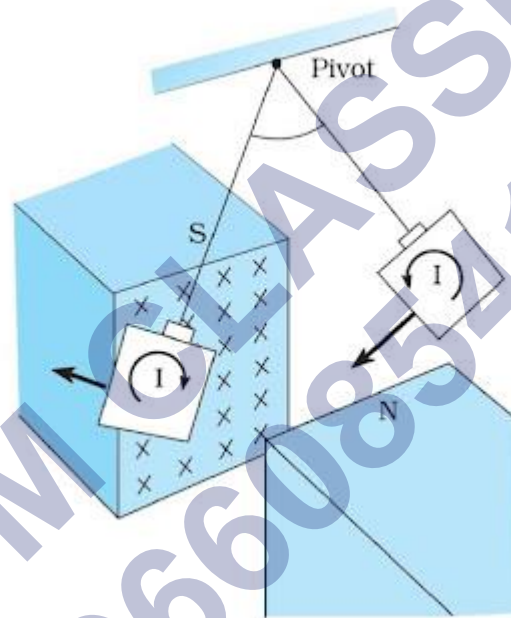
When a changing magnetic flux is given to a large piece of conducting material, it induces circling currents known as eddy currents. Eddy currents have huge magnitudes and heat up the conductor because the bulk conductor's resistance is usually low.

- These are circulating currents, similar to water eddies.
- The "Foucault current" is named after Focault's experimental hypothesis.
- In a metallic block, the generation of eddy currents results in the loss of electric energy in the form of heat.
- As a result of the lamination and slotting processes, the resistance channel for eddy current circulation increases, weakening and lowering them and also reducing losses caused by them.

Eddy Current Applications:

Although eddy currents are generally unwelcome, they do have some helpful applications, as listed below.

- **Dead-Beat Galvanometer:** When a current is delivered via its coil, a deadbeat galvanometer's pointer comes to rest in the final equilibrium position instantaneously, with no oscillation around the equilibrium position.

  This is accomplished by winding the coil around a metallic frame, which induces significant eddy currents that give electromagnetic damping.

- **When the train is running, the wheel moves in the air:** When the train is stopped by electric brakes, the wheel is made to move in an electromagnet created field. Eddy currents created in the wheels as a result of the changing flux work against the cause and bring the train to a halt.

- **Induction Furnace:** The heat of Joule causes a metal item to melt when it is placed in a rapidly changing magnetic field.

- **Speedometer:** In an automobile's speedometer, a magnet is geared to the vehicle's main shaft and rotates in accordance with the vehicle's speed. Hair springs are used to secure the magnet in an aluminium cylinder. When the magnet rotates, it produces eddy currents in the drum and drags it through an angle, which indicates the speed of the vehicle on a calibrated scale.

- **Energy Meter:** The armature coil of an energy meter has a metallic aluminium disc that rotates between the poles of a pair of permanent horseshoe magnets. The current induced in the disc as the armature spins tend to oppose the motion of the armature coil. Deflection is proportional to the energy consumed due to this braking effect.

Induced Charge Flow:

When a current is induced in the circuit due to the flux change, charge flows through the circuit and the net amount of charge which flows along the circuit is given as:

$$q = \int i\,dt = \int \frac{1}{R}\left|\frac{d\emptyset}{dt}\right|dt = \frac{1}{R}\int d\emptyset \quad q = \frac{|\Delta\emptyset|}{R} \text{ and } q = N\frac{|\Delta\emptyset|}{R} \text{ for N tums}$$

The Experiments of Faraday and Henry:

Figure shows a coil C_1 connected to a galvanometer G. When the North-pole of a bar magnet is pushed towards the coil, the pointer in the galvanometer deflects, indicating the presence of electric current in the coil. The galvanometer does not show any deflection when the magnet is held stationary. When the magnet is pulled away from the coil, the galvanometer shows deflection in the opposite direction, which indicates reversal of the current's direction.
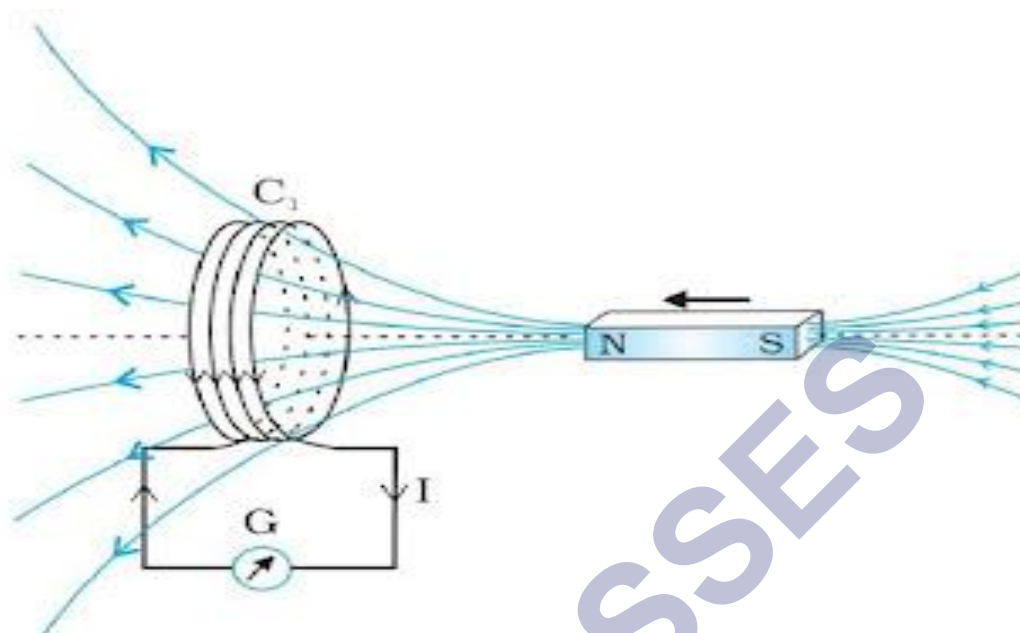
Moreover, when the South-pole of the bar magnet is moved towards or away from the coil, the deflections in the galvanometer are opposite to that observed with the North-pole for similar movements. Further, the deflection is found to be larger when the magnet is pushed towards or pulled away from the coil faster. Instead, when the bar magnet is held fixed and the coil C_1 is moved towards or away from the magnet, the same effects are observed. It shows that it is the relative motion between the magnet and the coil that is responsible for generation of electric current in the coil.

Fleming's Right Hand Rule:

If we stretch the thumb, the fore finger and the central finger of right hand in such a way that all three are perpendicular to each other, if thumb represent the direction of motion, the forefinger represent tile direction of magnetic field, then centra} finger will represent the direction of induced current.

If R is the electrical resistance of the circuit, then induced current in the circuit is given by

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

If induced current is produced in a coil rotated in uniform magnetic field, then.

$I = NBA \, \omega \sin \frac{\omega t}{R} = I_o \sin \omega t$

where, $I_o = NBA \, \omega$ = peak value of induced current,

N = number of turns in the coil,

B= magnetic induction,

ω = angular velocity of rotation and

A = area of cross-section of the coil.

Self-Induction:

The phenomena of production of induced emf in a circuit due to change in current flowing in its own, is called self-induction.
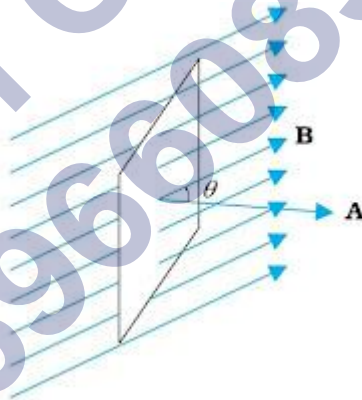
Mutual Induction:

The phenomena of production of induced emf in a circuit due to the change in magnetic flux in its neighbouring circuit, is called mutual induction.

Magnetic Flux:

Like electric flux, magnetic flux is proportional to the number of magnetic field lines passing through a surface. It is denoted by ΦB. It is a scalar quantity.

Mathematically, $\emptyset B = \vec{B}\vec{A} = BA\cos\theta$

SI unit of magnetic flux is weber (Wb) (1Wb = 1 tesla-m^2). C.G.S. unit of magnetic flux is maxwell. The dimensional formula of magnetic flux is [ML^{2}T^{-2}A^{-1}].

Motional Emf:

If a rod of length 1 moves perpendicular to a magnetic field B, with a velocity v, then induced emf produced in it given by.

E = B × v × l = Bvl

If a metallic rod of length 1 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.
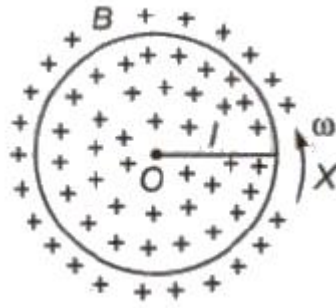
$$E = \frac{1}{2}b\omega r^2 = BAf$$

where, ω = angular velocity of rotation, f = frequency of rotation and A = πr^2 = area of disc.

The direction of induced current in any conductor can be obtained from Fleming's right hand rule.

A rectangular coil moves linearly in a field when coil moves with constant velocity in a uniform magnetic field, flux and induced emf will be zero.

A rod moves at an angle θ with the direction of magnetic field, velocity E = - Blv sin θ.

An emf is induced:

- When a magnet is moved with respect to a coil.
- When a conductor falls freely in East-West direction.
- When an Aeroplan flies horizontally.
- When strength of current flowing in a coil is increased or decreased, induced current is developed in the coil in same or opposite direction.
- When a train moves horizontally in any direction.

Induced Electric Field:

An electric field is induced in any region of space in which a magnetic field is changing with time. Induced electric field and magnetic field are at right angles to each other.

Consider a particle of charge q0 moving around the ring in a circular path. The work done by the induced electric field in one revolution is W = q0ε, where ε is the induced emf.

Also work done

$$W = \int \vec{F}.\vec{dl}$$

$$W = q_0 \int \vec{E}.\vec{dl}$$

$$q_0\varepsilon = q_0 \int \vec{E}.\vec{dl}$$

$$\varepsilon = \int \vec{E}.\vec{dl}$$

By Faraday's law

$$\varepsilon = \frac{-d\emptyset B}{dt}$$

$$\therefore \int \vec{E}.\vec{dl} = \frac{-d\emptyset B}{dt}$$

Lenz's Law and Conservation of Energy:

Lenz's law is in accordance with law of conservation of energy. As the induced current opposes the change in flux, work has to be done against the opposition offered by induced current in changing the flux. The work done appears as electrical energy in the loop.

AC Generator:

An ac generator converts mechanical energy into electrical energy.
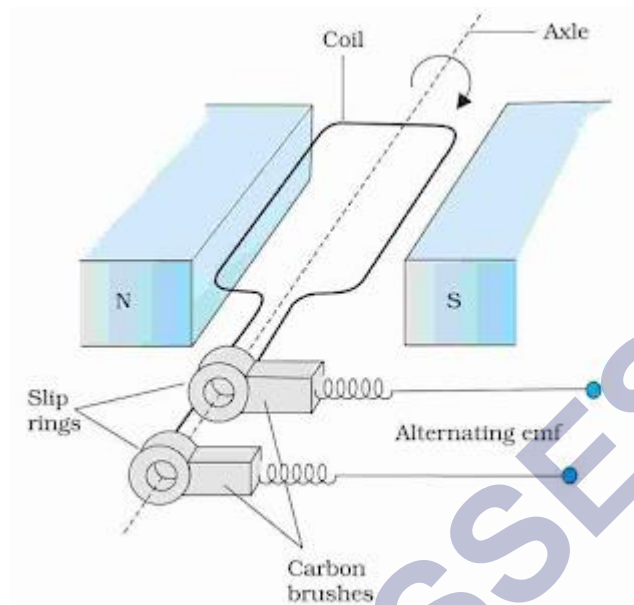
It consists of a coil mounted on a rotor shaft. The axis of rotation of the coil is perpendicular to the direction of the magnetic field. The coil (called armature) is mechanically rotated in the uniform magnetic field by some external means. The rotation of the coil causes the magnetic flux through it to change, so an emf is induced in the coil. The ends of the coil are connected to an external circuit by means of slip rings and brushes.

When the coil is rotated with a constant angular speed ω, the angle θ between the magnetic field vector B and the area vector A of the coil at any instant t is θ = ωt. As a result, the effective area of the coil exposed to the magnetic field lines changes with time, and the flux at any time to is.

$$\phi_B = BA\cos\theta$$

$$\phi_B = BA\cos\theta$$

From Faraday's law, the induced emf for the rotating coil of N turns is, then,

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

$$\varepsilon = -NBA\frac{d}{dt}(\cos\omega t)$$

Thus, the instantaneous value of the emf is,

$$\varepsilon = NBA\omega \sin\omega t$$

If we denote NBAω as ε_0,

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

The direction of the current changes periodically and therefore the current is called alternating current (ac).

Class : 12th Physics
Chapter- 6 : Electromagnetic Induction

$L = \mu_0 n^2 \pi r^2 l$
n = no. of turns per unit length
ϕ = flux = $(\mu_0 n i) \pi r^2$
r = radius of each loop of solenoid
- Growth of current in LR Circuit
$i = \dfrac{E}{R}(1 - e^{tR/L}) = i_0(1 - e^{-t/r})$
- Decay of current
$i = i_0 e^{-t/r}$
- Energy stored in an Inductor
$U = \dfrac{1}{2}Li^2$

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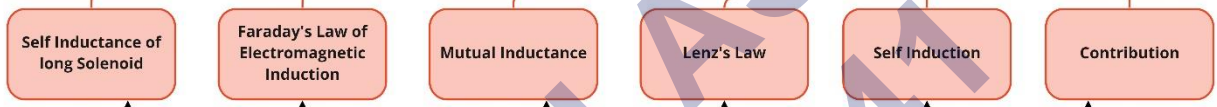is the flux of the magnetic field through the area.

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

$\phi = Mi$
$\dfrac{d\phi}{dt} = -M\dfrac{di}{dt}$
$M_{12} = \mu_0\, n_1 n_2\, \pi r_1^2 l$
$M_{21} = \mu_0 n_1 n_2 \pi r_2^2 l$
Emf induced in an AC generator, $E = NBA\omega \sin \omega t$
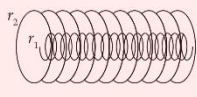
In 1831, Michael Faraday discovered electromagnetic induction and James Clerk Maxwell mathematically described it.

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

Self Inductance of long Solenoid

Faraday's Law of Electromagnetic Induction

Mutual Inductance

Lenz's Law

Self Induction

Contribution

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

Induced current

Electromagnetic Induction

Eddy Current

It is induced when magnetic flux linked with the conductor changes

Induced EMF

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

Motional EMF

EMF induced in a rotating conductor

Rectangular loop
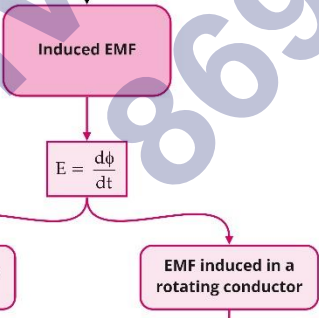
$E = \left|\dfrac{d\phi}{dt}\right| = \left|Bl\dfrac{dx}{dt}\right|$
$= Blv$
$i = vbl/(R+r)$
r = resistance of rod moving with velocity v in uniform magnetic field $\vec{B}$

$E = \dfrac{1}{2}B\omega l^2$
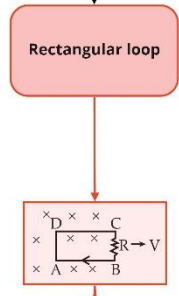
emf induced
$E = vBl$
$i = \dfrac{vBl}{R}$

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

Important Questions

Multiple Choice questions-

1. The north pole of a long bar magnet was pushed slowly into a short solenoid connected to a short galvanometer. The magnet was held stationary for a few seconds with the north pole in the middle of the solenoid and then withdrawn rapidly. The maximum deflection of the galvanometer was observed when the magnet was

(a) moving towards the solenoid
(b) moving into the solenoid
(c) at rest inside the solenoid
(d) moving out of the solenoid

2. The magnetic flux linked with a coil of N turns of area of cross section A held with its plane parallel to the field B is

(a) $\dfrac{NAB}{2}$ (b) NAB   (c) $\dfrac{NAB}{4}$ (d) zero

3. Faraday's laws are consequence of the conservation of

(a) charge
(b) energy
(c) magnetic field
(d) both (b) and (c)

4. Two identical coaxial coils P and Q carrying equal amount of current in the same direction are brought nearer. The current in

(a) P increases while in Q decreases
(b) Q increases while in P decreases
(c) both P and Q increases
(d) both P and Q decreases

5. Direction of current induced in a wire moving in a magnetic field is found using

(a) Fleming's left-hand rule
(b) Fleming's right-hand rule
(c) Ampere's rule
(d) Right hand clasp rule

6. Lenz's law is a consequence of the law of conservation of

(a) charge
(b) energy
(c) induced emf
(d) induced current

7. A solenoid is connected to a battery so that a steady current flows through it. If an iron core is inserted into the solenoid, the current will

(a) increase
(b) decrease
(c) remain same
(d) first increase then decrease

8. Which of the following statements is not correct?

(a) Whenever the amount of magnetic flux linked with a circuit change, an emf is induced in circuit.
(b) The induced emf lasts so long as the change in magnetic flux continues.
(c) The direction of induced emf is given by Lenz's law.
(d) Lenz's law is a consequence of the law of conservation of momentum.

9. There is a uniform magnetic field directed perpendicular and into the plane of the paper. An irregular shaped conducting loop is slowly changing into a circular loop in the plane of the paper. Then

(a) current is induced in the loop in the anti-clockwise direction.
(b) current is induced in the loop in the clockwise direction.
(c) ac is induced in the loop.
(d) no current is induced in the loop.

10. In the given figure current from A to B in the straight wire is decreasing. The direction of induced current in the loop is A

(a) clockwise
(b) anticlockwise
(c) changing
(d) nothing can be said

Very Short:

1. What is the function of a step-up transformer? (CBSE AI 2011C)

2. State Lenz's law. (CBSE AI 2012C)

3. How can the self-inductance of a given coil having 'N' number of turns, area of cross-section of 'A' and length T be increased? (CBSE AI 2012C)

4. How does the mutual inductance of a pair of coils change when

(a) the distance between the coils is increased and

(b) the number of turns in the coils is increased. (CBSE AI 2013)

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

6. Why is the core of a transformer laminated? (CBSE Delhi 2013C)

7. A metallic piece gets hot when surrounded by a coil carrying a high frequency alternating current. Why? (CBSE Delhi 2014C)

8. Name any two applications where eddy currents are used to advantage. (CBSE Delhi 2016C)

9. A long straight current-carrying wire passes normally through the centre of the circular loop. If the current through the wire increases, will there be an induced emf in the loop? Justify. (CBSE Delhi 2017)

10. Predict the polarity of the capacitor in the situation described below. (CBSE AI 2017)
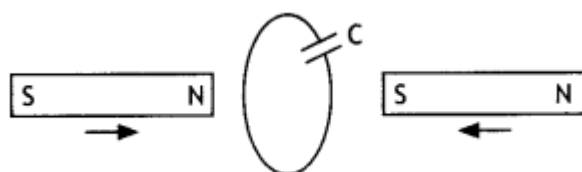
Short Questions:

1. An induced current has no direction of its own, comment.

2. How are eddy currents produced? Mention two applications of eddy currents?

3. Name and define the unit used for measuring the coefficient of mutual inductance. State the relation of this unit with the units of magnetic flux and electric current.

4. What are eddy currents? Write any two applications of eddy currents. (CBSE A! 2011)

5.

(a) Obtain the expression for the magnetic energy stored in a solenoid in terms of the magnetic field B, area A and length l of the solenoid.

(b) How is this magnetic energy per unit volume compared with the electrostatic energy per unit volume stored in a parallel plate capacitor? (CBSE Delhi 2011C)

6. State Lenz's Law.

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

7. Starting from the expression for the energy $W = 1/2LI^2$, stored in a solenoid of self-inductance L to build up the current l, obtain the expression for the magnetic energy in terms of the magnetic field B, area A and length l of the solenoid having n

number of turns per unit length. Hence show that the energy density is given by 8z/2m0. (CBSE Delhi 2013C)

(i) The magnetic energy is

(ii) The magnetic energy per unit volume is

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

Long Questions:

1. 11 kW of electric power can be transmitted to a distant station at (i) 220 V or (ii) 22,000 V. Which of the two modes of transmission should be preferred and why? Support your answer with possible calculations.

2. A coil A is connected to a voltmeter V and the other coil B to an alternating current source D. If a large copper sheet C is placed between the two coils, how does the induced emf in coil A change due to current in coil B. Justify your answer.
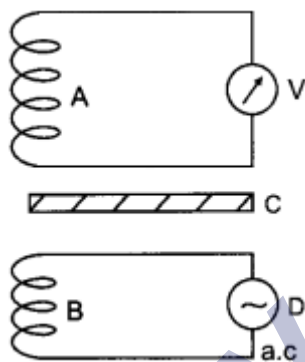
Assertion and Reason Questions-

1. Two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

   a) Both A and R are true and R is the correct explanation of A.

   b) Both A and Rare 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 also false.

Assertion (A): An aircraft flies along the meridian, the potential develops at the ends of its wings.

Reason (R): Whenever there is change in the magnetic flux e.m.f. induces.

2. Two statements are given-one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer to these questions from the codes (a), (b), (c) and (d) as given below.

    a) Both A and R are true and R is the correct explanation of A.

    b) Both A and Rare 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 also false.

Assertion (A): An artificial satellite with a metal surface is moving above the earth in a circular orbit. A current will be induced in satellite if the plane of the orbit is inclined to the plane of the equator.

Reason (R): The current will be induced only when the speed of satellite is more than 8km/ sec.

Case Study Questions-

1. In year 1820 Oersted discovered the magnetic effect of current. Faraday gave the thought that reverse of this phenomenon is also possible i.e., current can also be produced by magnetic field. Faraday showed that when we move a magnet towards the coil which is connected by a sensitive galvanometer. The galvanometer gives instantaneous deflection showing that there is an electric current in the loop.

Whenever relative motion between coil and magnet takes place an emf induced in coil. If coil is in closed circuit then current is also induced in the circuit. This phenomenon is called electromagnetic induction.
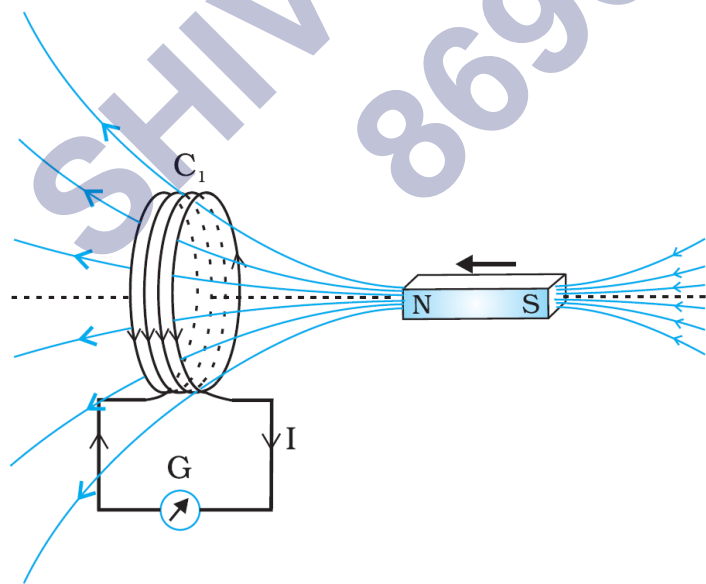
(i) The north pole of a long bar magnet was pushed slowly into a short solenoid connected to a galvanometer. The magnet was held stationary for a few seconds with the north pole in the middle of the solenoid and then withdrawn

rapidly. The maximum deflection of the galvanometer was observed when the magnet was:

   a) Moving towards the solenoid.

   b) Moving into the solenoid.

   c) At rest inside the solenoid.

   d) Moving out of the solenoid.

(ii) Two similar circular loops carry equal currents in the same direction. On moving the coils further apart, the electric current will.

   a) Remain unaltered.

   b) Increases in one and decreases in the second.

   c) Increase in both.

   d) Decrease in both.

(iii) A closed iron ring is held horizontally and a bar magnet is dropped through the ring with its length along the axis of the ring. The acceleration of the falling magnet is.

   a) Equal to g.

   b) Less than g.

   c) More than g.

   d) Depends on the diameter of the ring and length of magnet.

(iv) Whenever there is a relative motion between a coil and a magnet, the magnitude of induced emf set up in the coil does not depend upon the:

   a) Relative speed between the coil and magnet.

   b) Magnetic moment of the coil.

   c) Resistance of the coil.

   d) Number of turns in the coil.

(v) A coil of metal wire is kept stationary in a non-uniform magnetic field:

   a) A n emf and current both are induced in the coil.

   b) A current but no emf is induced in the coil.

   c) An emf but no current is induced in the coil.

   d) Neither emf nor current is induced in the coil.

2. Currents can be induced not only in conducting coils, but also in conducting sheets or blocks. Current is induced in solid metallic masses when the magnetic flux threading

through them changes. Such currents flow in the from of irregularly shaped loops throughout the body of the metal. These currents look like eddies or whirlpools in water so they are known as eddy currents. Eddy currents have both undesirable effects and practically useful applications. For example it causes unnecessary heating and wastage of power in electric motors, dynamos and in the cores of transformers.

(i) The working of speedometers of trains is based on:

    a) Wattless currents.

    b) Eddy currents.

    c) alternating currents.

    d) pulsating currents.

(ii) Identify the wrong statement.

    a) Eddy currents are produced in a steady magnetic field.

    b) Induction furnace uses eddy currents to produce heat.

    c) Eddy currents can be used to produce braking force in moving trains.

    d) Power meters work on the principle of eddy currents.

(iii) Which of the following is the best method to reduce eddy currents?

    a) Laminating core.

    b) Using thick wires.

    c) By reducing hysteresis loss.

    d) None of these.

(iv) The direction of eddy currents is given by:

    a) Fleming's left hand rule.

    b) Biot-Savart law.

    c) Lenz's law

    d) Ampere-circuital law.

(v) Eddy currents can be used to heat localised tissues of the human body. This branch of medical therapy is called:

    a) Hyperthermia.

    b) Diathermy.

    c) Inductothermy.

    d) None of these.

✓ Answer Key:

Multiple Choice Answers-

1. Answer: d
2. Answer: d
3. Answer: b
4. Answer: d
5. Answer: b
6. Answer: b
7. Answer: b
8. Answer: d
9. Answer: a
10. Answer: b

Very Short Answers:

1. Answer: The function of a step-up transformer is to step-up the alternating voltage.
2. Answer: It states that the direction of induced emf is such that it opposes the cause of its production.
3. Answer: By inserting a core of high permeability inside the coil.
4. Answer:

    (a) decreases

    (b) increases.
5. Answer: Production of eddy current.
6. Answer: To reduce the effects of eddy currents.
7. Answer: Due to the production of eddy current which generates heat.
8. Answer:

    - Electromagnetic damping
    - Induction furnace.
9. Answer: Yes, as there will be a change in magnetic flux.
10. Answer: The upper plate will be positive with respect to the lower plate in the capacitor.

Short Questions Answers:

1. Answer: Yes, it is perfectly correct to say that an induced current has no fixed direction of its own. The direction of induced current depends upon the change in magnetic flux because in accordance with Lenz's law the induced current always opposes the change in magnetic flux.

2. Answer: Eddy currents are the currents induced in the body of a thick conductor when the magnetic flux linked with the conductor changes. When a thick conductor is moved in a magnetic field, magnetic flux linked with it changes. In situations like these, we can have induced currents that circulate throughout the volume of a material.

   Because their flow patterns resemble swirling eddies in a river, therefore they are called eddy currents.

   - Electromagnetic braking, and
   - Induction furnace.

3. Answer:

   In SI the unit of mutual inductance is henry (H). Now from the expression

   $$\varepsilon = -\frac{d\phi}{dt} = -M\frac{dI}{dt}$$

   we have $M = \varepsilon \, I \, \frac{dI}{dt}$.

   Let ε = 1 volt and dI/dt = 1 As-1, then

   M = 1 volt/1 As-1 = 1 henry.

   The mutual inductance of a coil is said to be 1 henry if a rate of change of current of 1 ampere per sec in the neighbouring coil induces in at an emf of 1 volt.

4. Answer:

   Eddy currents are the currents induced in the body of a thick conductor when the magnetic flux linked with a bulk piece of conductor changes.

   - Dead Beat Galvanometer, and
   - Induction furnace.

5. Answer:

   The magnetic field stored in a solenoid is given by the expression $U = -\frac{1}{2}LI^2$.

   But for a solenoid $B = \mu_0 nI$

   or

   $I = B / \mu_0 n$

   Substituting in the above expression we have

$$U = \frac{1}{2} \times (\mu_0 n^2 Al) \left(\frac{B}{\mu_0 n} \right)^2 \text{ as } L = \mu_0 n^2 A l$$

$$U = \frac{1}{2} \frac{B^2 Al}{\mu_0}$$

We know that the energy stored per unit volume in a parallel plate capacitor is

$$U_E = \frac{1}{2} \varepsilon_0 E^2$$

It is clear that in both cases the energy stored per unit volume is proportional to the square of the field intensity.

6. Answer: Lenz's law states that the polarity of the induced emf is such that it tends to oppose the cause of its production.

   Yes, as it will cut the horizontal component of the earth's magnetic field.

7. Answer:

   (i)

   $$U = \frac{1}{2} LI^2 = \frac{1}{2} L \left(\frac{B}{\mu_0 n} \right)^2 \text{ since } B = \mu_0 nl$$

   Now $L = \mu_0 n^2 Al$, therefore we have

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

   (ii)

   $$U_B = \frac{U_B}{V} = \frac{U_B}{Al} = \frac{B^2}{2\mu_0}$$

8. Answer: Mutual inductance is numerically equal to the magnetic flux linked with a coil when the unit current passes through the neighbouring coil.

   Given M = 1.5 H, dl = 20 - 0 = 20 A,

   dt = 0.5 s, Φ = ?

   $$\Phi = -M \frac{dl}{dt}$$

   or

   $$\Phi = -1.5 \times \frac{20}{0.5} = -60 \text{ Wb}$$

Long Questions Answers:

1. Answer:

   1. Consider that 11000 watt of energy has to be transmitted. First at 220 V and then at 22000 V. When the power is transmitted at 220 V then the current flowing through the wires is 11000/220 = 50 A

2. When power is transmitted at 22000 V then the current through the wires is 11000 / 22000 = 0.5 A. If R is the resistance of the line wire then the energy dissipated in the two cases is 2500R joule per sec and 0.25R. joule per sec.

This shows that if energy is transmitted at low voltages there is more loss in energy than when it is transmitted at high voltages. Furthermore, if power is to be transmitted at low voltage, then the resistance of the line wire should be low, as such thick wires will be required. To support these thick wires strong poles situated close to each other will be needed. This will increase the cost of transmission. But at high voltages, even thin wires will do.

2. Answer:

In the absence of sheet C, an induced emf is set up in coil due to mutual induction phenomenon when an alternating current is passed through coil B.
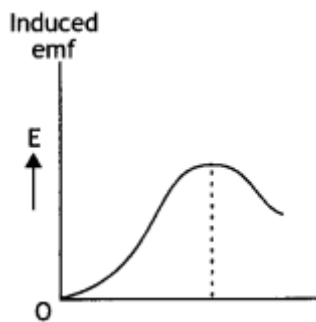
However, when induced copper sheet C is placed, eddy currents are set up in the sheet due to a change in flux.

Thus, now coil A has a positive effect due to coil B and a negative effect due to eddy currents in C. Consequently, the flux of coil A and hence the induced emf in coil A is decreased, i.e. the reading of voltmeter V is reduced.

Assertion and Reason Answers-

1. (a) Both A and R are true and R is the correct explanation of A.

Explanation:

As the aircraft flies, magnetic flux changes through its wings due to the vertical component of the earth's magnetic field. Due to this, induced emf is produced across the wings of the aircraft.

2. (c) Both A and R are true and R is the correct explanation of A.

Explanation:

When the satellite move in inclined plane with equatorial plane the value of magnetic field will change both in magnitude and direction. Due to this, the magnetic flux through the satellite will change and hence induced currents will be produced in the metal of the satellite. But no current will induce if satellite orbits in the equatorial

plane because the magnetic flux does not change through the metal of the satellite in this plane.

Case Study Answers-

1. Answer :

(i) (d) Moving out of the solenoid.

Explanation:

More rapid is the movement of bar magnet, more is the deflection observed in the galvanometer.

(ii) (c) Increase in both.

Explanation:

Two circular loops carrying current in the same direction will attract each other. If they are now separated, induced currents will try to keep status quo, by increasing the current in both the coils.

(iii)(b) Less than g.

Explanation:

Acceleration of the magnet will not be equal tog. It will be less than g. This is because, as the magnet falls, amount of magnetic flux linked with the ring changes.

An induced emf is developed in the ring which opposes the downward motion of the magnet.

(iv)(c) Resistance of the coil.

Explanation:

The magnitude of induced emf set up in the coil does not depend upon the resistance of the coil whereas induced current set up in the coil depend upon the resistance of the coil.

(v) (d) Neither emf nor current is induced in the coil.

Explanation:

As long as a coil of metal is kept stationary in a magnetic field, even if it is non-uniform, unless it is changing with respect to time, there will be no induced emfor current in the coil.

2. Answer :

(i) (b) Eddy currents.

Explanation:

The working of speedometers is based on eddy currents.

(ii) (a) Eddy currents are produced in a steady magnetic field.

(iii) (a) Laminating core.

Explanation:

To reduce the eddy currents in the metal armature of motors, wire is wrapped around a number of thin metal sheets called lamination.

(iv) (c) Increase.

Explanation:

Eddy currents also oppose the change in magnetic flux, so their direction is given by Lenz's law.

(v) (c) Henry.