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ELECTRO- MAGNETIC INDUCTION

Helpline +91-9939586130 +91-7739650505

2nd FLOOR ,SATKOUDI COMPLEX THANA CHOWK, RAMGARH JHARKHAND - 829122

PHYSICS — ELECTRO-MAGNETIC INDUCTION

Trace the Mind Map: • First Level • Second Level • Third Level

Electromagnetic Induction

Faraday's law of electromagnetic induction

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

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.

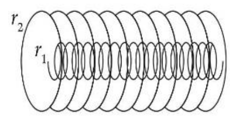
Mutual induction

$\phi = Mi$

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

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

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



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, $E = -N\frac{d}{dt}\int \vec{B}.\vec{ds}$

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**

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

- **Decay of current**

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

- **Energy stored in an Inductor**

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

Eddy current

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

Induced current

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

Induced EMF

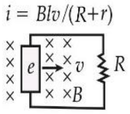
$E = \frac{-d\phi}{dt}$

Motional EMF

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

$= Blv$

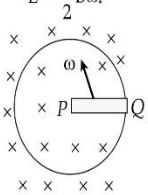
$i = Blv/(R+r)$



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

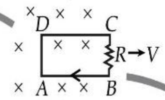
EMF induced in a rotating conductor

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



Where l = Length of rod

Rectangular loop



EMF induced
$E = vBl$
$i = \frac{vBl}{R}$

Magnetic force on the loop
$F = B^2l^2 v/R$
= Force required to move the loop with constant velocity (v)

Thermal power developed in the loop is
$P = \frac{v^2B^2l^2}{R}$

Syllabus

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

Trend Analysis

List of Concepts	2018		2019		2020	
	OD	D	OD	D	OD	D
Magnetic Flux and Faraday's Laws		1 Q (5 M)	1 Q (5 M)		1 Q (1 M)	1 Q (3 M)
Eddy Currents, Self and Mutual Induction and AC Generator		1 Q (5 M)			2 Q (3 M)	

TOPIC-1
Magnetic Flux and Faraday's Laws

Revision Notes

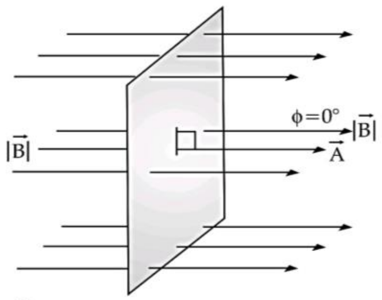
(a) Concept Notes

Electromagnetic induction

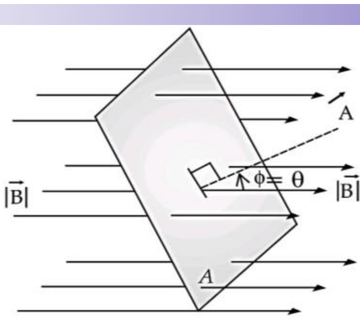
- Electromagnetic induction is the process of generating the electric current with a changing magnetic field.
- It takes place whenever a magnetic field is changing or electric conductors move relative to one another when they are in fluctuating magnetic field.
- The current produced by electromagnetic 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:

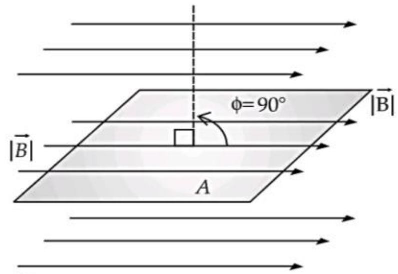
- Magnetic flux through an enclosed area is the number of magnetic field lines cutting through a surface area *A*, defined by unit area vector.
- The unit of magnetic flux is weber, where, 1 Wb = 1 T/m^2.
- Magnetic flux (ϕ_B) is related to number of field lines passing through a given area.
- If magnetic 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 ($\phi = 0°$)
magnetic flux $\phi_B = BA$.



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



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

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, $$B = \frac{d\phi}{dA} \qquad \text{....(i)}$$

  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.

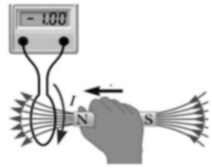
Induced emf and current

- 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 $E = B.l.v\sin\theta$

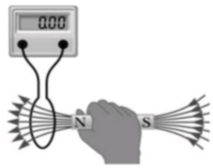
Induced current

- When a conductor moves across flux lines, magnetic forces on the free electrons induce an electric current.

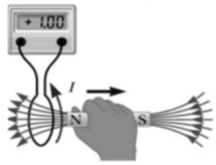
- When a magnet is moved towards a loop of wire connected to an ammeter, ammeter shows current induced in the loop.



- 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

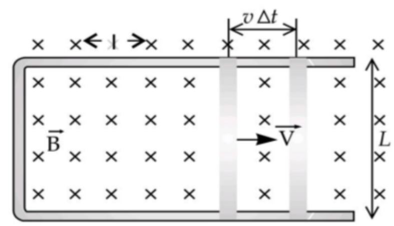
- The relationship between an induced emf ε in a wire or a conductor moving at a constant speed v through a magnetic field B is given by:

$$\phi_B = Blx$$

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

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

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



- 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

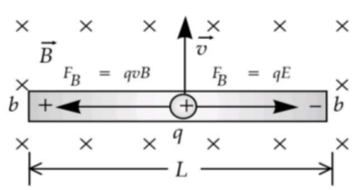
$$F_E = F_B$$

$$qE = qvB$$

$$E = vB$$

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

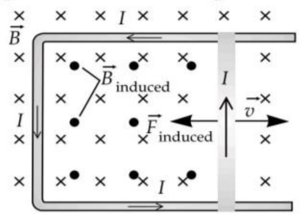
$$V = Bvl$$



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.

Know the Terms

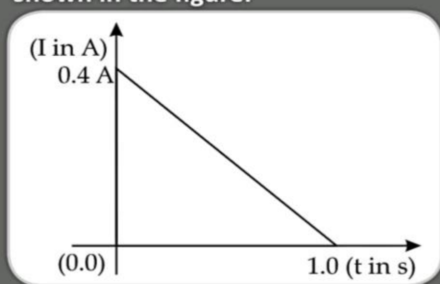
- **Electric generator:** Device for converting mechanical work into electrical energy that induces an emf by rotating a coil in magnetic field
- **Induced electric field:** Field generated due to changing magnetic flux with time
- **Induced emf:** A short-lived voltage generated by a conductor or coil, 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

Know the Formulae

- Magnetic flux: $\phi_m = \int \vec{B}.d\vec{A}$
- Faraday's law: $\varepsilon = -N\dfrac{d\phi_m}{dt}$
- Motional induced emf: $\varepsilon = Blv$
- Motional emf around a circuit: $\varepsilon = \oint E.dl = -\dfrac{d\phi_m}{dt}$
- EMF produced by an electric generator $\varepsilon = NBA\sin\omega t$

How is it done on the GREENBOARD?

Q. 1. When a conducting loop of resistance 10 Ω and area 10 cm² is removed from external magnetic field acting normally, the variation of induced current in the loop with time is as shown in the figure:



Find the:

(a) total charges passed through the loop.

(b) change in magnetic flux through the loop.

(c) magnitude of the magnetic field applied.

U [CBSE DEL SET, 2020]

Solution:

Step I: Given,

Area = A = 10 cm² $= \frac{10}{10000} m^2$

Resistance = R = 10 Ω

From the graph, change in current = 0.4 A

Change in time = 1.0 s

Step II: (a) Total charge passed through the loop = current × time = 0.4 × 1.0 = 0.4 C

Step III: (b) $|e| = \frac{\Delta\phi}{\Delta t}$

or, $iR = \frac{\Delta\phi}{\Delta t}$

or, $0.4 \times 10 = \frac{\Delta\phi}{1.0}$

$\therefore$ **Change in flux = $\Delta\phi$ = 4 Wb**

Step IV: (c) $|e| = A\frac{\Delta B}{\Delta t}$

or, $iR = A\frac{\Delta B}{\Delta t}$

or, $0.4 \times 10 = \frac{10}{10000}\frac{\Delta B}{1.0}$

$\therefore$ **ΔB = 4000 T**

Mnemonics

Concept: Induced emf in a conductor moving in a magnetic field:

Mnemonics: **I** **e**at **L**oaf and **B**oiled **V**egetables

Interpretation:

I: **I**nduce

eat: **e**mf

Loaf and: **L**ength of Conductor

Boiled: **B** (magnetic field)

Vegetables: **V** (Velocity)

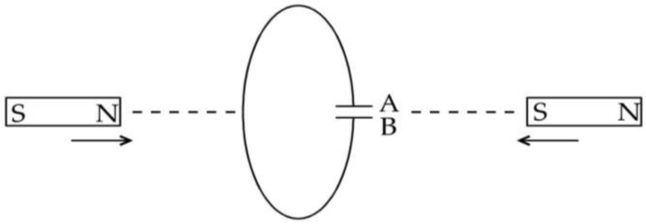
Very Short Answer Type Questions (1 mark each)

Q. 1. A circular loop of radius r, carrying a current I lies in *y-z* plane with its centre at the origin. How the net magnetic flux through the loop is related with the radius of the loop ?

R [CBSE OD SET 1, 2020 Modified]

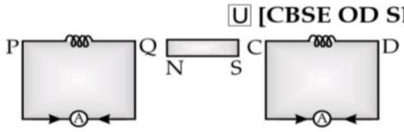
Ans. The net magnetic flux is zero. **1**

Q. 2. Predict the polarity of the capacitor in the situation described below: U [CBSE OD SET 1, 2017]



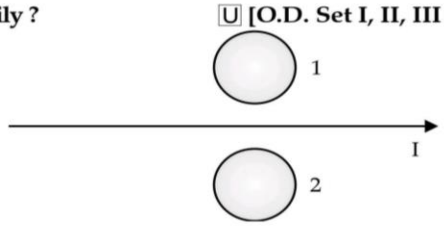
Ans. A is positive and ½
B is negative ½
(Also accept: A is negative and B is positive) **1**
[CBSE Marking Scheme, 2017]

Q. 3. A bar magnet is moved in the direction indicated by the arrow between two coils PQ and CD. Predict the direction of the induced current in each coil. U **[CBSE OD SET 2, 2017]**



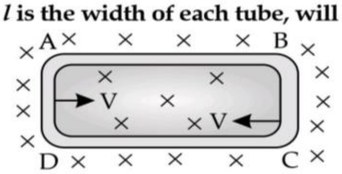
Ans. Q to P through ammeter and ½
D to C through ammeter ½
(**Alternatively:** Anticlockwise as seen from left in coil PQ clockwise as seen from left in coil CD)
[CBSE Marking Scheme, 2017]

Q. 4. What are the directions of induced currents in metal rings 1 and 2 when current I in the wire is increasing steadily ? U **[O.D. Set I, II, III 2017]**



Ans. Clockwise in loop 1. ½
Anti clockwise in loop 2. ½
[CBSE Marking Scheme, 2017]

Q. 5. One conducting U-tube can slide inside another as shown in figure, maintaining electrical contacts between the tubes. The magnetic field B is perpendicular to the plane of the figure. If each tube moves towards the other at a constant speed v, then the emf induced in the circuit in terms of B, l and v, where l is the width of each tube, will be: A&E



Ans. Relative velocity $= v-(-v) = 2v = \frac{dl}{dt}$ ½

Now, $e = \frac{d\phi}{dt} \Rightarrow e = \frac{Bldl}{dt}$ $[\because \phi = BA]$

Induced emf, $e = 2Blv$ $\left[\because \frac{dl}{dt} = 2v\right]$ ½

Q. 6. A conducting circular loop is placed in a uniform magnetic field $B = 0.020$ T with its plane perpendicular to the field. The radius of the loop starts shrinking at a constant rate of 1.0 mm/s. Find the induced emf in the loop at an instant when the radius is 2 cm ? A

Ans. Magnetic flux, $\phi = B.A$
$= B.\pi r^2$

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

$= 0.025 \times \pi \times 2 \times 2 \times 10^{-2} \times 1 \times 10^{-3}\,\pi\,\mu V$ **1**

Commonly Made Error

- The students find some difficulty in deciding the dependent and the independent variable while differentiating the equation for flux.

Answering Tip

- After the differentiation, the calculation error must be avoided while putting the values in the formula.

Q. 7. How would you detect the presence of magnetic field on an unknown planet? R

Ans. A space traveller can detect the presence of magnetic field on an unknown planet by connecting the coil with the galvanometer and rotate the coil. This is because if magnetic field is present, there will be a change of magnetic flux on rotating the coil. So, an induced current will flow. **1**

Q. 8. Will an induced emf develop in a conductor, when moved in a direction parallel to the magnetic field? U

Ans. No, because the magnetic flux linked with the conductor does not change when it is moved parallel to the magnetic field. Moreover, the magnetic Lorentz force on the free electrons of the conductor is zero, so no emf is induced across the ends of the conductor. **1**

Q. 9. Does the change in magnetic flux induce emf or current? U

Ans. The change in magnetic flux always induces an emf. However, the current is induced only when the circuit is closed in case of electromagnetic induction. **1**

Short Answer Type Questions-I (2 marks each)

Q. 1. A coil of wire enclosing an area 100 cm^2 is placed with its plane making an angle 60° with the magnetic field of strength 10^{-1} T. What is the flux through the coil ? If magnetic field is reduced to zero in 10^{-3} s, then find the induced emf. A **[SQP 2020-21]**

Ans. Calculation of magnetic flux, $\phi = BA\cos\theta$, where $\theta = 30° = \sqrt{\frac{3}{2}} \times 10^{-3}$ Wb 1

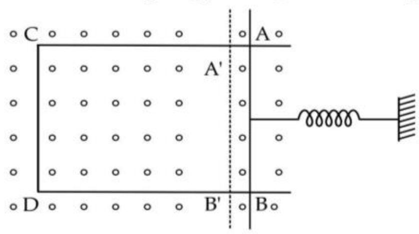
Calculation of induced emf, $E = A.\cos\theta\frac{dB}{dt}$

$= 0.5$ V. 1

Detailed Answer:

$$\phi = BA\cos\theta$$
$$B = 10^{-1}T$$
$$A = 100\ cm^2 = 10^{-2}\ m^2$$
$$\text{Cos}\ \theta = \cos 30^0 = \frac{\sqrt{3}}{2}$$
$$\therefore \quad \phi = 10^{-1} \times 10^{-2} \times \frac{\sqrt{3}}{2}$$
$$\therefore \quad \phi = \frac{\sqrt{3}}{2} \times 10^{-3}\ \text{Wb} \quad 1$$
$$\text{Induced emf} = |e| = d\phi/dt$$
$$= \frac{\frac{\sqrt{3}}{2}\times 10^{-3}}{10^{-3}}$$
$$= \frac{\sqrt{3}}{2}\ \text{V} \quad 1$$

AI Q. 2. A rectangular frame of wire is placed in a uniform magnetic field directed outwards, normal to the paper. *AB* is connected to a spring which is stretched to *A'B'* and then released at time $t = 0$. Explain qualitatively how induced e.m.f. in the coil would vary with time. (Neglect damping of oscillations of spring) A **[CBSE Comptt. I, 2018]**



Ans. SHM nature of oscillation of the wire *AB* ½
Expression for instantaneous magnetic flux ½
Expression for instantaneous induced emf ½
Qualitative explanation ½

The wire *AB* would oscillate in a simple harmonic way ½

We can write

$$x = -a\cos\omega t$$

as $x = -a$ at $t = 0$

Therefore Instantaneous magnetic Flux ½

$$\phi(t) = Blx \quad (l = AB)$$

Instantaneous induced emf,

$$e(t) = -\frac{d\phi}{dt} = aBl\omega\sin\omega t \quad ½$$

The induced emf, therefore varies with time sinusoidally. ½

[CBSE Marking Scheme, 2018]

Q. 3. A horizontal conducting rod 10 m long extending from east to west is falling with a speed 5.0 ms–1 at right angles to the horizontal component of the Earth's magnetic field, 0.3×10^{-4} Wb m^{-2}. Find the instantaneous value of the emf induced in the rod. A **[CBSE OD SET I, 2017]**

Ans. Induced emf $= BlV$ ½
$\therefore E = 0.3 \times 10^{-4} \times 10 \times 5$ Volt ½
$E = 1.5 \times 10^{-3}$ V $= 1.5$ mV 1

[CBSE Marking Scheme, 2017]

Detailed Answer:

$l = 10$ m, $\mu = 5$ m/s, $B = 0.3 \times 10^{-4}$ Wb/m^2

$$\therefore \quad \varepsilon = Blv \quad 1$$
$$= 0.3 \times 10^{-4} \times 10 \times 5$$
$$= 15 \times 10^{-4}\ \text{V} \quad 1$$

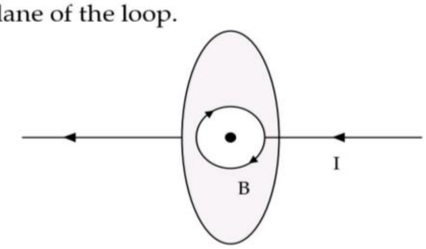
Q. 4. A long straight current carrying wire passes normally through the centre of circular loop. If the current through the wire increases, will there be an induced emf in the loop ? Justify. R **[Delhi I, II, III 2017]**

Ans. No, ½
As the magnetic field due to current carrying wire will be in the plane of the circular loop, so magnetic flux will remain zero. ½
Alternatively,
[Magnetic flux does not change with the change of current.] 1

[CBSE Marking Scheme, 2017]

Detailed Answer:

No, there will not be an induced emf in the loop as magnetic flux linked with the circular loop doesn't change because magnetic field lines are parallel to the plane of the loop.



1

As, induced emf (e) is proportional to the rate of change of magnetic flux (ϕ_B),

and $\phi_B = B{\cdot}A = BA\cos\theta$

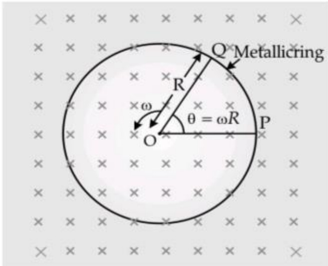
Here, $B \perp A \Rightarrow \phi_B = BA\cos 90° = 0$

So, induced emf $= 0$

Hence, a change in current will not create any emf in the loop. 1

AI Q. 5. A metallic rod of length '*L*' is rotated with angular frequency of 'ω' with one end hinged at the centre and the other end at the circumference of a circular metallic ring of radius *R*, about an axis passing through the centre and perpendicular to the plane of the ring. A constant and uniform magnetic field *B* parallel to the axis is present everywhere. Deduce the expression for the emf between the centre and the metallic ring. U

Ans.



1

The magnitude of the emf, generated across a length dr of the rod, as it moves at right angles to the magnetic field, is given by

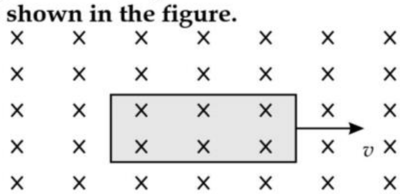
$$d\varepsilon = Bvdr$$

Therefore,

$$\varepsilon = \oint d\varepsilon = \int_0^R Bvdr = \int_0^R B\omega r dr = \frac{B\omega R^2}{2}$$ 1

Short Answer Type Questions-II (3 marks each)

Q. 1. A rectangular loop which was initially inside the region of uniform and time - independent magnetic field, is pulled out with constant velocity v as shown in the figure.



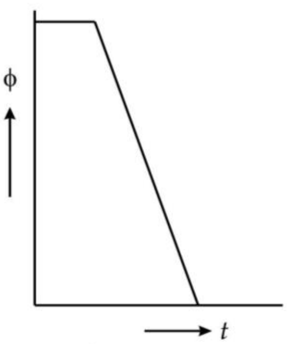
(a)

(a) Sketch the variation of magnetic flux, the induced current, and power dissipated as Joule heat as function of time.

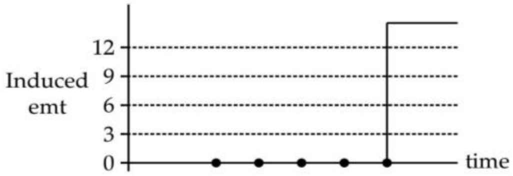
(b) If instead of rectangular loop, circular loop is pulled out; do you expect the same value of induced current? Justify your answer. Sketch the variation of flux in this case with time.

U [SQP 2020-21]

Ans. (a)



½



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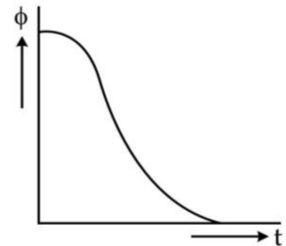
(b) Induced current and power, sketch is same as shown above. In case of circular coil, rate of change of area of the loop during its passage out of field is not constant, hence induced current varies accordingly. 1



1

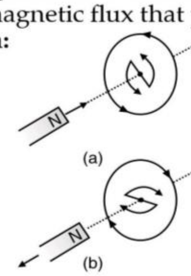
Q. 2. State Lenz's law. Explain, by giving examples that Lenz's law is a consequence of conservation of energy. U [Delhi Comptt I, II, III 2017]

Ans. Statement of Lenz's Law 1
Explanation (with example) 2
[CBSE Marking Scheme, 2017]

Detailed Answer:

Statement: The polarity of induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produced it.

Explanation:

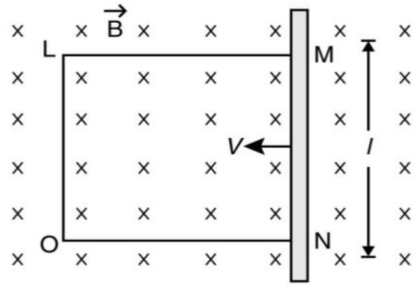


1

When the north pole of a bar magnet is pushed towards the close coil, the magnetic flux through coil increases and the current is induced in the coil in such a direction that it opposes the increase in flux. This is possible when the induced current in the coil is in the anti-clockwise direction. The opposite will happen when the north pole is moved away from the coil. 1

In either case, it is the work done against the force of magnetic repulsion/attraction that gets 'converted' into the induced emf. 1

AI **Q. 3. A rectangular conductor $LMNO$ is placed in a uniform magnetic field of 0.5 T. The field is directed perpendicular to the plane of the conductor.**



When the arm *MN* of length of 20 cm is moved towards left with a velocity of 10 ms^{-1}, calculate the emf induced in the arm. Given the resistance of the arm to be 5 Ω (assuming that other arms are of negligible resistance), find the value of the current in the arm. [A]

Ans. Let *ON* be at some point *x*.

The emf induced in the loop = ε

$$\varepsilon = \frac{-d\phi}{dt} = \frac{-d(Blx)}{dt} = Blv \quad 1$$

$$= 0.5 \times 0.2 \times 10 = 1 \text{ V} \quad 1$$

∴ Current in the arm,

$$I = \frac{\varepsilon}{R} = \frac{1}{5} = 0.2 \text{ A} \quad 1$$

Long Answer Type Questions

(5 marks each)

Q. 1 (a) Derive an expression for the induced emf developed when a coil of *N* turns, and area of cross-section *A*, is rotated at constant angular speed ω in a uniform magnetic field *B*.

(b) A wheel with 100 metallic spokes each 0.5 m long is rotated with a speed of 120 rev/min in a plane normal to the horizontal component of the Earth's magnetic field. If the resultant magnetic field at that place is 4×10^{-4} T and the angle of dip at the place is 30°, find the emf induced between the axle and the rim of the wheel. [A & U] **[CBSE OD SET 1, 2019]**

Ans. Deriving expression for e.m.f. 3

Finding induced e.m.f. between the axel and rim of wheel 2

(a) Flux linked with the coil at any instant of time is:

$$\phi = NBA\cos\omega t \quad ½$$

$$\frac{d\phi}{dt} = NB\omega(-\sin\omega t)A \quad ½$$

$$\varepsilon = -\frac{d\phi}{dt} \quad 1$$

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

$$\varepsilon = \varepsilon_0 \sin\omega t \quad (\text{Here } \varepsilon_0 = NBA\omega) \quad 1$$

(b) l = 0.5 m, ν = 120 rpm = 2 rps

$\omega = 2\pi\nu = 4\pi$ rad / s, $B = 4 \times 10^{-4}$T, δ = 30° ½

$$B_H = 4 \times 10^{-4} \times \frac{\sqrt{3}}{2}$$

$$B_H = 2\sqrt{3} \times 10^{-4} \text{ T} \quad ½$$

$$\varepsilon = \frac{1}{2}B\omega l^2 \quad ½$$

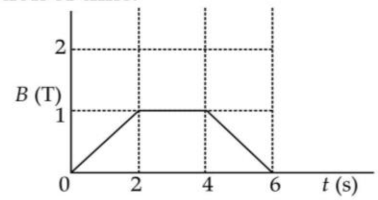
$$\varepsilon = \frac{1}{2} \times 2\sqrt{3} \times 10^{-4} \times 4\pi \times (0.5)^2$$

$$\varepsilon = 5.4 \times 10^{-4} \text{ volt} \quad ½$$

[CBSE Marking Scheme, 2019]

Q. 2. (i) State Faraday's laws of electromagnetic induction.

(ii) The magnetic field through a circular loop of wire 12 cm in radius and 8.5 Ω resistance, changes with time as shown in the figure. The magnetic field is perpendicular to the plane of the loop. Calculate the induced current in the loop and plot it as a function of time.



(iii) Show that Lenz's law is a consequence of conservation of energy. [R] **[Foreign I, II, III 2017]**

Ans. (i) Faraday's Laws of Electromagnetic Induction:

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. If the conductor circuit is closed, current is also induced which is called induced 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 will be

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

ε_B is magnetic flux through the circuit 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 a loop, then emf is induced in every loop making Faraday law as

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

where, ε = Induced emf [*V*],

N = Number of turns in the coil

Δϕ = Change in the magnetic flux [*Wb*],

Δ*t* = Change in time [s] 2

• The negative sign means that ε opposes its cause.

(ii) $\varepsilon = \frac{d\phi}{dt}$ ½

$= -\pi R^2 \times \frac{dB}{dt}$

$= -\frac{22}{7} \times (0.12)^2 \times \frac{1}{2}$

$\varepsilon = -0.023$ V,

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

$= -2.7$ mA for $0 < I < 2$s. **2**

(iii) Try yourself similar Q. 3 of short answer type Questions-II **1**

[CBSE Marking Scheme 2017]

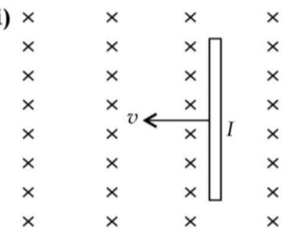
Q. 3. (i) A metallic rod of length *l* is moved perpendicular to its length with velocity *v* in a magnetic field *B* acting perpendicular to the plane in which rod moves. Derive the expression for the induced emf.

(ii) A wheel with 15 metallic spokes each 60 cm long, is rotated at 360 rev/min in a plane normal to the horizontal component of earth's magnetic field. The angle of dip at that place is 60°. If the emf induced between rim of the wheel and the axle is 400 mV, calculate the horizontal component of earth's magnetic field at the place. How will the induced emf change, if the number of spokes is increased ? U **[O.D. Comptt. I, II, III 2017]**

Ans. (i) Derivation of induced emf **2½**
(ii) Numerical **2½**
[CBSE Marking Scheme 2017]

Detailed Answer:

(i)



½

$\phi_B = Blx$ ½

$\varepsilon = \frac{-d\phi_B}{dt}$ ½

$= -Bl\frac{dx}{dt}$ ½

$= Blv$ $\left[-\frac{dx}{dt} = v\right]$ ½

(ii) $\omega = 360 \times \frac{2\pi}{60} = 12\pi$ rad/s ½

$\varepsilon = \frac{1}{2}B_H l^2 \omega$ ½

$\therefore$ $400 \times 10^{-3} = \frac{1}{2}.B_H \times (60 \times 10^{-2})^2 \times 12\pi$ ½

$\therefore$ $B_H = \frac{5}{27\pi} = 0.06$ T ½

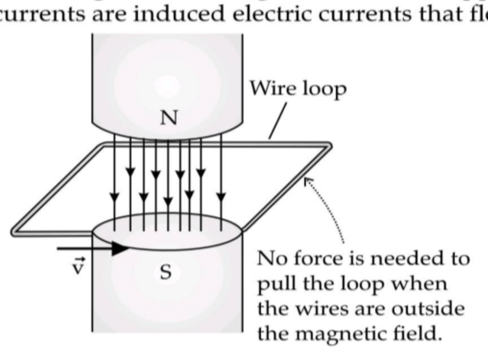
There will not be any change in emf if the number of spokes is increased. ½

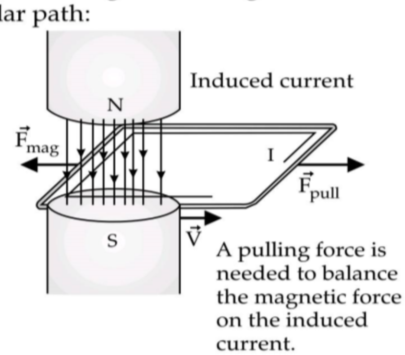
TOPIC-2
Eddy Currents, Self and Mutual Induction and AC Generator

Revision Notes

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:
  $$\phi \propto \text{I} \text{ or } \phi = LI \qquad \text{...(i)}$$
  where, L is the constant of proportionality. It is called **coefficient of self-induction.**
  The induced emf ε in the coil is given by
  $$\varepsilon = -\frac{d\phi}{dt} = -L\frac{dI}{dt} \qquad \text{...(ii)}$$
  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:
  $$L = \varepsilon / (dI/dt) \qquad \text{...(iii)}$$
  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, $H = \frac{Wb}{A} = \frac{Vs}{A} = \Omega.s$
- The self inductance of a circular coil is given by:

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

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

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

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

AC Generator
- It converts mechanical energy into electrical energy.
- It is based on the principle of mutual induction. It has mainly three components:
  - **Rotator Coil:** It can rotate about an axis on a shaft.
  - **Stator Coil:** It provides magnetic field.
  - **Commutator:** It is pair of slip rings and carbon brushes. It will facilitate flow of current between moving coil and stationary circuit.

$$\phi_B = B.A\cos\theta \text{ or } BA\cos\omega t \qquad (\theta = \omega t)$$

The induced emf is given by

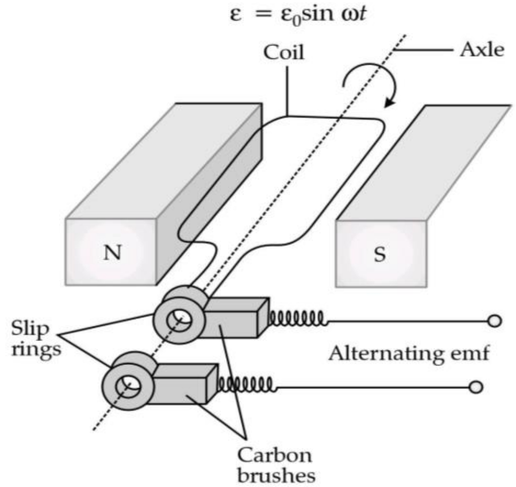
$$\varepsilon = -N\frac{d\phi_B}{dt}$$

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

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

Maximum value of emf, $\varepsilon_0 = NBA\,\omega$
(when $\sin\omega t = 1$)

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



Know the Terms

- **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

- For Self Induction $\quad \varepsilon = \frac{d\phi}{dt} = -L\frac{dI}{dt}$
- For Mutual Induction $\quad \varepsilon = \frac{d\phi}{dt} = -M\frac{dI}{dt}$
- The inductance in series is given by $\quad L_s = L_1 + L_2 + L_3 + ...$
- The inductance in parallel is given by $\quad \frac{1}{L_p} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + ...$
- 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 $\varepsilon = \varepsilon_0 \sin 2\pi\nu t$

Objective Type Questions **(1 mark each)**

[A] Very Short Answer Type Questions

Q. 1. An iron-cored solenoid has self-inductance 2.8 H. When the core is removed, the self inductance becomes 2 mH. What is the relative permeability of the core used ? U **[Delhi Comptt I, II, III 2017]**

Ans. Relative permeability,

$$\mu_r = \frac{L}{L_0}$$

$$\mu_r = \frac{2.8}{20 \times 10^{-3}} \quad ½$$

$$= 1400 \quad ½$$

[CBSE Marking Scheme, 2017]

Q. 2. What Will be change in self inductance of number of turns per unit length of a coil is doubled ? A

Ans. It will be 4 times. 1

Detailed Answer:

The self inductance of coil or solenoid is given by

$$L = \mu_0 n^2 A l$$

where μ_0 is permeability of free space, n is number of turns per unit length of a coil, A is cross sectional area of coil and l is length of coil.

If A and l are constant terms, then inductance is directly proportional to square of number of turns. According to question, the number of turns in a coil is doubled without any change in inductance lending of the coil. So, inductance of coil becomes four times.

Q. 3. A coil of certain radius has 100 turns and a self inductance of 15 mH. What will be the change in self inductance if number of turns in increased to 500? U

Ans. The new self inductance will be 375 mH. 1

Detailed Answer:

Self inductance of a coil of wire $= L = \frac{\mu N^2 A}{l}$

As the number of turns become 5 times, the self inductance must become 25 times of the initial value.

Thus new self inductance $= 25 \times 15$ mH $= 375$ mH 1

Q. 4. What is the name of the current that flows in circles inside a disc ?

Ans. Eddy current. 1

Q. 5. Which inductor will have the least eddy current loss ?

Ans. Air core inductor will have least eddy current loss. 1

Q. 6. A train is moving with uniform speed from north to south. (i) Will any potential difference be

induced between the ends of its axle? (ii) Will the answer be affected if the train moves from east to west? U

Ans. (i) Yes, emf will appear because the axle is intercepting the vertical component of the Earth's magnetic field. ½

(ii) No, here also the axle intercepts the vertical component of the Earth's magnetic field, so the emf is induced across the ends of the axle. ½

Q. 7. A cylindrical bar magnet is kept along the axis of a circular coil. Will there be a current induced in the coil if the magnet is rotated about its axis? Give reasons. U

Ans. No, because the magnetic flux linked with the circular coil does not change when the magnet is rotated about its axis. 1

Q. 8. A solenoid with an iron core and a bulb is connected to a d.c. source. How does the brightness of the bulb change when the iron core is removed from the solenoid? U

Ans. The brightness of the bulb remains unchanged because inductive reactance in a d.c. circuit is zero. 1

[B] Assertion and Reason Type Questions

For the following questions, two statements are given-one labelled as Assertion (A) and the other labelled as 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 R are true but R is not the correct explanation of A (c) A is true but is false (d) A is false and R is also false.

1. **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. (b) 1

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.

2. **Assertion (A):** The cores of electromagnets are made of soft iron.

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

Ans. (a)

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.

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

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

Ans. (c) 1

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.

Short Answer Type Questions

(2 & 3 marks each)

AI **Q. 1. A light bulb and a solenoid are connected in series across an *ac* source of voltage. Explain, how the glow of the light bulb will be affected when an iron rod is inserted in the solenoid.**

U **[Foreign I, II, III 2017]**

Ans. Effect on brightness ½

Explanation ½

Brightness decreases ½

Explanation: Self inductance of solenoid increases; this increases the impedance of the circuit and hence current decreases. ½

(Even student just writes self inductance increases, award this 1 mark.)

[CBSE Marking Scheme, 2017]

Detailed Answer:

(i) Brightness will decrease when an iron rod is inserted in the solenoid. 1

(ii) When an iron rod is inserted in the solenoid, the iron rod will cut the magnetic field lines of an inductor, so as per Kirchhoff's and Faraday's Laws, cutting of magnetic field will tend to induce a current inside the inductor which opposes the direction of it's cause. So when the current is being induced by the moving rod, it opposes the flow of existing current in the circuit, causing the bulb's brightness to go down as there is less current passing through it. 1

Q. 2. (a) Differentiate between self-inductance and mutual inductance.

(b) The mutual inductance of two coaxial coils is 2 H. The current in one coil is changed uniformly from zero to 0.5 A in 100 ms. Find the:

(i) change in magnetic flux through the other coil.

(ii) emf induced in the other coil during the change.

A **[CBSE OD SET 1, 2020]**

Ans. (a) In self inductance, the change in the strength of current in the coil is opposed by the coil itself by inducing an e.m.f.

In mutual inductance, a pair of coils are involved. If current changes in one coil, the other nearby coil opposes the change by inducing an e.m.f. in itself.

(b) Induced emf $= |e| = M\frac{dI}{dt} = 2\times\frac{0.5}{100\times10^{-3}} = 5\text{V}$

Induced emf $= |e| = \frac{d\phi}{dt}$

$$5 = \frac{d\phi}{100\times10^{-3}}$$

$d\phi$ = change in flux = $5 \times 100 \times 10^{-3} = 0.5$ Wb **3**

Q. 3 Explain the principle of the device with diagram, which is used to provide electricity at the proper voltage for household purposes.

Briefly discuss loss of energy in it due to flux leakage and its minimization.

R [CBSE OD SET 2 2020]

Ans. Try Yourself. See question no. 4 of 3 marks questions.

Quite often there is air gap between the magnetic poles and the armature. Leakage flux occurs here, causing the loss of energy. **2**

(i) To reduce the flux leakge:

(ii) Air gap should be minimised.

(iii) Curvature of magnetic poles should be made similar to the curvature of the rotating armature. **1**

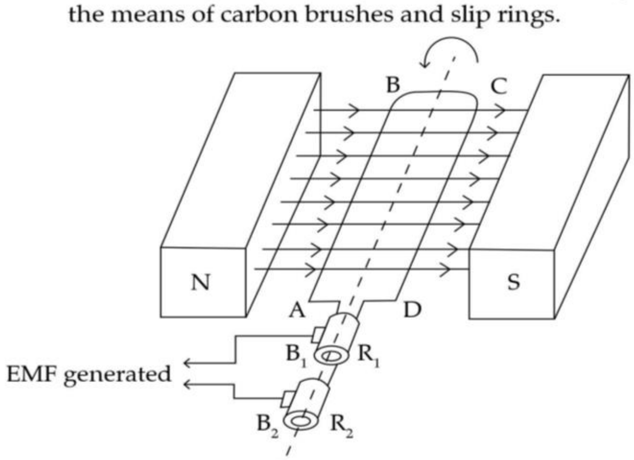
Q. 4. Draw the labelled diagram of an AC generator. Briefly explain its working and obtain the expression for the emf produced in the coil.

R [CBSE OD SET 3, 2020]

Ans. AC generator

Construction:

A coil of n turns rotates (called armature) between the magnetic poles by the means of an external agent (steam, running water, etc). The ends of the coils are connected to an external circuit through the means of carbon brushes and slip rings.



Principle of working:

AC generator works on the principle of Faraday's Laws of electromagnetic induction. According to it, when there is change of magnetic flux through a conducting loop, an emf is induced across the ends of the loop.

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

Working:

The strong magnetic field is created between the poles. The coil $ABCD$ is rotated by external means in this field. As the coil rotates, the angle between the magnetic field and the coil changes which induces an alternating emf. The ends of the coil is connected to an external circuit by the means of carbon brushes (B_1 & B_2) and slip rings R_1 & R_2) . When the external circuit is closed, an alternating current flows through the coil.

Expression of emf produced:

B = The magnetic field produced by the magnet

The coil is placed such that at t = 0, the angle between the surface area vector of the coil and the magnetic field is $\frac{\pi}{2}$.

ω = Angular speed of the coil

Angle between surface area vector of the coil and the magnetic field after time t is given by:

$$\theta = \theta_0 + \omega t$$

Magnetic flux through the coil is then:

$$\phi_B = \int B.dA$$

Or, $\phi_B = BA\cos\theta$

Or, $\phi_B = BA\cos(\theta_0+\omega t)$

By Faraday's law of electromagnetic induction, magnitude of induced emf through a coil of n–turns is given by:

$$e = n\frac{d\phi_B}{dt}$$

Or, $$e = n\frac{d}{dt}[BA\cos(\theta_0+\omega t)]$$

$\therefore$ $|e| = nBA\omega\sin(\theta_0+\omega t)$ **3**

Q. 5. (a) Define the term 'self-inductance' and write its S.I. unit.

(b) Obtain the expression for the mutual inductance of two long co-axial solenoids S_1 and S_2 wound one over the other, each of length L and radii r_1 and r_2 and n_1 and n_2 number of turns per unit length, when a current I is set up in the outer solenoid S_2.

R & A [CBSE DEL SET 3 2017]

Ans. (a) Definition of self inductance and its SI unit. **1 + ½**

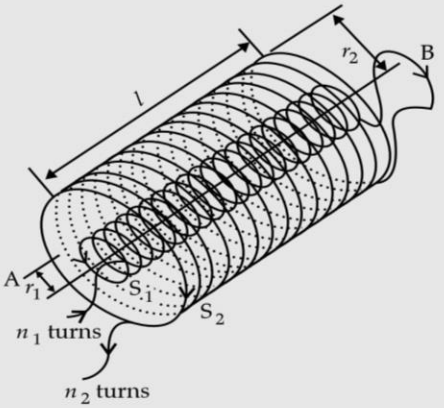
(b) Derivation of expression for mutual inductance. **1 ½**

Self inductance of a coil equals the magnitude of the magnetic flux, linked with it, when a unit current flows through it. 1

Alternatively

Self inductance of a coil, equals the magnitude of the emf induced in it, when the current in the coil, is changing at a unit rate.

SI unit: henry / (weber/ampere) / (ohm second.) ½



½

When current I_2 is passed through coil, it in turn sets up a magnetic flux through S_1:

$$\phi = n_1 \times \mu_0 \frac{n_2}{l} \times I_2 \times \pi r_1^2$$

$$= \left(\mu_0 \frac{n_1 n_2}{l} \pi r_1^2\right) I_2 = M_{12} I_2$$

where $M_{12} = \mu_0 \frac{n_1 n_2}{l} \pi r_1^2$ 1

[**Note:** If the student derives the correct expression, without giving the diagram of two coaxial coils, full credit can be given]

[CBSE Marking Scheme, 2017]

Q. 6. Define mutual inductance between a pair of coils. Derive an expression for the mutual inductance of two long coaxial solenoids of same length wound one over the other. A **[CBSE OD SET 1, 2017]**

Ans. Definition of mutual inductance:

Try yourself. See Q 8 (i) of 3 marks question 1

Try yourself. For derivation, See Q. No. 5(b) of 3 Marks Questions. 2

Q. 7. Define self-inductance of a coil. Obtain the expression for the energy stored in an inductor L connected across a source of emf.

A **[CBSE OD SET 1, 2017]**

Ans. Definition of self inductance 1

Expression for energy stored 2

(i) Try Yourself. See Q. No. 5(a) of 3 Mark Questions.

(ii) The work done against back /induced emf is stored as magnetic potential energy. ½

The rate of work done, when a current i is passing through the coil, is

$$\frac{dW}{dt} = |\varepsilon| i = \left(L\frac{di}{dt}\right) i \quad ½$$

$$\therefore W = \int dW = \int_0^I L i\, di \quad ½$$

$$= \frac{1}{2} L i^2 \quad ½$$

[CBSE Marking Scheme, 2017]

Q. 8. (i) Define mutual inductance.

(ii) 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 ?

R & A **[CBSE DEL SET 1, 2014]**

Ans. (i) Definition of mutual inductance 1

(ii) Calculation of change of flux linkage. 2

(i) Magnetic flux, linked with the secondary coil due to the unit current flowing in the primary coil, $\phi_2 = MI_1$ 1

[Alternatively,

Induced emf associated with the secondary coil, for a unit rate of change of current in the primary coil.

$$e_2 = -M\frac{dI_1}{dt}\,] \quad 1$$

[Also, accept the definition of Mutual Induction, as per the Hindi translation of the questions]

[*i.e.*, the phenomenon of production of induced emf in one coil due to change in current in neighbouring coil]

(ii) Change of flux linkage,

$d\phi = MdI$ 1

$= 1.5 \times (20 - 0)$ W ½

$= 30$ weber ½

[CBSE Marking Scheme, 2016]

Q. 9. The current through two inductors of self-inductance 15 mH and 25 mH is increasing with time at the same rate. Draw graphs showing the variation of the:

(i) emf induced with the rate of change of current

(ii) energy stored in each inductor with the current flowing through it.

Compare the energy stored in the coils, if the powers dissipated in the coils are same.

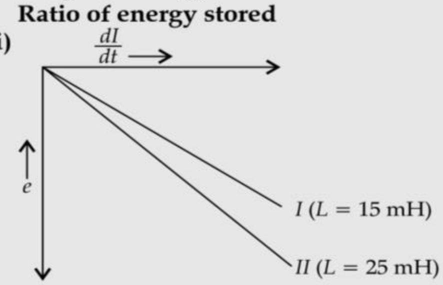
U **[O.D. Comptt. II 2017]**

Ans. Graph of emf ½

Graph of energy stored ½

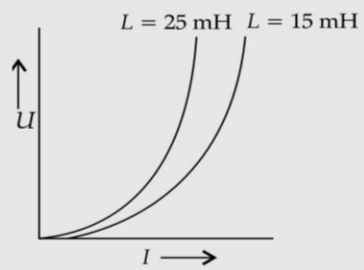
Ratio of energy stored 2

(i)



½

(ii)



½

$$\frac{U_1}{U_2} = \frac{\frac{1}{2}L_1 i_1^2}{\frac{1}{2}L_2 i_2^2}$$ ½

But $\varepsilon_1 i_1 = \varepsilon_2 i_2$ ½

($\because$ power dissipated is same)

$\therefore$ $$\frac{i_1}{i_2} = \frac{\varepsilon_2}{\varepsilon_1} = \frac{L_2}{L_1}$$ ½

$$\left(\because \frac{dI}{dt} \text{ is same and } \varepsilon = -L\frac{dI}{dt}\right)$$

$\therefore$ $$\frac{U_1}{U_2} = \frac{L_1}{L_2}\left(\frac{L_2}{L_1}\right)^2$$

$$\frac{L_2}{L_1} = \frac{25}{15} = 1.67$$ ½

[CBSE Marking Scheme, 2017]

Long Answer Type Questions (5 marks each)

Q. 1. (a) State the principle of ac generator.
(b) Explain with the help of a well labelled diagram, its working and obtain the expression for the emf generated in the coil.
(c) Is it possible to generate emf without rotating the coil ? Explain. R & U **[SQP 2020-21]**

Ans. (a) & (b) Try Yourself. See Q. No. 4 of 3 Marks Questions. **2 + 2**

(c) No. To develop an induced emf, there should be relative motion between the coil and the magnetic field. **1**

Q. 2. (a) State the principle of an *ac* generator and explain its working with the help of a labelled diagram. Obtain the expression for the emf induced in a coil having *N* turns each of cross-sectional area *A*, rotating with a constant angular speed 'ω' in a magnetic field $\vec{B}$, directed perpendicular to the axis of rotation.

(b) An aeroplane is flying horizontally from west to east with a velocity of 900 km/hour. Calculate the potential difference developed between the ends of its wings having a span of 20 m. The horizontal component of the Earth's magnetic field is 5×10^{-4} T and the angle of dip is 30°. R,U & A **[CBSE 2018]**

Ans. (a) Principle of *ac* generator ½
Working ½
Labelled diagram 1
Derivation of the expression for induced emf 1½
(b) Calculation of potential difference 1½

(a) Try Yourself. See Q. No. 4 of 3 mark Questions. **3½**

(b) Potential difference developed between the ends of the wings $e = Blv$ ½

Given: Velocity, v = 900 km/hour = 250 m/s

Wing span, l = 20 m

Vertical component of Earth's magnetic field

$B_v = B_H \tan\delta$

$= 5\times10^{-4}$ (tan 30°) tesla ½

$\therefore$ Potential difference,

$= 5\times10^{-4}(\tan 30°)\times 20\times 250$

$= \dfrac{5\times20\times250\times10^{-4}}{\sqrt{3}}$

$= 1.44$ volt ½

[CBSE Marking Scheme, 2018]

Commonly Made Error

- The students get confused with the relationship between Earth's magnetic field and its horizontal component

Answering Tip

- While answering the question related to ac generator always remember to draw a proper and labelled diagram following with explanation of principle, construction and working of generator.

Q. 3 (a) Draw a labelled diagram of *AC* generator. Derive the expression for the instantaneous value of the emf induced in the coil.
(b) A circular coil of cross-sectional area 200 cm² and 20 turns is rotated about the vertical diameter with angular speed of 50 rad s^{-1} in a uniform magnetic field of magnitude 3.0×10^{-2} T. Calculate the maximum value of the current in the coil. R & A **[CBSE DEL SET 1, 2017]**

Ans. (a)Labelled diagram of AC generator 1½
Expression for instantaneous value of induced emf. 1½
(b) Calculation of maximum value of current 2

(a) Try Yourself See Q. No. 4 of 3 Marks Questions. **3**

(b) Maximum value of emf,

$e_0 = NBA\,\omega$

$= 20 \times 200 \times 10^{-4} \times 3 \times 10^{-4} \times 50$ V

$= 600$ mV 1½

Maximum induced current

$$i_0 = \frac{e_0}{R} = \frac{600}{R}\text{mA} \qquad ½$$

[Note 1: If the student calculates the value of the maximum induced emf and says that "since R is not given, the value of maximum induced current cannot be calculated", the ½ mark, for the last part, of the question, can be given.]

[**Note 2:** The direction of magnetic field has not been given. If the student takes this direction along the axis of rotation and hence obtains the value of induced emf and, therefore, maximum current, as zero, award full marks for this part.]

[CBSE Marking Scheme, 2017]

Q. 4. (a) Draw a labelled diagram of an ac generator. Obtain the expression for the emf induced in the rotating coil of N turns each of cross-sectional area A, in the presence of a magnetic field $\vec{B}$.

(b) A horizontal conducting rod 10 m long extending from east to west is falling with a speed 5.0 ms^{-1} at right angles to the horizontal component of the Earth's magnetic field, 0.3 × 10^{-4} Wb m^{-2}. Find the instantaneous value of the emf induced in the rod.

R & A [CBSE OD SET 1, 2017]

Ans. (a) Try Yourself. See Q. No. 4 of 3 Marks Questions. **3**

(b) l = 10 m, u = 5 m/s, $B = 0.3 \times 10^{-4}$ Wb/m^2

$\therefore \quad \varepsilon = Blv$ **1**

$= 0.3 \times 10^{-4} \times 10 \times 5$

$= 15 \times 10^{-4}$ V **1**

Q. 5. (a) Explain the meaning of the term mutual inductance. Consider two concentric circular coils, one of radius r_1 and the other of radius r_2 ($r_1 < r_2$) placed coaxially with centres coinciding with each other. Obtain the expression for the mutual inductance of the arrangement.

(b) A rectangular coil of area A, having number of turns N is rotated at 'f' revolutions per second in a uniform magnetic field B, the field being perpendicular to the coil. Prove that the maximum emf induced in the coil is $2\pi f NBA$. **R & A [CBSE OD SET 1, 2016]**

Ans. (a) Meaning of Mutual Inductance **1**

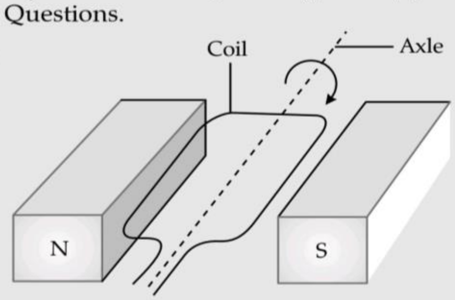
Expression **1½**

(b) Proof

Diagram

(a) Try Yourself. See Q. No. 8(i) and 5(b) of 3 Marks Questions. ½

(b)



1

Flux at any time 't'.

$$\phi_B = BA\cos\theta = BA\cos\omega t$$

From Faraday's Law, induced emf

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

Thus the instantaneous value of emf is

$$E = NBA\,\omega\sin\omega t$$

For maximum value of emf $\sin\omega t = \pm 1$

i.e., $\quad e_0 = NBA\omega = 2\pi f NBA$ **2**

[CBSE Marking Scheme, 2016]

Visual Case-based Questions

(1×4=4 marks)

Attempt any 4 sub-parts from the given 5 Questions. Each question carries 1 mark.

Q. 1. 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.

(i) 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. (a) 1

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

(ii) 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. (c) 1

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 then *AC* to *DC*.

(iii) 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. (b) 1

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.

(iv) Bulb of bicycle light glows when:

(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. (c) 1

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.

(v) 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. (a)

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.

Q. 2. 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).

(i) Eddy current is generated in a:

(a) Metallic pipe **(b)** *PVC* pipe

(c) Glass pipe **(d)** Wooden pipe

Ans. (a) 1

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

(ii) Eddy current was first observed by:

(a) Helmhotlz **(b)** Foucault

(c) D'Arsonval **(d)** Shock ley

Ans. (b) 1

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

(iii) 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 slowing down the motion of a magnet moving through a metal pipe due to electromagnetically induced current.

Ans. (d) 1

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.

(iv) 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. (a) **1**

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.

(v) 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. (b) **1**

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.

❑❑