EMI, Faraday’ laws of Electromagnetic Induction

CLASS-XII

SUBJECT : PHYSICS
CHAPTER NUMBER: 06
CHAPTER NAME : ELECTROMAGNETIC INDUCTION

CHANGING YOUR TOMORROW

Website: www.odmegroup.org
Email: info@odmps.org

Toll Free: **1800 120 2316**
Sishu Vihar, Infocity Road, Patia, Bhubaneswar- 751024

Magnetic Flux (Φ):

Magnetic Flux through any surface is the number of magnetic lines of force passing normally through that surface.

It can also be defined as the product of the area of the surface and the component of the magnetic field normal to that surface.

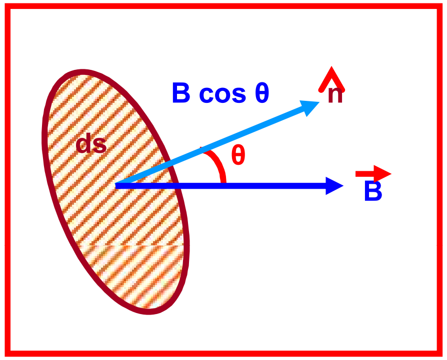
$$d\Phi = \vec{B} \cdot \vec{ds} = \vec{B}.ds.\hat{n}$$

$$d\Phi = B \cdot ds \cos\theta$$

$$\Phi = \vec{B} \cdot \vec{A} = \vec{B}.A.\hat{n}$$

$$\Phi = B \cdot A \cos\theta$$

Direction of $\vec{ds}$ is along the normal to the surface and $\hat{n}$ is unit normal vector.



Positive Flux:
Magnetic Flux is positive for $0° \le \theta < 90°$ & $270° < \theta \le 360°$

Zero Flux:
Magnetic Flux is zero for $\theta = 90°$ & $\theta = 270°$

Negative Flux:
Magnetic Flux is negative for $90° < \theta < 270°$

Flux is maximum when $\theta = 0°$ and is $\Phi = B \cdot A$

Magnetic Flux (Φ):

$$\boxed{\Phi = B \, . \, A \cos \theta}$$

Magnetic Flux across a coil can be changed by changing :

1) the strength of the magnetic field B

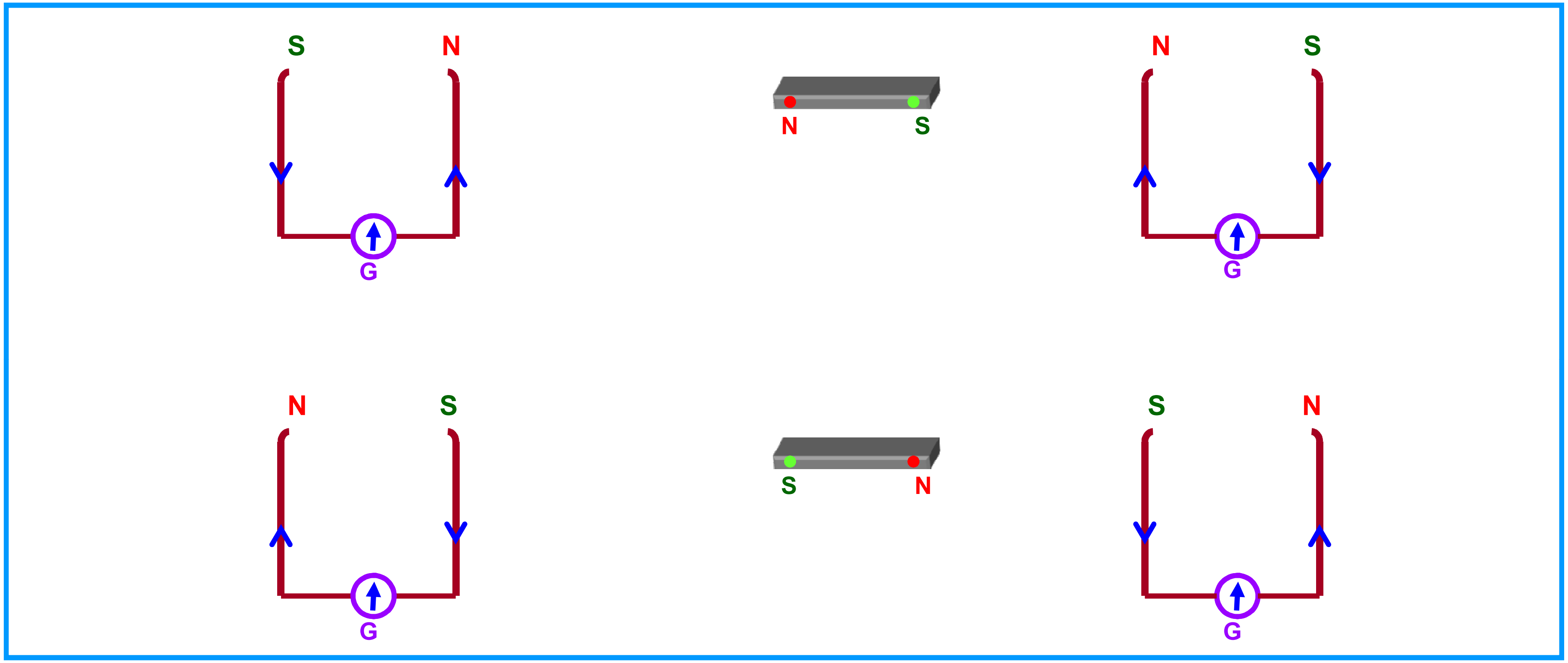
2) the area of cross section of the coil A

3) the orientation of the coil with magnetic field θ or

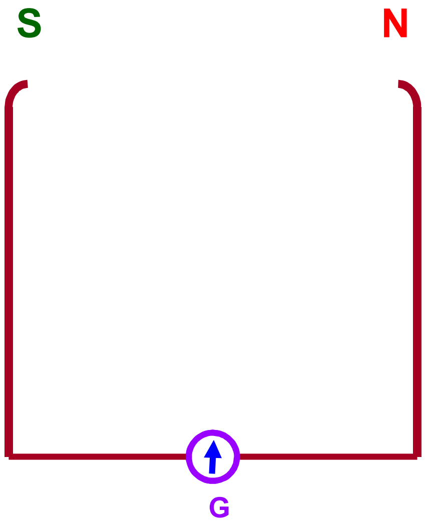
4) any of the combination of the above

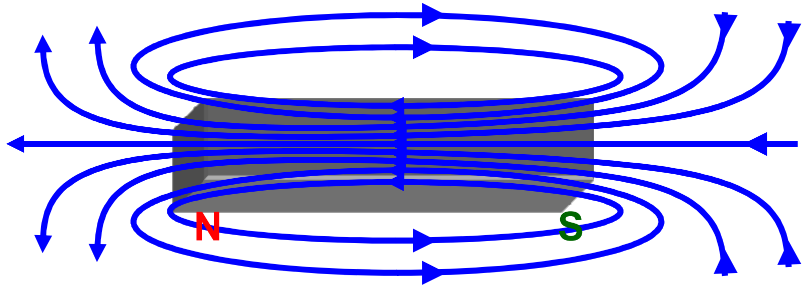
* Magnetic flux is a scalar quantity.
* SI unit of magnetic flux is weber or tesla-metre^2 or (wb or Tm^2).
* cgs unit of magnetic flux is maxwell.
* 1 maxwell = 10^{-8} weber
* Magnetic flux (associated normally) per unit area is called Magnetic Flux Density or Strength of Magnetic Field or Magnetic Induction (B).

Faraday's Experiment - 1:



Faraday's Experiment - 1:





Magnetic flux linked with the coil changes relative to the positions of the coil and the magnet due to the magnetic lines of force cutting at different angles at the same cross-sectional area of the coil.

ODM PUBLIC SCHOOL

Faraday's Experiment - 1:

Observation:

a) the relative motion between the coil and the magnet

b) the induced polarities of magnetism in the coil

c) the direction of current through the galvanometer and hence the deflection in the galvanometer

d) that the induced current (e.m.f) is available only as long as there is relative motion between the coil and the magnet

Note:

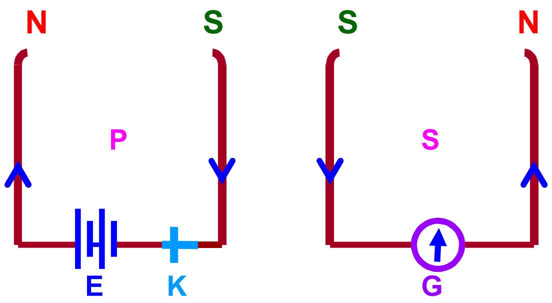
a) coil can be moved by fixing the magnet

b) both the coil and magnet can be moved (towards each other or away from each other) i.e. there must be a relative velocity between them

c) magnetic flux linked with the coil changes relative to the positions of the coil and the magnet

d) current and hence the deflection is large if the relative velocity between the coil and the magnet and hence the rate of change of flux across the coil is more

Faraday's Experiment - 2:



When the primary circuit is closed current grows from zero to maximum value.

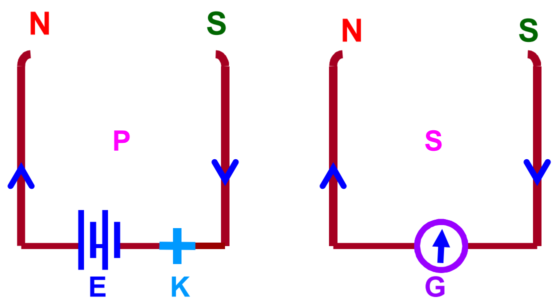
During this period changing, current induces changing magnetic flux across the primary coil.

This changing magnetic flux is linked across the secondary coil and induces e.m.f (current) in the secondary coil.

Induced e.m.f (current) and hence deflection in galvanometer lasts only as long as the current in the primary coil and hence the magnetic flux in the secondary coil change.

ODM PUBLIC SCHOOL

Faraday's Experiment - 2:



When the primary circuit is open current decreases from maximum value to zero.

During this period changing current induces changing magnetic flux across the primary coil.

This changing magnetic flux is linked across the secondary coil and induces current (e.m.f) in the secondary coil.

However, note that the direction of current in the secondary coil is reversed and hence the deflection in the galvanometer is opposite to the previous case.

Induced EMF and Current, Lenz's law

CLASS-XII

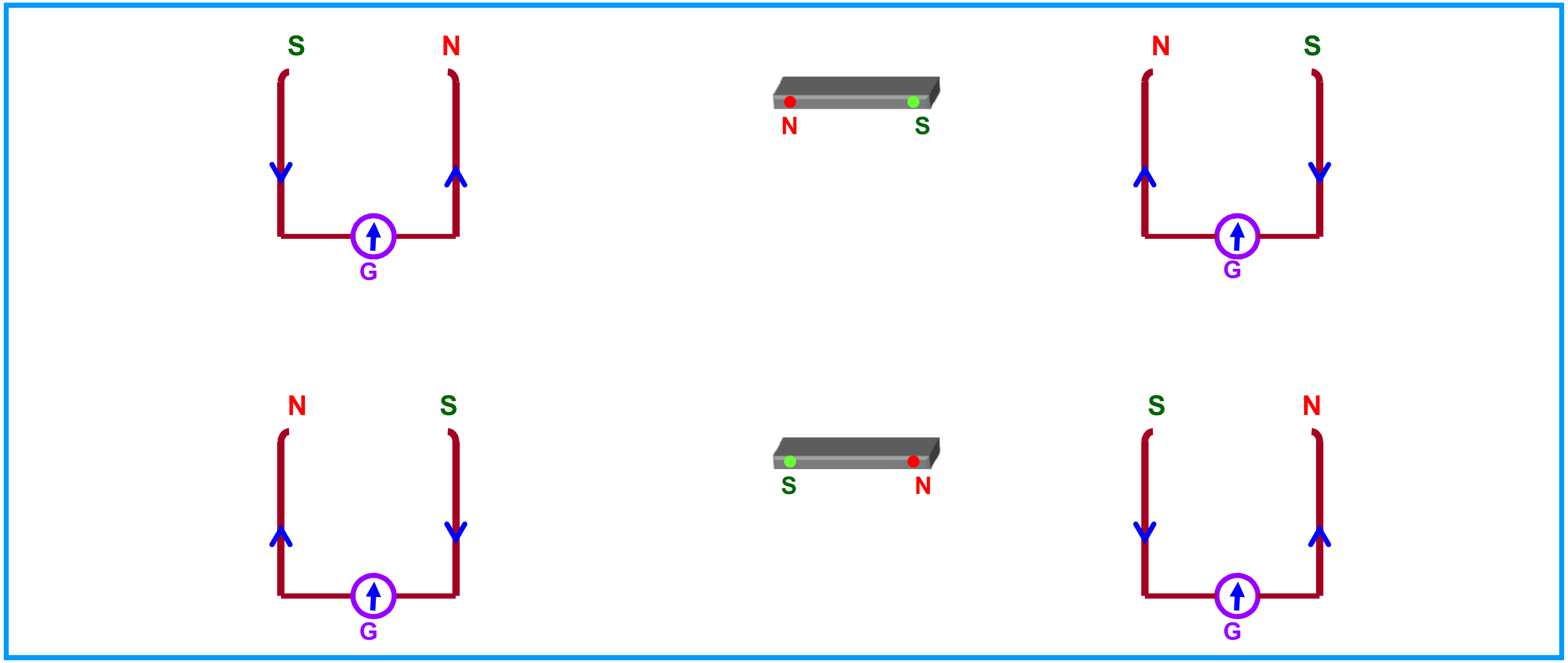
SUBJECT : PHYSICS
CHAPTER NUMBER: 06
CHAPTER NAME : ELECTROMAGNETIC INDUCTION

CHANGING YOUR TOMORROW

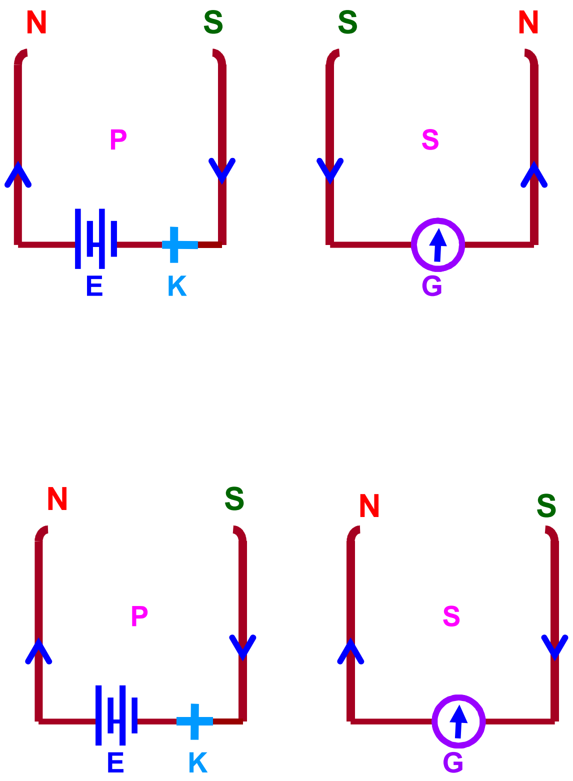
Website: www.odmegroup.org
Email: info@odmps.org

Toll Free: **1800 120 2316**
Sishu Vihar, Infocity Road, Patia, Bhubaneswar- 751024

Faraday's Experiment - 1:



Faraday's Experiment - 2:



Faraday’s Laws of Electromagnetic Induction:

- Based on experiments (described above) Faraday concluded that.
- (a) Whenever there is a change in magnetic flux linked with the circuit, an emf is induced in it. The phenomenon is called electromagnetic induction
- (b) The induced emf last as long as the change in flux continues.
- (c) The magnitude of the induced emf in a circuit is equal to the time rate of change of magnetic flux through the circuit.
- Mathematically$|\varepsilon| = \frac{d\phi}{dt}$
- (d) The direction of induced emf is such as to oppose the change or cause which creates it. This law is called **Lenz’s Law.**

All the above statements taken together are known as Faraday’s laws of electromagnetic induction and are expressed analytically as

$$\varepsilon = -\frac{Nd\phi}{dt}$$

-ve sign shows that if flux increases, ε is –ve and vice versa.

ODM PUBLIC SCHOOL
SCHOOL OF HUMAN EXCELLENCE

Faraday's Laws of Electromagnetic Induction:

I Law:

Whenever there is a change in the magnetic flux linked with a circuit, an emf and hence a current is induced in the circuit. However, it lasts only so long as the magnetic flux is changing.

II Law:

The magnitude of the induced emf is directly proportional to the rate of change of magnetic flux linked with a circuit.

$$E \propto d\Phi / dt \implies E = k\, d\Phi / dt \implies E = d\Phi / dt \implies E = (\Phi_2 - \Phi_1) / t$$

(where k is a constant and units are chosen such that k = 1)

ODM PUBLIC SCHOOL

Lenz’s Law:

The direction of the induced emf or induced current is such that it opposes the change that is producing it.

i.e. If the current is induced due to motion of the magnet, then the induced current in the coil sets itself to stop the motion of the magnet.

If the current is induced due to change in current in the primary coil, then induced current is such that it tends to stop the change.

Lenz's Law:

Example – 1, (Attraction and repulsion concept)

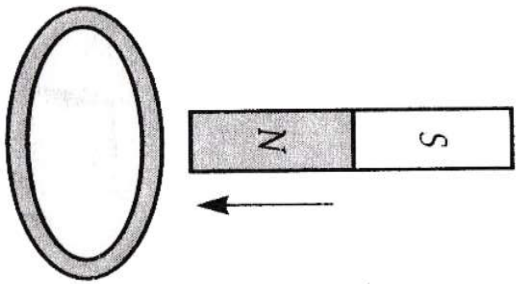
Suppose N-pole of a bar magnet is being pushed towards the coil.

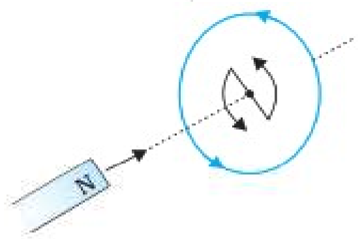
As it moves, the magnetic flux through the coil increases

Current is induced in the coil

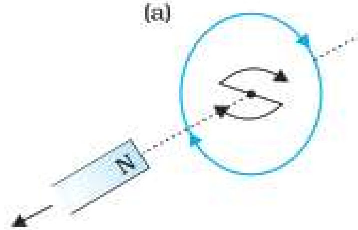
The direction of induced current in the coil is in such a direction that it opposes the increase in flux

This is possible only if the current in the coil is in anticlockwise direction w.r.t an observer situated on the side of the magnet.





(a)

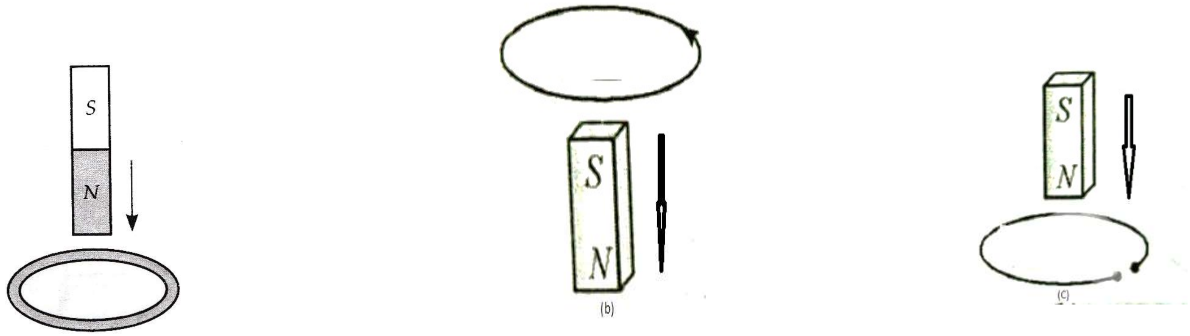


(b)

Note:-The direction shown by N and S indicate the directions of induced current.

NUMERICAL

Question: -A copper ring is held horizontally and a bar magnet is dropped through the ring with its length along the axis of the ring as shown in the following diagrams. State whether its acceleration a is equal to, greater than or less than the acceleration due to gravity g.



NUMERICAL

Solution:-

(a) $a = \frac{mg - F}{m} = g - \frac{F}{m}$

Whereof the bar magnet

$F \rightarrow$ Force of repulsion on approaching magnet

Hence a < g

(b) $a = \frac{mg - F}{m} = g - \frac{F}{m}$

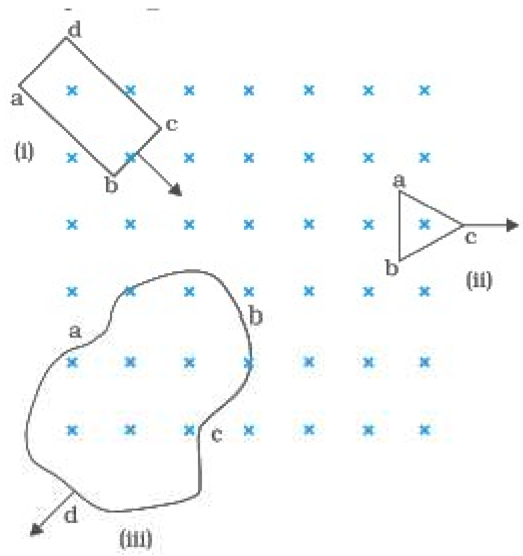
$\Rightarrow a < g$

Here, F is the force of attraction on receding magnet

(c) Here an emf will be induced in the ring but no current will flow. So the coil can no more oppose the approach of the magnet. Hence a = g

Lenz’s Law:

The figure shows planar loops of different shapes moving out of or into a region of the magnetic field which is directed normal to the plane of the loop away from the reader. Determine the direction of induced current in each loop using Lenz’s law.



Lenz’s Law:

Solution:-

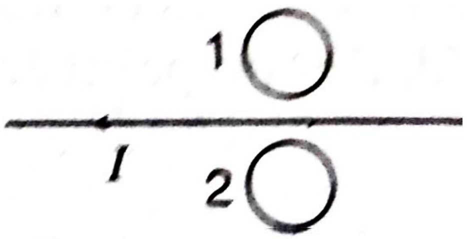
(a) Due to the motion of loop abcd into the region of the magnetic field. The cross magnetic field ⊗ through loop increases. Then induced current will produce dot magnetic field to produce ⊙ a magnetic field, the induced current should be anti-clockwise (follow along the path bcdab)

(b) Due to the outward motion of the triangular loop (abc), the cross magnetic field ⊗ through abc decreases. Then induced current will produce a cross magnetic field to produce ⊗ magnetic field, the induced current should be clockwise (follow along the path bacb)

(c) Clockwise (along path cdabc)

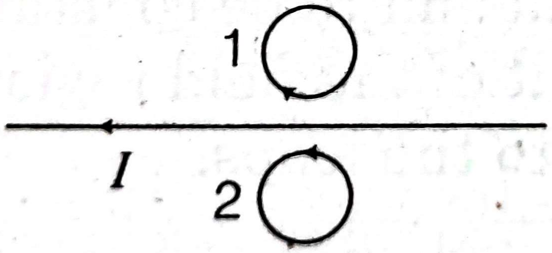
Numerical

Question: Predict the direction of induced current in metal rings 1 and 2 when current I in the wire is steadily decreasing?



Numerical

12. Current in the wire is steadily decreasing, so the induced current in rings 1 and 2 will flow in such a way that it opposes the decrease of current. So, it will flow in same direction. Now, from the figure. It is clear that the direction of induced current in



(i) ring 1 is clockwise.

(ii) ring 2 is anti-clockwise. **(1)**

Faraday's Laws of Electromagnetic Induction:

NOTE:-

- In the case of E.M.I, an emf $|\varepsilon| = \frac{d\phi}{dt}$ always existed, either the circuit is closed or open but the current will exist only if the circuit is closed.
- If the circuit is closed, induced current

$I = \frac{\varepsilon}{R} = -\frac{Nd\phi}{Rdt}$ (Where R is the total resistance of the circuit)

- Induced charge $dq = Idt = -\frac{Nd\phi}{R}$ (Independent of time)
- $inducedpower(P) = \varepsilon I = \frac{N^2}{R}\left(\frac{d\phi}{dt}\right)^2$
- Induced field: - Time-varying magnetic field induces electric field which is related to induced emf as

$$\varepsilon = \int E_{in} . d\ell$$

Since $\int E.dl \neq 0$this indicate induced electric field is a **non-conservative** field.

NUMERICAL

Question: - In Faraday's experiment

(a) What would you do to obtain a large deflection of the galvanometer?

(b) How would you demonstrate the presence of induced current in the absence of a galvanometer [**NCERT]**

NUMERICAL

A square loop of side 10cm and resistance 0.5Ω is placed vertically in the east-west plane. A uniform magnetic field of 0.1 T is set up across the plane in the north-east direction. The magnetic field is decreased to zero in 0.7 s at a steady rate.

(a) Determine the magnitudes of induced emf

(b) Determine the induced current during this internal **[NCERT]**

NUMERICAL

Solution:-

$\phi = BA\cos\theta$

Initial flux = $BA\cos 45^\circ$ [$\therefore$ Area vector makes 45° with field]

$= \left(0.1\times10^{-2}\right)\frac{1}{\sqrt{2}}$

Final flux = 0

(a) $\varepsilon = \frac{\phi_{initial} - \phi_{final}}{\Delta t} = 1\,mv$

(b) $I = \frac{\varepsilon}{R} = \frac{10^{-3}\,v}{0.5\Omega} = 2\,mA$

Lenz’s Law and Law of Conservation of Energy:

- According to Lenz’s law, the induced emf opposes the change that produces it.
- It is this opposition against which we perform mechanical work in causing the change in magnetic flux. Therefore, mechanical energy is converted into electrical energy.
- Thus, Lenz’s law is in accordance with the law of conservation of energy.
- If, however, the reverse would happen (i.e. the induced emf does not oppose or aids the change), then a little change in magnetic flux would produce an induced current which would help the change of flux further thereby producing more current.
- The increased emf would then cause further change of flux and it would further increase the current and so on. This would create energy out of nothing which would violate the law of conservation of energy.

THANKING YOU

ODM EDUCATIONAL GROUP