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Introduction

Key Points

- Moving electric charges produce magnetic fields (Oersted, Ampere).
- Electric current is induced in a closed coil by varying magnetic fields (Faraday, Henry).
- Electromagnetic induction: generation of electric current by changing magnetic fields.

Solved Examples

Ex 1

- Given a coil and a moving magnet, determine if current is induced.
- When magnet moves relative to coil, current is induced due to changing magnetic flux.
- Use concept: Current induced only when magnetic field changes.

Practice Set

- Q1: Who discovered that moving electric charges produce magnetic fields?
 - A. Faraday
 - B. Oersted
 - C. Henry
 - D. Ampere
- Q2: What causes electric current in a coil during electromagnetic induction?
 - A. Constant magnetic field
 - B. Varying magnetic field
 - C. Static electric field
 - D. No magnetic field
- Q3: Electromagnetic induction is the phenomenon of
 - A. Generating magnetic field by electric current
 - B. Generating electric current by varying magnetic field
 - C. Generating electric current by static magnetic field
 - D. Generating electric current by constant magnetic field

Answer Key

- Q1: B - Oersted discovered moving charges produce magnetic fields.
- Q2: B - Electric current is induced by varying magnetic fields.
- Q3: B - Electromagnetic induction is current generation by changing magnetic fields.

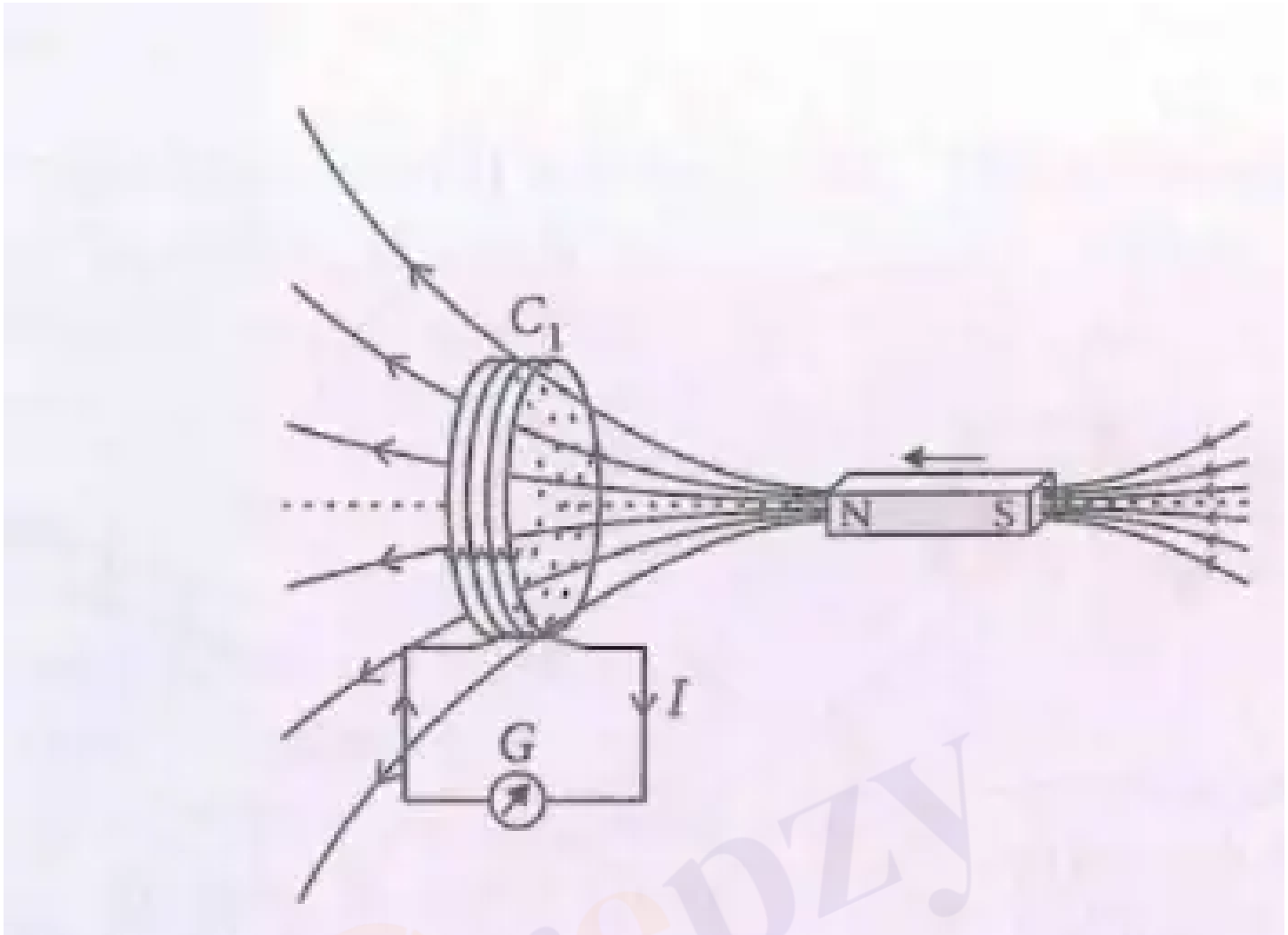
Memory Aids

- Moving charges → Magnetic field (Oersted).
- Changing magnetic field → Induced current (Faraday's law).
- Static field → No induction.

Faraday and Henry Experiments

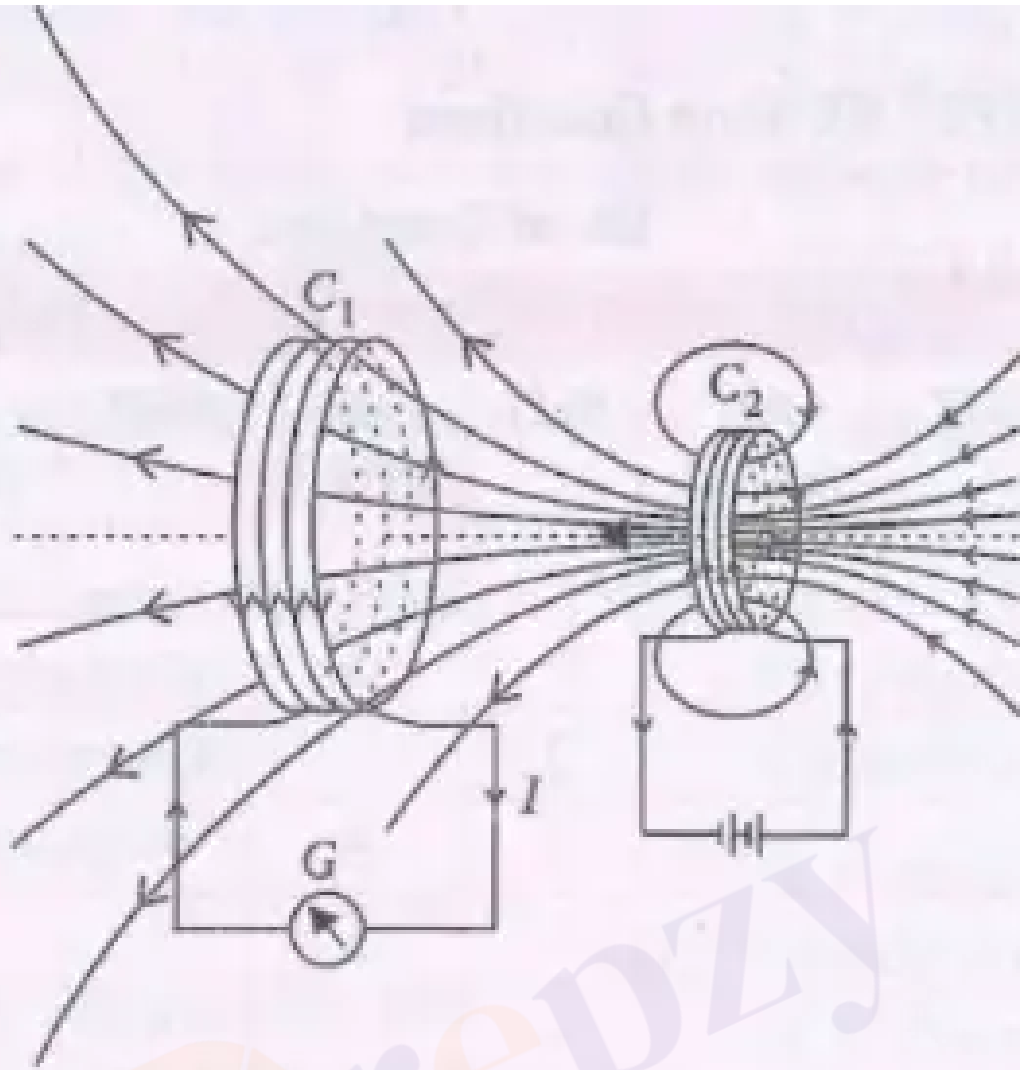
Experiment 1: Moving Magnet and Coil

- Moving bar magnet towards coil induces current (galvanometer deflects).
- Current flows only while magnet moves (changing magnetic flux).
- Direction of current reverses if magnet moves away.



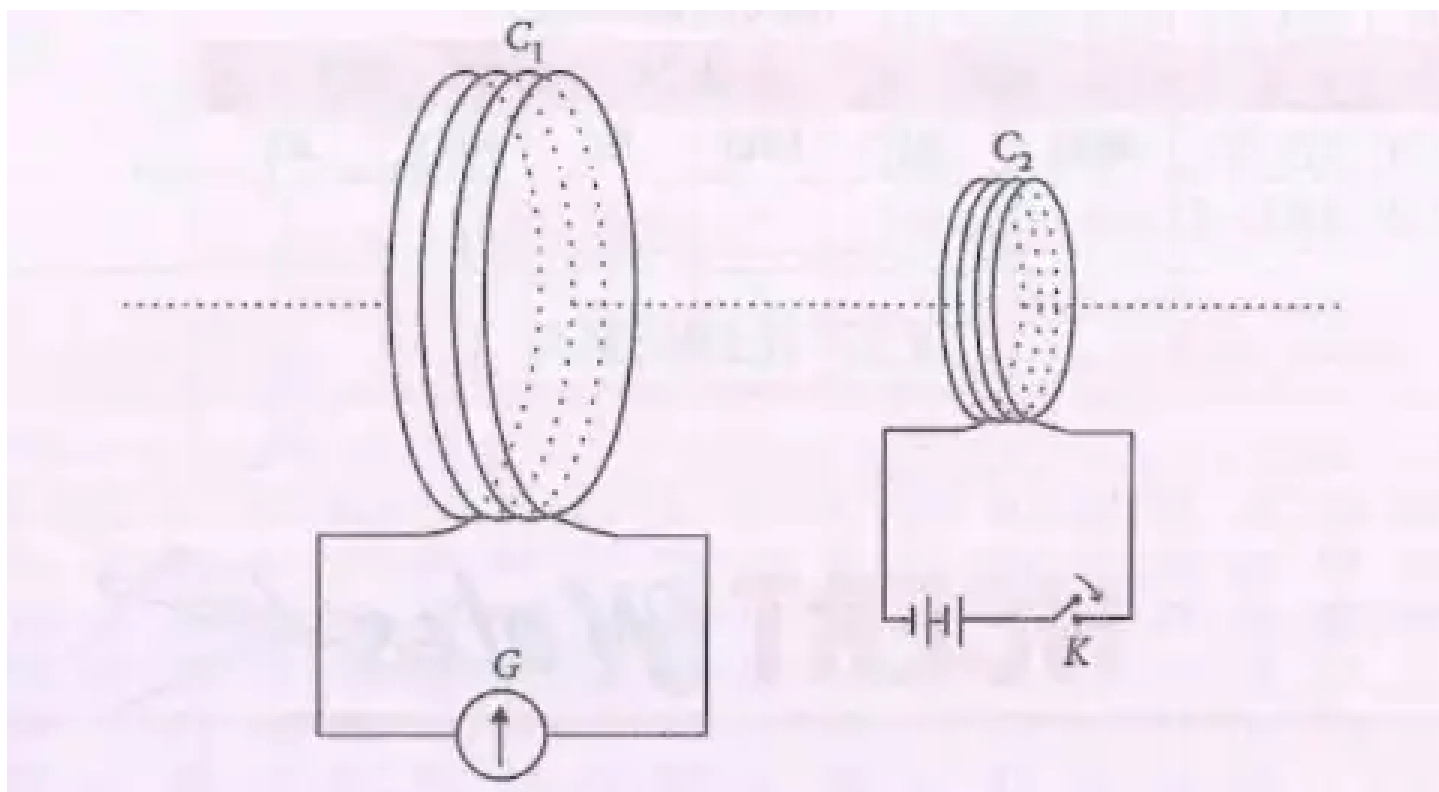
Experiment 2: Current Induced by Moving Current-Carrying Coil

- Current in coil C1 induced by motion of current-carrying coil C2.
- Changing magnetic field from moving coil induces current in nearby coil.



Experiment 3: Two Coils with Battery and Galvanometer

- Coil C2 connected to battery and key K; coil C1 connected to galvanometer G.
- Closing key K causes current in C2, changing magnetic field around C1.
- Changing magnetic field induces current in C1, detected by galvanometer deflection.
- Deflection is momentary when key is pressed or released; no deflection when key is held closed.



Solved Examples

Ex 1

- Calculate induced current direction when magnet moves towards coil.
- Use Lenz's law: induced current opposes change in magnetic flux.

Practice Set

- Q1: What happens to galvanometer when magnet moves towards coil?
 - A. No deflection
 - B. Deflection indicating induced current
 - C. Deflection indicating no current
 - D. Constant deflection
- Q2: When key K is kept closed, galvanometer shows
 - A. Continuous deflection
 - B. No deflection
 - C. Momentary deflection
 - D. Increasing deflection
- Q3: Induced current in coil C1 is due to
 - A. Constant magnetic field from C2

- B. Changing magnetic field from C2
- C. Static electric field
- D. No magnetic field

Answer Key

- Q1: B - Moving magnet changes magnetic flux, inducing current.
- Q2: B - No deflection when key is held closed (steady current).
- Q3: B - Induced current caused by changing magnetic field.

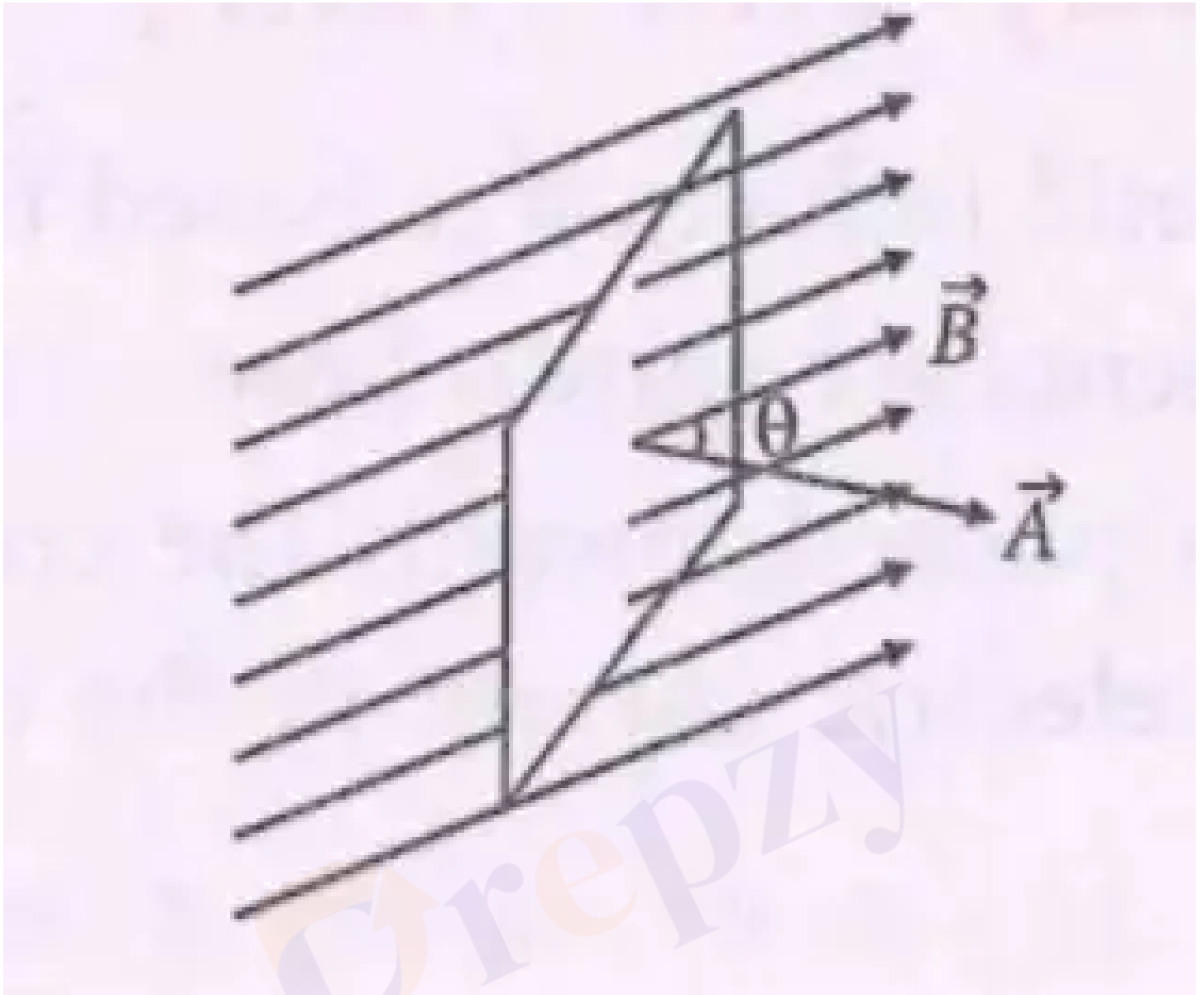
Memory Aids

- Magnet motion → Induced current (galvanometer deflects).
- Steady current → No induction.
- Changing magnetic field → Induction.

Magnetic Flux

Definition and Formula

- Magnetic flux (ϕ) through a surface of area vector $\vec{A}$ in a uniform magnetic field $\vec{B}$ is $\phi = \vec{B} \cdot \vec{A}$.
- Formula: $\phi = BA \cos \theta$, where:
 - B = magnetic field strength (Tesla, T)
 - A = area of the surface (m^2)
 - θ = angle between $\vec{B}$ and $\vec{A}$
- Area vector $\vec{A}$ is perpendicular to the surface.
- Magnetic flux measures the amount of magnetic field passing through the surface.



Solved Examples

- **Ex 1:** Calculate magnetic flux if $B = 0.5\text{ T}$, $A = 2\text{ m}^2$, and $\theta = 60^\circ$.
 - Use $\phi = BA \cos \theta = 0.5 \times 2 \times \cos 60^\circ = 0.5 \times 2 \times 0.5 = 0.5\text{ Wb}$.

Practice Set

- **Q1:** Magnetic flux is maximum when θ is:
 - A) 0°
 - B) 90°
 - C) 45°
 - D) 180°
- **Q2:** If magnetic field $B = 1\text{ T}$, area $A = 3\text{ m}^2$, and $\theta = 90^\circ$, magnetic flux is:

- A) 3 Wb
 - B) 0 Wb
 - C) 1 Wb
 - D) 90 Wb
- **Q3:** A surface of area 4 m^2 is placed in a magnetic field of 0.2 T at an angle of 60° . Find magnetic flux:
 - A) 0.4 Wb
 - B) 0.8 Wb
 - C) 1.6 Wb
 - D) 2.0 Wb

Answer Key

- **Q1:** A) 0° — Magnetic flux $\phi = BA \cos \theta$ is maximum when $\cos \theta = 1$, i.e., $\theta = 0^\circ$.
- **Q2:** B) 0 Wb — At 90° , $\cos 90^\circ = 0$, so flux is zero.
- **Q3:** B) 0.8 Wb — $\phi = 0.2 \times 4 \times \cos 60^\circ = 0.8 \text{ Wb}$.

Memory Aids

- Magnetic flux $\phi = BA \cos \theta$ — remember $\cos 0^\circ = 1$ for max flux.
- Area vector $\vec{A}$ is always perpendicular to surface.
- Flux zero when field is perpendicular to area vector ($\theta = 90^\circ$).

Faraday's Law

Faraday's and Lenz's Laws

- According to **Faraday's law**, whenever a conductor is associated with varying magnetic flux, then emf is induced.
- According to **Lenz's law**, an induced current always flows in a direction such that it opposes the cause that has produced it.

The coil repulses the magnet

When the "N" Pole of the magnet is moved towards the coil, end of the coil becomes "N" Pole.

The coil attracts the magnet

When the "N" Pole of the magnet is moved away from the coil, end of the coil becomes "S" Pole.

Explanation

- Change in magnetic flux through a coil induces emf.
- Induced emf exists only while flux changes.
- Mathematical form: $\varepsilon = -\frac{d\phi}{dt}$.
- For N turns, $\varepsilon = -N\frac{d\phi}{dt}$.
- Polarity given by Lenz's law (opposes change).

Solved Examples

- **Ex 1:** A coil with 50 turns experiences a flux change of 0.1 Wb in 0.02 s. Find induced emf.
Solution: $\varepsilon = -N\frac{d\phi}{dt} = -50 \times \frac{0.1}{0.02} = -250 \text{ V}$.

Practice Set

- Q1: What causes emf in a coil?
A) Constant magnetic flux
B) Change in magnetic flux

- C) Electric current
- D) Resistance
- Q2: If magnetic flux changes from 0.5 Wb to 0.1 Wb in 0.1 s in a single turn coil, emf induced is:
 - A) 4 V
 - B) 0.4 V
 - C) 5 V
 - D) 0.05 V
- Q3: A coil of 100 turns has flux changing at 0.02 Wb/s. Induced emf is:
 - A) 2 V
 - B) 0.5 V
 - C) 5 V
 - D) 0.2 V

Answer Key

- Q1: B - emf induced only by change in magnetic flux.
- Q2: A - $\varepsilon = -\frac{d\phi}{dt} = -\frac{0.1-0.5}{0.1} = 4 \text{ V}$.
- Q3: A - $\varepsilon = -N\frac{d\phi}{dt} = -100 \times 0.02 = 2 \text{ V}$.

Memory Aids

- "Change in flux → emf"
- Formula: $\varepsilon = -N\frac{d\phi}{dt}$
- Lenz's law gives polarity (opposes change)

Lenz's Law

Explanation

- Induced current opposes the cause of flux change.
- When magnet's North pole approaches coil, coil acts as North pole (repels).
- When magnet's North pole moves away, coil acts as South pole (attracts).
- Direction of induced current shown by galvanometer.

Solved Examples

- **Ex 1:** Magnet's North pole moves toward coil, galvanometer deflects right. What is coil's pole?
Solution: Coil acts as North pole (repels magnet).
- **Ex 2:** Magnet's North pole moves away, galvanometer deflects left. Coil's pole?
Solution: Coil acts as South pole (attracts magnet).

Practice Set

- Q1: Lenz's law states induced current:
 - A) Supports flux change
 - B) Opposes flux change
 - C) Is independent
 - D) Is zero
- Q2: When magnet approaches coil, coil behaves like:
 - A) South pole
 - B) North pole
 - C) Neutral
 - D) No pole
- Q3: Galvanometer shows current direction. If magnet moves away, coil's induced pole is:
 - A) North
 - B) South
 - C) Neutral
 - D) None

Answer Key

- Q1: B - Induced current opposes flux change.
- Q2: B - Coil acts as North pole to repel approaching magnet.
- Q3: B - Coil acts as South pole to attract receding magnet.

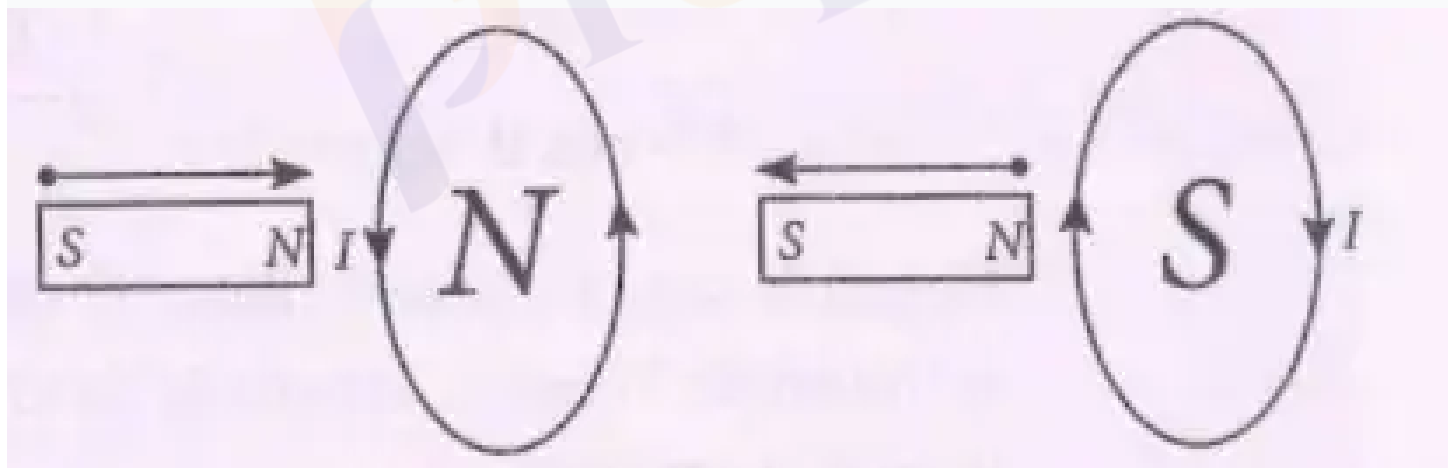
Memory Aids

- "Induced current fights change"
- Approach → coil repels (same pole)
- Recede → coil attracts (opposite pole)

Lenz's Law

Explanation

- Lenz's law states that the induced current in a circuit flows to oppose the change in magnetic flux that produces it.
- Mathematically, $\varepsilon = -\frac{d\phi}{dt}$, where the negative sign shows opposition.
- This law aligns with the conservation of energy: work must be done against the induced emf to change the flux.
- Energy spent by an external source appears as electrical energy in the circuit.
- Example: Moving a magnet towards a loop induces current that creates a magnetic field opposing the magnet's motion.



Solved Examples

- **Ex 1:** A magnet is moved towards a coil. Direction of induced current?
 - Answer: Anticlockwise to create a north pole opposing the magnet's approach.
- **Ex 2:** Magnet moved away from coil. Induced current direction?
 - Answer: Clockwise to create a south pole attracting the magnet, opposing its motion.

Practice Set

- Q1: Lenz's law states that induced current flows to:
 - A) Increase magnetic flux
 - B) Oppose change in magnetic flux
 - C) Align with magnetic field
 - D) Flow randomly
- Q2: The formula for induced emf according to Lenz's law is:
 - A) $\varepsilon = \frac{d\phi}{dt}$
 - B) $\varepsilon = -\frac{d\phi}{dt}$
 - C) $\varepsilon = \phi \times t$
 - D) $\varepsilon = 0$
- Q3: When a magnet is moved towards a coil, the induced current:
 - A) Attracts the magnet
 - B) Has no effect
 - C) Repels the magnet
 - D) Depends on coil resistance

Answer Key

- Q1: B - Induced current opposes the change in magnetic flux as per Lenz's law.
- Q2: B - Negative sign in $\varepsilon = -\frac{d\phi}{dt}$ shows opposition.
- Q3: C - Induced current creates a magnetic field repelling the approaching magnet.

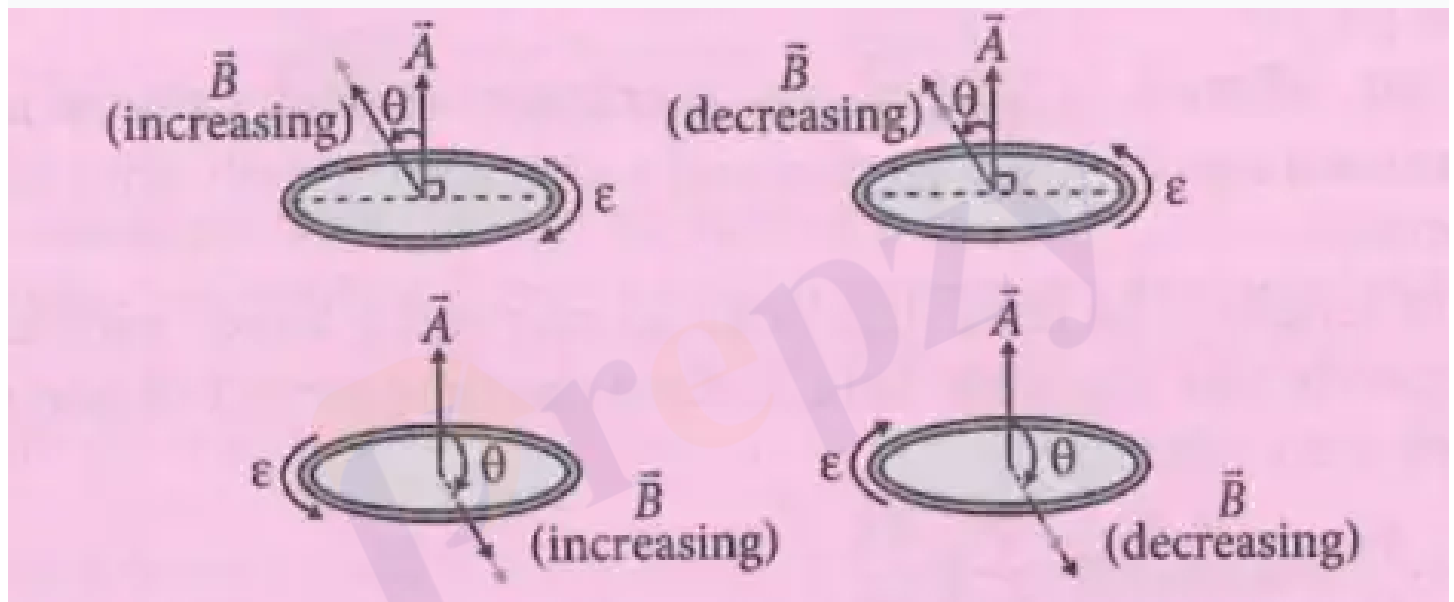
Memory Aids

- "Lenz's law = Oppose change"
- Formula: $\varepsilon = -\frac{d\phi}{dt}$
- Induced current always fights the cause.

Direction of Induced EMF

Explanation

- Magnetic flux $\phi = BA \cos \theta$, depends on magnetic field B , area A , and angle θ .
- Induced emf depends on the rate of change of magnetic flux.
- Flux increases if B increases and $\theta = 0^\circ$ (field perpendicular to loop).
- Flux decreases if B decreases and $\theta = 0^\circ$.
- Flux is zero or negligible if $\theta = 90^\circ$ (field parallel to loop), regardless of B change.
- Induced emf magnitude is proportional to the relative speed of coil and magnet.
- Induced emf does not depend on coil resistance.



Solved Examples

- **Ex 1:** Magnetic field B increases perpendicular to coil. Induced emf direction?
 - Answer: Opposes increase, direction given by Lenz's law.
- **Ex 2:** Magnetic field decreases at 0° angle. Induced emf direction?
 - Answer: Induced emf tries to increase flux, opposite to decrease.

Practice Set

- Q1: Magnetic flux is zero when $\theta =$:
 - A) 0°

- B) 45°
- C) 90°
- D) 180°
- Q2: Induced emf depends on:
 - A) Coil resistance
 - B) Rate of change of magnetic flux
 - C) Coil material
 - D) Temperature
- Q3: If magnetic field B is constant but angle θ changes from 0° to 90° , induced emf is:
 - A) Maximum
 - B) Zero
 - C) Half
 - D) Double

Answer Key

- Q1: C - Flux is zero when field is parallel to loop ($\theta = 90^\circ$).
- Q2: B - Induced emf depends on rate of change of magnetic flux, not coil resistance.
- Q3: B - Flux change is zero if B constant and angle changes to 90° , so emf is zero.

Memory Aids

- Flux $\phi = BA \cos \theta$
- Emf $\propto$ rate of flux change
- Zero flux at 90° angle

Motional Electromotive Force

Concept and Formulas

- When a conducting rod moves in a magnetic field cutting the field lines, free electrons shift from one end to another, inducing an emf called motional emf.
- Emf induced in a small segment $d\vec{l}$: $d\varepsilon = (\vec{v} \times \vec{B}) \cdot d\vec{l}$
- Total emf across the rod: $\varepsilon = \int (\vec{v} \times \vec{B}) \cdot d\vec{l} = vBl \sin \theta$

- Induced electric field in the rod: $\vec{E}_{in} = -(\vec{v} \times \vec{B}) = (\vec{B} \times \vec{v})$
- If any two of $\vec{v}$, $\vec{B}$, and $d\vec{l}$ are parallel or antiparallel, emf $\varepsilon = 0$.

Rotating rod :

- When a conducting rod moves in an external magnetic field in such a way it cuts the field, so, all the free electrons in the rod transfer from one end to another end (C to D) and emf is induced in the rod. This emf is known as motional emf.

- The emf induced within $d\vec{l}$

$$d\varepsilon = (\vec{v} \times \vec{B}) \cdot d\vec{l}$$

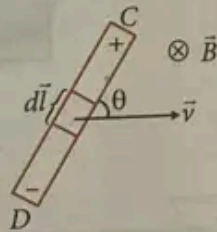
Net emf across the rod,

$$\varepsilon = \int (\vec{v} \times \vec{B}) \cdot d\vec{l} = vBl \sin \theta$$

Induced electric field in the rod,

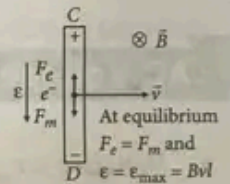
$$\vec{E}_{in} = -(\vec{v} \times \vec{B}) = (\vec{B} \times \vec{v})$$

- If any two out of $\vec{v}$, $\vec{B}$ and $d\vec{l}$ become parallel or antiparallel, ε will become zero.



- If $\theta = 90^\circ$, i.e., $\vec{v}$, $\vec{B}$ and $\vec{l}$ are perpendicular to each other.

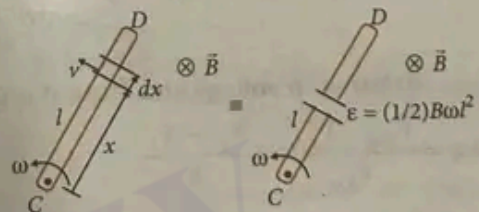
Induced emf, $\varepsilon = Blv$



- Rotating straight conductor :** emf induced in small element dx

$$d\varepsilon = (\vec{v} \times \vec{B}) \cdot d\vec{x} = -vBdx$$

$$\text{Net emf } \varepsilon = -\int_0^l vBdx = -B\omega \int_0^l xdx = -\frac{1}{2} B\omega l^2$$



Solved Examples

- Ex 1:** A rod of length 0.5 m moves at 4 m/s perpendicular to a magnetic field of 0.3 T. Find the emf induced.

$$\text{Solution: } \varepsilon = vBl = 4 \times 0.3 \times 0.5 = 0.6 \text{ V}$$

Practice Set

- Q1: A rod of length 1 m moves at 5 m/s perpendicular to a magnetic field of 0.2 T. What is the induced emf?
A) 1 V
B) 0.5 V
C) 2 V
D) 0.1 V
- Q2: If velocity $\vec{v}$ and magnetic field $\vec{B}$ are parallel, the induced emf is:
A) Maximum
B) Zero

- C) Depends on length
- D) Depends on angle
- Q3: A rod of length 0.4 m moves at 3 m/s at an angle 30° to a magnetic field of 0.5 T. Calculate emf.
 - A) 0.3 V
 - B) 0.6 V
 - C) 0.9 V
 - D) 0.15 V

Answer Key

- Q1: A) 1 V — $\varepsilon = vBl = 5 \times 0.2 \times 1 = 1 \text{ V}$
- Q2: B) Zero — Parallel vectors produce zero emf.
- Q3: A) 0.3 V — $\varepsilon = vBl \sin 30^\circ = 3 \times 0.5 \times 0.4 \times 0.5 = 0.3 \text{ V}$

Memory Aids

- Motional emf $\propto v, B, l, \sin \theta$
- Zero emf if velocity and magnetic field are parallel
- Use right-hand rule for direction of induced field

Methods of Producing Induced emf

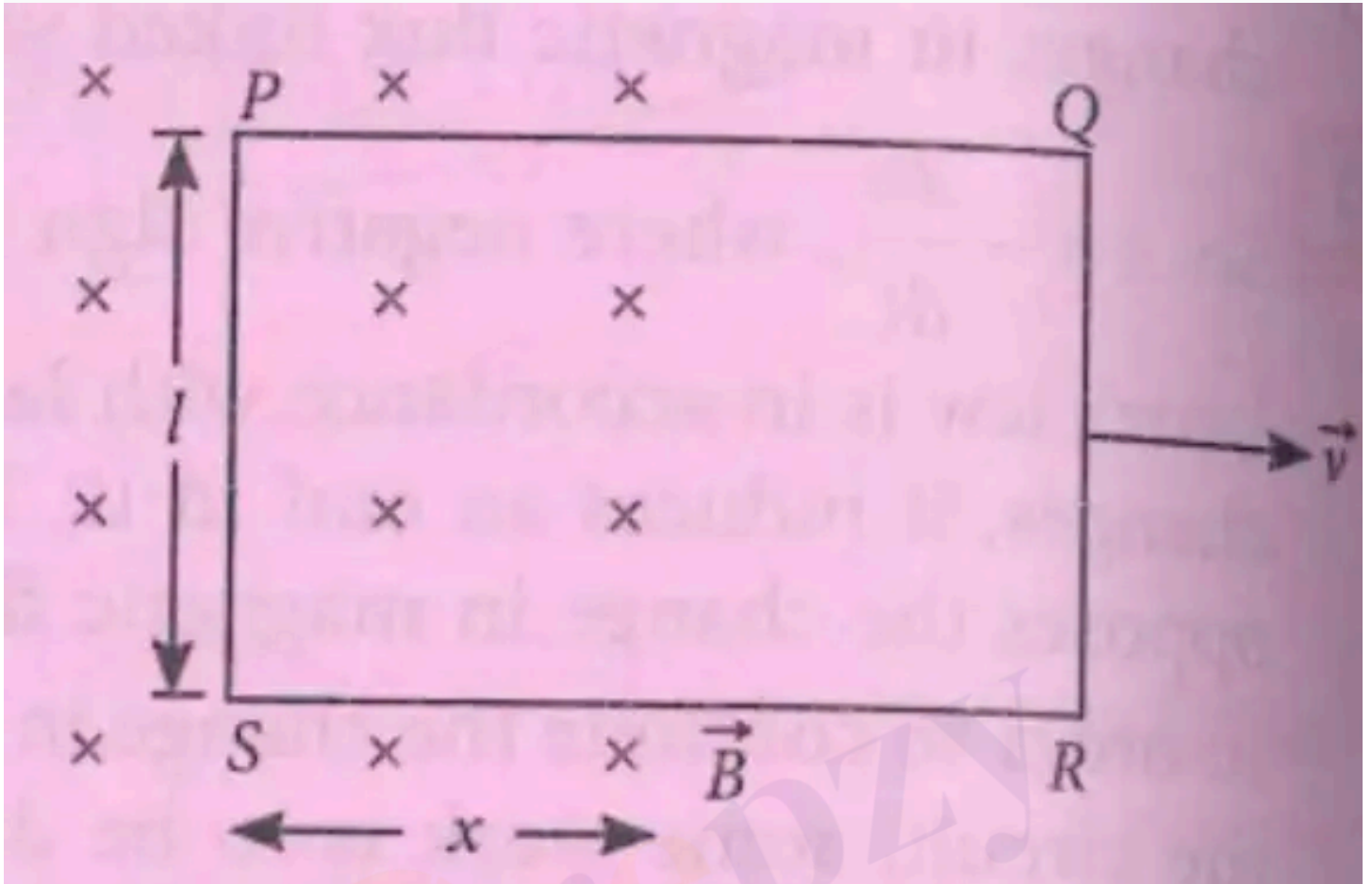
By Changing Magnetic Field

- Changing magnetic field intensity B in a closed circuit changes flux ϕ , inducing emf.
- Formula: $\varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(BA \cos \theta)$
- Or $\varepsilon = -A \cos \theta \frac{dB}{dt}$, where $\frac{dB}{dt}$ is rate of change of magnetic field.

By Changing Area of Circuit Inside Magnetic Field

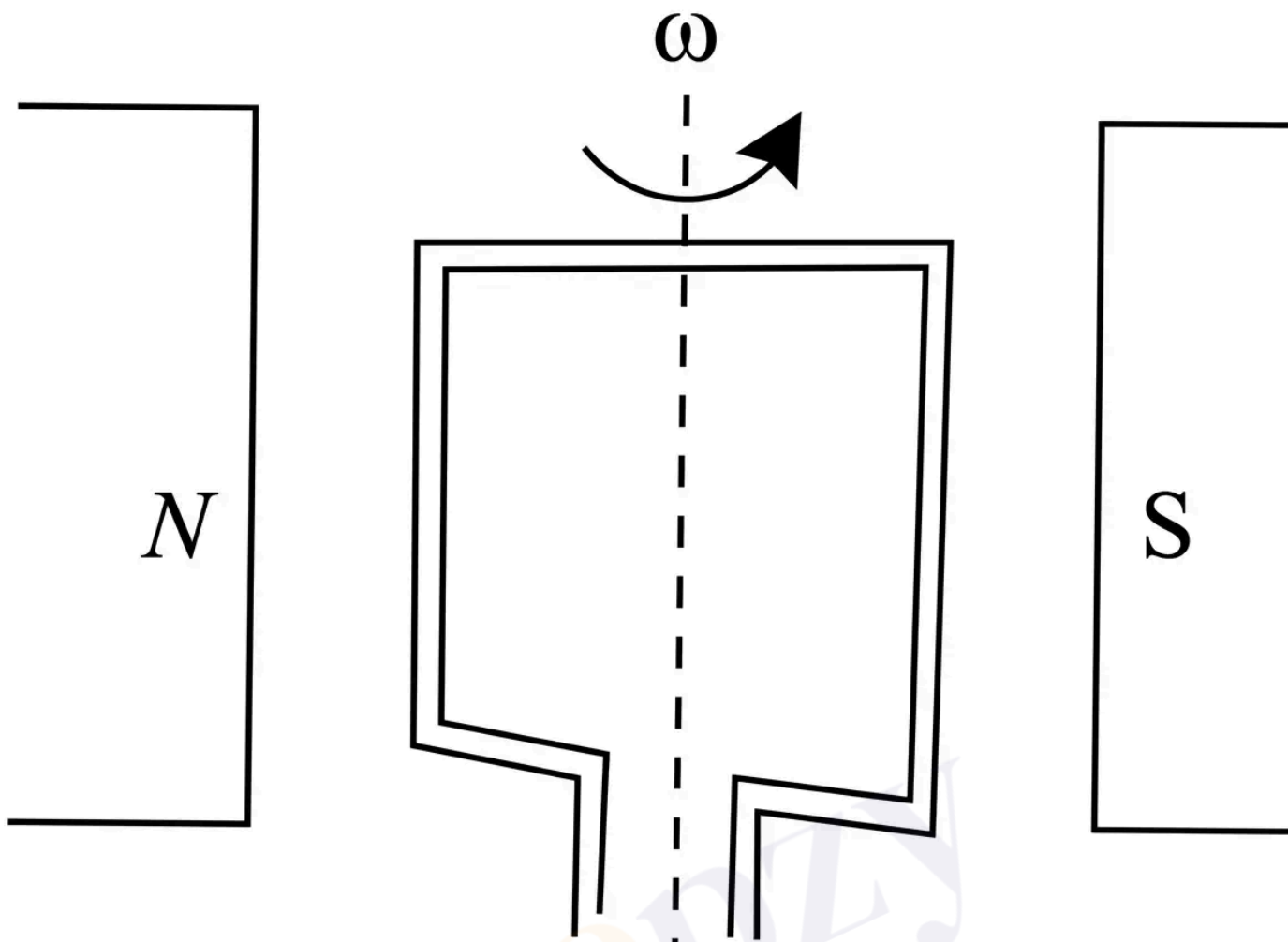
- Changing area A inside magnetic field changes flux, inducing emf.
- Formula: $\varepsilon = -\frac{d\phi}{dt} = -B \cos \theta \frac{dA}{dt}$

- For rectangular loop moving out of field with velocity v : $\varepsilon = Blv \cos \theta$



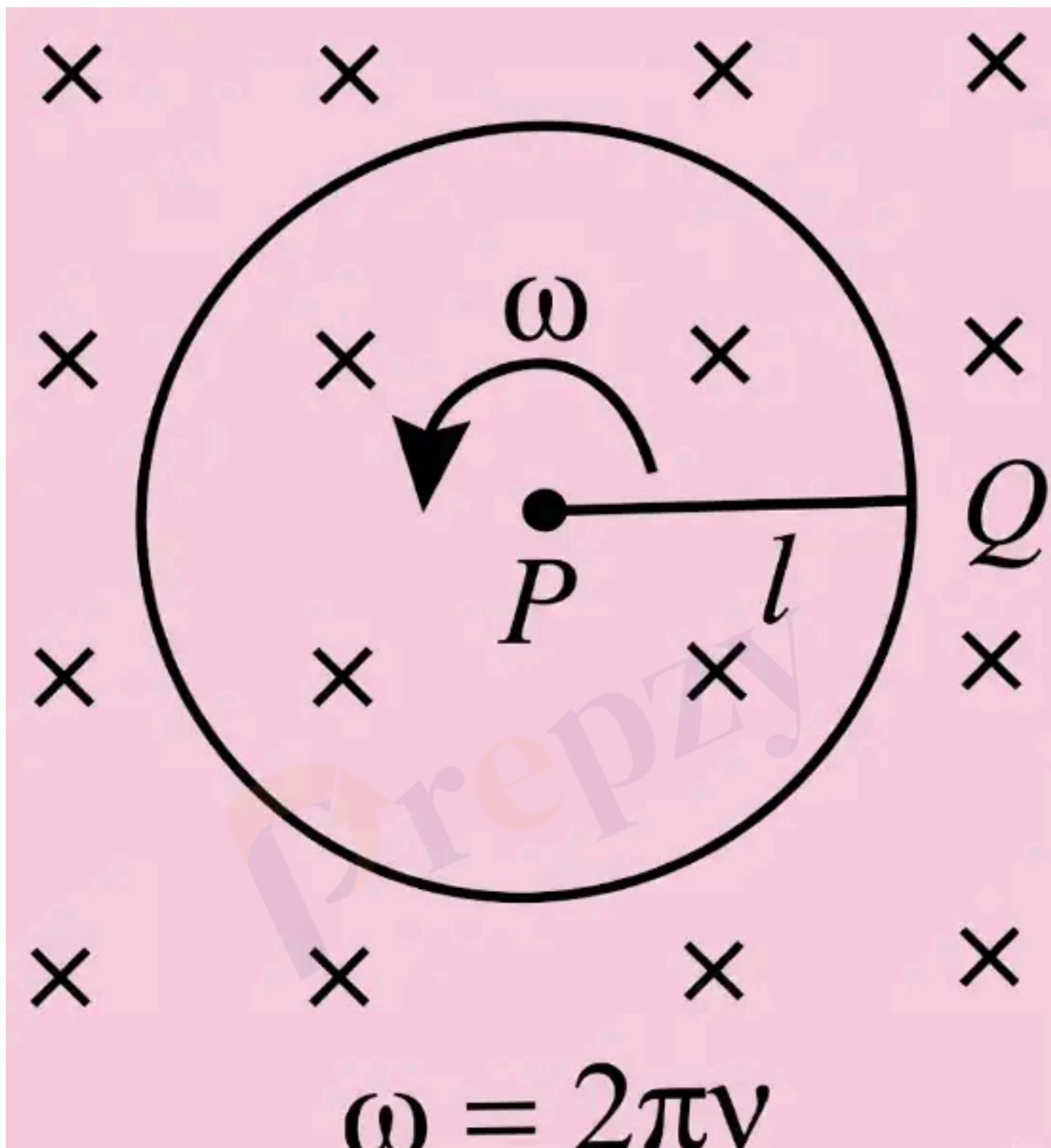
By Changing Orientation of Coil or Angle θ

- Coil of area A , turns N , rotating with angular velocity ω in magnetic field B .
- Flux linked: $\phi = NBA \cos(\omega t)$
- Induced emf: $\varepsilon = -\frac{d\phi}{dt} = NBA\omega \sin(\omega t) = \varepsilon_0 \sin(\omega t)$
- $\varepsilon_0 = NBA\omega$ is peak emf; emf varies sinusoidally (AC emf).



Revolving Rod in Magnetic Field

- Rod PQ of length l rotates with angular velocity ω in perpendicular magnetic field B .
- Time period $T = \frac{2\pi}{\omega}$.
- Induced emf: $\varepsilon = -B \frac{dA}{dt} = -\frac{B\pi l^2}{T} = -\frac{Bl^2\omega}{2} = -\pi Bl^2\nu$, where $\nu = \frac{\omega}{2\pi}$ is frequency.



Solved Examples

- **Ex 1:** A coil with 100 turns, area 0.01 m^2 rotates at 50 rad/s in 0.2 T field. Find peak emf.
Solution: $\varepsilon_0 = NBA\omega = 100 \times 0.2 \times 0.01 \times 50 = 10 \text{ V}$
- **Ex 2:** Rod of length 0.3 m rotates at 60 Hz in 0.5 T field. Find emf.
Solution: $\varepsilon = -\pi Bl^2\nu = -3.14 \times 0.5 \times 0.3^2 \times 60 = -8.5 \text{ V}$

Practice Set

- Q1: A coil of 50 turns, area 0.02 m^2 rotates at 40 rad/s in 0.3 T field. Peak emf is:
A) 12 V
B) 24 V
C) 8 V
D) 6 V
- Q2: A rod of length 0.4 m rotates at 100 Hz in 0.4 T field. Induced emf is:
A) 20 V
B) 10 V
C) 5 V
D) 15 V
- Q3: A coil rotates in magnetic field producing emf $\varepsilon = 15 \sin 200t$. If $N = 100$, $A = 0.01 \text{ m}^2$, $B = 0.3 \text{ T}$, find angular velocity ω .
A) 50 rad/s
B) 150 rad/s
C) 200 rad/s
D) 100 rad/s

Answer Key

- Q1: A) $12 \text{ V} - \varepsilon_0 = NBA\omega = 50 \times 0.3 \times 0.02 \times 40 = 12 \text{ V}$
- Q2: B) $10 \text{ V} - \varepsilon = \pi Bl^2\nu = 3.14 \times 0.4 \times 0.4^2 \times 100 = 10 \text{ V}$
- Q3: C) $200 \text{ rad/s} - \varepsilon_0 = NBA\omega = 15 \Rightarrow \omega = \frac{15}{100 \times 0.01 \times 0.3} = 200$

Memory Aids

- Peak emf $\varepsilon_0 = NBA\omega$
- Emf varies sinusoidally with time in rotating coil
- Revolving rod emf $\propto Bl^2\nu$

Eddy Currents

Concept and Applications

- Eddy currents are currents induced in the bulk of a conductor when magnetic flux linked with it changes.
- Direction found by Lenz's law or Fleming's right hand rule.
- Applications:
 - Induction furnace (heating effect)
 - Speedometer (measures vehicle speed)
 - Energy meter (records electricity consumption)

Inductance

Concepts

- Inductance opposes change in current, analogous to inertia in mechanics.
- Scalar quantity; SI unit: henry (H), dimensions: $[ML^2T^{-2}A^{-2}]$.
- **Self Inductance:** Change in current in a coil induces emf opposing the change:
$$\varepsilon = -L \frac{dI}{dt}.$$
- When current is constant, no emf induced.
- Self inductance formula: $L = \frac{N\Phi}{I} = \frac{NBA}{I} = \frac{\phi_{total}}{I}.$
- Real inductor modeled as resistor R in series with ideal inductor L .
- Self inductance of long solenoid: $L = \frac{\mu_0\mu_r N^2 A}{l} = \mu_0\mu_r n^2 Al = \mu_0\mu_r n^2 V$, where $V = Al$.
- **Mutual Inductance:** emf induced in one coil due to change in current in another coupled coil.
- Mutual inductance formula: $M = \frac{N_2\Phi_2}{I_1} = \frac{N_2B_1A_2}{I_1}.$
- Mutual inductance of two coaxial solenoids: $M = \frac{\mu_0 N_1 N_2 A}{l}.$
- Mutual inductance of two concentric coplanar coils: $M_{c_1c_2} = \frac{N_2 B_1 A_2}{I_1} = \frac{\mu_0 N_1 N_2 \pi r^2}{2\pi l}.$
- Factors affecting mutual inductance: number of turns, common cross-sectional area, separation distance, and relative orientation.
- Energy stored in inductor: $U = \frac{1}{2} LI^2.$
- Combination of inductors:
 - Series: $L_s = L_1 + L_2 + \dots + L_n.$
 - Parallel: $\frac{1}{L_p} = \frac{1}{L_1} + \frac{1}{L_2} + \dots + \frac{1}{L_n}.$

- Effective inductance of two inductors in series with mutual inductance M :

$$V = (L_1 + L_2 + 2M) \frac{di}{dt}.$$

Solved Examples

- Ex 1:** Calculate self inductance L of a solenoid with $N = 500$, area $A = 1 \times 10^{-4} m^2$, length $l = 0.5 m$, and permeability $\mu_r = 1$.
 - Use $L = \frac{\mu_0 \mu_r N^2 A}{l}$.
 - Calculate $L = \frac{4\pi \times 10^{-7} \times 1 \times 500^2 \times 1 \times 10^{-4}}{0.5} = 6.28 \times 10^{-3} H$.
- Ex 2:** Find mutual inductance M of two coaxial solenoids with $N_1 = 200$, $N_2 = 300$, area $A = 2 \times 10^{-4} m^2$, length $l = 0.4 m$.
 - Use $M = \frac{\mu_0 N_1 N_2 A}{l}$.
 - Calculate $M = \frac{4\pi \times 10^{-7} \times 200 \times 300 \times 2 \times 10^{-4}}{0.4} = 3.77 \times 10^{-3} H$.

Practice Set

- Q1: What is the SI unit of inductance?
 - A) Ohm
 - B) Henry
 - C) Tesla
 - D) Weber
- Q2: The self-induced emf in a coil is given by?
 - A) $\varepsilon = L \frac{dI}{dt}$
 - B) $\varepsilon = -L \frac{dI}{dt}$
 - C) $\varepsilon = LI$
 - D) $\varepsilon = -I \frac{dL}{dt}$
- Q3: Mutual inductance depends on?
 - A) Number of turns
 - B) Cross-sectional area
 - C) Distance between coils
 - D) All of the above

Answer Key

- Q1: B - Henry is the SI unit of inductance.
- Q2: B - Self-induced emf opposes change in current, hence negative sign.
- Q3: D - Mutual inductance depends on turns, area, and separation.

Memory Aids

- Inductance opposes current change like inertia opposes motion change.
- Self inductance formula: $\varepsilon = -L \frac{dI}{dt}$.
- Mutual inductance increases with turns and area, decreases with distance.
- Energy stored: $U = \frac{1}{2} LI^2$.

LR Circuits

Current Growth

- Emf equation: $V = IR + L \frac{dI}{dt}$.
- Current at time t : $I = I_0(1 - e^{-t/\tau})$, where $I_0 = \frac{V}{R}$, $\tau = \frac{L}{R}$ (time constant).
- At $t = 0$, inductor acts as open circuit (infinite resistance), current $I = 0$.
- At $t \rightarrow \infty$, inductor acts as short circuit (zero resistance), current $I = I_0$.
- Peak current independent of inductance.

Current Decay

- Emf equation: $IR + L \frac{dI}{dt} = 0$.
- Current at time t : $I = I_0 e^{-t/\tau}$, where $I_0 = \frac{V}{R}$, $\tau = \frac{L}{R}$.
- At $t = 0$, current $I = I_0$.
- At $t \rightarrow \infty$, current $I = 0$.

Solved Examples

- **Ex 1:** Calculate time constant τ for $L = 2H, R = 4\Omega$.
 - $\tau = \frac{L}{R} = \frac{2}{4} = 0.5s$.
- **Ex 2:** Find current I at $t = 1s$ for $I_0 = 5A, \tau = 0.5s$.
 - $I = I_0(1 - e^{-t/\tau}) = 5(1 - e^{-2}) = 4.32A$.

Practice Set

- Q1: What is the time constant τ in an LR circuit?
 - A) $L \times R$
 - B) $\frac{L}{R}$
 - C) $\frac{R}{L}$
 - D) $L + R$
- Q2: At $t = 0$, current in LR circuit is?
 - A) Maximum
 - B) Zero
 - C) Half of maximum
 - D) Infinite
- Q3: Current I at time t during growth is given by?
 - A) $I = I_0 e^{-t/\tau}$
 - B) $I = I_0(1 - e^{-t/\tau})$
 - C) $I = I_0$
 - D) $I = 0$

Answer Key

- Q1: B - Time constant $\tau = \frac{L}{R}$.
- Q2: B - Inductor initially opposes current, so current is zero at $t = 0$.
- Q3: B - Current growth follows $I = I_0(1 - e^{-t/\tau})$.

Memory Aids

- Time constant $\tau = \frac{L}{R}$ controls current change speed.

- Current starts at zero and grows exponentially in LR circuit.
- Inductor acts as open circuit at start, short circuit at steady state.

AC Generator

Definition and Parts

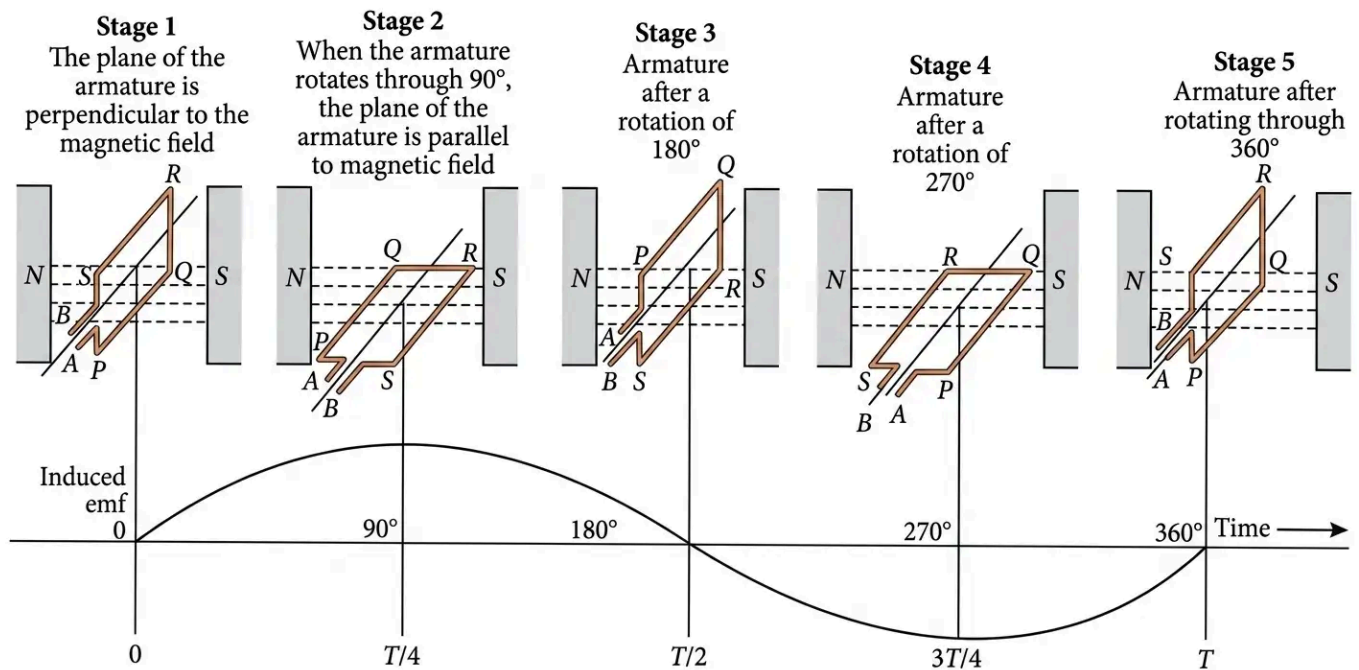
- Device producing alternating current (AC) by converting mechanical energy into electrical energy.
- Current changes direction periodically.
- Essential parts: armature, field magnets (N and S), slip rings, brushes.

Principle

- Based on electromagnetic induction.
- Changing magnetic flux linked with coil induces emf.
- Direction of induced current given by Fleming's right-hand rule.

Working

- Loop of wire rotates in magnetic field, inducing alternating emf.
- Induced emf varies sinusoidally with rotation angle.
- Magnetic flux linked: $\phi = NBA \cos \theta$, where N = turns, B = magnetic field, A = coil area.
- With $\theta = \omega t$, flux: $\phi = BAN \cos \omega t$.
- Induced emf: $\varepsilon = -\frac{d\phi}{dt} = BAN\omega \sin \omega t = \varepsilon_0 \sin \omega t$, where $\varepsilon_0 = BAN\omega$.
- Current: $I = \frac{\varepsilon}{R} = I_0 \sin \omega t$, where $I_0 = \frac{\varepsilon_0}{R}$.



Solved Examples

- **Ex 1:** Calculate maximum emf if $N = 100$, $B = 0.5 \text{ T}$, $A = 0.01 \text{ m}^2$, $\omega = 314 \text{ rad/s}$.
 - $\varepsilon_0 = BAN\omega = 0.5 \times 0.01 \times 100 \times 314 = 157 \text{ V}$

Practice Set

- Q1: What is the principle of AC generator?
 - A) Electrostatic induction
 - B) Electromagnetic induction
 - C) Magnetic attraction
 - D) Thermal conduction
- Q2: The emf induced in an AC generator varies as:
 - A) $\cos \omega t$
 - B) $\sin \omega t$
 - C) Constant
 - D) Linear with time
- Q3: If the frequency of rotation doubles, the maximum emf will:
 - A) Halve
 - B) Double
 - C) Remain same
 - D) Become zero

Answer Key

- Q1: B - Electromagnetic induction causes emf by changing magnetic flux.
- Q2: B - Emf varies sinusoidally as $\sin \omega t$.
- Q3: B - $\varepsilon_0 = BAN\omega$, doubling ω doubles emf.

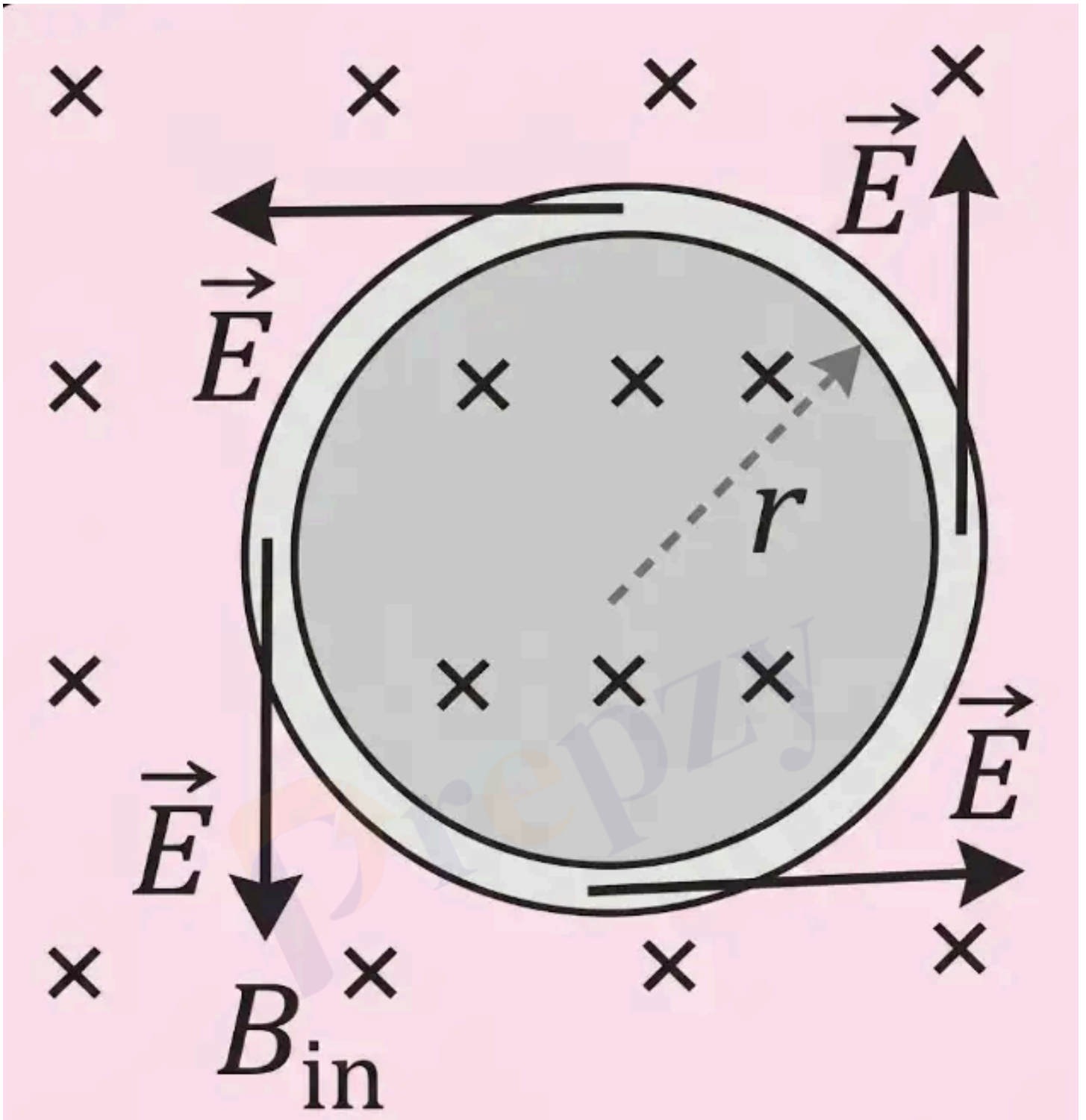
Memory Aids

- Emf formula: $\varepsilon = BAN\omega \sin \omega t$
- Current formula: $I = \frac{\varepsilon}{R}$
- Fleming's right-hand rule for current direction.

Induced Electric Field

Concept and Properties

- Changing magnetic flux induces emf and current in coil (Faraday's law).
- Induced electric field causes electron flow; magnetic field alone cannot move stationary charges.
- Induced electric field is non-conservative: $\oint \vec{E} \cdot d\vec{l} = \varepsilon = -\frac{d\phi}{dt} \neq 0$.
- Force on charge: $\vec{F} = q\vec{E}$.
- Electric field magnitude same at all points on circular loop; tangential direction.
- For symmetric cases: $El = \left| \frac{d\phi}{dt} \right| = A \left| \frac{dB}{dt} \right|$, where l = loop length, A = area.



Solved Examples

- **Ex 1:** Magnetic field changes at rate $\frac{dB}{dt} = 0.1 \text{ T/s}$ over area $A = 0.02 \text{ m}^2$, loop length $l = 0.5 \text{ m}$.
 - $E = \frac{A|dB/dt|}{l} = \frac{0.02 \times 0.1}{0.5} = 0.004 \text{ V/m}$

Practice Set

- Q1: Induced electric field is:
 - A) Conservative
 - B) Non-conservative
 - C) Electrostatic
 - D) Zero
- Q2: The line integral of induced electric field around a closed loop is:
 - A) Zero
 - B) Equal to emf
 - C) Negative
 - D) Constant
- Q3: For a circular loop of length 1 m and area 0.01 m², if magnetic field changes at 0.2 T/s, induced electric field magnitude is:
 - A) 0.002 V/m
 - B) 0.01 V/m
 - C) 0.2 V/m
 - D) 0.02 V/m

Answer Key

- Q1: B - Induced electric field is non-conservative due to changing magnetic flux.
- Q2: B - Line integral equals emf $\varepsilon = -d\phi/dt$.
- Q3: A - $E = \frac{A|dB/dt|}{l} = \frac{0.01 \times 0.2}{1} = 0.002 \text{ V/m}$.

Memory Aids

- Induced electric field: non-conservative, tangential to loop.
- Formula: $El = A|dB/dt|$.
- Force on charge: $\vec{F} = q\vec{E}$.