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6. ELECTROMAGNETIC INDUCTION

PGT Physics-Practice Set

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SUMMARY

1. The magnetic flux through a surface of area $\vec{A}$ placed in a uniform magnetic field $\vec{B}$ is defined as,

$$\Phi_B = \vec{B}\cdot\vec{A} = BA\cos\theta$$

where θ is the angle between $\vec{B}$ and $\vec{A}$.

2. Faraday's laws of induction imply that the emf induced in a coil of N turns is directly related to the rate of change of flux through it,

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

Here Φ_B is the flux linked with one turn of the coil. If the circuit is closed, a current $I = \varepsilon/R$ is set up in it, where R is the resistance of the circuit.

3. Lenz's law states that the polarity of the induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produces it. The negative sign in the expression for Faraday's law indicates this fact.

4. When a metal rod of length l is placed normal to a uniform magnetic field B and moved with a velocity v perpendicular to the field, the induced emf (called motional emf) across its ends is

$$\varepsilon = Blv$$

5. Changing magnetic fields can set up current loops in nearby metal (any conductor) bodies. They dissipate electrical energy as heat. Such currents are eddy currents.

6. Inductance is the ratio of the flux-linkage to current. It is equal to $N\Phi/I$.

7. A changing current in a coil (coil 2) can induce an emf in a nearby coil (coil 1). This relation is given by,

$$\varepsilon_1 = -M_{12}\frac{dI_2}{dt}$$

The quantity M_{12} is called mutual inductance of coil 1 with respect to coil 2. One can similarly define M_{21}. There exists a general equality, $M_{12} = M_{21}$

8. When a current in a coil changes, it induces a back emf in the same coil. The self-induced emf is given by,

$$\varepsilon = -L\frac{dI}{dt}$$

L is the self-inductance of the coil. It is a measure of the inertia of the coil against the change of current through it.

9. The self-inductance of a long solenoid, the core of which consists of a magnetic material of permeability μ_r, is given by

$$L = \mu_r \mu_0 n^2 Al$$

where A is the area of cross-section of the solenoid, l its length and n the number of turns per unit length.

10. In an ac generator, mechanical energy is converted to electrical energy by virtue of electromagnetic induction. If coil of N turn and area A is rotated at ν revolutions per second in a uniform magnetic field B, then the motional emf produced is

$$\varepsilon = NBA(2\pi\nu)\sin(2\pi\nu t)$$

where we have assumed that at time $t = 0$ s, the coil is perpendicular to the field.

Quantity	Symbol	Units	Dimensions	Equations
Magnetic Flux	Φ_B	Wb (weber)	$[ML^2T^{-2}A^{-1}]$	$\Phi_B = \vec{B}.\vec{A}$
EMF	ε	V (volt)	$[ML^2T^{-3}A^{-1}]$	$\varepsilon = -d(N\Phi_B)/dt$
Mutual Inductance	M	H (henry)	$[ML^2T^{-2}A^{-2}]$	$\varepsilon_1 = -M_{12}(dI_2/dt)$
Self-Inductance	L	H (henry)	$[ML^2T^{-2}A^{-2}]$	$\varepsilon = -L(dI/dt)$

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Question 1:

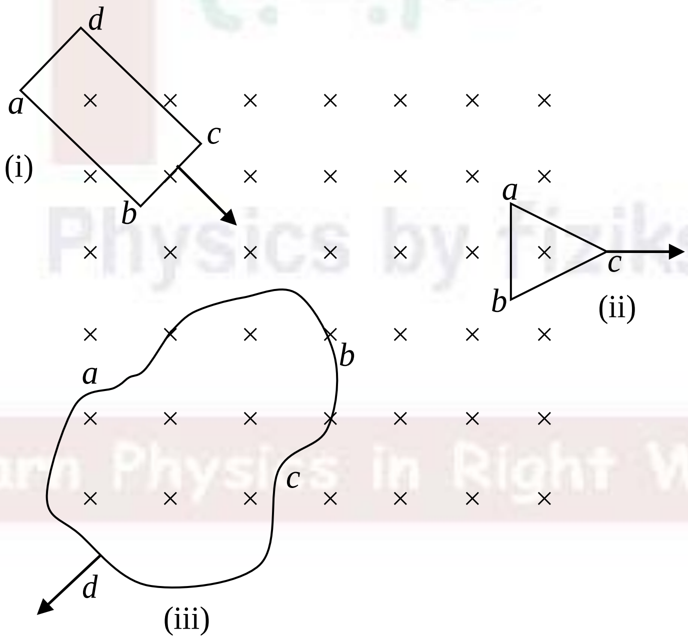
A square loop of side $10\,cm$ and resistance 0.5Ω is placed vertically in the east-west plane. A uniform magnetic field of $0.10\,T$ is set up across the plane in the north-east direction. The magnetic field is decreased to zero in $0.70\,s$ at a steady rate. Determine the magnitudes of induced emf and current during this time-interval.

Question 2:

A circular coil of radius $10\,cm, 500$ turns and resistance 2Ω is placed with its plane perpendicular to the horizontal component of the earth's magnetic field. It is rotated about its vertical diameter through $180°$ in $0.25\,s$. Estimate the magnitudes of the emf and current induced in the coil. Horizontal component of the earth's magnetic field at the place is $3.0\times10^{-5}\,T$.

Question 3:

Figure below shows planar loops of different shapes moving out of or into a region of a 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.



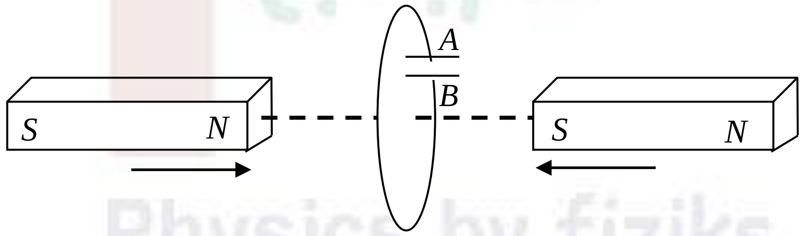
Question 4:

(a) A closed loop is held stationary in the magnetic field between the north and south poles of two permanent magnets held fixed. Can we hope to generate current in the loop by using very strong magnets?

(b) A closed loop moves normal to the constant electric field between the plates of a large capacitor. Is a current induced in the loop (i) when it is wholly inside the region between the capacitor plates (ii) when it is partially outside the plates of the capacitor? The electric field is normal to the plane of the loop.

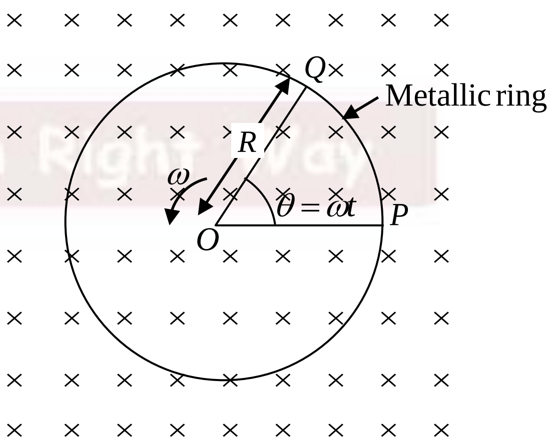
(c) A rectangular loop and a circular loop are moving out of a uniform magnetic field region (Figure below) to a field-free region with a *constant velocity* v. In which loop do you expect the induced emf to be constant *during* the passage out of the field region? The field is normal to the loops.

(d) Predict the polarity of the capacitor in the situation described by Fig. 6.9.



Question 5:

A metallic rod of $1m$ length is rotated with a frequency of $50\,\text{rev/s}$, with one end hinged at the center and the other end at the circumference of a circular metallic ring of radius $1m$, about an axis passing through the center and perpendicular to the plane of the ring (Fig. 6.11). A constant and uniform magnetic field of $1T$ parallel to the axis is present everywhere. What is the emf between the center and the metallic ring?



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Question 6:

A wheel with 10 metallic spokes each $0.5\,m$ long is rotated with a speed of $120\,\text{rev/min}$ in a plane normal to the horizontal component of earth's magnetic field H_E at a place. If $H_E = 0.4\,G$ at the place, what is the induced emf between the axle and the rim of the wheel? Note that $1G = 10^{-4}T$.

Question 7:

A long solenoid with 15 turns per cm has a small loop of area $2.0\,cm^2$ placed inside the solenoid normal to its axis. If the current carried by the solenoid changes steadily from $2.0\,A$ to $4.0\,A$ in $0.1\,s$, what is the induced emf in the loop while the current is changing?

Question 8:

A rectangular wire loop of sides $8\,cm$ and $2\,cm$ with a small cut is moving out of a region of uniform magnetic field of magnitude $0.3\,T$ directed normal to the loop. What is the emf developed across the cut if the velocity of the loop is $1\,cms^{-1}$ in a direction normal to the (a) longer side, (b) shorter side of the loop? For how long does the induced voltage last in each case?

Question 9:

A circular coil of radius $8.0\,cm$ and 20 turns is rotated about its vertical diameter with an angular speed of $50\,rad\,s^{-1}$ in a uniform horizontal magnetic field of magnitude $3.0\times10^{-2}\,T$. Obtain the maximum and average emf induced in the coil. If the coil forms a closed loop of resistance 10Ω, calculate the maximum value of current in the coil Calculate the average power loss due to Joule heating. Where does this power come from?

Question 10:

A horizontal straight wire $10\,m$ long extending from east to west is falling with a speed of $5.0\,ms^{-1}$, at right angles to the horizontal component of the earth's magnetic field, $0.30\times10^{-4}\,Wbm^{-2}$.

(a) What is the instantaneous value of the emf induced in the wire?

(b) What is the direction of the emf ?

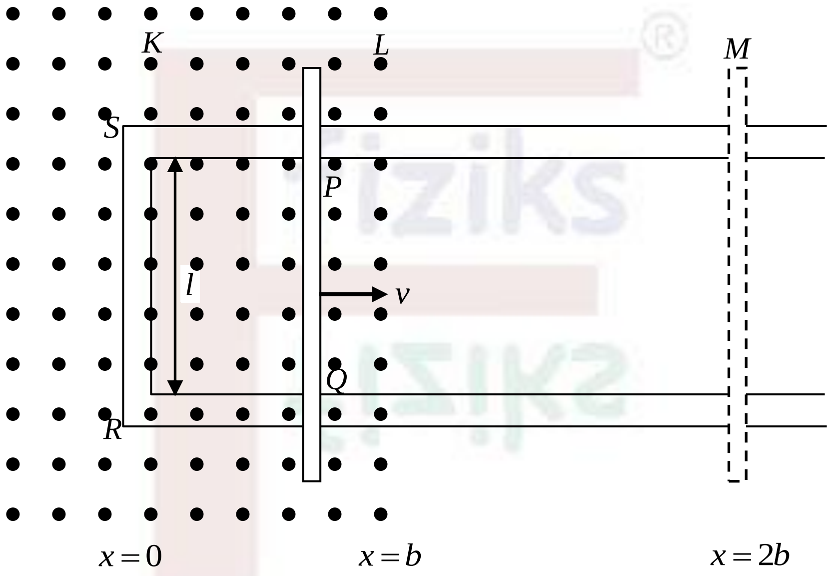
(c) Which end of the wire is at the higher electrical potential?

Question 11:

Current in a circuit falls from $5.0\,A$ to $0.0\,A$ in $0.1\,s$. If an average emf of $200\,V$ induced, give an estimate of the self-inductance of the circuit.

Question 12:

The arm PQ of the rectangular conductor is moved from $x=0$, outwards. The uniform magnetic field is perpendicular to the plane and extends from $x=0$ to $x=b$ and is zero for $x>b$. Only the arm PQ possesses substantial resistance r. Consider the situation when the arm PQ is pulled outwards from $x=0$ to $x=2b$, and is then moved back to $x=0$ with constant speed v. Obtain expressions for the flux, the induced emf, the force necessary to pull the arm and the power dissipated as Joule heat. Sketch the variation of these quantities with distance.



Question 13: Two concentric circular coils, one of small radius r_1 and the other of large radius r_2, such that $r_1 << r_2$, are placed co-axially with centers coinciding. Obtain the mutual inductance of the arrangement.

Question 14:

(a) Obtain the expression for the magnetic energy stored in a solenoid in terms of magnetic field B, area A and length l of the solenoid. (b) How does this magnetic energy compare with the electrostatic energy stored in a capacitor?

Question 15:

Kamla peddles a stationary bicycle. The pedals of the bicycle are attached to a 100 turn coil of area $0.10\,m^2$. The coil rotates at half a revolution per second and it is placed in a uniform magnetic field of $0.01T$ perpendicular to the axis of rotation of the coil. What is the maximum voltage generated in the coil?

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