1. Assertion (A) and Reason (R) type questions. Two statements are given one labelled Assertion (A) and the other labelled Reason (R). Select the correct answer from the codes (A), (B), (C) and (D) as given below. (2024)

(A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of the Assertion (A).

(B) Both Assertion (A) and Reason (R) are true, but Reason (R) is not the correct explanation of the Assertion (A).

(C) Assertion (A) is true, but Reason (R) is false.

(D) Assertion (A) is false and Reason (R) is also false.

Assertion (A): The mutual inductance between two coils is maximum when the coils are wound on each other.

Reason (R): The flux linkage between two coils is maximum when they are wound on each other.

Ans. (A) Both Assertion (A) and Reason (R) are true and Reason (R) is the correct explanation of the Assertion (A).

2. (i) Derive an expression for potential energy of an electric dipole $\vec{p}$ in an external uniform electric field $\vec{E}$. When is the potential energy of the dipole (1) maximum, and (2) minimum ?

(ii) An electric dipole consists of point charges $-1{\cdot}0$ pC and $+1{\cdot}0$ pC located at (0, 0) and (3 mm, 4 mm) respectively in $x-y$ plane. An electric field $\vec{E} = \left(\frac{1000\ \mathrm{V}}{\mathrm{m}}\right)\hat{i}$ is switched on in the region. Find the torque $\vec{\tau}$ acting on the dipole.

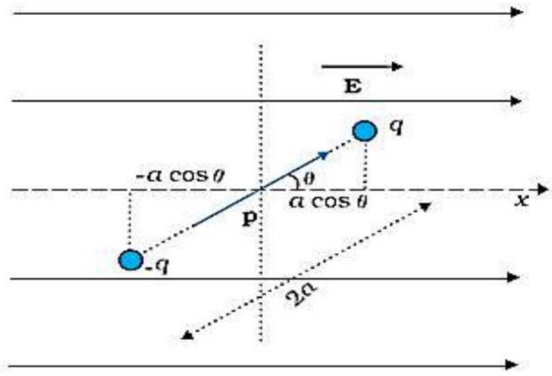
(2024)

Ans. (i)

- Deriving the expression for potential energy
- Maximum & Minimum value of potential energy

(ii) Finding the torque.

(i)



The amount of work done in rotating the dipole from θ = θ_0 to θ = θ_1 by the external torque

$$W = \int_{\theta_0}^{\theta_1} \tau_{ext}\, d\theta$$

$$= \int_{\theta_0}^{\theta_1} pE \sin\theta \; d\theta$$

$$W = pE(\cos\theta_0 - \cos\theta_1)$$

For $\theta_0 = \frac{\pi}{2}$ and $\theta_1 = \theta$

$$= pE(\cos\frac{\pi}{2} - \cos\theta)$$

$$U(\theta) = -pE\ \cos\theta$$

$$= -\vec{p}.\vec{E}$$

(1) Potential energy is maximum when:

$\vec{p}$ is antiparallel to $\vec{E}$

Alternatively:

$\theta = 180°$ or π radians

$$r_1^2 = r^2 + a^2 - 2ar\cos\theta$$

$$r_2^2 = r^2 + a^2 + 2ar\cos\theta$$

$$r_1^2 = r^2\left(1 - \frac{2a\cos\theta}{r} + \frac{a^2}{r^2}\right)$$

$$\cong r^2\left(1 - \frac{2a\cos\theta}{r}\right)$$

Similarly, $r_2^2 \cong r^2\left(1 + \frac{2a\cos\theta}{r}\right)$

Using binomial theorem & retaining terms upto the first order in $\frac{a}{r}$; we obtain

$$\frac{1}{r_1} \cong \frac{1}{r}\left(1-\frac{2a\cos\theta}{r}\right)^{-\frac{1}{2}} \cong \frac{1}{r}\left(1+\frac{a}{r}\cos\theta\right) \qquad \text{----- (ii)}$$

$$\frac{1}{r_2} \cong \frac{1}{r}\left(1-\frac{2a\cos\theta}{r}\right)^{-\frac{1}{2}} \cong \frac{1}{r}\left(1-\frac{a}{r}\cos\theta\right) \qquad \text{----- (iii)}$$

3.

(i) An electric dipole (dipole moment $\vec{p} = p\hat{i}$), consisting of charges $-q$ and q, separated by distance $2a$, is placed along the x-axis, with its centre at the origin. Show that the potential V, due to this dipole, at a point x, ($x >> a$) is equal to $\frac{1}{4\pi\varepsilon_0} \cdot \frac{\vec{p}\cdot\hat{i}}{x^2}$.

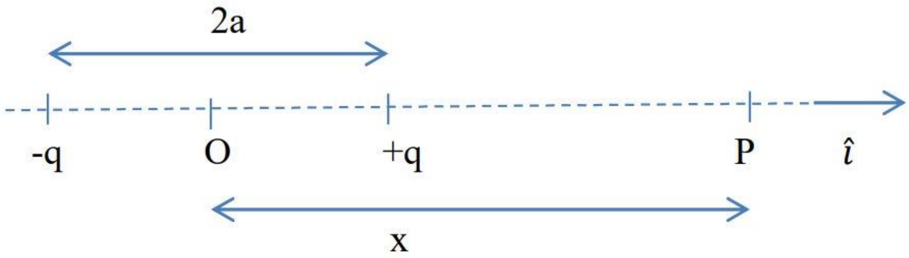
(ii) Two isolated metallic spheres S_1 and S_2 of radii 1 cm and 3 cm respectively are charged such that both have the same charge density $\left(\frac{2}{\pi}\times 10^{-9}\right) C/m^2$. They are placed far away from each other and connected by a thin wire. Calculate the new charge on sphere S_1.

(2024)

Ans. (i) Deriving expression for potential

(ii) New charge on Sphere S_1

(i)



$$V = \frac{1}{4\pi\varepsilon_0}\frac{q}{r}$$

$$V = V_{+q} - V_{-q}$$

$$V = \frac{1}{4\pi\varepsilon_0}\left[\frac{q}{(x-a)} - \frac{q}{(x+a)}\right]$$

$$= \frac{q}{4\pi\varepsilon_0}\left[\frac{x+a-x+a}{(x^2-a^2)}\right]$$

$$V = \frac{q}{4\pi\varepsilon_0}\frac{2a}{(x^2-a^2)} = \frac{p}{4\pi\varepsilon_0(x^2-a^2)}$$

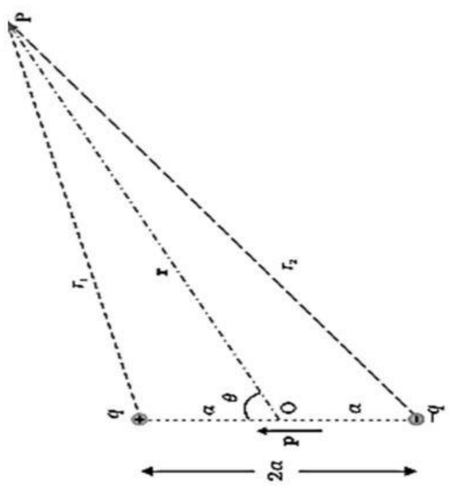
As p is along x-axis, so

$$V = \frac{1}{4\pi\varepsilon_0}\frac{\vec{p}.\hat{i}}{(x^2-a^2)}$$

If x>>a

$$V = \frac{1}{4\pi\varepsilon_0}\frac{\vec{p}.\hat{i}}{x^2}$$

Alternatively:



$$V = \frac{1}{4\pi\varepsilon_0}\left(\frac{q}{r_1} - \frac{q}{r_2}\right) \qquad \text{----- (i)}$$

By geometry

$$r_1^2 = r^2 + a^2 - 2ar\,cos\theta$$

$$r_2^2 = r^2 + a^2 + 2ar\,cos\theta$$

$$r_1^2 = r^2\left(1 - \frac{2acos\theta}{r} + \frac{a^2}{r^2}\right)$$

$$\cong r^2\left(1 - \frac{2a\cos\theta}{r}\right)$$

Similarly, $r_2^2 \cong r^2\left(1 + \frac{2a\cos\theta}{r}\right)$

Using binomial theorem & retaining terms upto the first order in $\frac{a}{r}$; we obtain

$$\frac{1}{r_1} \cong \frac{1}{r}\left(1 - \frac{2a\cos\theta}{r}\right)^{-\frac{1}{2}} \cong \frac{1}{r}\left(1 + \frac{a}{r}\cos\theta\right) \qquad \text{----- (ii)}$$

$$\frac{1}{r_2} \cong \frac{1}{r}\left(1 - \frac{2a\cos\theta}{r}\right)^{-\frac{1}{2}} \cong \frac{1}{r}\left(1 - \frac{a}{r}\cos\theta\right) \qquad \text{----- (iii)}$$

Using equations (i) ,(ii) & (iii) & p = 2qa

$$V = \frac{q}{4\pi\varepsilon_0}\frac{2a\cos\theta}{r^2} = \frac{p\cos\theta}{4\pi\varepsilon_0 r^2}$$

$$\mathrm{p}\cos\theta = \vec{p}\,.\,\hat{r}$$

As $\vec{r}$ is along the x – axis.

$$\Rightarrow \vec{p}.\hat{r} = \vec{p}.\hat{i}$$

$$\Rightarrow V = \frac{1}{4\pi\varepsilon_0}\frac{\vec{p}.\hat{i}}{x^2}$$

(ii)

Charge on sphere S_1 :

$$Q_1 = \text{surface charge density} \times \text{surface Area}$$

$$= \left(\frac{2}{\pi}\times 10^{-9}\right)\times 4\pi(1\times 10^{-2})^2$$

$$= 8\times 10^{-13}\,C$$

Charge on sphere S_2 :

$$Q_2 = \text{surface charge density} \times \text{surface Area}$$

$$= \left(\frac{2}{\pi}\times 10^{-9}\right)\times 4\pi(3\times 10^{-2})^2$$

$$= 72\times 10^{-13}\,C$$

When connected by a thin wire they acquire a common potential V and the charge remains conserved.

$$Q_1 + Q_2 = Q_1' + Q_2'$$

$$= C_1V + C_2V$$

$$Q_1 + Q_2 = (C_1 + C_2)V$$

$$\text{Common potential(V)} = \frac{Q_1 + Q_2}{C_1 + C_2}$$

$$C_1 = 4\pi\varepsilon_0 r_1 = \frac{1}{9\times 10^9}\times 10^{-2} = \frac{1}{9}\times 10^{-11}F$$

$$C_2 = 4\pi\varepsilon_0 r_2 = \frac{1}{9\times 10^9}\times 3\times 10^{-2} = \frac{1}{3}\times 10^{-11}F$$

$$V = \frac{80\times 10^{-13}}{\left(\frac{1}{9}+\frac{1}{3}\right)\times 10^{-11}} = 1.8\,V$$

$$Q_1' = C_1V = \frac{1}{9}\times 10^{-11}\times 1.8$$

$$Q_1' = 2\times 10^{-12}\,C$$

Alternatively:

Charge on sphere S_1 :

$$Q_1 = \text{surface charge density} \times \text{surface Area}$$

$$= \left(\frac{2}{\pi} \times 10^{-9}\right) \times 4\pi\,(1 \times 10^{-2})^2$$

$$= 8 \times 10^{-13}\,C$$

Charge on sphere S_2 :

$$Q_2 = \text{surface charge density} \times \text{surface Area}$$

$$= \left(\frac{2}{\pi} \times 10^{-9}\right) \times 4\pi(3 \times 10^{-2})^2$$

$$= 72 \times 10^{-13}\,C$$

When connected by a thin wire they acquire a common potential V and the charge remains conserved.

$$Q_1 + Q_2 = Q_1' + Q_2'$$

$$\frac{Q_2'}{Q_1'} = \frac{r_2}{r_1}$$

On solving, $Q_1' = 2 \times 10^{-12}\,C$

Previous Years' CBSE Board Questions

6.3 Magnetic Flux

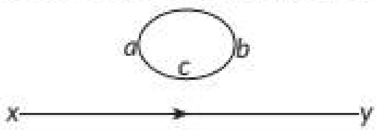
VSA (1 mark)

1. 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. *(Delhi 2017)*

6.4 Faraday's Law of Induction

MCQ

2. The direction of induced current in the loop abc is:



(a) along abc if I decreases
(b) along acb if I increases
(c) along abc if I constant
(d) along abc if I increases *(2023)* U

3. A square shaped coil of side 10 cm, having 100 turns is placed perpendicular to a magnetic field which is increasing at 1 T/s. The induced emf in the coil is
(a) 0.1 V (b) 0.5 V (c) 0.75 V (d) 1.0 V *(2023)*

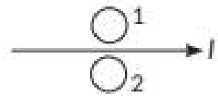
4. A coil of area 100 cm^2 is kept at an angle of 30° with a magnetic field of 10^{-1} T. The magnetic field is reduced to zero in 10^{-4} s. The induced emf in the coil is
(a) $5\sqrt{3}$ V (b) $50\sqrt{3}$ V
(c) 5.0 V (d) 50.0 V
(Term I 2021-22) Ap

6.5 Lenz's Law and Conservation of Energy

VSA (1 mark)

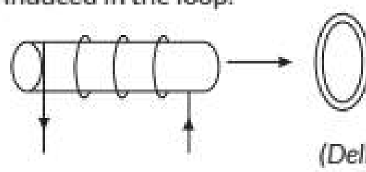
5. Predict the polarity of the capacitor in the situation described below:

7. What is the direction of induced currents in metal rings 1 and 2 when current I in the wire is increasing steadily?



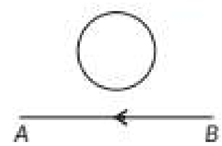
(AI 2017)

8. Figure shows a current carrying solenoid moving towards a conducting loop. Find the direction of the current induced in the loop.



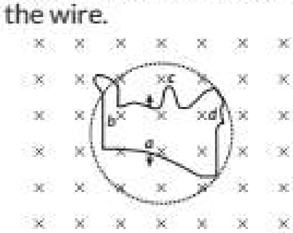
(Delhi 2015C) Ap

9. The electric current flowing in a wire in the direction from B to A is decreasing. Find out the direction of the induced current in the metallic loop kept above the wire as shown.



(AI 2014)

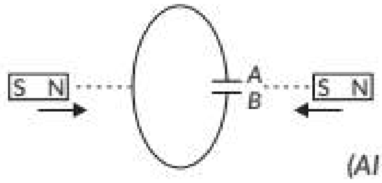
10. A flexible wire of irregular shape, *abcd*, as shown in the figure, turns into a circular shape when placed in a region of magnetic field which is directed normal to the plane of the loop away from the reader. Predict the direction of the induced current in the wire.



(Foreign 2014) Ap

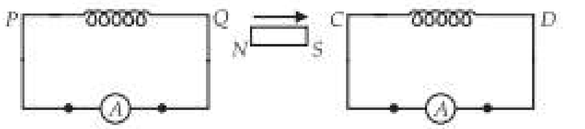
SA I (2 marks)

11. Two identical circular discs, one of copper and another of aluminium, are rotated about their



(AI 2017) Ap

6. 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.



(AI 2017)

13. Describe a simple experiment (or activity) to show that the polarity of emf induced in a coil is always such that it tends to produce a current which opposes the change of magnetic flux that produces it.

(2/5, Delhi 2014) An

OR

State Lenz's law. Give one example to illustrate this law. "The Lenz's law is a consequence of the principle of conservation of energy". Justify this statement.

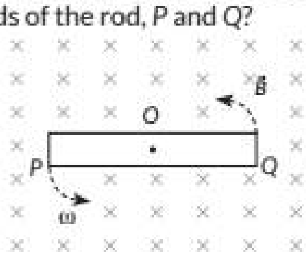
(3/5, AI 2014)

6.6 Motional Electromotive Force

VSA (1 mark)

14. A conducting rod of length l is kept parallel to a uniform magnetic field $\vec{B}$. It is moved along the magnetic field with a velocity $\vec{v}$. What is the value of emf induced in the conductor? (2020)

15. A metallic rod PQ of length l is rotated with an angular velocity ω about an axis passing through its mid-point (O) and perpendicular to the plane of the paper, in uniform magnetic field $\vec{B}$, as shown in the figure. What is the potential difference developed between the two ends of the rod, P and Q?

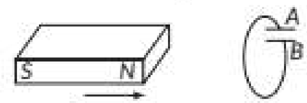


(2020) U

16. Plot a graph showing variation of induced e.m.f. with geometrical axes with same angular speed in the same magnetic field acting perpendicular to their planes. Compare the (i) induced emf, and (ii) induced current produced in discs between its centre and edge. Justify your answers. (2021C)

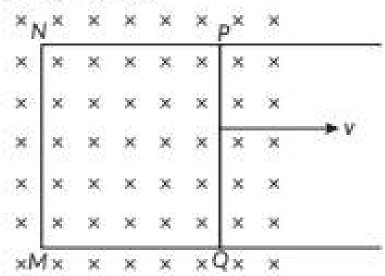
LA (5 marks)

12. State Lenz's law. Use it to predict the polarity of the capacitor in the situation given below :



(2/5, AI 2015C)

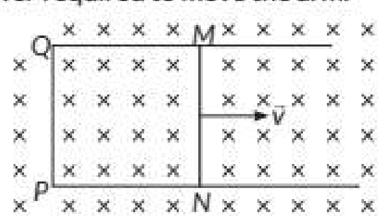
20. A rectangular loop $PQMN$ with movable arm PQ of length 10 cm and resistance 2 Ω is placed in a uniform magnetic field of 0.1 T acting perpendicular to the plane of the loop as is shown in the figure. The resistances of the arms MN, NP and MQ are negligible. Calculate the (i) emf induced in the arm PQ and (ii) current induced in the loop when arm PQ is moved with velocity 20 m/s.



(Delhi 2014C) An

SA II (3 marks)

21. A rectangular conductor $MNPQ$ with a movable arm MN (resistance r) is kept in a uniform magnetic field as shown in the figure. Resistance of arms MQ, QP an PN are negligible. Obtain the expression for the :
   (a) current induced in the loop specifying its direction, and
   (b) power required to move the arm.



(2023)

the rate of change of current flowing through a coil. *(2020)*

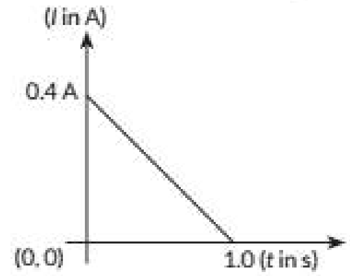
17. A horizontal conducting rod 10 m long extending from east to west is falling with a speed 5.0 m s^{-1} at right angles to the horizontal component of the Earth's magnetic field, 0.3×10^{-4} Wb m^{-2}. Find the instantaneous value of the emf induced in the rod. *(2/5, AI 2017)*

SA I (2 marks)

18. In a ceiling fan, each blade rotates in a circle of radius 0.5 m. If the fan makes 2 rotations per second and the vertical component of the earth's magnetic field is 8×10^{-5} T, calculate the emf induced between the inner and outer ends of each blade. *(2019 C)*

19. A square loop of side 10 cm with its sides parallel to *X* and *Y* axis is moved with a velocity of 8 cm s^{-1} in the positive *X*-direction containing a magnetic field in the positive *Z*-direction. The field is non-uniform and has a gradient of 10^{-3} T cm^{-1} along the negative *X*-direction (*i.e.* it increases by 10^{-3} T cm^{-1} as one moves in the negative *X*-direction). Calculate the emf induced. *(2019 C)*

22. When a conducting loop of resistance 10 Ω and area 10 cm^2 is removed from an external magnetic field acting normally, the variation of induced current in the loop with time is shown in the figure.



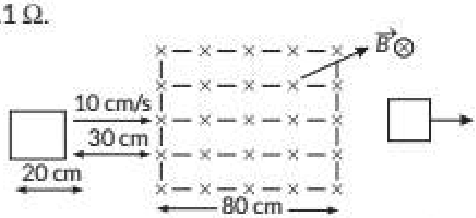
Find the
(i) total charge passed through the loop.
(ii) change in magnetic flux through the loop.
(iii) magnitude of the magnetic field applied. *(2020)* An

LA (5 marks)

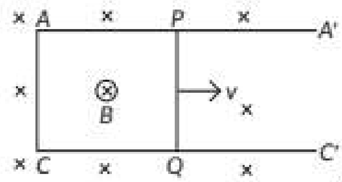
23. A conductor of length '*l*' is rotated about one of its ends at a constant angular speed 'ω' in a plane perpendicular to a uniform magnetic field *B*. Plot graphs to show variations of the emf induced across the ends of the conductor with (i) angular speed ω and (ii) length of the conductor *l*. *(2/5, 2020)*

24. A square loop of side 20 cm is initially kept 30 cm away from a region of uniform magnetic field of 0.1 T as shown in the figure. It is then moved towards the right with a velocity of 10 cm s^{-1} till it goes out of the field.

Plot a graph showing the variation of
(i) magnetic flux (ϕ) through the loop with time (*t*).
(ii) induced emf (ε) in the loop with time *t*.
(iii) induced current in the loop if it has resistance of 0.1 Ω.



(3/5, AI 2015C) Cr



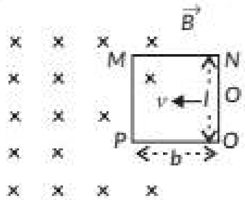
(3/5, 2020) Ev

27. A metallic rod of length *l* and resistance *R* is rotated with a frequency υ, 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.
(a) Derive the expression for the induced emf and the current in the rod.
(b) Due to the presence of the current in the rod and of the magnetic field, find the expression for the magnitude and direction of the force acting on this rod.
(c) Hence obtain the expression for the power required to rotate the rod. *(AI 2014C)*

6.A Energy Consideration : A Quantitative Study

SA II (3 marks)

25. The figure shows a rectangular conducting frame $MNOP$ of resistance R placed partly in a perpendicular magnetic field $\vec{B}$ and moved with velocity $\vec{v}$ as shown in the figure. Obtain the expression for the



(a) force acting on the arm 'ON' and its direction.

(b) power required to move the frame to get a steady emf induced between the arms MN and PO.

(AI 2019) An

LA (5 marks)

26. A conducting rod PQ of length 20 cm and resistance 0.1 Ω rests on two smooth parallel rails of negligible resistance AA' and CC'. It can slide on the rails and the arrangement is positioned between the poles of a permanent magnet producing uniform magnetic field B = 0.4 T. The rails, the rod and the magnetic field are in three mutually perpendicular directions as shown in the figure. If the ends A and C of the rails are short circuited, find the

(i) external force required to move the rod with uniform velocity v = 10 cm s^{-1} and

(ii) power required to do so.

6.7 Inductance

Mutual Inductance

MCQ

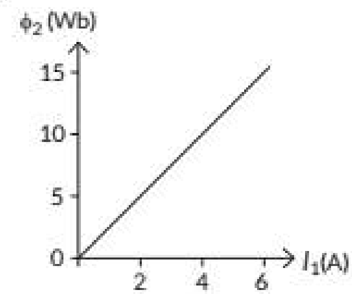
28. The current in the primary coil of a pair of coils changes from 7 A to 3 A in 0.04 s. The mutual inductance between the two coils is 0.5 H. The induced emf in the secondary coil is

(a) 50 V (b) 75 V (c) 100 V (d) 220 V

(Term I 2021-22)

SA I (2 marks)

29. Two coils C_1 and C_2 are placed close to each other. The magnetic flux ϕ_2 linked with the coil C_2 varies with the current I_1 flowing in coil C_1, as shown in the figure. Find



(i) the mutual inductance of the arrangement, and

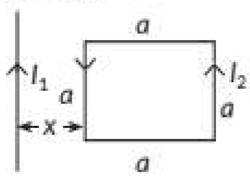
(ii) the rate of change of current $\left(\frac{dI_1}{dt}\right)$ that will induce an emf of 100 V in coil C_2. (2023)

SA II (3 marks)

30. Two concentric circular coils X and Y of radii r_1 and r_2 $(r_1 > r_2)$ having N_1 and N_2 turns respectively are placed coaxially with centres coinciding. Obtain an expression for (i) the mutual inductance for the arrangement, and (ii) the magnetic flux linked with coil Y when current I flows through coil X. (2021C)

31. (a) Define mutual inductance and write its S.I. unit.

(b) A square loop of side 'a' carrying a current I_2 is kept at distance x from an infinitely long straight wire carrying a current I_1 as shown in the figure. Obtain the expression for the resultant force acting on the loop.



(AI 2019)

37. Define mutual inductance of a pair of coils and write on which factors does it depend. (2/5, AI 2015C)

38. Deduce an expression for the mutual inductance of two long coaxial solenoids but having different radii and different number of turns. (3/5, AI 2014)

Self Inductance

MCQ

39. The self-inductance of a solenoid of 600 turns is 108 mH. The self-inductance of a coil having 500 turns with the same length, the same radius and the same medium will be

(a) 95 mH (b) 90 mH (c) 85 mH (d) 75 mH

32. 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. (AI 2017)

OR

Define the term 'mutual inductance' between the two coils. Obtain the expression for mutual inductance of a pair of long coaxial solenoids each of length l and radii r_1 and r_2 ($r_2 >> r_1$). Total number of turns in the two solenoids are N_1 and N_2 respectively. (AI 2014) An

33. (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 ? (Delhi 2016)

LA (5 marks)

34. Two concentric circular loops of radius 1 cm and 20 cm are placed coaxially.
(i) Find mutual inductance of the arrangement.
(ii) If the current passed through the outer loop is changed at a rate of 5 A/ms, find the emf induced in the inner loop. Assume the magnetic field on the inner loop to be uniform. (2/5, 2020) Ev

35. 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. (2/5, AI 2016)

36. (a) Define mutual inductance and write its S.I. units.
(b) Derive an expression for the mutual inductance of two long co-axial solenoids of same length wound one over the other.
(c) In an experiment, two coils C_1 and C_2 are placed close to each other. Find out the expression for emf induced in the coil C_1 due to a change in the current through the coil C_2. (Delhi 2015) Ev

solenoid changes steadily from 2.0 to 4.0 A in 0.1 s, what is the induced emf in the loop while the current is changing? (Foreign 2016) An

47. The currents flowing in the two coils of self-inductance L_1 = 16 mH and L_2 = 12 mH are increasing at the same rate. If the power supplied to the two coils are equal, find the ratio of (i) induced voltages, (ii) the currents

(Term I 2021-22) Ap

40. A constant current is flowing through a solenoid. An iron rod is inserted in the solenoid along its axis. Which of the following quantities will not increase?
(a) The magnetic field at the centre.
(b) The magnetic flux linked with the solenoid.
(c) The rate of heating.
(d) The self-inductance of the solenoid.
(Term I 2021-22)

VSA (1 mark)

41. The number of turns of a solenoid are doubled without changing its length and area of cross-section. The self-inductance of the solenoid will become ____ times. (2020)

42. Draw the graph showing variation of the value of the induced emf as a function of rate of change of current flowing through an ideal inductor. (2020)

43. Define the term 'self-inductance' of a coil. Write its S.I. unit. (AI 2015)

SA II (3 marks)

44. (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. (Delhi 2017) Ap

45. Define self-inductance of a coil. Obtain the expression for the energy stored in an inductor L connected across a source of emf. (AI 2017)

OR

Define the term self-inductance of a solenoid. Obtain the expression for the magnetic energy stored in an inductor of self-inductance L to build up a current I through it. (AI 2014)

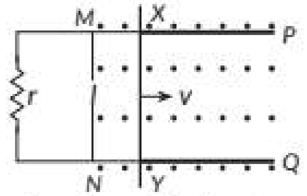
46. (i) Define self-inductance. Write its SI unit.
(ii) A long solenoid with 15 turns per cm has a small loop of area 2.0 cm^2 placed inside the solenoid normal to its axis. If the current carried by the

Show how an alternating emf is generated by a loop of wire rotating in a magnetic field.
(b) A circular coil of radius 10 cm and 20 turns is rotated about its vertical diameter with angular speed of 50 rad s^{-1} in a uniform horizontal magnetic field of 3.0×10^{-2} T.
(i) Calculate the maximum and average emf induced

and (iii) the energies stored in the two coils at a given instant. (Foreign 2014)

LA (5 marks)

48. (a) A conducting rod XY of length λ slides on two smooth parallel rails PM and QN with a uniform velocity v. The resistances of the rod and the rails are negligible.
A uniform magnetic field perpendicular to the plane $PMNQ$ is present in the region pointing vertically upwards as shown in the figure. A small resistance r is connected between the ends M and N of the rails. Obtain



(i) the expression for emf induced across the ends of the rod and its polarity.
(ii) the magnitude and direction of induced current that flows through resistance r. (2020C)

49. The current flowing through an inductor of self inductance L is continuously increasing. Plot a graph showing the variation of
(i) Magnetic flux versus the current
(ii) Induced emf versus dI/dt
(iii) Magnetic potential energy stored versus the current. (Delhi 2014) U

6.8 AC Generator

SA II (3 marks)

50. State the basic principle behind the working of an ac generator. Briefly describe its working and obtain the expression for the instantaneous value of emf induced. (2023)

51. (a) Write the principle of working of an ac generator. Derive the expression for the induced emf generated in it.
(b) Write the function of slip rings in an ac generator. (2020C)

LA (5 marks)

52. (a) Draw a schematic diagram for an ac generator. Explain its working and obtain the expression for the instantaneous value of the emf in terms of the magnetic field B, number of turns N of the coil of area A rotating with angular frequency ω. in the coil.
(ii) If the coil forms a closed loop of resistance 10 Ω, calculate the maximum current in the coil and the average power loss due to Joule heating. (AI 2019) Cr

53. 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. (3/5, 2018)

OR

Draw a labelled diagram of an ac generator. Obtain the expression for the emf induced in the rotating coil for N turns each of cross-sectional area A, in the presence of a magnetic field $\vec{B}$. (3/5, AI 2017)

54. (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 cm^2 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. (Delhi 2017) Ap

55. 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 $2\pi f NBA$. (3/5, AI 2016) Ev

56. (a) Draw a schematic sketch of an ac generator describing its basic elements. State briefly its working principle. Show a plot of variation of
(i) Magnetic flux and
(ii) Alternating emf versus time generated by a loop of wire rotating in a magnetic field.
(b) Why is choke coil needed in the use of fluorescent tubes with ac mains? (Delhi 2014) An

57. (a) Draw a labelled diagram of a.c. generator and state its working principle.
(b) How is magnetic flux linked with the armature coil changed in a generator?
(c) Derive the expression for maximum value of the induced emf and state the rule that gives the direction of the induced emf.
(d) Show the variation of the emf generated versus time as the armature is rotated with respect to the direction of the magnetic field. (Delhi 2014C)

CBSE Sample Questions

6.3 Magnetic Flux

MCQ

1. The magnetic flux linked with the coil (in Weber) is given by the equation
$\phi = 5t^2 + 3t + 16$
The induced EMF in the coil at time, $t = 4$ s will be
(a) -27 V (b) -43 V (c) -108 V (d) 210 V
(Term I 2021-22) Ap

SA I (2 marks)

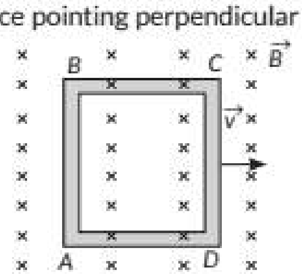
2. A coil of wire enclosing an area 100 cm^2 is placed with its plane making an angle 60° with the magnetic field of strength 10^{-1} T. What is the flux through the coil? If magnetic field is reduced to zero in 10^{-3} s, then find the induced emf? *(2020-21)*

6.6 Motional Electromotive Force

MCQ

3. A rectangular, a square, a circular and an elliptical loop, all in the $(x - y)$ plane, are moving out of a uniform magnetic field with a constant velocity $\vec{v} = v\hat{i}$. The magnetic field is directed along the negative z-axis direction. The induced emf, during the passage of these loops, out of the field region, will not remain constant for
(a) any of the four loops
(b) the circular and elliptical loops
(c) the rectangular, circular and elliptical loops
(d) only the elliptical loops *(2022-23)*

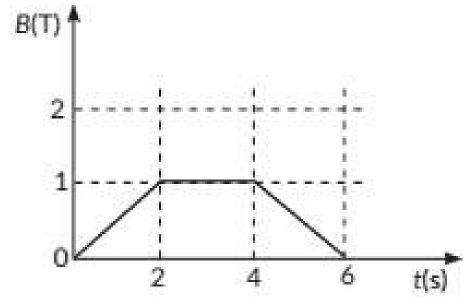
4. A conducting square loop of side 'L' and resistance 'R' moves in its plane with the uniform velocity 'v' perpendicular to one of its sides. A magnetic induction 'B' constant in time and space pointing perpendicular and into the plane of the loop exists everywhere as shown in the figure. The current induced in the loop is



(a) BLv/R Clockwise
(b) BLv/R Anticlockwise
(c) $2BLv/R$ Anticlockwise
(d) Zero. *(Term I 2021-22)* U

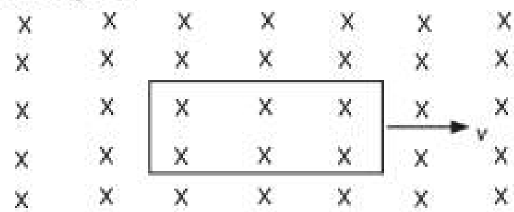
SA II (3 marks)

5. 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



(2022-23)

6. 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.

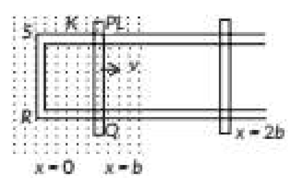


(a) Sketch the variation of magnetic flux, the induced current, and power dissipated as Joule heat as function of time.
(b) If instead of rectangular loop, circular loop is pulled out; do you expect the same value of induced current? Justify your answer. Sketch the variation of flux in this case with time.
(2020-21) An

6.7 Inductance

MCQ

7. Two coils are placed close to each other. The mutual inductance of the pair of coils depends upon the



(a) rate at which current change in the two coils
(b) relative position and orientation of the coils
(c) rate at which voltage induced across two coils
(d) currents in the two coils. *(Term I 2021-22)* R

8. An air-cored solenoid with length 30 cm, area of cross-section 25 cm^2 and number of turns 800, carries a current of 2.5 A. The current is suddenly switched off in a brief time of 10^{-3} s. Ignoring the variation in magnetic field near the ends of the solenoid, the average back emf induced across the ends of the open switch in the circuit would be

perpendicular to the plane of the loop. Calculate the current induced in the loop and plot a graph showing induced current as a function of time.

9. A circular loop of radius 0.3 cm lies parallel to much bigger circular loop of radius 20 cm. The centre of the small loop is on the axis of the bigger loop. The distance between their centres is 15 cm. If a current of 2.0 A flows through the smaller loop, then the flux linked with the bigger loop is
(a) 3.3×10^{-11} weber (b) 6×10^{-11} weber
(c) 6.6×10^{-9} weber (d) 9.1×10^{-11} weber
(Term I 2021-22)

10. If both the number of turns and core length of an inductor is doubled keeping other factors constant, then its self-inductance will be
(a) unaffected (b) doubled
(c) halved (d) quadrupled
(Term I 2021-22) R

(a) zero (b) 3.125 volts
(c) 6.54 volts (d) 16.74 volts
(Term I 2021-22) Ap

VSA (1 mark)

11. A solenoid with N loops of wire tightly wrapped around an iron-core is carrying an electric current I. If the current through this solenoid is reduced to half, then what change would you expect in inductance L of the solenoid. *(2020-21)*

6.8 AC Generator

LA (5 marks)

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

Detailed SOLUTIONS

Previous Years' CBSE Board Questions

1. The magnetic lines of force due to current are parallel to the plane of the loop. So angle between magnetic field and area vector is 90°. Hence, the flux linked with the loop ($Bds \cos 90°$) is zero. Hence, there will be no induced emf in the loop.

2. (d): Along abc if I increases. When current I in the straight conductor XY is increased, then induced current in loop will be in clockwise direction.

3. (d): $\frac{dB}{dt} = 1\,\text{T/s}$, side, l = 10 cm or 0.1 m, N = 100

$$e = NA\frac{dB}{dt} = 100 \times 0.1 \times 0.1 \times 1 = 1\text{V}$$

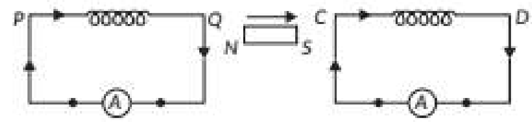
4. (a) : Here, area, $A = 100\ \text{cm}^2 = 100 \times 10^{-4}\ \text{m}^2$
magnetic field, $B = 10^{-1}$ T
angle, $\theta = 30°$, time, $t = 10^{-4}$ s
The induced emf is

$$\Rightarrow e = \frac{-d\phi}{dt} = \frac{d}{dt}(\vec{B}\cdot\vec{A})$$

$$e = -A\frac{dB}{dt}\cos\theta = -A\cos\theta \times \frac{dB}{dt}$$

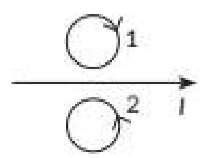
$$e = -100 \times 10^{-4} \times \cos 30° \times \frac{(0 - 10^{-1})}{10^{-4}}$$

$$e = 100 \times \frac{\sqrt{3}}{2} \times \frac{1}{10} = 5\sqrt{3}\ \text{V}$$

6.


According to Lenz's law, direction of current in loop PQ is from P to Q and in loop CD is from C to D.

7. The direction of induced current in metal ring 1 is clockwise. In metal ring 2 is anticlockwise when current I in the wire is increasing steadily.

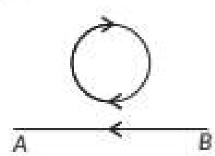


Answer Tips

- Using right hand thumb rule, first find out the direction of magnetic field, and then using Lenz's law direction induced current can be predicted.

8. The direction of current in the loop is anti-clockwise.

9. Clockwise, so that the magnetic field produced by the induced current is also directed inwards in the direction of decreasing magnetic field of current, in straight line.



10. The wire is expanding to form a circle, which means that force is acting outwards on each part of the wire because of the magnetic field (acting in the downward direction). The direction of the induced current should be such that it will produce magnetic field in upward direction (towards the reader). Hence, the force on the

Concept Applied

- Magnetic Flux, $\phi = \vec{B}.\vec{A} = BA\cos\theta$, where θ is the angle between area vector and field direction.

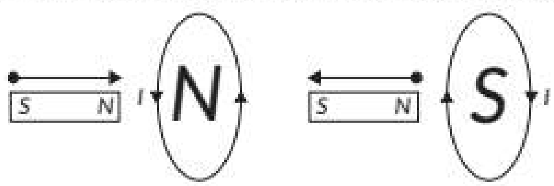
5. Polarity of plate A will be positive with respect to plate B in the capacitor, as induced current is in clockwise direction

where,
ω is angular velocity
B is uniform magnetic field
r is radius of disc
Therefore induced emf in both disc will be same at centre and at edge as they are of same area rotating with same angular speed in same magnetic field.

(ii) As we know, $I = \frac{\varepsilon}{R}$

so, copper disc with less resistance, will therefore induce more current.

12. Lenz's law states that the direction of the induced emf and the direction of induced current are such that they oppose the cause which produces them.
Here, the North pole is approaching the loop, so the induced current in the face of loop viewed from left side will flow in such a way that it will behave like North pole, so South pole developed on loop when viewed from right hand side of the loop. The flow of induced current is clockwise, hence A acquires positive polarity and B negative.
Whenever magnetic flux linked with a circuit changes, it induces an EMF in it. The induced current set up in the circuit flows in such a direction that it opposes the change in magnetic flux linked with the circuit.
In order to continue the change in magnetic flux linked with the circuit, some work is to be done or some energy is to be spent against the opposition offered by induced EMF. This energy spent by the external source ultimately appears in the circuit in the form of electrical energy.



This is why a magnet is moved near the closed loop with its N-pole towards the loop, then current is produced in loop on the side of a magnet in anticlockwise direction so as to develop the north pole which applies repulsive force on magnet opposing motion of magnet towards the loop.
Similarly when a magnet is moved away from the closed loop with its N-pole towards the loop, the current is produced in the loop on the side of magnet in clockwise direction, so as to develop the south pole which attracts

wire will be towards inward direction, *i.e.*, induced current is flowing in anticlockwise direction in the loop from c-b-a-d-c.

11. (i) The induced emf between centre and rim of the disc is given by

$$|\varepsilon| = \frac{B\omega r^2}{2}$$

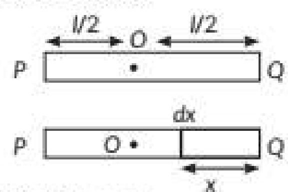
oppose the motion of the magnet towards the coil, by applying repulsive force on it.
In order to continue the change in magnetic flux linked with the circuit, some work is to be done or some energy has to be spent against the opposition offered by induced EMF. This energy spent by the external source ultimately appears in the circuit in the form of electrical energy.

Suppose that the Lenz's law is not valid. Then the induced current flows through the coil in a direction opposite to one dictated by Lenz's law. The resulting force on the magnet makes it move faster and faster, *i.e.*, the magnet gains speed and hence kinetic energy without expanding an equivalent amount of energy. This sets up a perpetual motion machine, violating the law of conservation of energy. Thus Lenz's law is valid and is a consequence of the law of conservation of energy.

14. Induced e.m.f. $\varepsilon = 0$, as $l, \vec{B}$ and $\vec{v}$ are all in same direction.

15. Consider a small element 'dx' on the rod, then the induced EMF on the element 'dx',

$$d\varepsilon = (\vec{v} \times \vec{B})dx = vB\,dx = B\omega x\,dx$$



$\therefore$ The total EMF induced,

$$\varepsilon = \int d\varepsilon = \int_{-\frac{l}{2}}^{\frac{l}{2}} B\omega x\,dx = \frac{B\omega}{2}[x^2]_{-\frac{l}{2}}^{\frac{l}{2}} = 0$$

Answer Tips

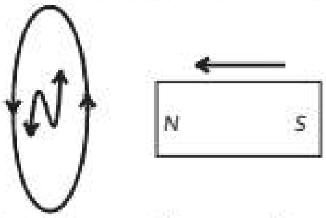
- Use the relation between angular velocity ω and the translational velocity v along the centre of mass of the rod.

Commonly Made Mistake

- Here, there is a common misconception among students that there is no emf induced between any two points of the rod, but there is induced emf between centre O and ends P or Q.

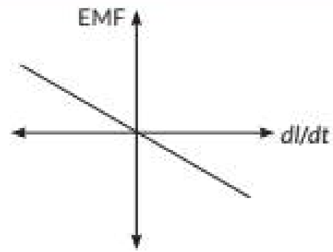
the bar magnet opposing its motion away from the loop.

13. Lenz's law states that the direction of the induced emf and the direction of induced current are such that they oppose the cause which produces them.



When the N pole of a magnet is moved towards a coil, the induced current in the coil flows in anticlockwise direction on the side of magnet, so as to acquire north polarity and

16.



17. $\varepsilon = Blv\sin\theta$

Given : $B = 0.3 \times 10^{-4}$ Wb m^{-2}

$v = 5$ m s^{-1}, $l = 10$ m, $\theta = 90°$

$\varepsilon = Blv\sin\theta = 0.3 \times 10^{-4} \times 10 \times 5 \times \sin 90°$

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

$\varepsilon = 1.5 \times 10^{-3}$ V $= 1.5$ mV

18. Here, no. of blades of fan, $N = 3$

Length of blades , l = radius, $r = 0.5$ m

Frequency, $n = 2$ rps

$B = 8 \times 10^{-5}$ T

As fan rotates, linear velocity at the outer end of blade $= r\omega$

linear velocity at the inner end of blade $= 0$

$\therefore$ Avg. linear velocity, $v = \dfrac{0 + r\omega}{2} = \left(\dfrac{1}{2}r\omega\right)$

As e.m.f. induced across the ends of each blade

$$e = Bvl = B\left(\frac{1}{2}r\omega\right)\cdot l = B\left(\frac{r}{2}(2\pi n)\right)\cdot l = B(r\pi n)\cdot l$$

$$= Br\pi nl = 8\times10^{-5}\times0.5\times\frac{22}{7}\times2\times0.5$$

$$= 12.57 \times 10^{-5} \text{ Volt}$$

19. Here, area of loop, $A = (10 \times 10^{-2})^2 = 10^{-2}$ m^2

Velocity, $v = 8$cm/s $= 8 \times 10^{-2}$ m/s

$$\frac{dB}{dx} = 10^{-3}\,\text{T cm}^{-1} = 10^{-3}\times10^{2}\,\text{T m}^{-1}$$

Rate of change of magnetic flux due to motion of loop in non uniform magnetic field.

$$\phi_1 = A\left(\frac{dB}{dx}\right)\left(\frac{dx}{dt}\right) = A\left(\frac{dB}{dx}\right)v$$

$$= 10^{-2}\times10^{-3}\times10^{2}\times8\times10^{-2} = 8\times10^{-5}\,\text{wb s}^{-1}$$

$\therefore$ Induced emf, $e = 8 \times 10^{-5} = 8 \times 10^{-5}$ V

20. (i) Induced emf $\varepsilon = Blv = 0.1 \times 0.1 \times 20 = 0.2$ V

(ii) Current $I = \dfrac{\varepsilon}{R} = \dfrac{0.2}{2} = 0.1$ A

Concept Applied

- The resistances of the arms MN, NP and MQ are negligible as compared to the resistance of the movable arm PQ. Thus, the overall resistance of the rectangular loop does not change when PQ is moved and remains the same *i.e.*, 2 Ω.

So, induced current flows through the circuit,

$$i = \frac{\varepsilon}{R} = \frac{Bvl}{R}$$, where R is the resistance of the rails.

(b) Retarding opposing force exerted on the metal rod by the action of induced current is given by,

$$\vec{F}_m = i(\vec{l}\times\vec{B}) \text{ or } F_m = Bil, \text{ where } \theta = 90°$$

$$\text{or } F_m = \frac{B^2l^2v}{R} \qquad \left[\text{As } i = \frac{Blv}{R}\right]$$

External mechanical force required for motion of the metal rod is given by

$$F_{ext} = F_m = \frac{B^2l^2v}{R} \text{ or } F_{ext} \propto v \text{ [if } B, l \text{ and } v \text{ are constants]}$$

For uniform motion of metal rod, mechanical power delivered by external source is given by

$$P_{mech} = P_{ext} = \vec{F}_{ext}\cdot\vec{v} = F_{ext}\,v \quad \text{or} \quad P_{mech} = P_{ext} = \frac{B^2l^2v^2}{R}$$

When, B, l and v are constant, then P_{mec} or $P_{ext} \propto v^2$.

22. (i) We know that, $I = \dfrac{dq}{dt} \Rightarrow dq = Idt$

$\therefore$ $q = \int Idt$ = Area under the I-t curve

$$= \frac{1}{2}\times0.4\times1 = 0.2\text{ C}$$

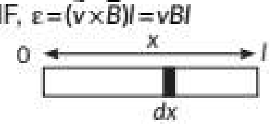
(ii) As we know $|\varepsilon| = \dfrac{d\phi}{dt} \Rightarrow \dfrac{dq}{dt}\times R = \dfrac{d\phi}{dt}$

$\Rightarrow$ $\phi = qR = 0.2\times10 = 2$ Wb

(iii) Now, $\phi = B.A = B(10 \times 10^{-4})$

$$\Rightarrow \quad B = \frac{2}{10\times10^{-4}} = 2000\text{ T}$$

23. Induced EMF, $\varepsilon = (\vec{v}\times\vec{B})l = vBl$



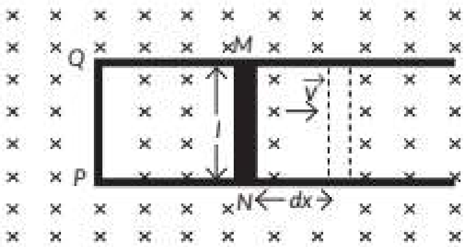
For the element dx, induced EMF,

$d\varepsilon = Bvdx = B\omega xdx$

21. (a) Let us consider a rod of length l moving with a uniform velocity $\vec{v}$ on two parallel imaginary conducting rails in the presence of uniform magnetic field which is directed inwards.

Let us consider in time dt, rod moves through a distance dx.

So, change in area of the loop, $dA = ldx$



$\therefore \quad \phi = B \cdot A = BA\cos\theta = BA \qquad [\because \theta = 0°]$

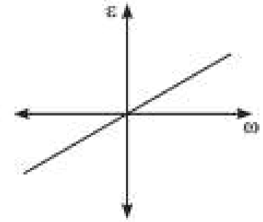
So, induced emf, $\varepsilon = \left|\frac{d\phi}{dt}\right|$

or $\varepsilon = B\frac{dA}{dt}$ or $\varepsilon = Bl\frac{dx}{dt}$ or $\varepsilon = Blv$

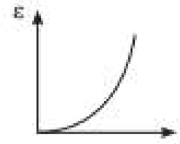
$\therefore \quad \varepsilon = \int d\varepsilon = \int_0^l B\omega x\,dx = \frac{B\omega l^2}{2}$

$\Rightarrow \quad \varepsilon \propto \omega$ and $\varepsilon \propto l^2$

(i)



(ii)



Commonly Made Mistake

- Sometimes, there is misunderstanding among students that, here no change in flux, so no emf will be induced. But this is not so. Here, emf will be induced because of flux cut.

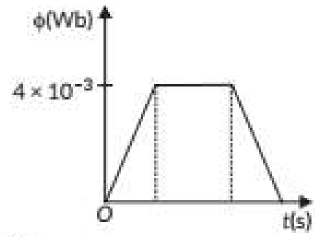
24. Given $l = 20$ cm $= 0.2$ m,

$B = 0.1$ T, $v = 10$ cm s^{-1} $= 0.1$ m s^{-1}

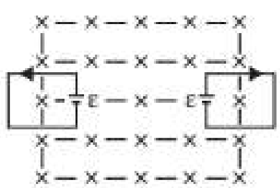
(i) Magnetic flux through loop

$\phi = B \cdot A = Blx$

$\phi_{max} = 0.1 \times 0.2 \times 0.2 = 0.004\text{ Wb} = 4 \times 10^{-3}\text{ Wb}$



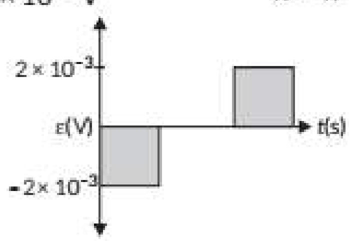
(ii) Induced emf,



$\varepsilon = \frac{-d\phi}{dt} = -Blv$

$|\varepsilon|_{max} = 0.1 \times 0.2 \times 0.1$

$= 0.002\text{ V} = 2 \times 10^{-3}\text{ V}$



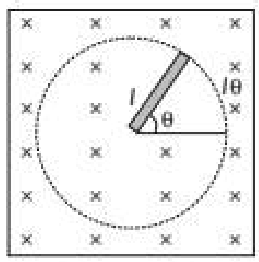
(iii) Induced current,

$I = \frac{|\varepsilon|}{R} = \frac{2\times10^{-3}}{0.1} = 2\times10^{-2}\text{ A}$

(ii) Power $P = Fv = 6.4 \times 10^{-3} \times 10 \times 10^{-2}$

$= 6.4 \times 10^{-4}$ W

27. (a)



If θ is the angle traced by the free electron in time t, then area swept out,

$A = \pi l^2 \times \left(\frac{\theta}{2\pi}\right) = \frac{1}{2}l^2\theta$

Magnetic flux linked, $\phi = B\left(\frac{1}{2}l^2\theta\right)\cos 0° \qquad [\because \phi = BA\cos\theta]$

$\phi = \frac{1}{2}Bl^2\theta$

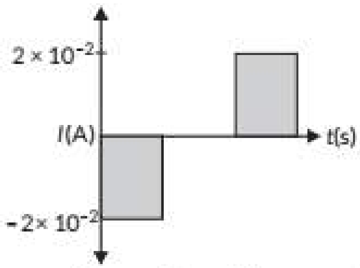
According to Faraday's laws of electromagnetic induction,

Induced emf, $\varepsilon = \frac{d\phi}{dt} = \frac{1}{2}Bl^2\frac{d\theta}{dt} = \frac{1}{2}Bl^2\omega$

$\therefore \quad$ Induced current, $i = \frac{\varepsilon}{R} = \frac{\frac{1}{2}Bl^2\omega}{R} = \frac{Bl^2\omega}{2R}$

(b) Force acting on the rod,

$F = ilB = \frac{\pi\upsilon B^2l^3}{R}$



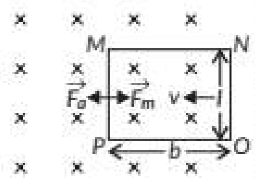
25. (a) As the rod is moving with a constant velocity, the applied force $\vec{F}_a$ must balance the magnetic force $F_m = ilB$ on the rod when it is carrying the induced current i.

$$i = \frac{\varepsilon}{R} = \frac{vBl}{R}$$

Thus force acting on arm 'ON' is

$$F_{ON} = \frac{l^2B^2v}{R}$$, if loop is partially in the magnetic field.

But $F_{ON} = 0$ inside the magnetic field.



(b) Now, power required to move frame to get a steady emf induced between the arms MN and PO is,

$$\therefore \quad P = F_a v = \frac{B^2l^2v^2}{R}$$

26. (i) $F = ilB = \frac{B^2l^2v}{R}$

$$= \frac{(0.4)^2 \times (20\times10^{-2})^2(10\times10^{-2})}{0.1} = 6.4\times10^{-3}\text{ N}$$

The external force required to rotate the rod opposes the Lorentz force acting on the rod. External force acts in the direction opposite to the Lorentz force.

(c) Power required to rotate the rod,

$$P = Fv = \frac{\pi\upsilon B^2l^3v}{R}$$

28. (a) : Change in current, $dI = 7\text{ A} - 3\text{ A} = 4\text{ A}$

Time, $dt = 0.04$ s

Mutual inductance, $M = 0.5$ H

The induced emf is given by

$$e = \frac{MdI}{dt} = 0.5\times\frac{4}{0.04} = 50\text{ V}$$

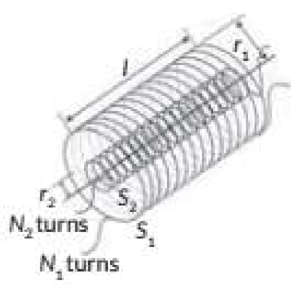
29. (i) Flux, $\phi = MI$

$$M = \frac{\phi}{I_1} = \frac{15-10}{6-4} = \frac{5}{2} = 2.5\text{Henry}$$

(ii) $e = \frac{MdI_1}{dt}$

$$\frac{dI_1}{dt} = \frac{e}{M} = \frac{100}{2.5} = 40\text{ A/s}$$

30. (i) Consider two long coaxial solenoids each of length l. Let n_1 be the number of turns per unit length of inner solenoid X of radius r_1, n_2 be the number of turns per unit length of outer solenoid Y of radius r_2. Let N_1 and N_2 be the total number of turns of solenoids X and Y respectively.



When a current I is passed through X, the magnetic flux linked with solenoid Y is

$N_2\phi_2 = M_{21}I$ ...(i)

where, M_{21} is called the mutual inductance of solenoid Y with respect to solenoid X. It is also referred as the coefficient of mutual induction.

The magnetic field due to current I in Y is

$B_2 = \mu_0 n_2 I$ ...(ii)

$\therefore$ The magnetic flux linked with Y is

$N_1\phi_1 = B_2(\pi r_1^2)n_1 l = \mu_0 n_1 n_2 \pi r_1^2 LlI$ ...(iii)

where, $n_1 l$ is the total number of turns in solenoid X.

From (i) and (iii), we get

$M_{21} = \mu_0 n_1 n_2 \pi r_1^2 l$ ...(iv)

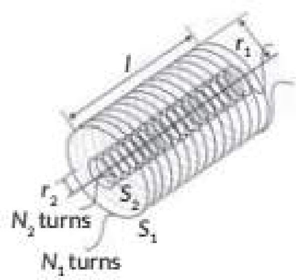
which is required expression.

Similarly, $M_{12} = \mu_0 n_1 n_2 \pi r_1^2 l$ ...(v)

Force of attraction on conductor, $F_2 = \frac{\mu_0}{4\pi}\frac{2I_1I_2a}{(x+a)}$

Net force on loop, $F_{Net} = F_1 - F_2 = \frac{\mu_0}{4\pi}\frac{2I_1I_2a^2}{x(x+a)}$

32. Mutual Inductance : The phenomenon according to which an opposing emf is produced as a result of change in current or magnetic flux linked with another coil. Consider two long coaxial solenoids each of length l. Let n_1 be the number of turns per unit length of inner solenoid S_1 of radius r_1, n_2 be the number of turns per unit length of outer solenoid S_2 of radius r_2. Let N_1 and N_2 be the total number of turns of solenoids S_1 and S_2 respectively.



When a current i is passed through S_2, the magnetic flux linked with solenoid S_1 is

$N_1\phi_1 = M_{12}i_2$ ...(i)

From (iv) and (v), we get

$M_{12} = M_{21} = M$

Hence, coefficient of mutual induction between two coaxial solenoids is

$$M = \mu_0 n_1 n_2 \pi r_1^2 l \text{ or, } M = \frac{\mu_0 N_1 N_2 \pi r_1^2}{l}$$

(ii) When current I passes through X, the magnetic flux linked with solenoid Y is

$N_{21}\phi_2 = M_{21} I$

M_{12} is mutual inductance.

Magnetic field due to current I_1 in X is

$B_1 = \mu_0 n_1 I$

Magnetic field linked with Y.

$N_{21}\phi_2 = B_1 (\pi r_2^2) n_2 l$

$= \mu_0 n_1 n_2 (\pi r_2^2) l i_2$

where, $n_2 l$ is total number of turns is solenoid Y.

31. (a) The phenomena of inducing emf in a circuit by changing the magnetic flux in a neighbouring circuit is called mutual induction. The S.I. unit of mutual inductance is Henry and is denoted by H.

(b) Consider two straight infinite parallel conducting wires with current I_1 and I_2 are separated by a distance x,

$\therefore$ Force per unit length,

$$\frac{F}{a} = \frac{\mu_0 I_1 I_2}{2\pi x}$$

μ_0 is magnetic permeability.

Force of repulsion on conductor,

$$F_1 = \frac{\mu_0}{4\pi}\frac{2I_1 I_2 a}{x}$$

(ii) Here, $M = 1.5$ H, $\Delta I_1 = 20$ A, $\Delta t = 0.5$ s, $\Delta\phi = ?$

We know, emf induced in the second coil,

$$\varepsilon = -\frac{(\Delta\phi)_2}{\Delta t} = -\frac{M\Delta I_1}{\Delta t}$$

$\therefore$ $(\Delta\phi)_2 = M\Delta I_1 = 1.5 \times 20 = 30$ Wb

Concept Applied

- Any varying current in a magnetic coupled coil would produce an induced emf in the other coil *i.e.*, $e = MdI/dt$ Also, the varying current is accompanied with a change in flux linkage *i.e.*, $d\phi/dt$.

34. (i) Given $r_1 = 1$ cm $= 1 \times 10^{-2}$ m and $r_2 = 20$ cm $= 20 \times 10^{-2}$ m Mutual inductance of two concentric and coplanar coils is given by, $M = \frac{\mu_0 N_1 N_2 \pi r_1^2}{2r_2}$

$$= \frac{4\pi\times10^{-7}\times1\times1\times\pi(1\times10^{-2})^2}{2(20\times10^{-2})} = \pi^2\times10^{-10}\text{H}$$

where M_{12} is called the mutual inductance of solenoid S_1 with respect to solenoid S_2.

It is also referred as the coefficient of mutual induction.

The magnetic field due to current i in S_2 is

$B_2 = \mu_0 n_2 i$ ...(ii)

$\therefore$ The magnetic flux linked with S_1 is

$N_1\phi_1 = B_2(\pi r_1^2) n_1 l = \mu_0 n_1 n_2 \pi r_1^2 l i_2$ ...(iii)

where $n_1 l$ is the total number of turns in solenoid S_1.

From (i) and (iii), we get

$M_{12} = \mu_0 n_1 n_2 \pi r_1^2 l$ ...(iv)

which is required expression.

Similarly, $M_{21} = \mu_0 n_1 n_2 \pi r_1^2 l$ ...(v)

From (iv) and (v), we get

$M_{12} = M_{21} = M$

Hence, coefficient of mutual induction between two coaxial solenoids is

$$M = \mu_0 n_1 n_2 \pi r_1^2 l \text{ or, } M = \frac{\mu_0 N_1 N_2 \pi r_1^2}{l}$$

Concept Applied

- Any varying current in a magnetic coupled coil would produce an induced emf in the other coil *i.e.*, $e = -\frac{MdI}{dt}$ Also, the varying current is accompanied with a change in flux linkage *i.e.*, $\frac{d\phi}{dt}$.

33. (i) The phenomena of inducing current in a circuit by changing the current or flux in a neighbouring circuit is called mutual induction. S.I. unit of mutual inductance is henry denoted by H.

When a current i_2 is passed through S_2, the magnetic flux linked with solenoid S_1 is

$N_1\phi_1 = M_{12} i_2$ ...(i)

where M_{12} is called the mutual inductance of solenoid S_1 with respect to solenoid S_2.

It is also referred as the coefficient of mutual induction.

The magnetic field due to current i_2 in S_2 is

$B_2 = \mu_0 n_2 i_2$ ...(ii)

$\therefore$ The magnetic flux linked with S_1 is

$N_1\phi_1 = B_2(\pi r_1^2) n_1 l = \mu_0 n_1 n_2 \pi r_1^2 l i_2$ ...(iii)

where $n_1 l$ is the total number of turns in solenoid S_1.

From (i) and (iii), we get

$M_{12} = \mu_0 n_1 n_2 \pi r_1^2 l$ ...(iv)

which is required expression.

Similarly, $M_{21} = \mu_0 n_1 n_2 \pi r_1^2 l$ ...(v)

From (iv) and (v), we get

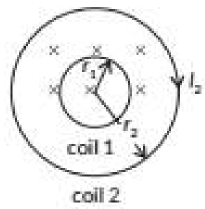
$M_{12} = M_{21} = M$

Hence, coefficient of mutual induction between two coaxial solenoids is

(ii) The induced emf,

$$|\varepsilon| = -M\left|\frac{dI}{dt}\right| = \pi^2 \times 10^{-10} \times 5 \times 10^3 = 4.93 \times 10^{-6}\,V = 4.93\,\mu V$$

35. Mutual inductance of a pair of coils is defined as the emf induced in one of the coils, when the rate of change of current is unity in the other coil.



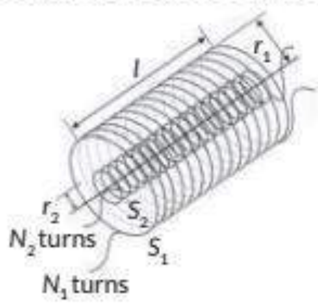
When current I_2 flows through the outer coil-2, magnetic field produced at its centre is given by $B_2 = \frac{\mu_0 I_2}{2r_2}$ directed normal to the plane of coils. As $r_1 < r_2$, so this magnetic field is almost uniform over the plane of coil-1. So, magnetic flux linked with coil-1 is

$\phi_{12} = B_2 A_1 \cos 0°$ or $\phi_{12} = \frac{\mu_0 I_2}{2r_2} \times \pi r_1^2 \times 1$

or $\frac{\phi_{12}}{I_2} = \frac{\mu_0 \pi r_1^2}{2r_2}$ or $M_{12} = \frac{\mu_0 \pi r_1^2}{2r_2}$

36. (a) The phenomena of inducing emf in a circuit by changing the current or flux in a neighbouring circuit is called mutual induction. S.I. unit of mutual inductance is henry denoted by H.

(b) Consider two long coaxial solenoids each of length l. Let n_1 be the number of turns per unit length of inner solenoid S_1 of radius r_1, n_2 be the number of turns per unit length of outer solenoid S_2 of radius r_2. Let N_1 and N_2 be the total number of turns of solenoids S_1 and S_2 respectively.



$N_1\phi_1 = M_{12} i_2$ ...(i)

where M_{12} is called the mutual inductance of solenoid S_1 with respect to solenoid S_2.

It is also referred as the coefficient of mutual induction.

The magnetic field due to current i_2 in S_2 is

$B_2 = \mu_0 n_2 i$ ...(ii)

$\therefore$ The magnetic flux linked with S_1 is

$N_1\phi_1 = B_2(\pi r_1^2) n_1 l = \mu_0 n_1 n_2 \pi r_1^2 l i$ ...(iii)

where $n_1 l$ is the total number of turns in solenoid S_1.

From (i) and (iii), we get

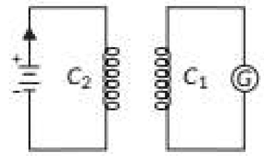
$M_{12} = \mu_0 n_1 n_2 \pi r_1^2 l$ ...(iv)

which is required expression.

Similarly, $M_{21} = \mu_0 n_1 n_2 \pi r_1^2 l$ ...(v)

$M = \mu_0 n_1 n_2 \pi r_1^2 l$ or, $M = \frac{\mu_0 N_1 N_2 \pi r_1^2}{l}$

(c)



Mutually induced emf in coil C_1 is

$\varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(Mi)$ or $\varepsilon = -M\frac{di}{dt}$

The rate of change of current in the neighbouring coil is $\frac{dI}{dt}$.

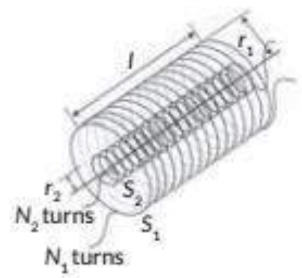
37. The flux (ϕ_B) linked with the secondary coil is directly proportional to the strength of the current (I) flowing through the primary coil, *i.e.*,

$\phi_B \propto i$ or $\phi_B = Mi$

where M is a constant of proportionality and is termed as the mutual inductance of one circuit with respect to the other.

The value of M depends upon : (i) the characteristics of both the circuits, and (ii) their orientation with respect to each other.

38. Consider two long coaxial solenoids each of length l. Let n_1 be the number of turns per unit length of inner solenoid S_1 of radius r_1, n_2 be the number of turns per unit length of outer solenoid S_2 of radius r_2. Let N_1 and N_2 be the total number of turns of solenoids S_1 and S_2 respectively.



When a current i is passed through S_2, the magnetic flux linked with solenoid S_1 is

$L = \frac{N\phi}{I}$

The unit of self-inductance is henry (H).

44. (a) Self inductance : When the current in a coil is changed, a back emf is induced in the same coil. This phenomenon is called self-inductance. If L is self-inductance of coil, then

$N\phi \propto I$

$N\phi = LI$

$L = \frac{N\phi}{I}$

The unit of self-inductance is henry (H).

(b) Consider two long coaxial solenoids each of length l. Let n_1 be the number of turns per unit length of inner

From (iv) and (v), we get

$M_{12} = M_{21} = M$

Hence, coefficient of mutual induction between two coaxial solenoids is

$$M = \mu_0 n_1 n_2 \pi r_1^2 l \text{ or, } M = \frac{\mu_0 N_1 N_2 \pi r_1^2}{l}$$

Answer Tips

- Coefficient of mutual inductance only depends upon geometrical parameters, not on current or magnetic field.

39. (d) : Self inductance, $L = 108$ mH

Number of turns $N = 600$

Now, $N' = 500$

Let the new self inductance is L'.

The self inductance of a solenoid is, $L = \frac{\mu_0 N^2 A}{l}$

So, $\frac{L'}{L} = \left(\frac{N'}{N}\right)^2 = \left(\frac{500}{600}\right)^2$; $L' = 108 \times \frac{5^2}{6^2} = 75$ mH

40. (c) : Current in solenoid = I

When iron rod is inserted in the solenoid, the magnetic field increases, flux linked increases and self inductance also increases. So, only the rate of heating does not change.

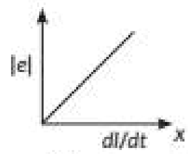
41. Self inductance, $L = \frac{\mu_0 \mu_r N^2 A}{l}$.

when $N' = 2N$, then

$$L' = \frac{\mu_0 \mu_r A (2N)^2}{l} = \frac{4\mu_0 \mu_r N^2 A}{l} = 4L$$

Thus, self inductance of the coil becomes four times.

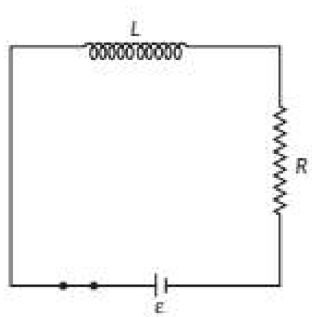
42. The graph showing the variation of the value of induced emf as a function of rate of change of current in an ideal inductor is given here.



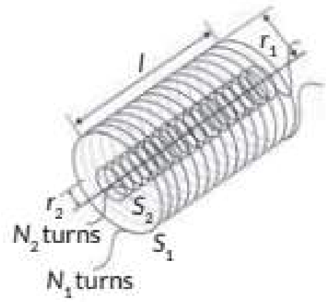
43. Self inductance : When the current in a coil is changed, a back emf is induced in the same coil. This phenomenon is called self-inductance. If L is self-inductance of coil, then

$N\phi \propto I$

$N\phi = LI$



Consider the circuit shown here, consisting of a solenoid S_1 of radius r_1, n_2 be the number of turns per unit length of outer solenoid S_2 of radius r_2. Let N_1 and N_2 be the total number of turns of solenoids S_1 and S_2 respectively.



When a current i_2 is passed through S_2, the magnetic flux linked with solenoid S_1 is

$N_1 \phi_1 = M_{12} I$ ...(i)

where M_{12} is called the mutual inductance of solenoid S_1 with respect to solenoid S_2.

It is also referred as the coefficient of mutual induction.

The magnetic field due to current i_2 in S_2 is

$B_2 = \mu_0 n_2 I$ ...(ii)

$\therefore$ The magnetic flux linked with S_1 is

$N_1 \phi_1 = B_2 (\pi r_1^2) n_1 l = \mu_0 n_1 n_2 \pi r_1^2 Il$ ...(iii)

where $n_1 l$ is the total number of turns in solenoid S_1.

From (i) and (iii), we get

$M_{12} = \mu_0 n_1 n_2 \pi r_1^2 l$ ...(iv)

which is required expression.

Similarly, $M_{21} = \mu_0 n_1 n_2 \pi r_1^2 l$ ...(v)

From (iv) and (v), we get

$M_{12} = M_{21} = M$

Hence, coefficient of mutual induction between two coaxial solenoids is

$$M = \mu_0 n_1 n_2 \pi r_1^2 l \text{ or, } M = \frac{\mu_0 N_1 N_2 \pi r_1^2}{l}$$

45. The phenomena of induced emf in a solenoid due to change in current or magnetic flux linked with the solenoid is called self inductance of the solenoid.

The self inductance of a long solenoid, the core of which consists of a magnetic material of permeability μ is given by

$L = \mu l_0 n^2 A l$

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

Induced emf in the loop

$$\varepsilon_2 = M \frac{\Delta i_1}{\Delta t} \text{ (numerically)}$$

$$= 120\pi \times 10^{-9} \frac{(4-2)}{0.1}$$

$$= 120 \times 3.14 \times 10^{-9} \times \frac{2}{0.1}$$

$= 7.5 \times 10^{-6}$ V $= 7.5$ µV

47. (i) Induced voltage $V = L\frac{di}{dt}$

inductor L and a resistor R, connected to a source of emf ε. As the connections are made, the current grows in the circuit and the magnetic field increases in the inductor. Part of the work done by the battery during the process is stored in the inductor as magnetic field energy and the rest appears as thermal energy in the resistor. After sufficient time, the current, and hence the magnetic field, becomes constant and further work done by the battery appears completely as thermal energy. If, I be the current in the circuit at time t, we have

Self induced emf $\varepsilon = L\frac{dI}{dt}$

$dW = \varepsilon I dt$

$dW = L\frac{dI}{dt} I dt$

$dW = LIdI$

Work done by source of emf to supply current I for a small time dt.

Now total work done by cell to establish current I_0 in inductor

$$W = \int dW = L\int_0^{I_0} I\,dI = \frac{1}{2}LI_0^2$$

Total work done is stored as magnetic energy in the solenoid.

Concept Applied

- Work done by the battery against inertial property of the inductor is stored as magnetic energy.

46. (i) Self inductance : When the current in a coil is changed, a back emf is induced in the same coil. This phenomenon is called self-inductance. If L is self-inductance of coil, then

$N\phi \propto I$

$N\phi = LI$

$L = \frac{N\phi}{I}$

The unit of self-inductance is henry (H).

(ii) Mutual inductance of solenoid coil system

$$M = \frac{\mu_0 N_1 N_2 A_2}{l}$$

Here, $N_1 = 15$, $N_2 = 1$, $l = 1\text{cm} = 10^{-2}\text{m}$,
$A = 2.0\text{ cm}^2 = 2.0 \times 10^{-4}\text{ m}^2$

$$\therefore\ M = \frac{4\pi \times 10^{-7} \times 15 \times 1 \times 2.0 \times 10^{-4}}{10^{-2}}$$

$= 120\pi \times 10^{-9}$ H

$\frac{V_1}{V_2} = \frac{L_1}{L_2}$ (as $\frac{di}{dt}$ is same)

$\Rightarrow\ \frac{V_1}{V_2} = \frac{16}{12} = \frac{4}{3}$

(ii) Power $P = iV$

$\frac{i_1}{i_2} = \frac{V_2}{V_1} = \frac{3}{4}$ (as P is same)

$\Rightarrow\ \frac{i_1}{i_2} = \frac{3}{4}$

(iii) Energy stored $E = \frac{1}{2}Li^2$

$\frac{E_1}{E_2} = \frac{L_1 i_1^2}{L_2 i_2^2} = \frac{16}{12} \times \frac{9}{16} = \frac{3}{4}$

$\Rightarrow\ \frac{E_1}{E_2} = \frac{3}{4}$

48. (i) Length of conducting XY rod = l

Velocity = v

magnetic field = B

Then induced emf is given as

$|e| = Blv\sin\theta$

Conducting rod XY is perpendicular to magnetic field i.e., $\theta = 90°$

$|e| = Blv$

(ii) Induced current, $I = \frac{\varepsilon}{R}$

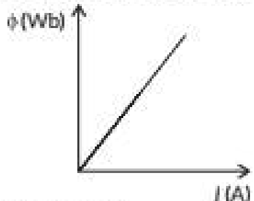
Resistance = r

$\therefore\ I = \frac{Blv}{r}$

49. (i) Suppose current I is flowing through an inductor of self inductance L. Then magnetic flux linked with the inductor is given by

$\phi = LI$

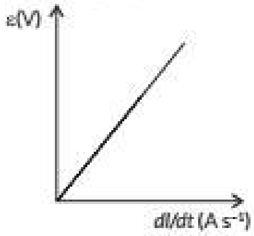
Magnetic flux versus the current graph,



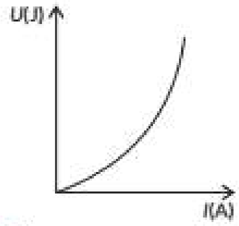
(ii) Induced emf is given by,

$$\varepsilon = -\frac{d\phi}{dt} = -\frac{d}{dt}(LI) = -L\frac{dI}{dt},\ |\varepsilon| = L\frac{dI}{dt}$$

Induced emf versus dI/dt graph,



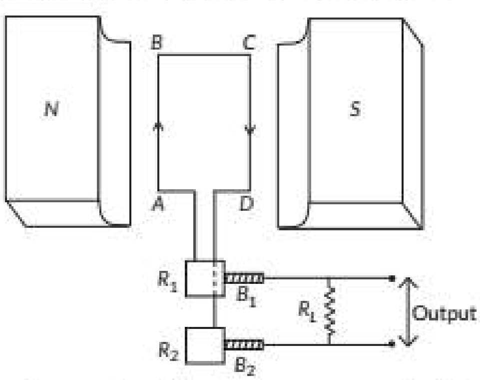
(iii) Magnetic potential energy stored versus the current graph, $U = \frac{1}{2}LI^2$



Concept Applied

- $AS, \phi \propto I, \varepsilon \propto I$ and $U \propto I^2$, thus respective graphs should be linear, linear and parabolic.

50. An electrical machine used to convert mechanical energy into electrical energy is known as a.c. generator.
Principle : It works on the principle of electromagnetic induction, *i.e.*, when a coil is rotated in a uniform magnetic field, emf is induced in it.
Construction : A.C. generator can be constructed by armature coil, strongfield magnet, slip rings and brushes.
Here, the armature coil (say $ABCD$) consists of a large number of turns of insulated copper wire wound over a soft iron core. The strong permanent magnet or electromagnet are cylindrical in shape acts as a field magnet. In this case the armature coil rotates between the pole of these magnet. The uniform magnetic field is perpendicular to the axis of rotation of the coil.



Here, the two ends of the coil are connected to two slip rings (R_1 and R_2) which also rotate with the coil. Two brushes B_1 and B_2 are fixed and are connected to the load through which the output is obtained.
Working : When the coil $ABCD$ rotates in the strong magnetic field, it cuts the magnetic lines of force, so the magnetic flux linked with the coil changes hence, emf is induced in the coil.
When the coil rotates with an angular velocity ω by an angle θ with time t, then

$\theta = \omega t$

$\therefore$ Magnetic flux, $\phi = BA\cos\omega t$

Now, emf produced in the coil is given by

$$\varepsilon = -\frac{d\phi}{dt} = \frac{-d}{dt}(BA\cos\omega t) \quad \text{or} \quad \varepsilon = BA\omega\sin\omega t$$

If the coil has N turns, then the total induced emf will be

$\varepsilon = NBA\omega\sin\omega t$ or $\varepsilon = \varepsilon_0\sin\omega t, = \varepsilon_0\sin 2\pi ft$

where $\varepsilon_0 = NBA\omega = 2\pi f\,NBA$ and f is the frequency of rotation of the coil.

51. (a) An electrical machine that is used to convert mechanical energy into electrical energy is known as a.c. generator.

It works on the principle of electromagnetic induction, *i.e.*, when a coil is rotated in a uniform magnetic field, emf is induced in it.

$\therefore$ Magnetic flux, $\phi = BA\cos\omega t$

where A is the area of coil and B is magnetic induction.
Now, emf produced in the coil is given by

$$\varepsilon = -\frac{d\phi}{dt} = \frac{-d}{dt}(BA\cos\omega t) \quad \text{or} \quad \varepsilon = BA\omega\sin\omega t$$

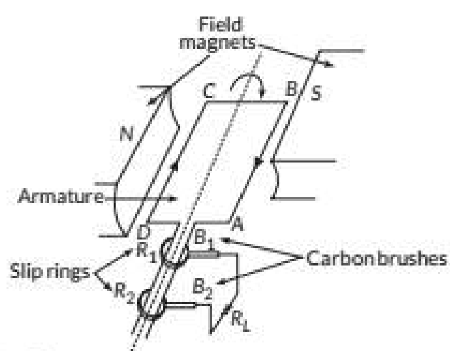
If the coil has N turns, then the total induced emf will be

$\varepsilon = NBA\omega\sin\omega t$ or $\varepsilon = \varepsilon_0\sin\omega t, = \varepsilon_0\sin 2\pi ft$

where $\varepsilon_0 = NBA\omega = 2\pi f\,NBA$ and f is the frequency of rotation of the coil.

(b) Slip rings used to provide movable contact of armature coil with external circuit containing load.

52. (a) Principle : AC generator is based on the principle of electromagnetic induction. It converts mechanical energy into electrical energy.



It consists of

(i) Armature coil of large number of turns of copper wire wound over soft iron core. Soft iron core is used to increase magnetic flux.

(ii) Field magnets used to apply magnetic field, in which armature coil is rotated with its axis perpendicular to field lines.

(iii) Slip rings used to provide movable contact of armature coil with external circuit containing load.

(iv) Brushes which are the metallic pieces used to pass on electric current from armature coil to the external circuit containing load.

When armature is rotated in the magnetic field, due to change in orientation of the coil magnetic flux through it

The current flows out through the brush B_1 in one direction of half of the revolution and through the Brush B_2 in the next half revolution in reverse direction and this process is repeated.

$\varepsilon = NBA\omega \sin \omega t$ $\quad [\because \phi = BA \cos \omega t]$

$$i = \frac{\varepsilon}{R} = \frac{NBA\omega}{R} \sin \omega t$$

Direction of induced current is given by Fleming's right hand rule.

(b) Radius of coil, r = 10 cm = 0.1 m

Area, $A = \pi r^2 = 3.14 \times (0.1)^2 = 0.0314\ m^2$

Number of turns, N = 20

Angular speed, ω = 50 rad s^{-1}

Magnetic field, $B = 3.0 \times 10^{-2}$ T

(i) Maximum induced emf $\varepsilon_{max} = NAB\omega$

$= 20 \times 0.0314 \times 3.0 \times 10^{-2} \times 50 = 0.942$ V

Average induced emf, $\varepsilon = \frac{\varepsilon_{max} + \varepsilon_{min}}{2} = \frac{0.942 + 0}{2} = 0.471$ V

(ii) Given, $R = 10\ \Omega$

Maximum current in the coil,

$$I_0 = \frac{\varepsilon_0}{R} = \frac{0.942}{10} = 0.0942 \text{ A}$$

Average current, $I = \frac{\varepsilon}{R} = \frac{0.471}{10} = 0.0471$ A

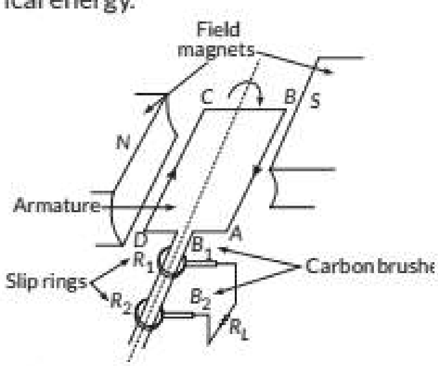
Now average power loss, $P = I^2 R$

$= (0.0471)^2 \times 10 = 0.022$ W

Answer Tips

- Use the concept of electromagnetic induction and Faraday's law to get the variation of the induced emf due to the rotation of the coil.

53. Principle : AC generator is based on the principle of electromagnetic induction. It converts mechanical energy into electrical energy.



It consists of

changes. Due to change in flux an e.m.f. is induced.

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

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

$\varepsilon = NBA\omega \sin \omega t$ $\quad [\because \phi = BA \cos \omega t]$

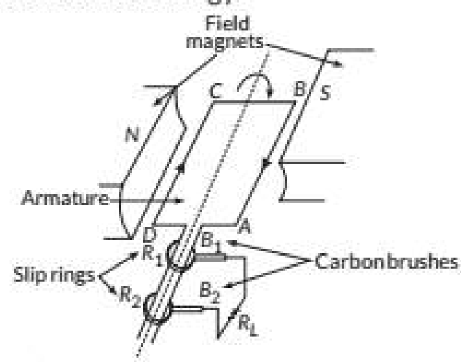
$$i = \frac{\varepsilon}{R} = \frac{NBA\omega}{R} \sin \omega t$$

Direction of induced current is given by Fleming's right hand rule.

Commonly Made Mistake

- Generally students get confused between the terms slip rings and split rings. Slip rings are used in AC generators whereas split rings also known as commutator are used in DC Generators.

54. (a) Principle : AC generator is based on the principle of electromagnetic induction. It converts mechanical energy into electrical energy.



It consists of

(i) Armature coil of large number of turns of copper wire wound over soft iron core. Soft iron core is used to increase magnetic flux.

(ii) Field magnets used to apply magnetic field, in which armature coil is rotated with its axis perpendicular to field lines.

(iii) Slip rings used to provide movable contact of armature coil with external circuit containing load.

(iv) Brushes which are the metallic pieces used to pass on electric current from armature coil to the external circuit containing load.

When armature is rotated in the magnetic field, due to change in orientation of the coil magnetic flux through it changes. Due to change in flux an e.m.f. is induced.

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

$\varepsilon = NBA\omega \sin \omega t$ $\quad [\because \phi = BA \cos \omega t]$

(i) Armature coil of large number of turns of copper wire wound over soft iron core. Soft iron core is used to increase magnetic flux.

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When armature is rotated in the magnetic field, due to change in orientation of the coil magnetic flux through it

$\varepsilon = NBA\omega \sin \omega t$ $\quad [\because \phi = BA \cos \omega t]$

$i = \dfrac{\varepsilon}{R} = \dfrac{NBA\omega}{R} \sin\omega t$

Direction of induced current is given by Fleming's right hand rule.

(b) Here, $A = 200 \text{ cm}^2 = 2 \times 10^{-2} \text{ m}^2$

$N = 20$, $\omega = 50 \text{ rad s}^{-1}$, $B = 3 \times 10^{-2}$ T, $I_{max} = ?$

Maximum emf induced in the coil,

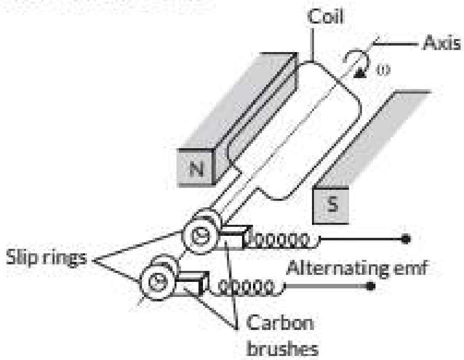
$\varepsilon_0 = NBA\omega = 20 \times 3 \times 10^{-2} \times 2 \times 10^{-2} \times 50 = 0.6$ V

If R is the resistance of the coil, the maximum value of the current is,

$I_{max} = \dfrac{\varepsilon_0}{R} = \dfrac{0.6 \text{ V}}{R}$

55. The magnetic flux linked with coil at any instant of time t is

$\phi = NBA \cos\theta = NBA \cos \omega t$



From Faraday's law of electromagnetic induction, the induced emf across the coil is

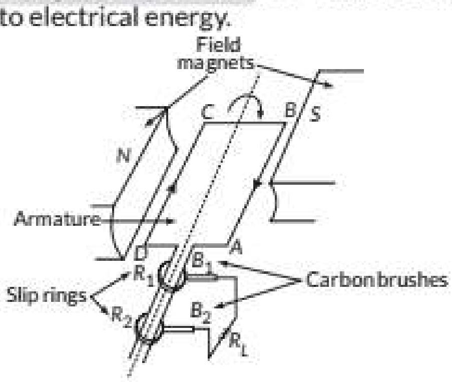
$\varepsilon = -\dfrac{d\phi}{dt} = -\dfrac{d}{dt}(NBA \cos \omega t)$

or $\quad \varepsilon = NBA\omega \sin \omega t$ or $\varepsilon = \varepsilon_0 \sin \omega t$

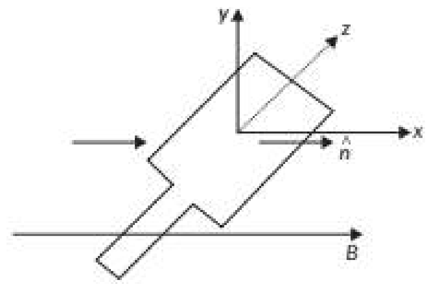
where, the maximum emf induced in the coil is when $\sin \omega t = +1$ and is given by $\varepsilon_0 = NBA\omega$

or $\quad \varepsilon_0 = 2\pi f NBA \quad [\because \omega = 2\pi f]$

56. (a) Principle : AC generator is based on the principle of electromagnetic induction. It converts mechanical energy into electrical energy.

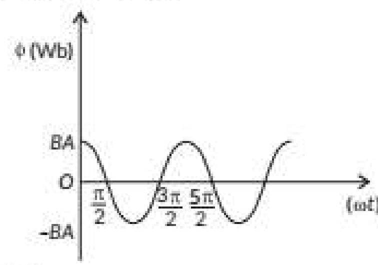


The plane of the coil is in yz plane and perpendicular to the x-axis *i.e.*, direction of magnetic field.



Maximum magnetic flux $\phi_{max} = B|A|$.

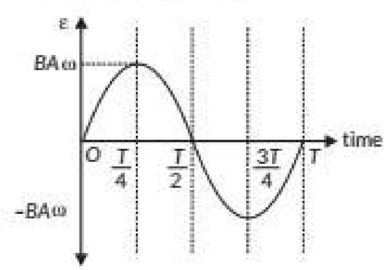
As the coil rotates with angular speed ω, magnetic flux at any instant t, (or at angle ωt)



$\phi = |B||A| \cos \omega t$

(i) Magnetic flux, $\phi = BA \cos \omega t$

(ii) Alternating emf, $\varepsilon = BA\omega \sin\omega t$



(b) A choke coil reduces current in an a.c. circuit without

It consists of

(i) Armature coil of large number of turns of copper wire wound over soft iron core. Soft iron core is used to increase magnetic flux.

(ii) Field magnets used to apply magnetic field, in which armature coil is rotated with its axis perpendicular to field lines.

(iii) Slip rings used to provide movable contact of armature coil with external circuit containing load.

(iv) Brushes which are the metallic pieces used to pass on electric current from armature coil to the external circuit containing load.

When armature is rotated in the magnetic field, due to change in orientation of the coil magnetic flux through it changes. Due to change in flux an e.m.f. is induced.

$\varepsilon = -N\dfrac{d\phi}{dt}$

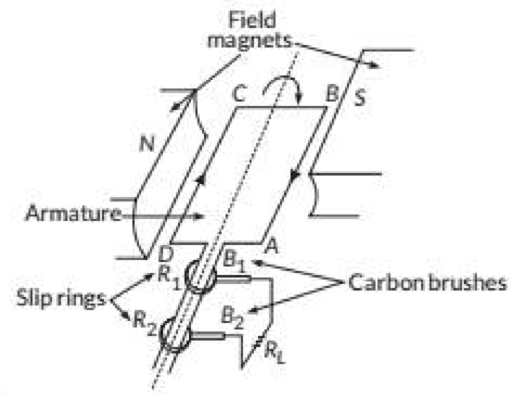
$\varepsilon = NBA\omega \sin \omega t$ $\quad [\because \phi = BA\cos\omega t]$

$i = \dfrac{\varepsilon}{R} = \dfrac{NBA\omega}{R}\sin\omega t$

Direction of induced current is given by Fleming's right hand rule.

dissipating any power. A rheostat also reduces current but it dissipates energy in the form of heat.

57. (a) Principle : AC generator is based on the principle of electromagnetic induction. It converts mechanical energy into electrical energy.



It consists of

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When armature is rotated in the magnetic field, due to change in orientation of the coil magnetic flux through it changes. Due to change in flux an e.m.f. is induced.

$\varepsilon = -N\dfrac{d\phi}{dt}$

$\varepsilon = NBA\omega \sin \omega t$ $\quad [\because \phi = BA\cos\omega t]$

$i = \dfrac{\varepsilon}{R} = \dfrac{NBA\omega}{R}\sin\omega t$

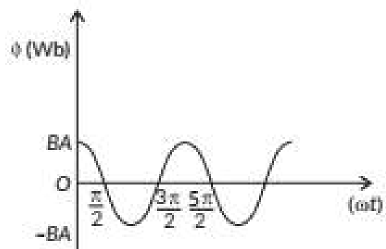
Direction of induced current is given by Fleming's right hand rule.

(b) In an ac generator we keep the armature coil fixed and rotate the field magnet so as to produce induced emf. It is because the flux linked with the coil will change and an induced emf is set up in it.

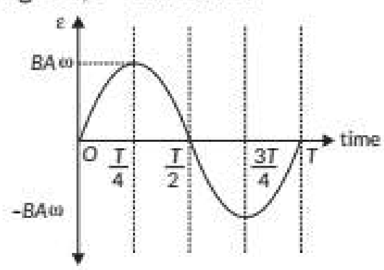
(c) The maximum value of the induced emf is called peak value. If $f = \left(\dfrac{\omega}{2\pi}\right)$ is frequency of a current, then

$I = I_0 \sin\omega t$

(i) Magnetic flux, $\phi = BA\cos\omega t$



(ii) Alternating emf, $\varepsilon = BA\omega \sin\omega t$



CBSE Sample Questions

1. (b) : Given : $\phi = 5t^2 + 3t + 16$

$$e = -\frac{d\phi}{dt} = -\frac{d}{dt}[5t^2 + 3t + 16] = -(10t + 3)$$

At $t = 4$, $e = -43$ V (0.77)

Similarly alternating voltage (emf) is

$V = V_0 \sin \omega t$.

Emf generated versus time : If N is the number of turns in coil, f is the frequency of rotation, A area of coil and B the magnetic induction, then induced emf,

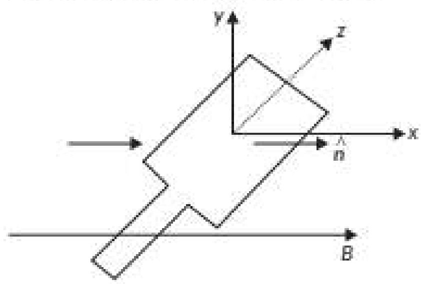
$$\varepsilon = \frac{d\phi}{dt} = \frac{d}{dt}(2\pi NBAf \cos 2\pi ft)$$

$= 2\pi NBAf \sin 2\pi ft$

$\varepsilon = \varepsilon_0 \sin 2\pi ft$, where $\varepsilon_0 = 2\pi NBAf$, the maximum emf induced.

The emf produced is alternating and hence the current is also alternating. Current produced by an ac generator cannot be measured by an moving coil ammeter, because the average value of ac over a complete cycle is zero.

(d) The plane of the coil is in yz plane and perpendicular to the x-axis *i.e.*, direction of magnetic field.



Maximum magnetic flux $\phi_{max} = B|A|$.

As the coil rotates with angular speed ω, magnetic flux at any instant t, (or at angle ωt)

$\phi = |B||A| \cos \omega t$

For $0 < t < 2$ s,

$$e_1 = -4.5 \times 10^{-2} \times \left\{\frac{1-0}{2-0}\right\} = -2.25 \times 10^{-2}\ \text{V}$$

$$\therefore \quad I_1 = \frac{e_1}{R} = \frac{-2.25\times10^{-2}}{8.5} \text{A} = -2.6\times10^{-3}\ \text{A} = -2.6\ \text{mA}$$

For $2\ \text{s} < t < 4$ s,

$$e_2 = -4.5\times10^{-2}\times\left\{\frac{1-1}{4-2}\right\} = 0$$

$$\therefore \quad I_2 = \frac{e_2}{R} = 0$$

For $4\ \text{s} < t < 6$ s,

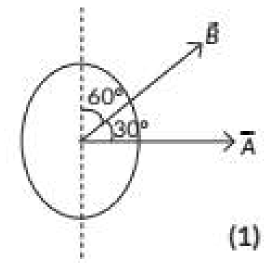
$$e_3 = -4.5\times10^{-2}\times\left\{\frac{0-1}{6-4}\right\}\text{A} = 0.023\ \text{V}$$

$$I_3 = \frac{e_3}{R} = \frac{0.023}{8.5} = 2.6\ \text{mA}$$ (2)

	$0\ \text{s} < t < 2\ \text{s}$	$2\ \text{s} < t < 4\ \text{s}$	$4\ \text{s} < t < 6\ \text{s}$
e(V)	− 0.023	0	+0.023
I(mA)	− 2.6	0	+2.6

2. Given : $A = 100\ \text{cm}^2$

$B = 10^{-1}$ T, $\theta = 30°$



Magnetic flux, $\phi = BA\cos\theta$

$= 10^{-1} \times 100 \times 10^{-4} \times \cos 30°$

$= \frac{\sqrt{3}}{2} \times 10^{-3}\ \text{T m}^2$ (1)

If magnetic field is reduced to zero in 10^{-3} s,

$$\frac{dB}{dt} = \frac{\Delta B}{\Delta t} = \frac{0-10^{-1}}{10^{-3}} = 10^2\ \text{T/s}$$

$$\varepsilon = \frac{d\phi}{dt} = A\cos\theta\frac{dB}{dt} = 0.866\ \text{V}$$ (1)

3. (b): Out of the four given loops, when circular and elliptical loops come out of the field, equal areas will not trace out in equal interval of time. So, for circular and elliptical loops, induced emf will not remain constant. (1)

4. (d) : Current induced is $I = \frac{|e|}{R}$

Now, $|e| = \frac{d\phi}{dt}$

But there is no change of flux with time, as $\vec{B}$, $\vec{A}$ and θ all remain constant with time.

$\therefore$ No current is induced. (0.77)

5. Area of the circular loop $= \pi r^2$

$= 3.14 \times (0.12)^2 = 4.5 \times 10^{-2}\ \text{m}^2$

Induced emf, $e = -\frac{d\phi}{dt} = -\frac{d}{dt}(BA) = -A\frac{dB}{dt} = -A\cdot\frac{B_2-B_1}{t_2-t_1}$

8. (d) : Magnetic field inside a solenoid,

$B = \mu_0 \frac{N}{l} i$

Flux linked with N turns

Initial flux, $\phi_1 = NBA = N\mu_0\frac{N}{l}iA$

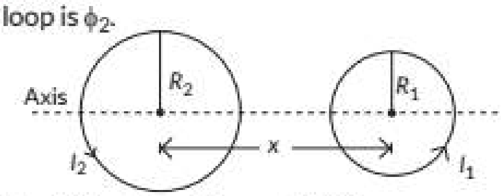
$$= \mu_0\frac{N^2}{l}iA = \frac{4\pi\times10^{-7}\times800\times800\times2.5\times25\times10^{-4}}{0.30}$$

$= 16.74 \times 10^{-3}$ Wb $\therefore$ Final flux, $\phi_2 = 0$

Average back emf,

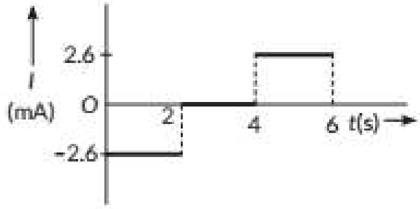
$$|e| = \frac{d\phi}{dt} = \frac{16.74\times10^{-3}-0}{10^{-3}} = 16.74\ \text{V}$$ (0.77)

9. (d) : Let flux linked with smaller loop is ϕ_1 and with bigger loop is ϕ_2.



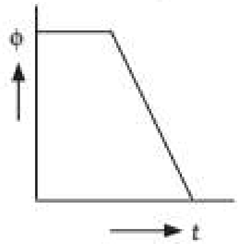
Given, $R_2 = 0.2$ m, $R_1 = 0.3$ cm $= 0.003$ m

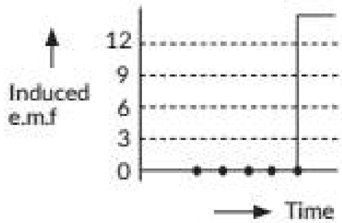
$x = 15$ cm $= 0.15$ m



(1)

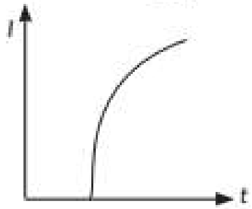
6. (a)





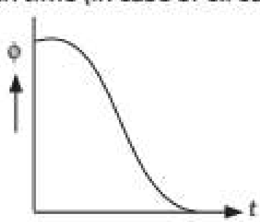
Induced current and power, sketch is same as shown above. (1)

(b) 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)

Variation of flux with time (in case of circular loop) :



(1)

7. (b) : Mutual inductance of a pair of two coils depends on the relative position and orientation of two coils.(0.77)

Now, $\phi_1 = B_2 A_1 = \frac{\mu_0}{4\pi}\left[\frac{2\pi R_2^2 I_2}{(R_2^2+x^2)^{3/2}}\right]\pi R_1^2$

$$M = \frac{\phi_1}{I_2} = \frac{\mu_0}{4\pi}\frac{2\pi R_2^2 \pi R_1^2}{(R_2^2+x^2)^{3/2}}$$

Now, $\phi_2 = MI_1 = \frac{\mu_0}{4\pi}\frac{2\pi R_2^2 \pi R_1^2}{(R_2^2+x^2)^{3/2}} \cdot I_1$

On putting the values, we get

$\therefore \quad \phi_2 = 9.1 \times 10^{-11}$ weber (0.77)

10. (b) : $L = \mu_0 \frac{N^2}{l} A$ ... (i)

$$L' = \mu_0 \frac{(2N)^2}{2l} A \quad \text{... (ii)}$$

On solving (i) and (ii), we get

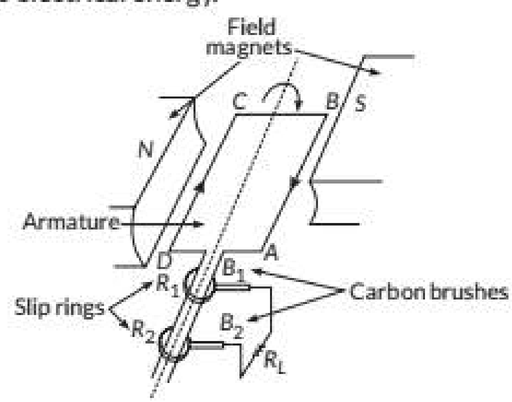
$$L' = 2\mu_0 \frac{N^2}{l} A = 2L$$ (0.77)

11. L remains same.

As, $L = \mu_0 N^2 A$/length, thus form formula it is clear that inductance does not depend on current. (1)

12. (a) Principle : AC generator is based on the principle of electromagnetic induction. It converts mechanical energy into electrical energy. (1)

(b)



(1)

It consists of

(i) Armature coil of large number of turns of copper wire wound over soft iron core. Soft iron core is used to increase magnetic flux.

(ii) Field magnets used to apply magnetic field, in which armature coil is rotated with its axis perpendicular to field lines.

(iii) Slip rings used to provide movable contact of armature coil with external circuit containing load.

(iv) Brushes which are the metallic pieces used to pass on electric current from armature coil to the external circuit containing load. (1)

When armature is rotated in the magnetic field, due to change in orientation of the coil magnetic flux through it changes. Due to change in flux an e.m.f. is induced.

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

$\varepsilon = NBA\omega \sin \omega t$ $[\because \phi = BA\cos\omega t]$

$i = \frac{\varepsilon}{R} = \frac{NBA\omega}{R}\sin\omega t$ (1)

Direction of induced current is given by Fleming's right hand rule.

(c) It is not possible to generate emf without rotating the coil, as this will not produce any flux change in the coil. (1)