Chapter 6

Electromagnetic Induction

Solutions (Set-1)

SECTION - A

School / Board Exam. Type Questions

Very Short Answer Type Questions :

1. As soon as current is switched on in a high voltage wire, the bird sitting on it flies away. Why?

Sol. When a current is switched on, induced current flows in the body of bird. Its wings experience mutual repulsion on account of opposite current.

2. Does change in magnetic flux induce emf current?

Sol. Emf is always induced but current will be induced when the circuit is complete.

3. Name the SI unit of magnetic flux and magnetic induction.

Sol. Weber, Tesla

4. Does Lenz's law hold for an open circuit?

Sol. Yes, it does hold.

5. Give two factors on which self inductance of an air cored coil depends.

Sol. Number of turns in the coil and radius of cross section of coil.

6. How does the mutual inductance of a pairs of coils change when (i) the distance between the coils increased (ii) number of turns in each coil is decreased?

Sol. The mutual inductance will decrease in both cases.

7. Write dimensional formula for induced emf.

Sol. $[ML^2T^{-3}A^{-1}]$

8. Write dimensional formula for mutual inductance of two coils.

Sol. $[ML^2T^{-2}A^{-2}]$ same as that of L.

9. Name the physical quantity in electrical circuit which plays the same role as inertia in mechanics.

Sol. Inductance

10. What is the effect of metallic core on the self inductance of a coil?

Sol. It increases

Short Answer Type Questions :

11. Give two factors on which self inductance of a long solenoid depends.

Sol. Number of turns, permeability of core-material.

12. What is an ideal inductor? Why are inductors made of copper?

Sol. An ideal inductor has zero resistance. Inductors are made of copper because, after silver, copper has lowest resistance.

13. How can a space traveller detect the presence of magnetic field on an unknown planet with the help of a sensitive galvanometer and a coil of wire?

Sol. If on connecting the coil with the galvanometer and rotating it, there is deflection in the galvanometer, a magnetic field is there otherwise not.

14. A coil is removed from a magnetic field (i) rapidly (ii) slowly. In which case more work is done?

Sol. More work will be done in removing the coil rapidly because then the rate of change of magnetic flux will be greater and hence a larger (opposing) emf will be induced.

15. As the speed of bicycle is increased, the illumination of its lamp increases, why?

Sol. The bi-cycle lamp is illuminated by dynamo. On increasing the speed, the rate of change of magnetic flux in the dynamo increases and so induced emf becomes larger.

16. A conducting loop is held stationary normal to the field between the pole-pieces of a fixed permanent magnet. Can we produce current in the loop by choosing a very strong magnet?

Sol. No, current is induced only when there is change in the magnetic flux linked with the loop.

17. Can one have an inductance without a resistance? How about a resistance with an inductance?

Sol. No, as every material has some resistance. Yes, we can coil a wire to have resistance with inductance.

18. A coil is wound on an iron core and looped back on itself so that the core has two sets of closely wound wires in series carrying currents in opposite senses. How is its self inductance affected?

Sol. As two sets of closely wound wires carry currents in opposite senses, therefore their induced effect cancel. The self inductance reduced in a special case, we may have

$L_{effective} = L_1 + L_2 - 2M = L + L - 2L = 0$

19. Explain why resistance coils are usually double wound.

Sol. The resistance coils are double wound to avoid induction effects. Magnetic field due to current in one half of the coil is cancelled by magnetic field due to current in the other half of the coil (which is in opposite direction.)

20. A glass rod of length L moves with velocity v in a uniform magnetic field B. What is the emf induced in the rod?

Sol. Induced emf is set up ($\varepsilon = Blv$). But current can't flow.

21. Are eddy currents useful or harmful?

Sol. They are both useful and harmful.

22. A train is moving with uniform speed from north to south. Will any induced emf appear across the ends of the axle?

Sol. Yes, induced emf will be obtained because the train is intercepting vertical component of earth's magnetic field.

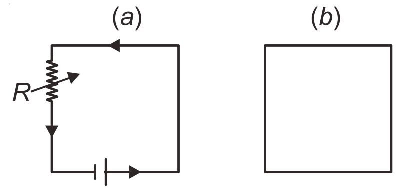
23. Two inductors having inductances L_1 and L_2 are connected (i) in series, (ii) in parallel. What is their equivalent?

Sol. In series combination $L_s = L_1 + L_2$

In parallel combination $L_p = \dfrac{L_1 L_2}{L_1 + L_2}$

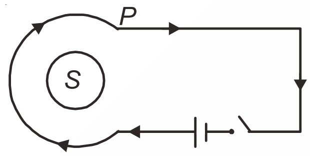
[Note : The two coils are far apart so that mutual induction is neglected]

24. If resistances R in circuit (a) of the figure shown, is decreased, what will be the direction of induced current in circuit (b)?



Sol. When R is decreased, current in (a) is increased. An emf is induced in (b) which opposes the increase of current in a. The induced current must, therefore be anticlockwise.

25. In the figure, P and S are two coils. What shall be the direction of induced momentary current in S immediately after the switch is closed? If the switch is opened, after it has been closed for some time?



Sol. When switch is closed, current in P grows. Induced current in S will oppose this growth. Hence the current in S must be anticlockwise.

When switch is closed, current in P decays from maximum to zero. Induced current in S will oppose the decay. Hence current in S must be clockwise.

26. Which factors govern the magnitude of emf induced in a coil?

Sol. From the formula $e_0 = NBA\omega$, we find that the magnitude of emf induced depends upon

(i) Number of turns in the coil (N)

(ii) Face area of coil (A)

(iii) Strength of magnetic field (B)

(lv) Angular velocity of the coil (ω)

27. A lamp in a circuit consisting of a coil of large number of turns and a battery does not light upto full brilliance instantly on switching on the circuit. Why?

Sol. When the circuit is switched on, current increases through the lamp and also through the coil. An induced emf develops in the coil which opposes the growth of current. As the current takes the time to grow to maximum value, the lamp does not light instantly upto full brilliance.

28. An electron moves in a circle with uniform speed in a stationary magnetic field normal to the plane of magnetic field. If the field magnitude is made to increase with time, will it continue to revolve in the same circle?

Sol. $Bqv_{\perp} = \dfrac{mv_{\perp}^2}{r}$

$\Rightarrow r = \dfrac{mv_{\perp}}{Bq}$

As B increases, r will decrease

29. A wheel with a certain number of spokes is rotated in a plane normal to earth's magnetic field, so that an emf is induced between the axle and rim of the wheel. Keeping all other things same, number of spokes is changed. How is the emf affected?

Sol. The emf induced between different spokes are in parallel. Therefore number of spokes does not affect the net emf.

30. A solenoid coil has 50 turns per cm along its length and a cross sectional area of 4 cm^2. Now 200 turns of another wire are wound round the first solenoid coaxially, the two coils are electrically insulated from each other. Calculate the mutual inductance between the two coils.

Sol. $M = \dfrac{\mu_0 N_1 N_2 A}{l}$

$$= \frac{(4\pi\times10^{-7})\times(5000l)\times(200\times4\times10^{-4})}{l} = 5.02\times10^{-4}\text{ H}$$

Long Answer Type Questions :

31. A toroidal solenoid with an air core has an average radius of 15 cm, area of cross section 12 cm^2 and 1200 turns. Obtain the self inductance of the toroid. Ignore field variation across the cross section of the toroid.

Sol. $L = \mu_0 \dfrac{N^2}{l} A = 4\pi\times10^{-7}\times\dfrac{(1200)^2\times12\times10^{-4}}{0.3\pi} = 2.304\times10^{-3}$ H

32. If in Question no. 31, a secondary coil of 300 turns is wound closely on the toroid above. If the current in the primary coil is increased from zero to 2.0 A in 0.05 s, obtain the induced emf in the second coil.

Sol. Here N_2 = 300, $\dfrac{dI}{dt} = \dfrac{2.0}{0.05} = 40$ amp/s. e = ?

$$e = M\frac{dI}{dt} = \left(\frac{\mu_0 N_1 N_2 A}{l}\right)\frac{dI}{dt} = 4\pi\times10^{-7}\times1200\times\frac{1200}{0.3\pi}\times12\times10^{-4}\times40 = 0.023\text{ volt}$$

33. Define self inductance. Write the SI unit. Find an expression for the self inductance of a coil. Give two factors on which self inductance of an air-cored coil depends.

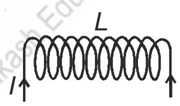
Sol. Self inductance is the property of a coil by virtue of which, the coil opposes any change in the strength of current flowing through it by inducing an e.m.f. itself.

$\phi \propto I$

$\phi = LI$

if $I = 1A$

$\phi = L$



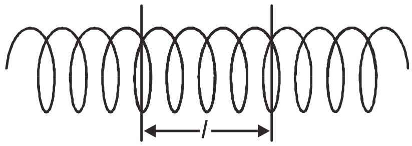
Coefficient of self inductance of a coil is numerically equal to the amount of magnetic flux linked with the coil when unit current flows through the coil.

SI unit of self inductance (L) is henery.

Consider a long solenoid having number of turns per unit length n. Consider a section of this solenoid, of length l. We have to find self inductances of this section. Magnetic flux linkage through the coil under consideration

$$\phi_B = \vec{B}.\vec{A} = (\mu_0 nI)(An\ell) = \mu_0 n^2 A\times\ell I$$

$$L = \frac{\phi_B}{I} = \mu_0 n^2 .A\times\ell$$



If the space inside the solenoid is filled with a material of relative permeability μ_r, then $L = \mu_0\mu_r n^2 A \times l$

34. State and explain Faraday's laws of electromagnetic induction, with their experimental demonstration.

Sol. First Law of Faraday : Whenever the amount of magnetic flux linked with a circuit changes, an e.m.f. is induced in the circuit. The induced e.m.f. lasts so long as the change in magnetic flux continues.

Second Law of Faraday : The magnitude of e.m.f. induced in a circuit is directly proportional to the rate of change of magnetic flux linked with the circuit.

Experiment 1

Figure shows a coil C_1 connected to a galvanometer G. When the North-pole of a bar magnet is pushed towards the coil, the pointer in the galvanometer deflects, indicating the presence of electric current in the coil. The deflection lasts as long as the bar magnet is in motion. The galvanometer does not show any deflection when the magnet is held stationary. When the magnet is pulled away from the coil, the galvanometer shows deflection in the opposite direction, which indicates reversal of the current's direction.

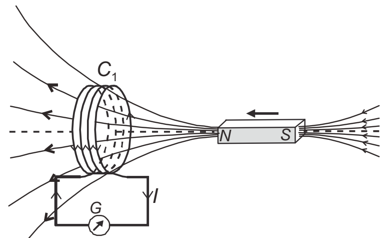


Figure : When the bar magnet is pushed towards the coil, the pointer in the galvanometer G deflects.

Moreover, when the South-pole of the bar magnet is moved towards or away from the coil, the deflections in the galvanometer are opposite to that observed with the North-pole for similar movements. Further, the deflection (and hence current) is found to be larger when the magnet is pushed towards or pulled away from the coil faster. Instead, when the bar magnet is held fixed and the coil C_1 is moved towards or away from the magnet, the same effects are observed. It shows that it is the relative motion between the magnet and the coil that is responsible for generation (induction) of electric current in the coil.

Experiment 2

In Figure the bar magnet is replaced by a second coil C_2 connected to a battery. The steady current in the coil C_2 produces a steady magnetic field. As coil C_2 is moved towards the coil C_1, the galvanometer shows a deflection. This indicates that electric current is induced in coil C_1. When C_2 is moved away, the galvanometer shows a deflection again, but this time in the opposite direction. The deflection lasts as long as coil C_2 is in motion. When the coil C_2 is held fixed and C_1 is moved, the same effects are observed. Again, it is the relative motion between the coils that induces the electric current.

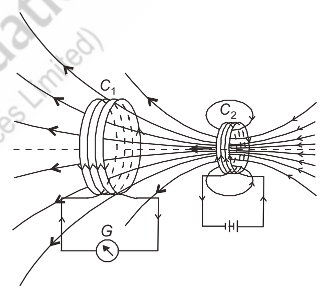


Figure : Current is induced in coil C_1 due to motion of the current carrying coil C_2.

Experiment 3

The above two experiments involved relative motion between a magnet and a coil and between two coils, respectively. Through another experiment, Faraday showed that this relative motion is not an absolute requirement. Figure shows two coils C_1 and C_2 held stationary. Coil C_1 is connected to galvanometer G while the second coil C_2 is connected to a battery through a tapping key K. It is observed that the galvanometer shows a momentary deflection when the tapping key K is pressed. The pointer in the galvanometer returns to zero immediately. If the key is held pressed continuously, there is no deflection in the galvanometer. When the key is released, a momentary deflection is observed again, but in the opposite direction. It is also observed that the deflection increases dramatically when an iron rod is inserted into the coils along their axis.

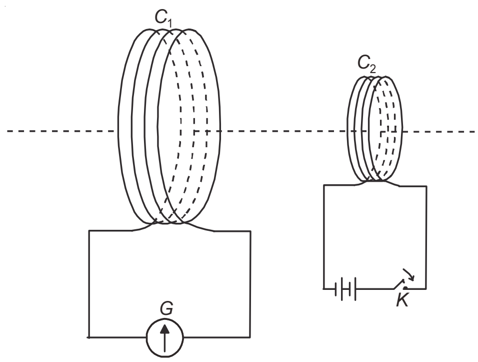


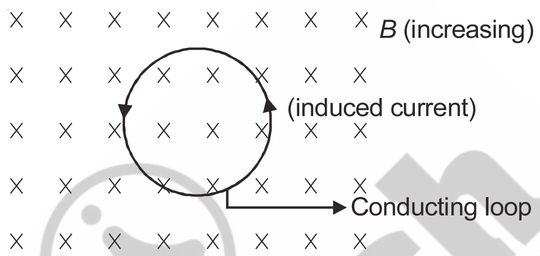
Figure : Experimental set-up for Experiment. 3

35. State and explain Lenz's law. How will you verify it experimentally? Does it obey the principle of conservation of energy?

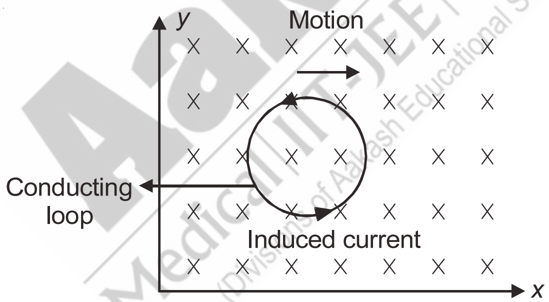
Sol. Lenz's law is in accordance with law of conservation of energy. As the induced emf opposes the change in flux, work has to be done against the opposition offered by induced emf/current in changing the flux. The work done appears as electrical energy in the circuit.

Applications of Lenz's law shall become more clear by carefully studying the following examples

(1) A conducting loop is kept in a uniform magnetic field B directed into the plane of paper. The magnetic field starts increasing with time. As the magnetic field increases, flux $(\phi = \vec{B}.\vec{A})$ starts increasing. Therefore, an induced current will flow into the loop. The current is induced due to increasing field, therefore, it will try to decrease the field. This can happen if induced current produces an outward field in the loop. Therefore, an anticlockwise current appears in the loop.



(2) There exists a non-uniform field $B = B_0x$ (inwards) in x-y plane as shown. The field increases as we move along $+x$-direction. A conducting loop is placed in the x-y plane. The loop is being moved towards $+x$-axis. As the loop moves towards $+x$-axis, the flux linked increases because magnetic field increases. The induced current will try to decrease the field. It can do so by decreasing the magnetic field in the loop. Therefore an anticlockwise current appears in the loop.

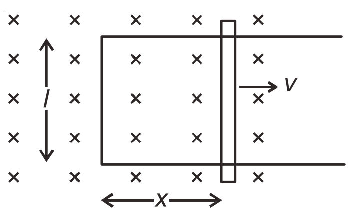


36. Discuss the various methods of producing emfs.

Sol. Various methods to produce induced e.m.f.

(i) Change the magnitude B of the magnetic field within the coil.

(ii) Change either the total area of the coil or the portion of that area that lies within the magnetic field (for example) by expanding the coil or sliding it into or out of the field.



(iii) Change the angle between the direction of magnetic field B and the plane of coil (for example), by rotating the coil so that field $\vec{B}$ is first perpendicular to the plane of the coil and then is along that plane.

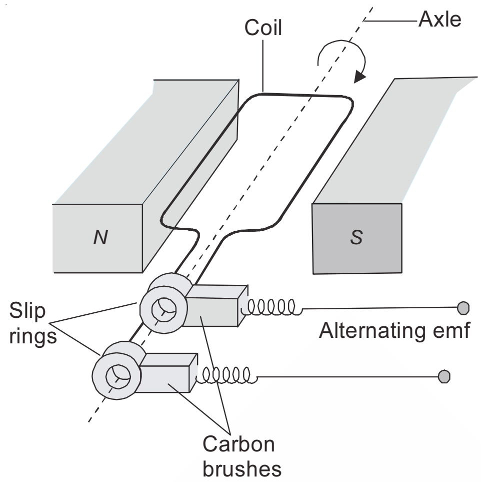


Figure : Ac Generator

37. What are eddy current? Discuss briefly any two applications of eddy current. How are they minimised?

Sol. So far we have studied the electric currents induced in well defined paths in conductors like circular loops. Even when bulk pieces of conductors are subjected to changing magnetic flux, induced currents are produced in them. However, their flow patterns resembles swirling eddies in water. This effect was discovered by physicist Foucault (1819-1868) and these currents are called eddy currents.

Consider the apparatus shown in Figure (a). A copper plate is allowed to swing like a simple pendulum between the pole pieces of a strong magnet. It is found that the motion is damped and in a little while the plate comes to a halt in the magnetic field. We can explain this phenomenon on the basis of electromagnetic induction. Magnetic flux associated with the plate keeps on changing as the plate moves in and out of the region between magnetic poles. The flux change induces eddy currents in the plate. Directions of eddy currents are opposite when the plate swings into the region between the poles and when it swings out of the region.

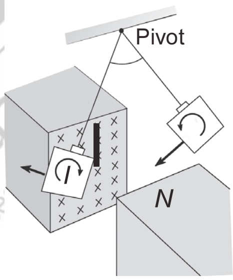


Figure (a) : Eddy currents are generated in the copper plate, while entering and leaving the region of magnetic field.

If rectangular slots are made in the copper plate as shown in Figure (b), area available to the flow of eddy currents is less. Thus, the pendulum plate with holes or slots reduces electromagnetic damping and the plate swings more freely. Note that magnetic moments of the induced currents (which oppose the motion) depend upon the area enclosed by the currents.

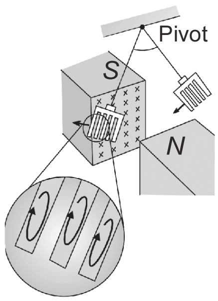


Figure (b) : Cutting slotsin the copper plate reduces the effect of eddy currents.

This fact is helpful in reducing eddy currents in the metallic cores of transformers, electric motors and other such devices in which a coil is to be wound over metallic core. Eddy currents are undesirable since they heat up the core and dissipate electrical energy in the form of heat. Eddy currents are minimised by using laminations of metal to make a metal core. The laminations are separated by an insulating material like lacquer. The plane of the laminations must be arranged parallel to the magnetic field, so that they cut across the eddy current paths. This arrangement reduces the strength of the eddy currents. Since the dissipation of electrical energy into heat depends on the square of the strength of electric current, heat loss is substantially reduced.

Eddy currents are used to advantage in certain applications like:

(i) **Magnetic braking in trains :** Strong electromagnets are situated above the rails in some electrically powered trains. When the electromagnets are activated, the eddy currents induced in the rails oppose the motion of the train. As there are no mechanical linkages, the braking effect is smooth.

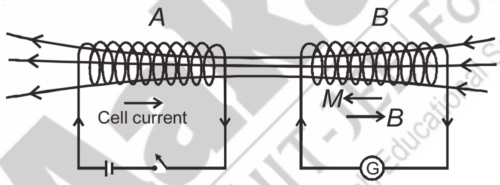
(ii) **Electromagnetic damping :** Certain galvanometers have a fixed core made of nonmagnetic metallic material. When the coil oscillates, the eddy currents generated in the core oppose the motion and bring the coil to rest quickly.

(iii) **Induction furnace :** Induction furnace can be used to produce high temperatures and can be utilised to prepare alloys, by melting the constituent metals. A high frequency alternating current is passed through a coil which surrounds the metals to be melted. The eddy currents generated in the metals produce high temperatures sufficient to melt it.

(iv) **Electric power meters :** The shiny metal disc in the electric power meter (analogue type) rotates due to the eddy currents. Electric currents are induced in the disc by magnetic fields produced by sinusoidally varying currents in a coil. You can observe the rotating shiny disc in the power meter of your house.

38. Explain the phenomenon of mutual induction. Define coefficient of mutual induction. What are its units? Calculate coefficient of mutual inductance between two long solenoids.

Sol. Mutual inductance is property of two coils by virtue of which each opposes any change in the strength of current flowing through the other by developing an induced e.m.f.



$\phi = MI$ for $I = 1$ A $\phi = M$

SI unit of M is henery

Consider Figure which shows two long co-axial solenoids each of length l. We denote the radius of the inner solenoid S_1 by r_1 and the number of turns per unit length by n_1. The corresponding quantities for the outer solenoid S_2 are r_2 and n_2, respectively. Let N_1 and N_2 be the total number of turns of coils S_1 and S_2, respectively.

When a current I_2 is set up through S_2, it in turn sets up a magnetic flux through S_1. Let us denote it by ϕ_1. The corresponding flux linkage with solenoid S_1 is

$$N_1\phi_1 = M_{12}I_2 \quad \text{...(i)}$$

M_{12} is called the mutual inductance of solenoid S_1 with respect to solenoid S_2. It is also referred to as the coefficient of mutual induction.

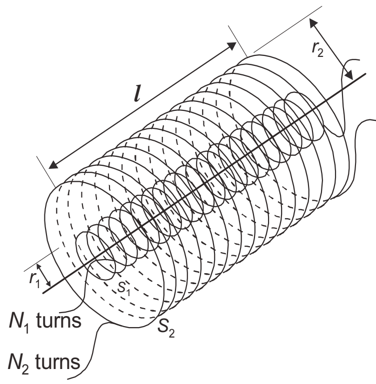


Figure : Two long co-axial solenoids of same length l.

For these simple co-axial solenoids it is possible to calculate M_{12}. The magnetic field due to the current I_2 in S_2 is $\mu_0 n_2 I_2$. The resulting flux linkage with coil S_1 is,

$N_1\phi_1 = (n_1 l)(\pi r^2_1)(\mu_0 n_2 I_2) = \mu_0 n_1 n_2 \pi r^2 l I_2$ ...(ii)

where $n_1 l$ is the total number of turns in solenoid S_1. Thus, from Equation (i) and (ii).

$M_{12} = \mu_0 n_1 n_2 \pi r^2_1 l$ ...(iii)

Note that we neglected the edge effects and considered the magnetic field $\mu_0 n_2 I_2$ to be uniform throughout the length and width of the solenoid S_2. This is a good approximation keeping in mind that the solenoid is long, implying $l >> r_2$.

We now consider the reverse case. A current I_1 is passed through the solenoid S_1 and the flux linkage with coil S_2 is,

$N_2\phi_2 = M_{21} I_1$ ...(iv)

M_{21} is called the mutual inductance of solenoid S_2 with respect to solenoid S_1.

The flux due to the current I_1 in S_1 can be assumed to be confined solely inside S_1 since the solenoids are very long. Thus, flux linkage with solenoid S_2 is

$N_2\phi_2 = (n_2 l)(\pi r^2_1)(n_0 n_1 I_1)$

where $n_2 l$ is the total number of turns of S_2. From Equation (iv)

$M_{21} = \mu_0 n_1 n_2 \pi r^2_1 l$ ...(v)

Using Equation (iii) and Equation (iv), we get

$M_{12} = M_{21} = M$ (say) ...(vi)

We have demonstrated this equality for long co-axial solenoids. However, the relation is far more general. Note that if the inner solenoid was much shorter than (and placed well inside) the outer solenoid, then we could still have calculated the flux linkage $N_1\Phi_1$ because the inner solenoid is effectively immersed in a uniform magnetic field due to the outer solenoid. In this case, the calculation of M_{12} would be easy. However, it would be extremely difficult to calculate the flux linkage with the outer solenoid as the magnetic field due to the inner solenoid would vary across the length as well as cross section of the outer solenoid. Therefore, the calculation of M_{21} would also be extremely difficult in this case. The equality $M_{12} = M_{21}$ is very useful in such situations.

We explained the above example with air as the medium within the solenoids. Instead, if a medium of relative permeability μ_r had been present, the mutual inductance would be

$M = \mu_r \mu_0 n_1 n_2 \pi r^2_1 l$

It is also important to know that the mutual inductance of a pair of coils, solenoids, etc., depends on their separation as well as their relative orientation.

39. How is mutual inductance of coils affected when

(i) separation between the coil is increased?

(ii) number of turns of each coil is increased?

(iii) a thin iron sheet is placed between the coils, other factors remaining the same? Explain your answer.

Sol. (i) decreased (ii) increased (iii) increased

40. A rectangular loop of sides 8 cm and 2 cm with a small cut is stationary in a uniform magnetic field directed normal to the loop. The magnetic field is reduced from its initial value of 0.3 T at the rate of 0.02 T s^{-1}. If the cut is joined and loop has a resistance of 1.6 Ω, how much power is dissipated as heat?

Sol. Induced emf $e = -\frac{d\phi}{dt} = -A\frac{dB}{dt} = -16\times10^{-4}\times(-0.02) = 32\times10^{-6}$ V

Power loss = $\frac{e^2}{R} = \frac{(32\times10^{-6})^2}{1.6} = 6.4\times10^{-10}$ W

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

Sol. $\phi = \pi r^2 B \quad \Rightarrow \frac{d\phi}{dt} = 2\pi r B\frac{dr}{dt}$

$$e = \left|\frac{d\phi}{dt}\right| = 2\times\frac{22}{7}\times(2\times10^{-2})(0.02)\times10^{-3} = 2.5\ \mu V$$

42. A 12 V battery connected to a 6 Ω, 10 H coil through a switch drives a constant current in the circuit. The switch is suddenly opened. Assuming that it took 1 ms to open the switch, calculate the average induced emf across the coil.

Sol. Steady state current $I = \frac{V}{R} = \frac{12}{6} = 2$ A

When switch is opened, final current is zero.

$$\therefore \quad \frac{dI}{dt} = \frac{0-2}{1\times10^{-3}} = -2\times10^{3}\ A\ s^{-1}$$

$$e = -L\frac{dI}{dt} = (-10)(-2\times10^{3}) = 2\times10^{4}\ V$$

43. A copper rod of length 0.5 m rotates about one of its ends at angular velocity of 32 radian/s in a uniform magnetic field of induction 0.4 Wb/m^2, the plane of rotation being at right angles to the field. Find the emf developed between the ends of the rod.

Sol. $e = \frac{B\times A}{t} = \frac{B\times\pi l^2}{2\pi/\omega} = \frac{1}{2}B\omega l^2 = \frac{1}{2}\times0.4\times0.5\times0.5\times32 = 1.6$ V

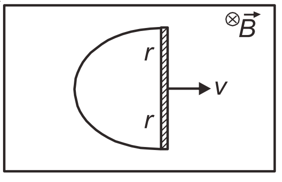
44. A metallic wire bent in the form of a semicircle of radius 0.1 m is moved in a direction parallel to its plane, but perpendicular to a magnetic field B = 20 mT with a velocity of 10 ms^{-1}. Find the emf induced in the wire.

Sol. Here r = 0.10 m, B = 20 mT = 20 × 10^{-3} T

v = 10 ms^{-1}, e = ?

In a small time dt,

let the semi-circular wire move through a small distance dx.



$$e = \left|\frac{d\phi}{dt}\right| = \frac{d}{dt}(B\times A) = B\times\frac{dA}{dt} = B\times\left(2r\frac{dx}{dt}\right) = 2Brv$$

= 2 × 20 × 10^{-3} × 0.1 × 10 = 0.04 V

The above result is valid when the loop is entering or leaving the region of magnetic field

Note: *If the entire loop remains inside the field despite moving, e = 0.*

45. An air-cored solenoid is of length 0.3 m. Area of cross section 1.2×10^{-3} m^2 and has 2500 turns. Around its central section, a coil of 350 turns is wound. The solenoid and the coil are electrically insulated from each other. Calculate the emf induced in the coil, if initial current of 3 A in the solenoid is reversed in 0.25 s.

Sol. $e = -M.\frac{dI}{dt} = -\mu_0 \frac{N_1 N_2 A}{l}\left(\frac{dI}{dt}\right)$

$$= \frac{4\pi \times 10^{-7} \times 2500 \times 350 \times 1.2 \times 10^{-3} \times (-6)}{0.3 \times 0.25}$$

= 0.1056 volt

SECTION - B

Model Test Paper

Very Short Answer Type Questions : [1 Mark]

1. The dimensional formula of weber is

Sol. $\phi = \vec{B}.\vec{A} = \frac{\text{N}}{\text{Amp.m}} \times \text{m}^2 = \frac{\text{N.m}}{\text{Amp.}} = \left[\text{ML}^2\text{T}^{-2}\text{A}^{-1}\right]$

2. Motional emf and induced emf are different (True/false)

Sol. False, they are same.

3. A thin conducting circular ring (radius r) is rotated with angular velocity ω in its own plane about its axis, in a region of uniform magnetic field B. The emf induced in the ring is______

Sol. Zero, because flux is not changing with time.

4. Lenz's law is conservation of mechanical energy. (True/false)

Sol. False, it is the law of conservation of energy and not mechanical energy.

5. Mutual induction of the two coil depends upon rate of change of current in one coil. (True/false)

Sol. False, For the same coil, $M = \frac{e_2}{\left|\frac{dI_1}{dt}\right|}$ = constant

6. Work done upon a charged particle in a region of induced electric field, from one point to another depends upon the path followed. (True/false)

Sol. Yes, since induced electric field in non-conservative.

7. In AC generators, when flux passing through the armature coil is maximum, the emf induced in the coil is also maximum. (True/false)

Sol. False, when flux is maximum, induced emf is zero.

8. The motional emf (due to the motion of a conductor, in perpendicular magnetic field) is due to the magnetic force upon the mobile charged particles due to magnetic field. (Yes/no)

Sol. Yes, the Lorentz force separates the mobile charged particles of opposite polarity.

Short Answer Type Questions : [2 Marks]

9. Consider the case when a bird is flying with 10 ms^{-1} where the perpendicular component of earth's magnetic field is 40 μT. Find the emf induced between two points upon bird's wing separated by 2 cm. Assuming ALL the vectors to be mutually perpendicular to each other.

Sol. $e = Blv = (4 \times 10^{-5}\text{ T})(2 \times 10^{-2}\text{ m})(10\text{ ms}^{-1}) = 8\ \mu\text{V}$

10. A small coil of area 5 cm^2, number of turns 50 is kept normal to a uniform magnetic field B tesla. The coil is rotated about its diameter through 180°, in 15 ms. The total charge flow is 50 mC. Find B, assume resistance $R = 10\ \Omega$.

Sol. $\Delta q = \frac{1}{R}|\Delta\phi| = \frac{1}{R}\times 2NBA \quad \Rightarrow B = \frac{\Delta q \times R}{2NA} = \frac{(50\times10^{-3}\text{ C})(10\ \Omega)}{2\times50\times5\times10^{-4}} = 10\text{ T}$

11. Derive the expression for the self inductance of a section of a long solenoid and hence show that self inductance is proportional to the square of number of turns per unit length.

Sol. $L = \mu_0 n^2 A \times l$. Hence $L \propto n^2$

12. Prove that the magnetic energy stored inside a solenoid is proportional to the square of magnetic field. Also show its analogy for electric energy stored in the space between the plates of capacitor.

Sol. $U = \frac{1}{2}LI^2 = \frac{1}{2}\left(\mu_0 n^2 \times A \times l\right)I^2 = \frac{1}{2}\left[\mu_0 nI\right]^2 \times \frac{1}{\mu_0} \times A \times l = \frac{B^2}{2\mu_0} \times A \times l$

Hence magnetic energy density = $\frac{U}{A \times l} = \frac{B^2}{2\mu_0}$

Similarly electric potential energy density = $\frac{1}{2}\varepsilon_0 E^2$ (symbols have their usual meaning)

13. Find the mutual inductance of two long concentric/coaxial solenoid for a length l. The inner solenoid has area of cross section A and number of turns per unit length are n_1 and n_2.

Sol. $M = \mu_0 n_1 n_2 A \times l$

For proof see text

14. A metallic rod of length l is rotating about an axis passing through one end and perpendicular to its length, in a region of uniform and perpendicular magnetic field B. The rod completes f revolutions per second. Find emf induced between the two ends of rod.

Sol. $\pi B f l^2$

[**Hint** : $e = \frac{1}{2}B\omega l^2 = \frac{1}{2}B \times 2\pi f \times l^2 = \pi B f l^2$]

15. Describe Faraday's law of Electromagnetic induction.

Sol. State and explain Faraday's laws of electromagnetic induction, with their experimental demonstration.

Long Answer Type Questions : [5 Marks]

16. Describe with neat and suitable diagram, the construction and working of AC generator. Derive the expression of the emf used.

Sol. $e = NBA\omega \times \sin\omega t$, $e = \frac{-d\phi}{dt} = -\frac{d}{dt}[NBA\cos\omega t]$, For construction see text.

17. Radius of a circular coil is given by $R = R_0\ (1 + \alpha t)$. If a constant magnetic field B_0 exists perpendicular to the coil

(i) Find the emf induced in the coil as function of time.

(ii) If the resistance of circular coil is r, find the charge flown in the coil during the time interval from $t = 0$ s to $t = 2$ s.

Sol. (i) $e_{(t)} = 2\pi B_0 R_0^2\ \alpha\ (1 + \alpha t)$

As $e = -\dfrac{d}{dt}\left(B_0 \times \pi r^2\right) = -\dfrac{d}{dt}\left(B_0 \times \pi R_0^2\ (1+\alpha t)^2\right)$

(ii) $\Delta q = \dfrac{4\pi B_0 \alpha R_0^2}{r}(1+\alpha)$

$\phi_{(t)} = \pi R^2 B_0 = \pi B_0 R_0^2\ (1 + \alpha t)^2$

$e_{(t)} = \left|\dfrac{d\phi}{dt}\right| = 2\pi B_0 R_0^2 \alpha (1+\alpha t)$

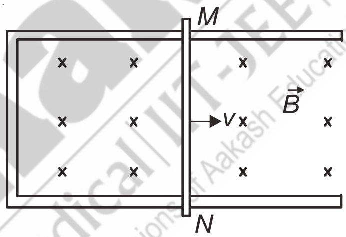
$\Rightarrow \quad I_{(t)} = \dfrac{2\pi B_0 R_0^2 \alpha (1+\alpha t)}{r}$

$\Delta q = \int I_{(t)} dt = \dfrac{4\pi B_0 \alpha R_0^2}{r}(1+\alpha)$

18. What are eddy current? How are they produced? How are they minimised? Describe some advantages of eddy currents?

Sol. What are eddy current? Discuss briefly any two applications of eddy current. How are they minimised?

19. Refer to the figure, the conductor MN is made to slide with constant velocity v in region of perpendicular uniform magnetic field. Find



(i) The induced current in the loop, if total resistances of circuit is R.

(ii) Force of external agents to pull the conductor with constant velocity v.

(iii) The power developed by the external agent to pull the conductor.

(iv) Verify the conservation of energy in the loop.

Sol. (i) $I = \dfrac{Bv\ell}{R}$

(ii) $F = BI\ell = \dfrac{B^2\ell^2}{R}v$

(iii) $P = \dfrac{B^2\ell^2 v^2}{R} = F \times v = P_{\text{mechanical}}$

(iv) $P_{\text{mechanical}} = I^2 \times R$ (electrical power)

20. Refer to the question 19. If the conductor *MN* is given velocity v_0 at $t = 0$ s and now no external force acts upon the conductor, find the velocity of the conductor at $t = t$ s.

Sol. $\phi_{(t)} = B \times l \times x(t)$ ...(i)

$$e_{(t)} = \left|\frac{d\phi}{dt}\right| = B\ell\frac{dx}{dt} = B\ell v_{(t)} \quad \text{...(ii)}$$

$$I_{(t)} = \frac{e_{(t)}}{r} = \frac{B\ell}{R}v_{(t)} \quad \text{..(iii)}$$

$$F_m = I\left[\vec{\ell}\times\vec{B}\right] = I\ell B = \frac{B^2\ell^2}{R}v \quad \text{...(iv)}$$

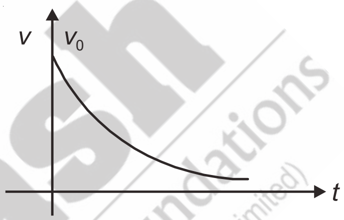
$$F_{\text{nett}} = F_m = ma = -m\frac{dv}{dt} = \frac{B^2\ell^2}{R}.v$$

$$\Rightarrow \quad -\frac{dv}{v} = \frac{B^2\ell^2}{mR}.dt$$

$$\Rightarrow \quad -[\log_e v]_{v_0}^{v} = \frac{B^2\ell^2}{mR}\int_0^t dt$$

$$\Rightarrow \quad -\log_e\frac{v}{v_0} = \frac{B^2l^2}{mR}.t$$

$$\Rightarrow \quad v = v_0 e^{-\frac{B^2l^2}{mR}t}$$



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Solutions (Set-2)

Objective Type Questions

(Magnetic Flux, Faraday's Law of Induction, Lenz's Law and Conservation of Energy)

1. Dimensional formula of magnetic flux is

(1) $[M L^2 T^{-2} A^{-1}]$ (2) $[M L^1 T^{-1} A^{-2}]$ (3) $[M L^2 T^{-3} A^{-1}]$ (4) $[M L^{-2} T^{-2} A^{-2}]$

Sol. Answer (1)

$\phi = BA$

and $F = ilB \Rightarrow B = \frac{F}{il}$

So dimensional formula will be $ML^2T^{-2}A^{-1}$

2. Flux ϕ (in weber) in a closed circuit of resistance 10 ohm varies with time t (in second) according to the equation $\phi = 6t^2 - 5t + 1$. What is the magnitude of the induced current at $t = 0.25$ s?

(1) 1.2 A (2) 0.2 A (3) 0.6 A (4) 0.8 A

Sol. Answer (2)

$\phi = 6t^2 - 5t + 1$

$\varepsilon = -\frac{d\phi}{dt} = -12t + 5$

$I = \frac{\varepsilon}{R} = \frac{-12\left(\frac{1}{4}\right) + 5}{10} = 0.2$ A

3. A cylindrical magnet is kept along the axis of a circular coil. On rotating the magnet about its axis, the coil will have induced in it

(1) No current (2) A current

(3) Only an e.m.f. (4) Both an e.m.f. and a current

Sol. Answer (1)

No change in flux, so no current will be induced.

4. A magnet is brought near a coil in two ways (i) rapidly (ii) slowly. The induced charge will be

(1) More in case (i) (2) More in case (ii)

(3) Equal in both the cases (4) More or less according to the radius of the coil

Sol. Answer (3)

Induced charged is independent of speed of magnet.

5. An emf can be induced in stationary coil if it is kept in

(1) Stationary uniform magnetic field (2) Stationary nonuniform magnetic field

(3) Time varying magnetic field (4) Not possible

Sol. Answer (3)

Time varying $\vec{B}$ will induce emf as

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

6. The induced e.m.f. in a coil does not depend on

(1) The number of turns in the coil (2) The rate of change of magnetic flux

(3) Time of rotation (4) The resistance of the circuit

Sol. Answer (4)

ε does not depend on resistance.

7. A circular loop of flexible conducting material is kept in a magnetic field directed perpendicularly into its plane. By holding the loop at diametrically opposite points its is suddenly stretched outwards, then

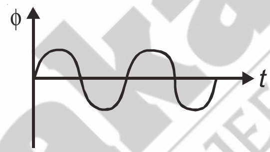
(1) No current is induced in the loop (2) Anti-clockwise current is induced

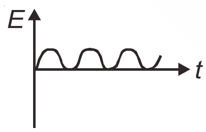
(3) Clockwise current is induced (4) Only e.m.f. is induced

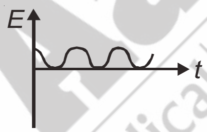
Sol. Answer (3)

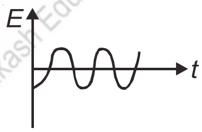
Flux will increase by stretching outwards so by Lenz's law clockwise current will be induced to oppose the change.

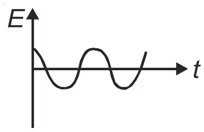
8. The magnetic flux through a coil varies with time t as shown in the diagram. Which graph best represents the variation of the e.m.f. E induced in the coil with time t?



(1) 

(2) 

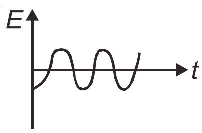
(3) 

(4) 

Sol. Answer (3)

$\phi = A\sin\omega t$

$$\varepsilon = -\frac{d\phi}{dt} = -A\omega\cos\omega t$$



9. A coil having 500 square loops each of side 10 cm is placed with its plane perpendicular to a magnetic field which increases at a rate of 1.0 T/s. The induced e.m.f. (in volts) is

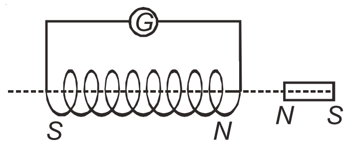
(1) 0.5 (2) 0.1 (3) 1.0 (4) 5.0

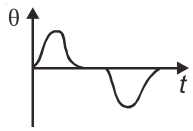
Sol. Answer (4)

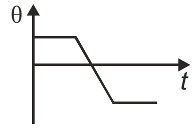
$$\varepsilon = NA\frac{dB}{dt}$$

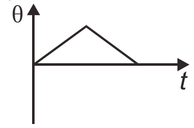
$$= (500)(0.1)^2(1) = 5\text{ V}$$

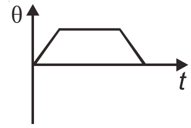
10. A short bar magnet passes at a steady speed right through a long solenoid. A galvanometer is connected across the solenoid. Which graph best represents the variation of the galvanometer deflection θ with time *t*?



(1) 

(2) 

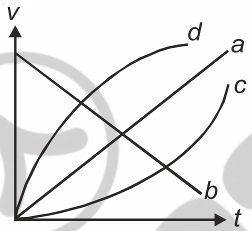
(3) 

(4) 

Sol. Answer (1)

Using Lenz's law

11. A bar magnet is made to fall through a long vertical copper tube. The speed (*v*) of the magnet as a function of time (*t*) is best represented by



(1) a (2) b (3) c (4) d

Sol. Answer (4)

12. A loop of irregular shape made of flexible conducting wire carrying clockwise current is placed in uniform inward magnetic field, such that its plane is perpendicular to the field. Then the loop

(1) Experiences force

(2) Develops induced current for a short time

(3) Changes to circular loop

(4) All of these

Sol. Answer (4)

13. A flat coil of 500 turns, each of area 50 cm^2, rotates in a uniform magnetic field of 0.14 Wb/m^2 about an axis normal to the field at an angular speed of 150 rad/s. The coil has a resistance of 5 Ω. The induced e.m.f. is applied to an external resistance of 10 Ω. The peak current through the resistance is

(1) 1.5 A (2) 2.5 A (3) 3.5 A (4) 4.5 A

Sol. Answer (3)

$N = 500$, $A = 50$ cm^2, $B = 0.14$ Wb/m^2

$\omega = 150$ rad/s, $R = 5\ \Omega$

$\varepsilon_{max} = NBA\omega$

$$I_{max} = \frac{\varepsilon_{max}}{R} = 3.5 \text{ A}$$

14. The physical quantity, which is conserved on the basis of Lenz's Law is

(1) Charge (2) Momentum (3) Mass (4) Energy

Sol. Answer (4)

(Motional Electromotive Force, Field Induction)

15. An aeroplane is flying horizontally with a velocity of 360 km/h. The distance between the tips of the wings of aeroplane is 25 m. The vertical component of earth's magnetic field is 4×10^{-4} Wb/m^2. The induced e.m.f. is

(1) 1 V (2) 100 V (3) 1 kV (4) Zero

Sol. Answer (1)

$\varepsilon = Bvl$

$$= 4\times10^{-4}\times360\times\frac{5}{18}\times25$$

16. A metallic ring with a cut is held horizontally and a magnet is allowed to fall vertically through the ring, then the acceleration of this magnet is

(1) Equal to g

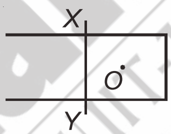
(2) More than g

(3) Less than g

(4) Sometimes less and sometimes more than g

Sol. Answer (1)

17. When a conducting wire XY is moved towards the right, a current flows in the anti-clockwise direction. Direction of magnetic field at point O is



(1) Parallel to motion of wire (2) Along XY

(3) Perpendicular outside the paper (4) Perpendicular inside the paper

Sol. Answer (3)

Using Lenz's law

18. A copper rod of length l is rotated about one end perpendicular to the uniform magnetic field B with constant angular velocity ω. The induced e.m.f. between its two ends is

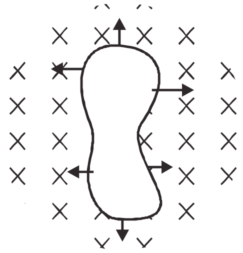
(1) $B\omega l^2$ (2) $\frac{3}{2}B\omega l^2$

(3) $\frac{1}{2}B\omega l^2$ (4) $2B\omega l^2$

Sol. Answer (3)

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

19. A loop of irregular shape of conducting wire *PQRS* (as shown in figure) placed in a uniform magnetic field perpendicular to the plane of the paper changes into a circular shape. The direction of induced current will be



(1) Clockwise (2) Anti-clockwise (3) No current (4) None of these

Sol. Answer (2)

Using Lenz's law, inward flux is increasing. So to oppose this change current will be anticlockwise.

20. Eddy currents are induced when

(1) A metal block is kept in a changing magnetic field

(2) A metal block is kept in a uniform magnetic field

(3) A coil is kept in a uniform magnetic field

(4) Current is passed in a coil

Sol. Answer (1)

(Self-Inductance, Self Inductances of Coil)

21. The current passing through a choke coil of self inductance 5 H is decreasing at the rate of 2 A/s. The e.m.f. developed across the coil is

(1) 10 V (2) – 10 V (3) – 2.5 V (4) 2.5 V

Sol. Answer (1)

$L = 5$ H, $\dfrac{di}{dt} = 2$ A/s

$$\varepsilon = \frac{Ldi}{dt} = 5(2) = 10 \text{ V}$$

22. When the number of turns in a solenoid are doubled without any change in the length of the solenoid, its self inductance becomes

(1) Half (2) Double (3) Four times (4) Eight times

Sol. Answer (3)

$L \propto n^2$

So if $n' = 2n$

$L' = 4L$

23. A coil of resistance 20 Ω and inductance 5 H has been connected to a 100 V battery. The energy stored in the coil is

(1) 31.25 J (2) 62.5 J (3) 125 J (4) 250 J

Sol. Answer (2)

$$I = \frac{100}{20} = 5 \text{ A}$$

$$\varepsilon = \frac{1}{2}LI^2 = \frac{1}{2}5(5)^2 = 62.5 \text{ J}$$

24. The magnetic energy stored in a long solenoid of area of cross-section A in a small region of length L is

(1) $\frac{B^2AL}{2\mu_0^2}$ (2) $\frac{AL}{2\mu_0}$ (3) $\frac{1}{2}\mu_0 B^2 AL$ (4) $\frac{B^2AL}{2\mu_0}$

Sol. Answer (4)

$$\frac{\text{Energy}}{\text{Volume}} = \frac{B^2}{2\mu_0} \Rightarrow \text{ Energy} = \frac{B^2(AL)}{2\mu_0}$$

25. An inductor is connected to a direct voltage source through a switch. Now

(1) Very large emf is induced in inductor when switch is closed

(2) Larger emf is induced when switch is opened

(3) Large emf is induced whether switch is closed or opened

(4) No emf is induced whether switch is closed or opened

Sol. Answer (2)

26. A long solenoid has self inductance L. If its length is doubled keeping total number of turns constant then its new self inductance will be

(1) $\frac{L}{2}$ (2) $2L$ (3) L (4) $\frac{L}{4}$

Sol. Answer (1)

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

$$L = \mu_0 \left(\frac{N}{l}\right)^2 Al$$

$$L = \frac{\mu_0 N^2}{l} A \Rightarrow L \propto \frac{1}{l}$$

$$\Rightarrow L' = \frac{L}{2}$$

27. If L and R denote inductance and resistance respectively, then the dimension of L/R is

(1) $[M^0L^0T^{-1}]$ (2) $[M^0L^0T^1]$ (3) $[M^0L^0T^2]$ (4) $[MLT^2]$

Sol. Answer (2)

$\tau = \frac{L}{R}$ represents time constant hence will have dimension of time.

28. A solenoid has 2000 turns wound over a length of 0.3 m. The area of its cross section is 1.2×10^{-3} m^2. Around its central section a coil of 300 turns is wound. If an initial current of 2 A is reversed in 0.25 s, the e.m.f. induced in the coil is equal to

(1) 6×10^{-4} V (2) 4.8×10^{-2} V (3) 2.4×10^{-2} V (4) 48 kV

Sol. Answer (2)

$$\phi = NBA \Rightarrow \varepsilon = \frac{d\phi}{dt} \Rightarrow \varepsilon = NA\frac{dB}{dt} = \left(NA\mu_0 n\frac{\Delta i}{\Delta t}\right)$$

$$\frac{\Delta i}{\Delta t} = \frac{4}{0.25}, \text{ So } \varepsilon = 4.8 \times 10^{-2} \text{ V}$$

(Mutual Inductance)

29. With the decrease of current in the primary coil from 2 A to zero in 0.01 s, the e.m.f. generated in the secondary coil is 1000 V. The mutual inductance of the two coil is

(1) 1.25 H (2) 2.50 H (3) 5.00 H (4) 10.00 H

Sol. Answer (3)

$\phi = Mi$

$$\frac{d\phi}{dt} = \frac{Mdi}{dt}$$

$$1000 = \frac{M(2)}{0.01}$$

$$M = \frac{1}{2}(10) = 5.00 \text{ H}$$

30. Two coaxial coils are very close to each other and their mutual inductance is 5 mH. If a current 50 sin 500t is passed in one of the coils then the peak value of induced e.m.f. in the secondary coil will be

(1) 5000 V (2) 500 V (3) 150 V (4) 125 V

Sol. Answer (4)

$\phi = Mi$

$$\frac{d\phi}{dt} = \frac{Mdi}{dt}$$

$$\varepsilon = 5 \times 10^{-3}(50)(500)\cos\omega t$$

ε_{max} = 125 V

31. The coefficient of self induction of two inductor coils are 20 mH and 40 mH respectively. If the coils are connected in series so as to support each other and the resultant inductance is 80 mH then the value of mutual inductance between the coils will be

(1) 5 mH (2) 10 mH (3) 20 mH (4) 40 mH

Sol. Answer (2)

L_1 = 20 mH, L_2 = 40 mH

$L = L_1 + L_2 \pm 2$ M

80 = 20 + 40 + 2 M

M = 10 mH

(AC Generator and Miscellaneous)

32. A coil having number of turns N and area A is rotated in a uniform magnetic field B with angular velocity ω about its diameter. Maximum e.m.f. induced in it is given by

(1) $NAB\omega$ (2) $\frac{NAB}{\omega}$ (3) $\frac{NA\omega}{B}$ (4) $\frac{B\omega}{NA}$

Sol. Answer (1)

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

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

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

$$\varepsilon_{max} = NBA\omega$$

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