6. ELECTROMAGNETIC INDUCTION

Questions with answers

1. Name the phenomena in which a current induced in coil due to change in magnetic flux linked with it.

Answer: Electromagnetic Induction

2. Define electromagnetic induction.

Answer: The phenomena of induction of an emf in a circuit due to change in magnetic flux linked with it is called electromagnetic induction.

3. What is magnetic flux? Explain.

Answer: Magnetic flux through a surface is the scalar product of the magnetic field and the area.

The magnetic flux through an area $d\vec{S}$ kept in a magnetic field $\vec{B}$ is given by:

$$\phi_B = \vec{B} \cdot d\vec{S} = B\, dS \cos\theta$$

Magnetic flux is a scalar quantity. Its SI unit is weber (Wb).

4. What does magnetic flux measure?

Answer: Magnetic flux through a surface is a measure of the number of lines of magnetic field lines passing through the surface.

5. Is magnetic flux scalar or a vector?

Answer: Scalar

6. What is the SI unit of magnetic flux?

Answer: it is weber (Wb) or T m^2

7. When is the flux through a surface a) maximum? B) zero?

Answer: a) when the plane of the surface is perpendicular to the magnetic field ($\theta = 0^0$)

b) when the plane of the surface is kept parallel to the magnetic field ($\theta = 90^0$)

8. What is the value of the magnetic flux through a closed surface:

Answer: Zero

9. Does a magnet kept near a coil induce current in it?

Answer: No. EMF is induced in the coil only when the magnet is moving relative the coil.

10. Why does a galvanometer connected to a coil show deflection when a magnet is moved near it?

Answer: Moving a magnet near the coil changes the magnetic field at the coil which in turn changes the magnetic flux linked with the coil. Therefore an emf is induced in the circuit hence a current.

11. What happens to the induced emf if an iron bar is introduced into the coils in Faraday's experiments?

Answer: The emf increases

12. State and explain Faraday's law of electromagnetic induction.

Answer: "The magnitude of the induced emf in a circuit is equal to the time rate of change of magnetic flux through the circuit".

If ϕ_B is the varying magnetic flux linked with a circuit then the magnitude of the induced emf in the circuit is:

$$|\varepsilon| = \left|\frac{d\phi_B}{dt}\right|$$

13. Give the mathematical form of Faraday's law of electromagnetic induction.

$$\text{Induced emf, } |\varepsilon| = N\left|\frac{d\phi_B}{dt}\right|$$

where N is the number of turns in the coil and ϕ_B is the magnetic flux linked with the coil.

14. Magnetic flux linked with a closed loop at a certain instant of time is zero. Does it imply that that induced emf at that instant is also zero?

Answer: No. The emf does not depend on the magnetic flux but on the change of magnetic flux.

15. Can you induce an emf in an open circuit by electromagnetic induction?

Answer: Yes.

16. Does the electromagnetically induced emf in a coil depend on the resistance of the coil?

Answer: No. But the current does.

17. If the number of turns in a coil subjected to a varying magnetic flux is increased, what happens to the induced emf?

Answer: EMF also increases (directly proportional to the number of turns)

18. How can magnetic flux linked with a surface be changed?

Answer: By changing a) the magnetic field b) area of the surface or c) by changing the orientation of the area with the magnetic field

19. Why did Faraday's law need a correction by Lenz?

Answer: Because Faraday's law was incompatible with the law of conservation of energy.

20. State Lenz's law.

Answer: "The polarity of the induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produced it.

21. Write Faraday's law with Lenz's correction.

$$\text{Induced emf}, \varepsilon = -\frac{d\phi_B}{dt}$$

22. What does the negative sign in the expression $\varepsilon = -\frac{d\phi_B}{dt}$ imply?

Answer: The negative sign implies that the direction of induced emf opposes its cause, the change in magnetic flux.

23. The magnetic flux linked with a coil changes from 12 x 10^{-3} Wb to 6 x 10^{-3} Wb in 0.01 second. Calculate the induced emf.

Answer:

$$\text{Induced emf, } \varepsilon = -\frac{d\phi_B}{dt} = -\frac{(6 \text{ x } 10^{-3} - 12 \text{ x } 10^{-3})}{0.01} = \frac{6 \text{ x } 10^{-3}}{10^{-2}} = 0.6\ V$$

24. If you bring the North Pole of a magnet near a face of a coil, what is the direction of the current induced in that side?

Answer: Anticlockwise. This makes that side of the coil magnetically North which repels the magnet coming towards it.

25. If the area of a coil kept in a magnetic field is changed, is there any induced current in it?

Answer: Yes. By changing the area we change the magnetic flux linked with the coil. The current induced is in a direction to counteract this change in magnetic flux.

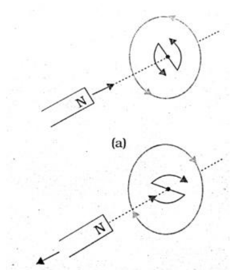
26. Is Lenz's law consistent with the law of conservation of energy?

Answer: Yes

27. Why does not the induced current in a coil flow in clockwise direction if the south pole of a magnet is moved away from it?

Answer: If the induced current flows in clockwise direction, that face of the coil becomes magnetic south. This repels the away – moving magnet and the magnet flies off without spending energy anymore. This would be inconsistent with the law of conservation of energy.

28. Use Lenz' law to find the direction of induced emf in a coil when (a) a north pole is brought towards the coil (b) north pole taken away from the coil (c) A south pole is brought towards the coil and (d) a south pole is taken away from the coil.



Answer: a) Anticlockwise b) Clockwise

c) Clockwise d) Anticlockwise

29. What is motional emf?

Answer: The emf induced in a conductor moving in a plane perpendicular to a magnetic field is called motional emf.

30. What happens to the magnitude of the motional emf if the a) velocity of the rod b) length of the rod c) the applied magnetic field are increased?

Answer: increases (in all of the three cases)

31. Is there an induced emf (motional emf) in a conductor if it moves in a plane parallel to a magnetic field?

Answer: No

32. A wire pointing north-south is dropped freely towards earth. Will any potential difference be induced across its ends?

Answer: No. (If it is made to fall in E –W direction, there is an emf across its ends)

33. When a glass rod moves perpendicular to a magnetic field, is there any emf induced in it?

Answer: No. Because glass is an insulator.

34. What are eddy currents?

Answer: When a bulk conductor is placed in a varying magnetic field, circulating currents are induced in it. These currents are called eddy currents.

35. What happens to a velocity of a conductor when it moves in a varying magnetic field?

Answer: Decreases. The eddy currents induced in the conductor damp the motion of the conductor.

36. Why are the oscillations of a copper disc in a magnetic field damped?

Answer: Because of the eddy currents produced in the disc.

37. Why are eddy currents undesirable?

Answer: Because they produce heating effect and damping effect.

38. Mention applications of eddy currents.

Answer: a. Magnetic braking in trains b. Magnetic damping in galvanometers

c. Induction furnaces d. Electric power meters

39. How does the magnetic braking in train work?

Answer: Strong electromagnets placed over the rails are activated. This produces eddy current in the rails which produce braking effect.

40. What is principle behind induction furnaces?

Answer: Eddy currents. In an induction furnace, a high frequency AC is passed through a coil which surrounds the metal to be melted. The eddy currents produced in the metal heats it to high temperatures and melts it.

41. How can eddy currents be minimized?

Answer: Eddy currents can be minimized by slicing the conductor into pieces and laminating them so that the area for circulating currents decreases.

42. What is inductance?.

Answer: Inductance of a coil is the magnetic flux linked with the coil per unit current producing it. $L = \phi_B / I$

43. On what factors does the inductance of a coil depend?

Answer: The inductance of coil depends on the geometry of the coil and intrinsic material properties.

44. What is the SI unit of inductance? Define it.

Answer: henry (H). One henry is defined as the inductance of a coil for which there is a magnetic flux of 1 Wb is linked with it when a current of 1 A is causing it.

45. What is mutual induction?

Answer: Mutual induction is the phenomena of production of emf induced in a coil due to a change in current in a nearby coil.

46. Define mutual inductance (coefficient of mutual inductance). Mention its SI unit.

Answer: Mutual inductance is the ratio of the magnetic flux linked with a coil due to a current in a nearby coil. Its SI unit is henry.

47. Mention the factors on which mutual inductance depends.

Answer: a. The number of turns per unit length in each coil, b. Area of the coils, c. Length of the coils, d. permeability of medium inside the coils, e. separation between the coils, f. the relative orientation of the coils

48. Give the expression for mutual inductance between two coils which are wound one over another.

Answer: $M = \mu_r \mu_0 n_1 n_2 \pi r_1^2 L$ where μ_r is the relative permeability of the medium inside the coils, μ_0 is the permeability of free space, n_1 and n_2 are the number turns per unit length of each coils, r_1^2 is the radius of the inner coil and L is the length of the coil.

49. Mention one device which works on the principle of mutual induction.

Answer: Transformer

50. How can mutual inductance be increased without changing the geometry of the coils?

Answer: By inserting a ferromagnetic material inside the coils

51. Mention the expression for the emf induced in a coil of a mutual inductance due to the change in current through another.

Answer: $\varepsilon_1 = -M \frac{dI_2}{dt}$

52. What is self-induction?

Answer: Self – induction is the phenomena of induction of an emf in a coil due to a change in the current through it.

53. What is self – inductance? Mention its SI unit.

Answer: Self – inductance is the ratio of the magnetic flux linked with a coil to the current flowing through it. Its SI unit is henry.

54. Mention the expression for the emf induced in a solenoid in terms of change in current through it.

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

55. What is electrical analogue of mass in mechanics? OR Which electrical device plays the role of electrical inertia?

Answer: Self – inductance.

56. What is back emf?

Answer: The emf induced in a coil which opposes the rise of current through a coil is called back emf.

57. Why does a bulb connected in series with a self – inductance glows brilliantly for a moment when the current in the circuit is switched off?

Answer: Because of the forward emf produced.

58. Mention the expression for the self – inductance.

Answer: $L = \mu_o \mu_r\, n^2 Al$

where μ_r is the relative permeability of the medium inside the coil, n is the number of turns per unit length of the coil, A is the area of the coil and l is the length of the coil.

59. Does emf rise instantaneously after the battery connected to it is switched on?

Answer: No. Because the back emf produced opposes the growth of current through the coil.

60. Can a thin wire act as an inductor?

Answer: No. Because a thin wire does not enclose a significant magnetic flux.

61. On what factors does the coefficient of self – inductance of a coil depend?

Answer: a) The length of the solenoid (α l), b) the number of turns per unit length in the solenoid (α n^2) c) the area of the coil (α A) d) the permeability of the medium inside the solenoid (α μ_r)

62. What happens to the self – induction of a coil if a soft – iron rod is inserted into it?

Answer: Increases. Since iron has large permeability, the inductance increases.

63. Mention the expression for the magnetic potential energy stored in an inductor.

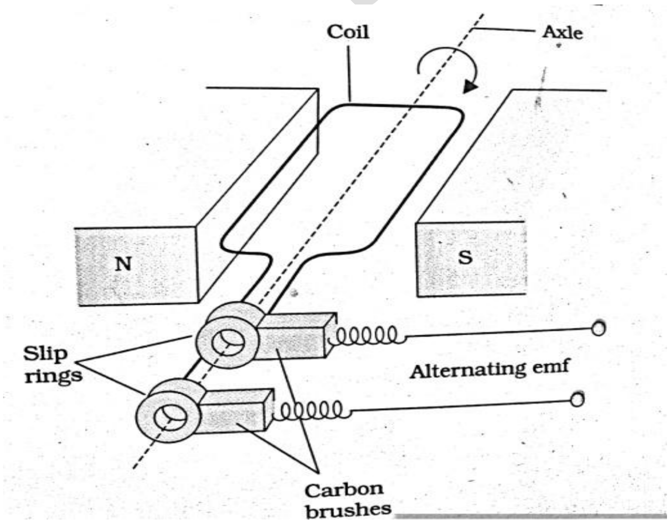
Answer: $$Energy, E = \frac{1}{2}LI^2$$

where L is the self – inductance of the inductor and I is the current flowing through it.

64. What is an AC generator? What is its principle?

Answer: An AC generator is which converts mechanical energy into electrical energy (alternating emf). It works on the principle of electromagnetic induction.

65. Draw a neat labeled diagram of an AC generator.



66. What is the frequency of AC in India?

Answer: 50 Hz

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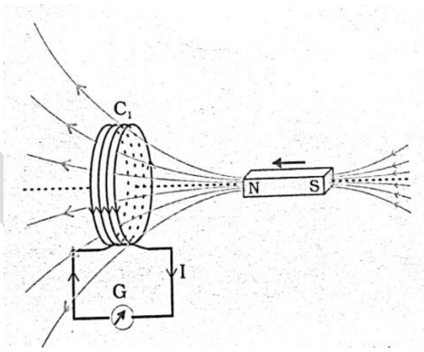
Long Answer Questions:

67. Explain coil and magnet experiment performed by Faraday to discover electromagnetic induction.

Answer: When the North-pole of a magnet is moved towards a coil connected to a galvanometer, the galvanometer in the circuit shows a deflection indicating a current (and hence an emf) in the circuit. The deflection continues as long as the magnet is in motion. A deflection can be observed if and only if the coil and the magnet are in relative motion. When the magnet is moved away from the coil, the galvanometer shows a deflection in the opposite direction.



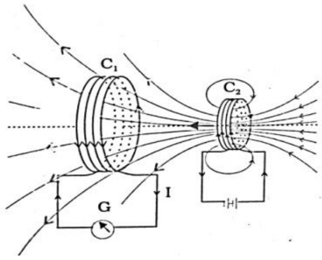
Bringing the South-pole towards the coil produces the opposite deflection as bringing the North-pole.

Faster the magnet or the coil is moved, larger is the deflection produced.

By this experiment we can conclude that: *the relative motion between the coil and the magnet generates an emf (current) in the coil.*

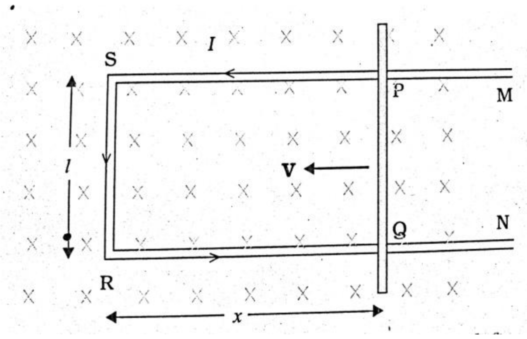
68. Explain the coil and coil experiment of Faraday.

Answer: If we replace the magnet by a current carrying coil, a similar observation can be made. When the current carrying coil is brought near the coil connected to the galvanometer, the galvanometer shows deflection indicating a current and hence an emf in the coil. Thus, *the relative motion between a coil and another coil carrying current induces an emf (current).*



69. Derive an expression for motional emf induced in a conductor moving in a magnetic field.

Answer: Consider metallic frame MSRN placed in a uniform constant magnetic field. Let the magnetic field $\vec{B}$ be perpendicular to the plane of the coil. Let a metal rod PQ of length l placed on it be moving towards left with a velocity $\vec{v}$ towards left as shown in the figure. Let the distance of PQ from SR be x.



The magnetic flux linked with the area SPQR is:

$$\phi_B = B\,A\cos\theta = B\,lx\cos 0 = B\,lx$$

As the rod PQ is moving towards left with a velocity $\vec{v}$, x is changing and $\vec{v} = -\frac{dx}{dt}$. Hence:

$$\text{Induced emf, } \varepsilon = -\frac{d\phi_B}{dt} = -\frac{d(Blx)}{dt} = -Bl\frac{dx}{dt}$$

$$\Longrightarrow \varepsilon = Blv$$

This emf is induced in the rod because of the motion of the rod in the magnetic field. Therefore this emf is called *motional emf.*

70. Derive an expression for magnetic potential energy stored in a self – inductor.

Answer: When a current is established in a solenoid (coil), work has to be done against the back emf. This work done is stored in the form of magnetic energy in the coil.

For a current I in the coil, the rate of work done (power) is: $\frac{dW}{dt} = \varepsilon I$

But we know that: $\varepsilon = L\frac{dI}{dt}$.

Therefore:

$$\frac{dW}{dt} = LI\frac{dI}{dt} \Longrightarrow dW = LIdI$$

Therefore the work done in establishing a current I is given by:

$$W = \int dW = \int LIdI = \frac{1}{2}LI^2$$

This work is stored in the coil in the form of energy. Therefore the energy stored in a solenoid is given by:

$$U = \frac{1}{2}LI^2$$

71. Explain the construction and working of an AC generator.

Answer: Fig (refer the figure of the AC generator) An AC generator consists of a coil (armature) placed in a magnetic field as shown. The coil can be rotated about an axis perpendicular to the magnetic field. When the coil is rotated, the angle (θ) between the magnetic field and the area changes. Therefore, the flux linked with the coil changes which induces an emf in the coil. The ends of the armature are connected to an external circuit.

72. Give the theory of an AC generator.

Answer: Let the area of the coil be A and the magnetic field be B. Let N be the number of turns in the armature. Let θ be the angle between the area and the magnetic field. If ω is the constant angular velocity of the rotation of the coil then θ = ωt.

The magnetic flux linked with the coil is:

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

From Faraday's law, the induced emf by rotating coil is given by:

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

$$\Longrightarrow \varepsilon = -NBA(-\omega\sin\omega t) = NBA\omega\sin\omega t$$

$$\Rightarrow \varepsilon = \varepsilon_0 \sin \omega t$$

where $\varepsilon_0 = NBA\omega$ is called the peak value of the emf or the maximum emf.

If ν is the frequency of rotation of the armature then: $\omega = 2\pi\nu$. Therefore,

$$\Rightarrow \varepsilon = \varepsilon_0 \sin 2\pi\nu t$$

This is the expression for the alternating emf produced by a generator.

As the time increases, the emf ε increases from zero to $+\varepsilon_0$ and then falls to zero. Then it becomes negative and reaches $-\varepsilon_0$. Then gradually it increases to become zero. This completes one cycle of AC.

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