CHAPTER 6
ELECTROMAGNETIC INDUCTION

1. Define electromagnetic induction.

Ans: *Whenever the magnetic flux linked with a coil changes, an emf is induced in the coil. This process is called electromagnetic induction.*

2. State Faraday's law of electromagnetic induction.

Ans: The magnitude of the induced emf is equal to the rate of change of magnetic flux.

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

ϕ is the magnetic flux.

3. The magnetic flux linked with a loop placed in field is given by $\phi = 6t^2 + 7t + 1$, where t is in seconds and ϕ is in milliweber. How much emf will be induced at t = 2s?

4. State Lenz's law.

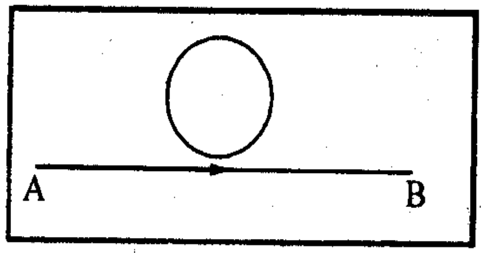
Ans: The direction of the induced e.m.f. is always such as to oppose the rate of change of magnetic flux.

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

The negative sign shows that induced emf opposes the change of flux.

Lenz's law gives the direction of induced e.m.f.

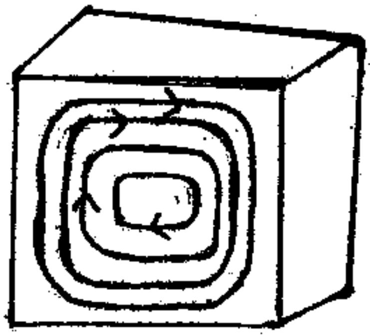
5. The current passing through the wire AB is increasing. In which direction does the induced current flow in the loop?



Eddy Currents

6. What are Eddy currents?

Ans: Whenever the magnetic flux liked with a metallic block changes, an e.m.f. is induced in it. And due to this e.m.f. circulating currents are produced in the metallic block. These circulating currents are called eddy currents.



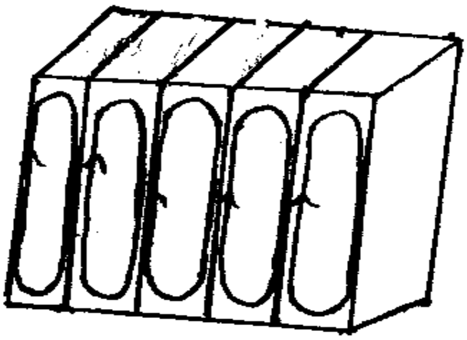
The direction of eddy currents also is given by Lenz's law.

7. What are the disadvantages of eddy currents?

Ans: Eddy currents are undesirable, in most of the electrical devices like transformer, induction coil, choke coil etc. Eddy currents produce heating in these devices, which is a wastage of energy.

8. How can you minimize eddy currents?

Ans: Eddy currents can be minimized by increasing the resistance of the metal. This can be done **by using laminated thin sheets of metal, instead of a single metallic block.**



9. What are the practical uses of eddy currents?

Ans: The main applications of eddy currents are the following:

(i) **Electromagnetic damping**

In a moving coil galvanometer when the coil oscillates in the m.f. eddy currents are set up in the frame (core) according to Lenz's law. These eddy currents oppose the oscillations and damping is produced very quickly. This helps for quick measurements.

(ii) **Induction furnace**

The metal to be heated is placed in a rapidly varying magnetic field produced by a high frequency AC. The eddy currents set up in the metal produce so much heat that the metal is melted.

(iii) **Electric brakes** (Brakes of train)

A strong magnetic field is applied across a metallic drum rotating with the axis of the train. The force developed due to the eddy currents is proportional to the speed of the train. So the breaking effect is smooth.

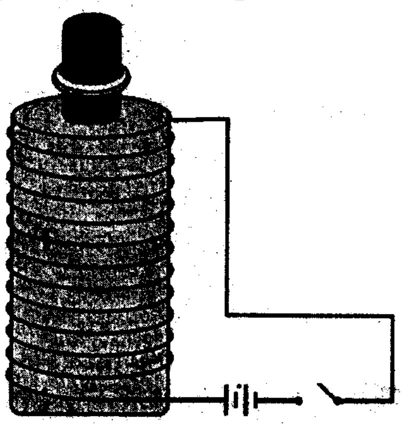
(iv) **Induction motor**

In the induction motor a rotating m.f. is produced with the help of two single phase A.C. Which have a phase difference of $\frac{\pi}{2}$. A metallic cylinder is pivoted between the electromagnets. When the m.f. is rotated eddy currents are developed in the cylinder. To reduce the relative motion, the cylinder also rotates with the rotating m.f.

(v) **Speedometer**

In the speedometer an aluminium drum rotates according to the speed of the vehicle. The aluminium drum is carefully pivoted and a magnet is placed inside it. As the vehicle moves the magnet rotates, the eddy currents are produced in the aluminium drum. These eddy currents try to reduce the relative motion. For this, the cylinder also rotates with the magnet. The pointer of the speedo meter moves according to the rotation of the drum.

10. An aluminium ring is placed around the projecting core of a powerful electromagnet as shown in the figure below. When the circuit is closed the ring jumps up to a surprising height. Why?

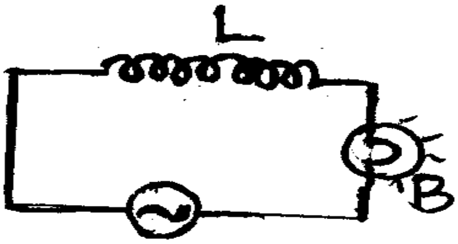


11[Q]. The motion of copper plates is damped when it is allowed to oscillate between the two poles of a magnet. If slots are cut in the, how will the damping be affected?

SELF INDUCTION

12. What is Self induction

Ans: *When the current through a coil changes, an e.m.f. is induced in it. This is called self induction*



$\phi \propto I$

⇨ $\phi = LI$

L is called **self inductance** of the coil or coefficient of self induction

According to Lenz's law.

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

$$= \frac{-d(LI)}{dt}$$

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

13. Define self-inductance of a solenoid.

Ans: We have $\varepsilon = -L\frac{dI}{dt}$

Let $\frac{dI}{dt} = 1$**A /s**

Then, $\varepsilon = L$ (numerically)

The self inductance of a coil is defined as the induced e.m.f developed in the coil when the rate of change of current through it is unity.

14. What is back emf ?

Ans: The induced emf in a coil opposes the growth or decay of current through it. Therefore, it is called back emf.

15. What is the S.I. unit of self-inductance?

Ans: henry (**H**)

16. Derive an expression for the self-inductance of a solenoid.

Ans: Consider a solenoid total no. of turns N, number of turns per unit length 'n' and length l.

Magnetic flux linked with the solenoid.

$\phi = BAN$

But the m.f. inside the solenoid.

$B = \mu_0 nI$

Therefore,

$\phi = \mu_0 nI\,AN$

⇨ $LI = \mu_0 nIAN$

⇨ $L = \mu_0 nAN$

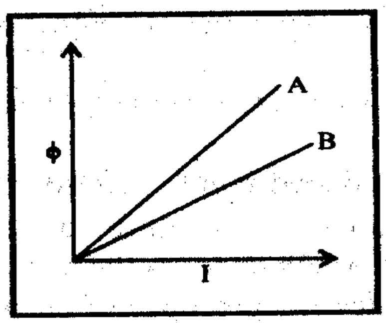
⇨ $L = \mu_0 nA(nl)$

⇨ $$\mathbf{L = \mu_0 n^2 Al}$$

17. A solenoid of length 1 metre has self-inductance L henry. If number of turns are doubled (without any change in its length), what is its new self-inductance?

18. Current in a circuit falls from 5A to 1A in 0.1 second. If an average emf of 200 volts is induced, find the self - inductance of the coil.

19.A plot of magnetic flux(ϕ) versus current(I) is shown in the figure for the two inductors A and B. Which of the two has larger value of self inductance?



20. Which of the following can produce maximum induced emf?

(a) 50A, DC

(b) 50A, 50Hz AC

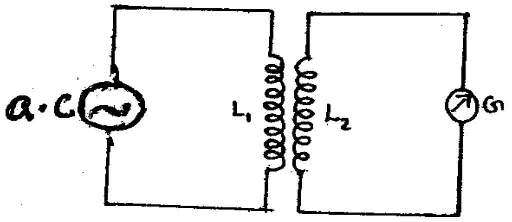
(c) 50A, 500Hz AC

(d) 100A, DC

MUTUAL INDUCTION

21. Define mutual induction

Ans: *When current through a coil changes an e.m.f. is induced in the neighboring coil. This is called mutual induction.*



$\phi \propto I_1$

⇨ $\phi = MI_1$

Therefore,

$\varepsilon = \frac{-d\phi_2}{dt} = \frac{-d}{dt}[MI_1]$

$$\varepsilon = -M\frac{dI_1}{dt}$$

22. Define mutual inductance of two coils.

Ans: We have, $\varepsilon = -M\frac{dI_1}{dt}$

Let $\frac{dI_1}{dt} = 1$

Then, $\varepsilon = -M$

$\varepsilon = M$ (numerically)

"*Mutual inductance of two coils is defined as the induced e.m.f developed in the secondary coil, when the rate of change of current through the primary is unity*".

23. Give the relation between mutual inductance and self-inductances.

Ans: $M \propto \sqrt{L_1L_2}$

$M = k\sqrt{L_1L_2}$

k → coefficient of coupling, for tight coupling k = 1, for loose coupling, k< 1

24. What is tight coupling?

Ans: If the primary and secondary coils are wound closely in such a way that the complete flux linked with the primary is available to the secondary, then the coupling is called tight coupling.

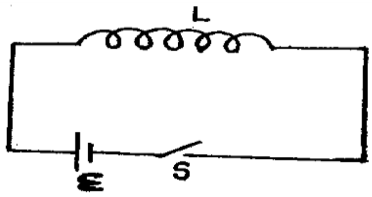
25. What is the SI unit of mutual inductance?

Ans: SI unit of mutual inductance is **henry** (H)

26. A pair of adjacent coils has a mutual inductance of 1.5H. If the current in one coil changes from 0 to 20A in 0.5s, (i) what is the change of flux linkage with the other coil? (ii) what is the emf induced in the other ?

27. Derive an expression for the energy stored in an Inductor.

Ans:



When current through a coil increases, back e.m.f. is developed. This e.m.f. opposes the growth of current through the circuit. Therefore some work has to be done by the voltage source to establish a current in the circuit.This work done is stored as the energy of the inductor.

Workdone in **dt** time

$dW = Pdt$

$= \varepsilon I.dt$

By Kirchhoff's voltage rule, $\varepsilon - L\frac{dI}{dt} = 0 \Rightarrow \varepsilon = L\frac{dI}{dt}$

Therefore, $dW = L\frac{dI}{dt} \times Idt$

⇨ $dW = LIdI$

Therefore the total work done in increasing the current from '0' to I_0 is given by,

$$W = \int_0^{I_0} dW$$

$$= \int_0^{I_0} LIdI$$

$$= L\int_0^{I_0} IdI$$

$$= L\left[\frac{I^2}{2}\right]_0^{I_0}$$

$$= L\left[\frac{I_0^2}{2} - \frac{0^2}{2}\right]$$

$$= \frac{LI_0^2}{2}$$

$$\mathbf{W = \tfrac{1}{2} LI_0^2}$$

Therefore, Energy of the inductor

$$\boxed{U_B = \frac{1}{2}LI_0^2}$$

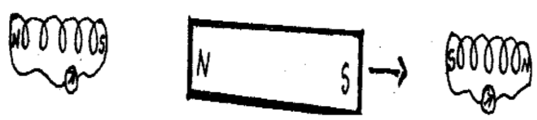
28. What is the form of energy stored in an inductor?

Ans: Energy stored in an inductor is in the form of a magnetic potential energy

29. A 50mH **coil carries a current of** 2 amperes. **Determine the energy stored in the inductor.**

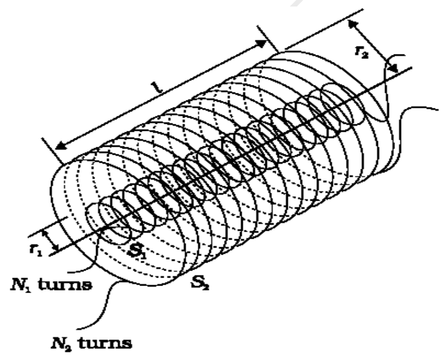
30. Lenz's Law is a statement of conservation of energy. Explain

Ans: When a magnet is brought near to a coil, an induced emf is developed in the coil. And the coil gets magnetized so as to oppose the motion of the magnet. Due to repulsion work has to be done to bring the coil towards the magnet. And this work is stored as energy, in the coil. Here mechanical energy is converted to electrical energy.



31. Derive an expression for mutual inductance of two coils.

Ans: Consider two coaxial solenoids S_1 and S_2 each of length l. Let r_1 and r_2 be their radii, n_1 and n_2, the number of turns per unit length and N_1 and N_2 the total number of turns.



Let a current I_2 flows through S_2. Then the magnetic flux linked with S_1 is

$\Phi_1 = M_{12} I_2$ ---------------- (1)

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

Magnetic field due to the current I_2 in the solenoid S_2.

$B_2 = \mu_0 n_2 I_2$

Then the resulting flux through S1

$\Phi_1 = B_2 A_1 N_1$

$= \mu_0 n_2 I_2 (\pi r_1^2)(n_1 \ell)$ $\qquad n_1 = \frac{N_1}{l}$

$= [\mu_0 n_1 n_2 (\pi r_1^2) \ell] I_2$-------------(2)

Comparing equations (1) and (2)

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

If we consider the reverse case, we can show that

$$\mathbf{M_{21} = \mu_0 n_1 n_2 \pi r_1^2 \ell}$$

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

32. Define magnetic flux

Ans:

Magnetic flux $\phi = \vec{B} \bullet \vec{A}$ $= \mathbf{BA\cos\theta}$

where θ is the angle between magnetic field and normal to the plane of the coil.

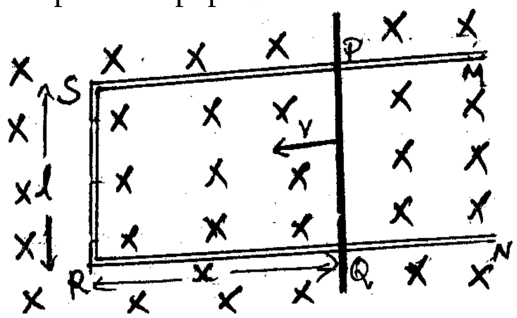
33. What is the SI unit of magnetic flux?

Ans: S.I. unit of magnetic flux is **weber (Wb)**.

Magnetic flux is a scalar quantity.

34. What is motional emf? Derive an expression for motional emf.

Ans: Consider a rectangular frame MSRN in which the conductor PQ can move, in the ⊥r m.f. directed inwards the plane of paper.



The straight conductor PQ is moved towards the left with a constant velocity v perpendicular to the uniform magnetic field B.

The magnetic flux linked with the rectangular loop PQRS.

$\Phi = BA = B(lx)$

As PQ moves the value of 'x' changes, there by changing the magnetic flux. Whenever the magnetic flux changes, an emf is induced.

Induced e.m.f.

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

$$= \frac{-d(Blx)}{dt}$$

$$= -Bl\frac{dx}{dt}$$

$$\varepsilon = -Bl\frac{dx}{dt}$$

$$\varepsilon = Blv$$

The induced e.m.f., $\boxed{\varepsilon = Blv}$ is called the motional e.m.f.

The direction of motional emf is given by Flemming's right hand rule.

35. State Flemming's right hand rule.

Ans: Stretch the 3 fingers in the right hand in 3 mutually ⊥r directions. If the forefinger gives the directions of magnetic field and the thumb gives the direction of motion of the conductor, then the middle finger will give the direction of the induced emf.

36. A jet plane is travelling towards west at a speed of 1800km/h. What is the voltage difference developed between the ends of the wing having a span of 25m, if the earth's magnetic field at the location has a magnitude of $5x\ 10^{-4}$T and dip angle is 30°.

37. Explain the principle, construction and working of an A.C. Generator.

Ans:

Construction

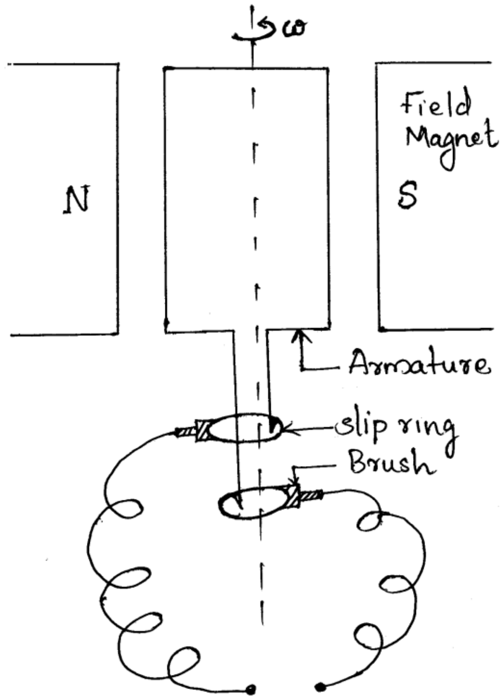
An ac generator consists of:

(i) *Field magnet*

(ii) *Armature*

(iii) *Slip rings*

(iv) *Brushes*



Principle

A.C. generator works on the principle of electro-magnetic induction. In a generator mechanical energy is converted in to electric energy

When the armature coil rotates between the pole pieces of field magnet, the effective area of the coil is A cos θ, where θ is the angle between A and B.

The flux at any time is $\phi = BAN \cos\theta$

$\Rightarrow \quad \phi = BAN \cos \omega t$

Where ω is the angular velocity of the coil.

The induced e.m.f.

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

$$= -N\frac{d}{dt}(BA\cos\omega t)$$

$$= -NAB \times -\sin\omega t \times \omega$$

$$\boxed{\varepsilon = NAB\omega \sin\omega t}$$

When sin ωt = +1 or -1

ε = NABω (numerically), which is the maximum value of induced emf. I.e., when $\omega t = 90^0$ or 270^0, the change of flux is maximum.

When the armature coil is mechanically rotated in a uniform magnetic field, the magnetic flux through the coil changes and hence an emf is induced in the coil. The ends of the coil are connected to external circuit by means of slip rings and brushes.

38. Why a.c. is preferred for all commercial purposes?

Ans: This is because a.c. voltage can be easily converted from one voltage to another using transformer. At the transmitting station current is reduced to a very small value using step up transformer. This is to reduce I^2R loss while transmitting through the power lines. At the places of distribution the current is increased to the required value using step down transformers.

39. Match the devices and the principle behind the working of the following devices.

AC generator	Self-Induction
Choke Coil	Mutual Induction
Transformer	Speedometer of Vehicles
Eddy Currents	Electromagnetic Induction

Ans:

AC generator	Electromagnetic Induction
Choke Coil	Self-Induction
Transformer	Mutual Induction
Eddy Currents	Speedometer of Vehicles