Unit IV ELECTROMAGNETIC INDUCTION & ALTERNATING CURRENT

EASY AND SCORING AREAS

1. **Faraday's law of EMI**
2. **Lenz's law**
3. **Problems based on Lenz's law**
4. **Eddy currents**
5. **Applications of eddy currents**
6. **Self-induction**
7. **Mutual Induction**
8. **Expression for impedance of LCR series circuit**
9. **Numericals based on impedance and resonance**
10. **AC Generator**
11. **Transformer**

1 Mark questions

1.State Faraday's laws of EMI.
Ans: $e = - d\phi/dt$

2.Write S.I. unit of magnetic flux. Is it a scalar or a vector?

Ans: Weber, Scalar.

3.On what factor does the self-inductance of a solenoid depends?

Ans: (a) No of turns in the solenoid (b) Length of the solenoid (c) Core inside the solenoid (d) Area of the cross-section.

4.Define self–inductance of a coil. Give its S.I. unit.

Ans: Magnetic Flux link in the coil when unit current flows through it. SI unit is henry.

5.Define self–induction of a coil. Give one example.

Ans: The phenomenon of electric current in a coil due to growth or detail of current in the coil.

Example: Back emf of motor.

6.How does the self-inductance of an air coil change, when (i) the number of turns in the coil is solenoid increased (ii) an iron rod is introduced in the coil.

Ans: (i) Since 'L' is directly proportional to n^2 (ii) Self-inductance increases when iron rod is introduced inside it because permeability of iron is high.

7. Bulb is connected in a closed circuit containing an air cored solenoid an a battery. How does the brightness of the bulb change, when (i) the number of turns in the coil is increased (ii)an iron rod is introduced in the coil.

Ans: (i) decreases because self-induction increases due to increase in number of turns of the eye of the current eye due to self-induction and after that it becomes same as earlier. (ii) Same

8.The electric current is increasing in a straight wire from A to B .What is the direction of induced current in the metallic loop kept above the wire as shown in the fig.

Ans: Since magnetic field is increasing due to increasing current in the wire in done work direction so accordingly to Lenz rule the magnetic field due to induction of current in the coil so as such that the flux in the coils should decrease so direction of the current should be in clock wise.

9. A bar magnet falls from a height 'h' through a metal ring. Will its acceleration be equal to g ? Give reason for your answer.

Ans: Acceleration will be less than 'g' because of induction of current in the coil as per o Lenz rule which opposes the falling of magnet.

10.Why does a metallic piece become very hot when it is surrounded by a coil carrying high frequency alternating current?

Ans: Due to production of Eddy currents, the metallic piece becomes very hot.

11. The instantaneous current in an ac circuit is i=2.0 sin314t, what is (i) frequency and (ii) rms value of the current.

Ans: (i) Frequency = 50 Hz

(ii) rms value of the current $I_{rms} = \frac{I_o}{\sqrt{2}}$ $= 2/\sqrt{2} = \sqrt{2}$ A

What is phase difference between voltage and current in LCR series circuit if power factor is 0.707?

Power Factor = $\cos\varphi$.

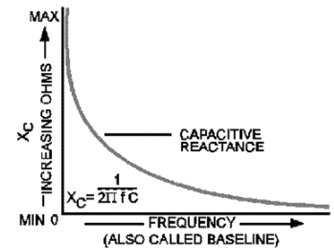
$0.707 = \cos\varphi$

$1/\sqrt{2} = \cos\varphi$

$\varphi = 45^o$

12.What is phase difference between voltage and current in LCR series circuit at resonance?
Ans = Zero degree
13.Sketch a graph showing variation of reactance of a capacitor with frequency of the applied voltage.

Ans:

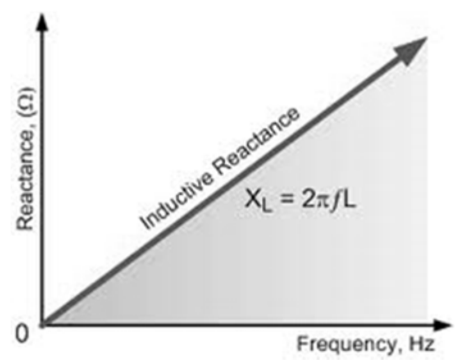


Since $X_C = \frac{1}{2\pi f C}$

14. Sketch a graph showing variation of reactance of an inductor with frequency of the applied voltage.

Ans: Since $X_L = \omega L$

$X_L = 2\pi f L$



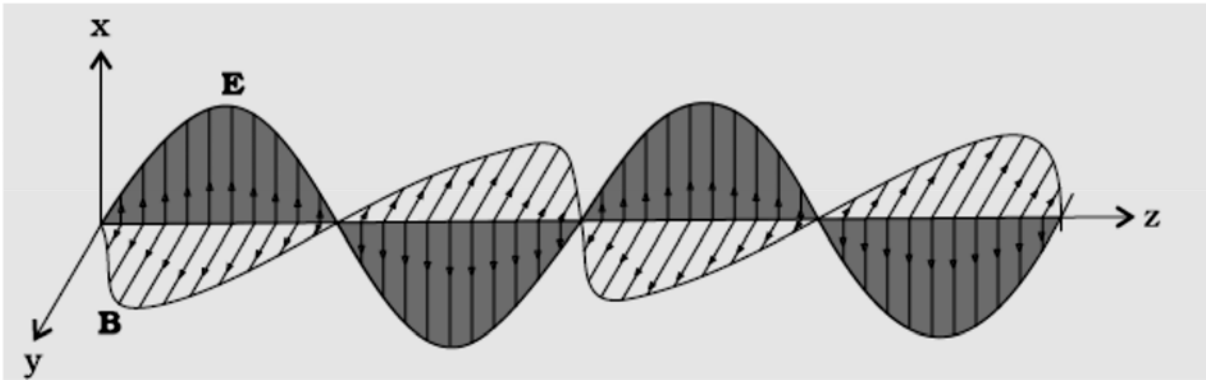
15.Why a capacitor blocks dc but allow ac?

Ans: Since, $X_C = \frac{1}{2\pi f C}$, the frequency of DC is 0 so capacitor offers infinite resistance for DC whereas AC has certain frequency so it offers finite resistance for AC.

16.The frequency of ac is doubled, what happens to (i) inductive reactance (ii) capacitive reactance?

Ans: (i) Double, Since $X_L = \omega L$ (ii) Half , Since $X_C = \frac{1}{2\pi f C}$

17. Draw the electric field, magnetic field and direction of propagation of an Electromagnetic Wave.



18. What is Displacement Current?

    Ans: $I_d = d\phi_e / dt$

19. Why a microwave oven heats up a food item containing water molecules most efficiently.

    Ans: The frequency of the microwave should match with the resonant frequency of water molecules.

20. Which part of the electromagnetic spectrum has the largest penetrating power?

    Ans: Gamma - rays.

21. Identify the part of the electromagnetic spectrum to which the following wavelength belong:
    (a) 10^{-1} m (b) 10^{-12} m

    Ans: (a) 10^{-1} m =10 cm belongs to short radio waves.

    (b) 10^{-12} m wavelength belongs to gamma rays.

22. Name the part of electromagnetic spectrum of wavelength 10^2 m and mention its one application.

    Ans: wavelength 10^2 m belongs to radio-waves. This is used to broadcast radio programs to long distances.

23. The following table gives the wavelength range of some constituents of the electromagnetic spectrum.

S.No.	Wavelength Range
1.	1nm to 700nm
2.	400nm to 1nm
3.	1nm to 10^{-3}nm
4.	< 10^{-3}nm

select the wavelength range and name the electromagnetic waves that are

(a) widely used in the remote switches of household electronic devices.

(b) produced in nuclear reactions.

Ans: (a) Infrared waves (wavelength range 1 mm to 700 nm).

(b) Gamma rays (wavelength range $<10^{-3}$ nm).

24. Name the characteristics of electromagnetic wave that
    (a) Increases
    (b) decreases
    (c) remains constant

    Ans: (a) Frequency increases

    (b) Wavelength decreases

    (c) Speed in vacuum remains constant

25. From the following identify the electromagnetic waves having the
    (i) Maximum (ii) minimum frequency

    (a) Radio waves (b) Gamma-rays (c) Visible light

    (d) Microwaves (e) Ultraviolet- rays (f) Infrared rays

    Ans: (a) The waves of maximum frequency are gamma rays.

    (b) The waves of minimum frequency are radio waves.

26. Identify the following electromagnetic radiations as per the wavelength given below.

    (a) 10^{-3} nm (b) 10^{-3} m (c) 1 nm

    Write one application of each

    Ans: (a) 10^{-3} nm - gamma radiation

    Application- Radio therapy or to initiate nuclear reactions.

    (b) 10^{-3} m - microwaves

    Application- in RADAR for aircraft navigation.

    (c) 1 nm - X-ray

    Application- In medical science for detection of fractures, stones in kidney, gall bladder etc.

27. Identify the following electromagnetic radiations as per the frequencies given below:

    (a) 10^{20} Hz (b) 10^{9} Hz (c) 10^{11} Hz

    Write one application of each.

    Ans: (a) 10^{20} Hz - Gamma-radiation

    Application- For treatment of cancer.

    (b) 10^{9} Hz - Radio wave

    Application- For broadcasting radio-programs to long distances.
    (c) 10^{11} Hz- Microwaves

    Application- For cooking in microwave oven.

2 Marks and 3 Marks questions

1. What are eddy currents? Give their one use.

Ans: When magnetic flux change across a thick conductor a whirl current is produced inside the conductor called Eddy current. It is used in electric brake.

2. State Lenz's law. Show that it is in accordance with the law of conservation of energy.

Ans: It states that the polarity of the induced current is always opposes the cause which produces it. When N-pole of the bar magnet is brought near a loop, the front face of the loop becomes N-pole and anti-clockwise current is set up in the coil, which opposes the motion of the magnet so the work must be done to do so and the work done is being converted in to electrical energy.

3. Two identical loops, one of copper and the other of aluminum, are rotated with the same angular speed in the same magnetic field. Compare (i) the induced emf and (ii) the current produced in the two coils. Justify your answer.

Ans:

(i) e = BVL

(ii) I = e/R = BVL /R

= BVL/(ρ.L/A) = BVA/ρ

Since resistivity of copper least than aluminum so current induced in copper is more than aluminum.

4. Prove that average power consumed over a complete cycle of ac through an ideal inductor is zero.

Ans: We have $P_{avg} = \dfrac{\int_0^T IV\, dt}{\int_0^T dt}$

$$Also,\ I = I_o \sin \omega t \ \&\ V = V_o \cos \omega t$$

$$P_{avg} = \frac{\int_0^T I_o V_o \sin \omega t \cos wt}{T}$$

$$= \frac{V_o I_o}{T} \int_0^T \sin 2\omega t\, dt$$

$$= V_o I_o / 2\omega\, [\cos 2\omega t]_o^T$$

$$= V_o I_o / 2\omega\, [\cos \pi - \cos 0]_o^T$$

$$= 0$$

5. Prove that average power consumed over a complete cycle of ac through an ideal capacitor is zero.

Ans: Same as Q.No.21

6. A copper ring is suspended by a thread in a vertical plane. North Pole of a magnet is brought horizontally towards the ring. Will the magnet affect the position of the ring? Explain.

Ans: Due to motion of the magnet, eddy current will be induced in copper coil and that will change the position of the coil.

6. Derive an expression for average power consumed over a complete cycle of ac through an LCR circuit.

Ans: In an electrical circuit, energy is supplied by the source of EMF, stored by the capacitive and inductive elements and dissipated in resistive elements.

Conservation of energy requires that, at any particular time, the rate at which energy is supplied by the source of EMF must equal the rate at which it is stored in the capacitive and inductive elements; plus the rate at which it is dissipated in the resistive element (we assume ideal capacitive and inductive elements have no internal resistances).

Let $E = E_o \sin wt$.

If dw be the work done by a source of EMF e on a charge dq, then
The power
Using equations (1) and (2),
$I = I_o \sin (wt - q)$
If this instantaneous power remains constant for small time dt. then
Total work done or energy spent in maintaining current over one full cycle.
The second term is zero over complete cycle i.e.,
Therefore,
The quantity $\cos\theta$ is called the power factor of the AC circuit.

7. What is the effect on the mutual inductance between the pair of coil when
(i) the distance between the coils is increased?
(ii) the number of turns in each coil is decreased? Justify your answer in each case.

Ans: (i) mutual inductance decreases on increasing the distance between the coils.
(iii) Mutual inductance decreases on decreasing the number of turns in each coils.

8. Discuss a series resonant circuit. Derive an expression for resonant frequency and show a graphical variation between current and angular frequency of applied ac. Define quality factor and derive an expression for it.

Ans: Since at the resonant frequency ω_0 the reactive parts cancel so that the circuit appears as just the resistance R.

5 marks questions

9. Explain with help off a labelled diagram the principal, construction and working of a transformer. Derive a relation between various energy losses in a transformer? Explain the role of transformer in long distance transmission of power?

Principle: It is based on the principal of mutual Induction.

The voltage induced across the secondary coil may be calculated from Faraday's law of induction, which states that:

Where V_s is the instantaneous voltage, N_s is the number of turns in the secondary coil and Φ is the magnetic flux through one turn of the coil. If the turns of the coil are oriented perpendicular to the magnetic field lines, the flux is the product of the magnetic flux density B and the area A through which it cuts. The area is constant, being equal to the cross-sectional area of the transformer core, whereas the magnetic field varies with time according to the excitation of the primary. Since the same magnetic flux passes through both the primary and secondary coils in an ideal transformer,[29] the instantaneous voltage across the primary winding equals

Taking the ratio of the two equations for V_s and V_p gives the basic equation[30] for stepping up or stepping down the voltage

N_p/N_s is known as the *turns ratio*, and is the primary functional characteristic of any transformer. In the case of step-up transformers, this may sometimes be stated as the reciprocal, N_s/N_p. *Turns ratio* is commonly expressed as an irreducible fraction or ratio: for example, a transformer with primary and secondary windings of, respectively, 100 and 150 turns is said to have a turns ratio of 2:3 rather than 0.667 or 100:150.

Ideal power equation

If the secondary coil is attached to a load that allows current to flow, electrical power is transmitted from the primary circuit to the secondary circuit. Ideally, the transformer is perfectly efficient; all the incoming energy is transformed from the primary circuit to the magnetic field and into the secondary circuit. If this condition is met, the incoming electric power must equal the outgoing power:

giving the ideal transformer equation

Transformers normally have high efficiency, so this formula is a reasonable approximation.

If the voltage is increased, then the current is decreased by the same factor. The impedance in one circuit is transformed by the *square* of the turns ratio.[29] For example, if an impedance Z_s is attached across the terminals of the secondary coil, it appears to the primary circuit to have an impedance of $(N_p/N_s)^2Z_s$. This relationship is reciprocal, so that the impedance Z_p of the primary circuit appears to the secondary to be $(N_s/N_p)^2Z_p$.

The simplified description above neglects several practical factors, in particular the primary current required to establish a magnetic field in the core, and the contribution to the field due to current in the secondary circuit.

Models of an ideal transformer typically assume a core of negligible reluctance with two windings of zero resistance.[31] When a voltage is applied to the primary winding, a small current flows, driving flux around the magnetic circuit of the core.[31] The current required to create the flux is termed the *magnetizing current*; since the ideal core has been assumed to have near-zero reluctance, the magnetizing current is negligible, although still required to create the magnetic field.

The changing magnetic field induces an electromotive force (EMF) across each winding.[32] Since the ideal windings have no impedance, they have no associated voltage drop, and so the voltages V_P and V_S measured at the terminals of the transformer, are equal to the corresponding EMFs. The primary EMF, acting as it does in opposition to the primary voltage, is sometimes termed the "back EMF".[33] This is due to Lenz's law which states that the induction of EMF would always be such that it will oppose development of any such change in magnetic field.

Various Power loss:

(i) Copper Loss : It is the energy loss in the form of ehat in the copper coils of a transformer. It occurs due to Joule's heating of conducting wires.

(ii) Iron loss: It is the enter loss in the form of heat in the softy iron core of the transformer It occurs because of eddy currents.

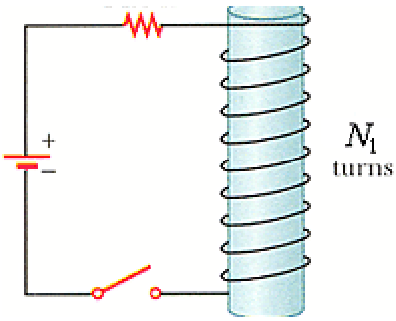
(iii) Magnetic flux Leakage: The rate of change of magnetic flux linked with the secondary is alsways elss that that of primary. This will always occur inspite of best possible insulations.

(iv) Hysteresis loss: This loss of emernergy occurs because of repeated magnetization and demagnetization of the iron core when alternating current is fed to it.

10. Deduce an expression for the self-inductance of a long solenoid of N turns, having air in its core.

Ans: For defination of self inducatance and its unit, refer answer to the above question. Consider a long solenoid of length , and radius , which has n turns per unit length, and carries a current . The longitudinal (*i.e.*, directed along the axis of the solenoid) magnetic field within the solenoid is approximately uniform, and is given by

$$B=\mu_0 nI$$



This result is easily obtained by integrating Ampère's law over a rectangular loop whose long sides run parallel to the axis of the solenoid, one inside the solenoid, and the other outside, and whose short sides run perpendicular to the axis. The magnetic flux though each turn of the loop is

Thus, the self-inductance of the solenoid is

Note that the self-inductance only depends on geometric quantities such as the number of turns per unit length of the solenoid, and the cross-sectional area of the turns.

11. Define mutual inductance and give its SI unit. Derive an expression for the mutual inductance of two long coaxial solenoids of same length wound over the other.

Ans: Mutual inductance of two long solenoids.

Let

L = length of each solenoid

r_1 , r_2 = radii of the two solenoids

$A = \pi r_1^2$

= are of cross-section of inner solenoid S_1 N_1, N_2 = number of turns in the two solenoids

First we pass a time varying current I_2 through S_2. The magnet field set up inside S_2 due to I_2 is

$$B_2 = \mu_0 n_2 I_2,$$

Total magnetic flux linked with the inner coil S_1 is

$\Phi_1 = B_2 A N_1 = \mu_0 n_2 I_2 . A N_1$

Mutual inductance of coil 1 with respect to coil 2 is

$M_{12} = \Phi_1 / I_2 = \mu_0 n_2 I_2 .AN_1 / I = \mu_0 \; N_1, N_2 A / l$

We now consider the flux linked with the outer solenoid S_2 due to the current I_1 in the inner solenoid S_1. The field B_1 due to I_1 inside

r_1 , r_2 = radii of the two solenoids

$A = \pi r_1^2$

= are of cross-section of inner solenoid S_1 N_1, N_2 = number of turns in the two solenoids

First we pass a time varying current I_2 through S_2. The magnet field set up inside S_2 due to I_2 is

$$B_2 = \mu_0 n_2 I_2,$$

Total magnetic flux linked with the inner coil S_1 is

$\Phi_1 = B_2 AN_1 = \mu_0 n_2 I_2 .AN_1$

Mutual inductance of coil 1 with respect to coil 2 is

$M_{12} = \Phi_1 / I_2 = \mu_0 n_2 I_2 .AN_1 / I = \mu_0 \; N_1, N_2 A / l$

S_1

$$B1 = \mu_0 \, n_1 I_1$$

Total magnetic flux linked with the inner coil S_2 is

$$\Phi_2 = B_1 AN_2 \;\; = \mu_0 \, n_1 I_1 \, AN_2 \;\; = \mu_0 n_1 \, n_2 \, AI_1 \, l$$

$M_{21} = \;\; \Phi_2 / 1_1 \;\; = \;\; \mu_0 n_1 \, n_2 \, A \, l = \;\; \mu_0 \; N_1, N_2 A / l$

Hence, $M_{12} = M_{21} = M$ (say)

Hence, $M = \; \mu_0 \; N_1, N_2 A / l$

12.Describe briefly the basic elements of an ac generator. Write expression for the emf produced. Also show graphically the emf produced by ac generator.
An a.c. generator consist a coil of 50 turns and area 2.5 m^2 rotating at an angular speed of 60rad/s in a uniform magnetic field B = 0.30T between two fixed pole pieces . The resistance of the circuit including that coil the coil is 500W.

(i) Find the maximum current drawn from the generator.

(ii) What will be the orientation of the coil with respect to the magnetic field to have (a) maximum (b) zero magnetic flux?

Ans:

(i) Field Magnet with poles N and S
(ii) Armature (Coil) PQRS
(iii) Slip Rings (R1 and R2)
(iv) Brushes (B1 and B2)
(v) Load

$$e = e_o sin\omega t$$

$$i_{max} = \frac{NBAw}{R} = 4.5\ A$$

For max flux: $\theta = 0^o$
For min flux $\theta = 90^o$