Physics Notes (Electromagnetism & Simple AC Circuit)

Table of Contents

7. Electromagnetic Field 7.1 Concept of electromagnetic field 7.2 Interaction between magnetic field and current 7.3 Force between conductors carrying current 7.4 Motion of a current-carrying loop or coil in a magnetic field 7.5 Applications of electromagnetic field 7.6 Electromagnetic induction 7.7 Induced e.m.f. in a straight conductor 7.8 Laws of electromagnetic induction 7.9 Eddy currents 7.10 Electrical devices using electromagnetic induction 7.11 Transformer 7.12 Power transmission 7.13 Induction coil 7.14 Summary
8. Simple A.C. Circuits 8.1 Nomenclature in A.C. circuits 8.2 Peak and r.m.s. value of A.C. 8.3 a. Resistance in A.C. circuit b. Capacitance in A.C. circuit c. Induction in A.C. circuit 8.4 Series circuit containing Resistance, Inductance and Capacitance 8.5 Phase relation between I and V in an A.C. circuit 8.6 Power in an A.C. circuit 8.7 Resonance in RLC Series circuit 8.8 Summary

7. Electromagnetic Field

7.1 Concept of Electromagnetic Field

- **Definition:** A fundamental physical field that mediates electromagnetic interaction. It describes the force between charged particles. It is the combination of electric and magnetic fields.
- **Maxwell's Equations:** A set of four equations that describe how electric and magnetic fields are generated and altered by each other and by charges and currents. They predict the existence of electromagnetic waves.

7.2 Interaction Between Magnetic Field and Current

- **Motor Effect:** A current-carrying conductor placed in an external magnetic field experiences a force.
- **Direction:** Given by **Fleming's Left-Hand Rule**.

- **Factors Affecting Force:** Current (I), length of conductor in field (L), magnetic field strength (B), angle between wire and field ($\sin\theta$).
    - **Formula:** $F = BIL\sin\theta$

7.3 Force Between Conductors Carrying Current

- When two parallel current-carrying conductors are placed near each other, they exert magnetic forces on each other.
- **Same Direction Current:** Forces are **attractive**.
- **Opposite Direction Current:** Forces are **repulsive**.
- This principle is used to define the Ampere (SI unit of current).

7.4 Motion of a Current-Carrying Loop or Coil in a Magnetic Field

- A current-carrying coil in a uniform magnetic field experiences a **torque** (turning effect).
- This torque causes the coil to rotate.
- **Principle:** This is the basis of **DC electric motors** and **galvanometers**. The torque depends on the current, area of the coil, number of turns, and magnetic field strength.

7.5 Applications of Electromagnetic Field

- **Electric Motors:** Convert electrical energy into mechanical energy using the motor effect.
- **Galvanometers:** Detect and measure small currents by the deflection of a coil in a magnetic field.
- **Loudspeakers:** Convert electrical signals into sound waves using the force on a coil in a magnetic field.
- **Magnetic Resonance Imaging (MRI):** Uses strong magnetic fields and radio waves to create detailed images of organs and tissues inside the body.

7.6 Electromagnetic Induction

- **Definition:** The process of generating an electromotive force (EMF) and hence current, in a conductor by changing the magnetic flux linked with the conductor.
- **Magnetic Flux (\Phi):** The number of magnetic field lines passing through a given area.
    - **Formula:** $\Phi = BA\cos\theta$
    - **Unit:** Weber (Wb).

7.7 Induced e.m.f. in a Straight Conductor

- When a straight conductor moves through a magnetic field such that it cuts the magnetic field lines, an EMF is induced across its ends.

- Formula: $E = BLv \sin\theta$ (where θ is the angle between B and v).

- **Direction of Induced Current/EMF:** Given by **Fleming's Right-Hand Rule** (Thumb: Motion, Forefinger: Field, Middle Finger: Current).

7.8 Laws of Electromagnetic Induction

- **Faraday's Law of Electromagnetic Induction:** The magnitude of the induced EMF is directly proportional to the rate of change of magnetic flux linkage.
    - Formula: $E = -N \frac{\Delta\Phi}{\Delta t}$ (where N is number of turns, negative sign is due to Lenz's Law).
- **Lenz's Law:** The direction of the induced current (or EMF) is always such as to oppose the change in magnetic flux that produced it. This is a consequence of the conservation of energy.

7.9 Eddy Currents

- **Definition:** Loops of electric current induced within bulk conductors by a changing magnetic field.
- **Consequences:** They produce heat (Joule heating) and can oppose the motion that caused them.
- **Uses:** Damping in sensitive electrical instruments, magnetic braking in trains, induction furnaces.
- **Reduction:** Laminating (layering) cores in transformers and motors reduces eddy currents by breaking up the paths of current flow.

7.10 Electrical Devices Using Electromagnetic Induction

- **Generators (Dynamos):** Convert mechanical energy into electrical energy based on Faraday's law. (AC generators produce alternating current, DC generators produce direct current).
- **Microphones:** Convert sound waves into electrical signals by induction.
- **Metal Detectors:** Use electromagnetic induction to detect metallic objects.

7.11 Transformer

- **Definition:** A device used to change the voltage of an alternating current (AC) without significant loss of power. Works on the principle of mutual induction.
- **Construction:** Consists of two coils (primary and secondary) wound around a laminated soft iron core.
- **Types:**
    - **Step-up Transformer:** Increases voltage (more turns in secondary coil than primary).
    - **Step-down Transformer:** Decreases voltage (fewer turns in secondary coil than primary).

- Transformer Equation: $\frac{V_s}{V_p} = \frac{N_s}{N_p} = \frac{I_p}{I_s}$ (for an ideal transformer, $P_p = P_s$).

7.12 Power Transmission

- **High Voltage Transmission:** Electrical power is transmitted over long distances at very high voltages (and low currents) to minimize power loss ($P_{loss} = I^2R$) in the transmission lines.
- **Transformers' Role:** Step-up transformers are used at power stations to increase voltage for transmission, and step-down transformers are used near consumers to reduce voltage for safe use.

7.13 Induction Coil

- **Definition:** A device for producing high-voltage pulses from a low-voltage DC supply using electromagnetic induction. It's essentially a type of transformer with an interrupter.
- **Uses:** Old spark plugs in cars, X-ray tubes, gas discharge tubes.

7.14 Summary

- Electromagnetic fields combine electric and magnetic forces.
- Current-carrying conductors experience forces in magnetic fields (motor effect).
- Electromagnetic induction is the generation of EMF by changing magnetic flux (Faraday's and Lenz's Laws).
- Transformers use mutual induction to change AC voltages efficiently for power transmission.
- Eddy currents are induced currents that can be useful or detrimental.

8. Simple A.C. Circuits

8.1 Nomenclature in A.C. Circuits

- **Alternating Current (AC):** Electric current that periodically reverses its direction and continuously changes its magnitude with time, in contrast to direct current (DC) which flows in only one direction.
- **Cycle:** One complete set of positive and negative values of an alternating quantity.
- **Frequency (f):** Number of cycles per second (Hz).
- **Period (T):** Time taken for one cycle (T = 1/f).
- **Instantaneous Value:** The value of an alternating quantity at any given instant.
- **Peak Value (Amplitude):** The maximum value of an alternating quantity in a cycle.
- **Root Mean Square (r.m.s.) Value:** A special kind of average value for AC, effectively representing the DC equivalent that would produce the same heating effect.

8.2 Peak and r.m.s. value of A.C.

- For a sinusoidal AC waveform:
  - **Peak Value (V_0 or I_0):** The maximum voltage or current.
  - **r.m.s. Value (V_{rms} or I_{rms}):**
    - $$V_{rms} = \frac{V_0}{\sqrt{2}} \approx 0.707 V_0$$
    - $$I_{rms} = \frac{I_0}{\sqrt{2}} \approx 0.707 I_0$$

Most AC measurements (e.g., household voltage) are given as r.m.s. values.

8.3 a. Resistance in A.C. Circuit

- **Resistor:** In an AC circuit, a resistor behaves similarly to a DC circuit. It offers opposition to current flow.
- **Phase:** Voltage and current are **in phase** across a pure resistor (they reach their peaks and zeros at the same time).
- **Ohm's Law:** V = IR (using r.m.s. values).

8.3 b. Capacitance in A.C. Circuit

- **Capacitor:** Blocks DC but allows AC to pass.
- **Capacitive Reactance (XC):** The opposition offered by a capacitor to the flow of AC.

- **Formula:** $X_C = \frac{1}{2\pi fC}$
- Unit: Ohms (Ω).

- **Phase:** Current **leads** voltage by 90° (or $\pi/2$ radians) in a pure capacitive circuit.

8.3 c. Inductance in A.C. Circuit

- **Inductor (Coil):** A coil of wire that opposes changes in current.
  - **Inductive Reactance (X_L):** The opposition offered by an inductor to the flow of AC.
    - **Formula:** $X_L = 2\pi fL$ (where L is inductance in Henrys).
    - Unit: Ohms (Ω).
  - **Phase:** Voltage **leads** current by 90° (or $\pi/2$ radians) in a pure inductive circuit.

8.4 Series Circuit Containing Resistance, Inductance and Capacitance (RLC Series Circuit)

- **Impedance (Z):** The total opposition to current flow in an AC circuit, combining resistance and reactance.
  - **Formula:** $Z = \sqrt{R^2 + (X_L - X_C)^2}$
  - Unit: Ohms (Ω).
- **Ohm's Law for AC:** $V_{rms} = I_{rms} Z$

8.5 Phase Relation Between I and V in an A.C. Circuit

- In a series RLC circuit, the phase difference (ϕ) between the total voltage and total current is given by:
  - $$\tan \phi = \frac{X_L - X_C}{R}$$
- ϕ is positive if the circuit is inductive (voltage leads current), negative if capacitive (current leads voltage).

8.6 Power in an A.C. Circuit

- **Average Power:** Unlike DC, power in AC circuits (especially with reactive components) is not simply V \times I.

- **Power Factor ($\cos\phi$):** The cosine of the phase angle between voltage and current.
- **Formula:** $P_{avg} = V_{rms} I_{rms} \cos\phi$
    - Only the power consumed by the resistor (resistive part) contributes to actual power dissipation. Reactive components store and release energy.

8.7 Resonance in RLC Series Circuit

- **Resonance:** A condition in an RLC series circuit where the inductive reactance equals the capacitive reactance (XL = XC).
- **At Resonance:**
    - Impedance (Z) is minimum and equal to Resistance (R).
    - Current is maximum.
    - Voltage and current are in phase ($\phi = 0$, $\cos\phi = 1$).
    - **Resonant Frequency (f_0):** $f_0 = \frac{1}{2\pi\sqrt{LC}}$
- **Applications:** Tuning circuits in radios and televisions (selecting a specific frequency).

8.8 Summary

- AC characteristics include peak and r.m.s. values.
- Resistors keep V and I in phase. Capacitors cause current to lead voltage. Inductors cause voltage to lead current.
- Reactance (capacitive XC, inductive XL) and resistance combine to form impedance (Z).
- Power in AC depends on the power factor.
- Resonance occurs when XL = XC, leading to maximum current.