## TOPIC: 5 ELECTROMAGNETIC INDUCTION

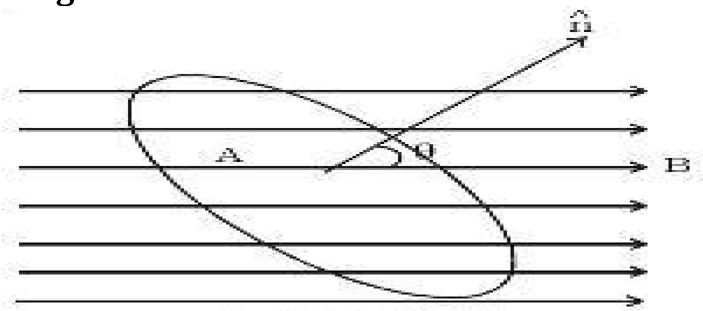
### Electromagnetic Induction

Electromagnetic induction is the process of generating an electromotive force (emf) or voltage across a conductor when it is exposed to a changing magnetic field.

**magnetic field.**

The magnetic field describes a region of space around the magnetic substance where magnetic force can be exerted. The magnetic force can be generated by magnets or moving charges, The magnetic field is a vector quantity, The SI unit of magnetic field is the tesla (T). Magnetic field is typically represented by vector arrows or field lines. The density of field lines indicates the strength of the magnetic field at various points.

### Magnetic Flux:



Magnetic flux

(i) The magnetic flux associated with an area placed in a magnetic field is equal to the total number of magnetic lines of force passing naturally through that area. It can also be defined as The magnetic flux or flux linkage (ϕ) linked with the surface area A, placed in a magnetic field is equal to the total amount of magnetic lines of force passing through a surface.

Resultant flux through the surface is expressed as

$$\phi = \oint B \cdot dA = BA\cos\theta$$

Θ is the angle between the normal and magnetic field vector. If Θ = 0

$\phi = BA$

If Θ = 90° then ϕ = 0

Magnetic flux is a scalar quantity. It's measured in weber (wb)

**MAGNETIC FORCE ON A CHARGE MOVING IN A MAGNETIC FIELD**

A moving charge sets up its own magnetic field because motion of a charge is essentially a current. Thus a moving charge placed in a magnetic field due to other sources is acted upon by a magnetic force. The magnitude of the magnetic force ($F_B$) acting on a charge moving in a magnetic field is proportional to the speed of the charge ($v$), the strength of the field ($B$), the charge ($q$) and the sine of the angle ($\theta$) between the field and the velocity of the charge.

$$F_B = |q|vB\ sin\ (\theta)$$

## MAGNETIC FORCE ON A CURRENT CARRYING STRAIGHT WIRE PLACED IN A MAGNETIC FIELD

The magnitude of the magnetic force ($F_B$) on a current carrying straight wire placed in a magnetic field is directly proportional to the current ($I$), length ($l$) of the wire, strength of the field ($B$) and the sine of the angle ($\theta$) between the wire (whose direction is taken to be the direction of the current) and the magnetic field.

$$F_B = IlB\ sin\ (\theta)$$

## Faraday's Laws of Electromotive Force:

Two laws were proposed by Michael Faraday based on his studies associated with the electromagnetic induction phenomenon, to determine the magnitude of the induced e.m.f. in a circuit

A) **First law:** An induced emf is formed in a circuit whenever the number of magnetic lines of force (magnetic flux) travelling through it changes.
B) **Second law**: The magnitude of induced emf is proportional to the rate of change of magnetic flux linking the circuit. I.e

$$e = -\frac{d\phi}{dt}\ .\text{For N turns}\ e = -\frac{Nd\phi}{dt}$$

Negative sign indicates that induced emf (e ) opposes the change of flux.

**Factors Influencing Induced Electromotive Force (emf):**

1. Rate of Change of Magnetic Flux: The greater the rate of change of magnetic flux through a circuit, the greater the induced EMF. This can be achieved by changing the magnetic field strength, the area of the loop, or the angle between the magnetic field and the loop.

2. Number of Turns in the Coil: Increasing the number of turns in the coil increases the induced EMF. This is because each turn of the coil contributes to the total magnetic flux through the circuit.

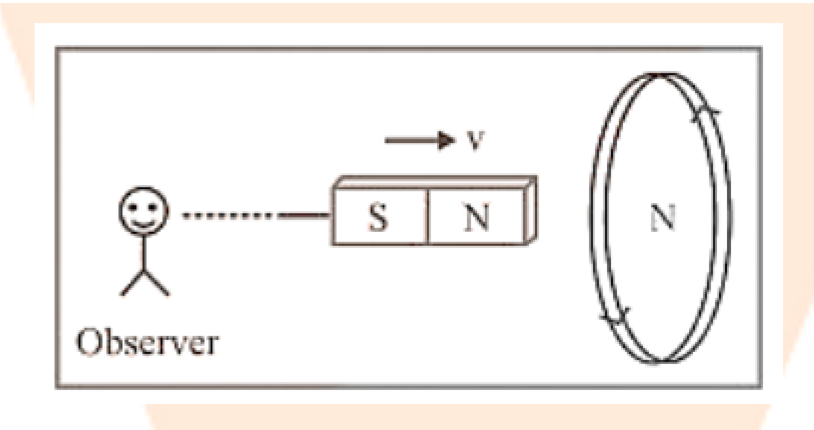
## Methods of Producing induced E.M.F.

Since e.m.f. is induced in a circuit, whenever the amount of magnetic flux linked with the circuit is changed. Hence there are three methods of producing such an induced e.m.f.
(i) By adjusting the magnetic field B's magnitude,
(ii) By altering region , i.e., shrinking, stretching, or modifying the coil's shape.
(iii) By changing the angle between the direction of and the normal to the surface area , i.e. modifying the surface area's and magnetic field's relative orientation.

## Lenz's Law:

In 1835,H.F. Lenz a Russian scientist discovered the direction of emf/current induced in a circuit in his experiment associated with electromagnetic induction concept.The direction of induced emf/induced current is determined by this law.
The direction of induced emf or current in a circuit, according to this law, is such that it opposes the source that produces it.

- When the N-pole of a bar magnet advances towards the coil, the flux linked with the loop increases, causing an emf. Induced current flows through the loop circuit. As the north pole is approaching the loop, current is induce in the loop directed in such a way that the front face of the loop behaves like the north pole. Therefore induced current as seen by observer is in anticlockwise direction. As shown below




Source; www.vedantu.com

The cause of generated emf in the coil can also be linked to as relative motion of the loop. As a result, the relative motion between the two objects works against the cause.The loop and the incoming magnet should be in opposition. As a result, the loop will begin to move in the direction of the magnet is moving.

**Factors Affecting Magnetic Flux**

I. Strength of the Magnetic Field: A stronger magnetic field results in a greater magnetic flux through a given area.
II. Area Perpendicular to the Field Lines: Increasing the area perpendicular to the magnetic field lines increases the magnetic flux.
III. Orientation of the Area: The angle between the magnetic field and the normal to the area affects the magnitude of magnetic flux. Maximum flux occurs when the area is perpendicular to the magnetic field.

## Applications of Magnetic Flux

1. Electromagnetic Induction: Magnetic flux plays a crucial role in electromagnetic induction, where changes in magnetic flux induce electromotive forces (EMFs) in conductors.
2. Magnetic Sensors: Devices such as Hall effect sensors utilize changes in magnetic flux to detect the presence, strength, and direction of magnetic fields.
3. Magnetic Resonance Imaging (MRI): MRI machines use magnetic flux to generate detailed images of the internal structures of the human body by detecting the response of hydrogen atoms to changes in magnetic fields.

# TOPIC 5 : TRANSFORMER

Transformers use electromagnetic induction to change the voltage level of alternating current (AC) electricity. By varying the number of turns in the primary and secondary coils, transformers can step up or step down the voltage as needed for transmission and distribution.

# TOPIC 5 : CAPACITORS

A *capacitor* is two conductors separated by an insulator. A capacitor is used to store charges or electrical energy. When a capacitor is connected to a potential difference, electrons are transferred from one of the conductor to the other and both conductors acquire equal but opposite charges. The charge accumulated by a capacitor is directly proportional to the potential difference between the plates. The constant of proportionality (ratio) between the charge and the potential difference is called the capacitance (*C*) of the capacitor.

$$Q = C\Delta V$$

$Q$ represents the charge accumulated by the capacitor and $\Delta V$ stands for the potential difference between the two conductors of the capacitor. The unit of measurement for capacitance is C/V which is defined to be the Farad and abbreviated as F. The following diagram shows the circuit symbol for a capacitor.

The capacitance of a capacitor depends only on the geometry of the capacitor. For example the capacitance of a parallel plate capacitor depends only on the area of the plates and the separation between the plates. The capacitance of a parallel plate capacitor is directly proportional to the area of the plates and inversely proportional to the distance between the plates.

$$C_{||} = \varepsilon_o A/d$$

$C_{||}$ is the capacitance of a parallel plate capacitor (in vacuum or approximately air) of area $A$ separated by a distance $d$. $\varepsilon_o$ is a universal constant called electrical permittivity of vacuum. It is related with Coulomb's constant as $\varepsilon_o = 1/(4\pi k)$. Its value is $8.85e\text{-}12$ F/m.

*Example*: Calculate the capacitance of a capacitor that stores a charge of $50$ C when connected to a potential difference of $100$ V.

*Solution*: $Q = 50$ C; $\Delta V = 100$ V; $C = ?$

$$Q = C\,\Delta V$$

$$C = Q/\Delta V = 50/100 \text{ F} = 0.5 \text{ F}$$

# ELECTRICAL ENERGY STORED BY A CAPACITOR

When the two conductors of a charged capacitor are connected by a conducting wire, charges will flow from one of the conductors to the other which indicates that there is stored electrical energy in a charged capacitor. As a capacitor is charged, the potential difference between the plates will increase linearly. This means the charges are not being transported through a constant potential difference. For a certain small charge $dQ$ the change in potential energy (which is equal to the energy stored by the capacitor) is equal to the product of the charge $dQ$ and the potential difference $\Delta V$ across which it was transported. Thus the energy ($dU$) stored in transporting this charge is given as $dU = dQ\Delta V$. These contributions from all the charges transported should be added to get the total energy stored. This sum can be obtained from the graph of potential difference versus charge as the area enclosed between the potential difference versus charge curve and the charge axis. Since the graph is linear, the total energy is equal to the area of a right angled triangle of base $Q$ (total charge stored) and height $\Delta V$ (potential difference corresponding to the charge $Q$).

$$U = Q\Delta V/2$$

$U$ stands for electrical energy stored by a capacitor of charge $Q$ and potential difference $\Delta V$. An expression for $U$ in terms of capacitance and potential difference can be obtained by replacing $Q$ by $C\Delta V$.

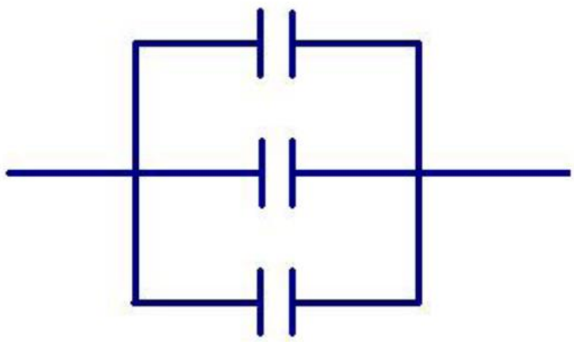
$$U = C\Delta V^2/2$$

Also, it can be expressed in terms of capacitance and charge by replacing $\Delta V$ by $Q/C$.

$$U = Q^2/(2C)$$

# PARALLEL COMBINATION OF CAPACITORS

Parallel connection is branched connection. The following diagram shows three capacitors connected in parallel.



The parts of each capacitor that are connected by conducting wires are at the same potential because there is no potential drop across a conducting wire. This means capacitors connected in parallel have the same potential difference which is also equal to the total potential difference across the combination.

$$\Delta V = \Delta V_1 = \Delta V_2 = \Delta V_3 = \ldots$$

$\Delta V_1$, $\Delta V_2$, $\Delta V_3$ … are the potential differences across capacitors $C_1$, $C_2$, $C_3$, … connected in parallel. $\Delta V$ is the potential difference across the combination. The total charge accumulated by capacitors in parallel is equal to the sum of the charges of the individual capacitors.

$$Q = Q_1 + Q_2 + Q_3 + \ldots$$

$Q_1$, $Q_2$, $Q_3$, … are charges accumulated by capacitors $C_1$, $C_2$, $C_3$, … connected in parallel. $Q$ is the total charge accumulated by the combination.

*Equivalent Capacitance* of ($C_{eq}$) a combination of capacitors is the single capacitor that can replace the combination with the same effect. It is equal to the ratio between the total charge of the combination and the total potential difference across the combination.

$$C_{eq} = Q / \Delta V$$

An expression for the equivalent capacitance of capacitors in parallel in terms of the capacitances can be obtained by starting from the fact that the total charge is equal to the sum of the individual charges, by replacing each charge with the product of its capacitance and potential difference, and by using the fact that all the potential differences are equal. After removing the common factor, potential difference, the following expression for the equivalent capacitance of capacitors connected in series can be obtained.

$$C_{eq} = C_1 + C_2 + C_3 + \ldots$$

# SERIES COMBINATION OF CAPACITORS

*Series connection* is connection in a single line. The following diagram shows the series combination of three capacitors.

When a series combination of capacitors is connected to a potential difference, charges will be transferred from one of the conductors directly connected to the potential difference to the other conductor connected directly to the potential difference. The other conductors are charged by induction. Thus the charges of all the capacitors are equal and they are equal to the total charge stored by the combination.

$$Q = Q_1 = Q_2 = Q_3 = \dots$$

$Q_1$, $Q_2$, $Q_3$, … are charges accumulated by capacitors $C_1$, $C_2$, $C_3$, … connected in series. $Q$ is the total charge accumulated by the combination. The total potential difference across the combination is equal to the sum of the potential differences across the individual capacitors.

$$\Delta V = \Delta V_1 + \Delta V_2 + \Delta V_3 + \dots$$

$\Delta V_1$, $\Delta V_2$, $\Delta V_3$ … are the potential differences across capacitors $C_1$, $C_2$, $C_3$, … connected in parallel. $\Delta V$ is the potential difference across the combination.

An expression for the equivalent capacitance of capacitors in series in terms of the capacitances can be obtained by starting from the fact that the total potential difference is equal to the sum of the individual potential differences, by replacing each potential difference with the ratio between its charge and its capacitance, and by using the fact that all the charges are equal. After removing the common factor, charge, the following expression for the equivalent capacitance of capacitors connected in series can be obtained.

$$1 / C_{eq} = 1 / C_1 + 1 / C_2 + 1 / C_3 + \dots$$

For two capacitors, this expression can be simplified by direct addition: $1 / C_{eq} = (C_1 + C_2) / (C_1 \; C_2)$. And an expression for the equivalent capacitance can be obtained by inverting both sides of the equation.

$$C_{eq} = C_1 \; C_2 / (C_1 + C_2)$$

# SIMPLE A.C CIRCUIT

An alternating current (a .c ) changes its direction periodically. A.C are produced by alternating voltages. Alternating currents and alternating voltage are repesented follows.

## Inductors in AC Circuits

Consider the circuit containing a pure inductive coil of inductance L Henry. When an alternating voltage V (RMS) is applied across the coil, an alternating current I (RMS) will flow through the circuit. Due to this alternating current, a back emf (e) is induced in the coil due to inductance of it. This back emf at every instant opposes the any change in current through the coil.

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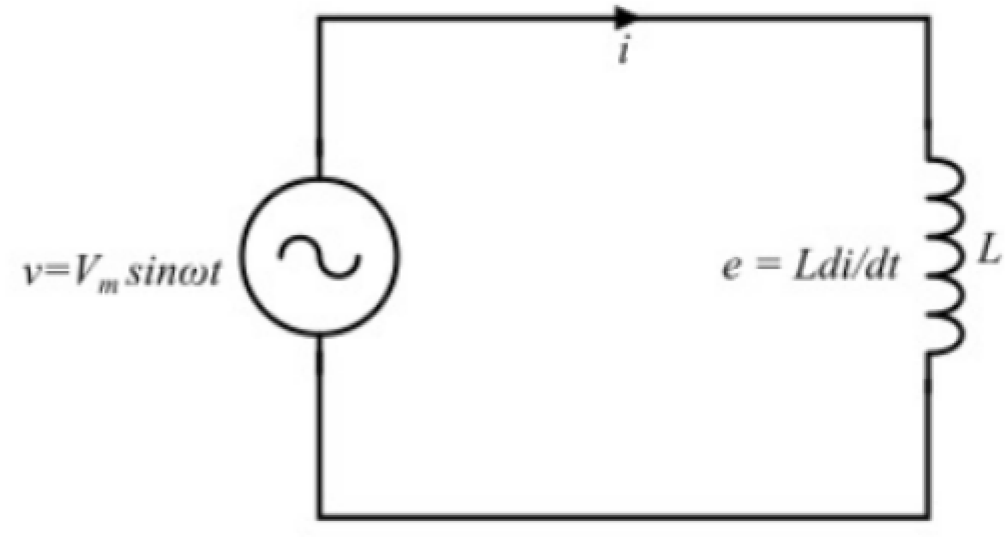


Let the applied alternating voltage is

$$u = V_m \sin \omega t$$

8Certainly! Here's a structured lecture note on capacitors that covers fundamental concepts and applications:

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## Capacitors: Lecture Notes

### 1. Introduction to Capacitors

- **Definition:** A capacitor is an electronic component that stores electrical energy in an electric field.
- **Symbol:** \( C \)
- **Unit:** Farad (F)

### 2. Capacitance

- **Capacitance (C):** The ability of a capacitor to store charge.
- **Formula:**
  \[
  C = \frac{Q}{V}
  \]
  where \( Q \) is the charge stored on the capacitor and \( V \) is the voltage across it.

### 3. Capacitor Construction

- **Components:**
  - Two conductive plates (usually metal) separated by a dielectric (insulating material).
  - Leads for connection.

### 4. Capacitor Types

- **Fixed Capacitors:**
  - Ceramic capacitors
  - Electrolytic capacitors
  - Film capacitors

- **Variable Capacitors:**
  - Used for tuning circuits, with adjustable capacitance.

### 5. Capacitor Behavior

- **Charging and Discharging:**
  - **Charging:** Capacitor charges exponentially towards the applied voltage.
  - **Discharging:** Capacitor releases stored energy when discharged.

- **Energy Stored:**
  $$
  E = \frac{1}{2} CV^2
  $$

### 6. Series and Parallel Capacitors

- **Series Capacitors:**
  $$
  \frac{1}{C_{\text{total}}} = \frac{1}{C_1} + \frac{1}{C_2} + \ldots
  $$

- **Parallel Capacitors:**
  $$
  C_{\text{total}} = C_1 + C_2 + \ldots
  $$

### 7. Capacitors in Circuits

- **Filtering:** Smoothing out fluctuations in voltage.
- **Timing:** In timing circuits, capacitors determine the time intervals.

### 8. Applications of Capacitors

- **Power Supply Decoupling:** Filtering noise in power lines.
- **Signal Coupling:** Allowing AC signals while blocking DC.
- **Timing Circuits:** Oscillators, timers, and phase shifters.

### 9. Capacitor Characteristics

- **Temperature Coefficient:** Capacitance varies with temperature.
- **Leakage:** Small current leakage due to imperfect dielectrics.

### 10. Capacitor Safety and Handling

- **Polarity:** Electrolytic capacitors are polarized; observe correct polarity.3

### Conclusion

Capacitors are versatile components crucial in electronics for energy storage, signal coupling, timing, and filtering applications. Understanding their characteristics and behavior is fundamental for designing and troubleshooting electronic circuits.

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These notes cover essential aspects of capacitors, providing a foundational understanding suitable for introductory lectures.4