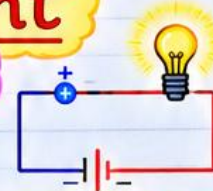




Effects of Current

Handwritten Notes

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Effect of Current

1. Electric Charge and Electric Current

1. Electric Charge

- Electric charge is a fundamental property of matter due to which it experiences electric force.
- It is denoted by Q or q .
- SI unit : coulomb (C)
- It is a scalar quantity.
- It can be positive or negative.
- Like charges repel and unlike charges attract.

Two types of charge :

- Positive charge (+)
- Negative charge (-)

Charge on electron = -1.6×10^{-19} C

Charge on proton = $+1.6 \times 10^{-19}$ C

Charge on neutron = 0



2. Conservation of Charge

- Charge can neither be created nor destroyed.
- It can only be transferred from one body to another.
- The total charge of an isolated system remains constant.

Example : When a glass rod is rubbed with a silk cloth, electrons are transferred from the glass rod to the cloth. The rod becomes positively charged and the cloth becomes negatively charged, but the total charge remains zero.

3. Conductors and Insulators

- Conductors :** Substances which allow electric charge to flow through them.

Examples : metals (copper, aluminium, silver), human body, salt solution etc.

- Insulators :** Substances which do not allow electric charge to flow.

Examples : rubber, plastic, glass, dry wood, air etc.

Reason :

In conductors, electrons are loosely bound and can move freely. In insulators, electrons are tightly bound and cannot move freely.

4. Electric Current

- Electric current is the rate of flow of electric charge through a conductor.
- It is denoted by I .

$$I = \frac{Q}{t} \quad \left\{ \begin{array}{l} I = \text{current (A)} \\ Q = \text{charge (C)} \\ t = \text{time (s)} \end{array} \right.$$

- SI unit : ampere (A)

$$1 \text{ A} = \frac{1 \text{ coulomb}}{1 \text{ second}}$$

Types of current flow :

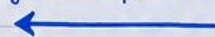
- Conventional current :**

Flow of positive charge from positive to negative terminal.



- Electron current :**

Flow of electrons (negative charge) from negative to positive terminal.



Examples and Numericals

Example 1 : A charge of 12 C flows through a wire in 3 s. Find the current.

Solution : $I = \frac{Q}{t} = \frac{12}{3} = 4 \text{ A}$

Example 2 : How much charge flows through a conductor in 10 s if the current is 0.5 A ?

Solution : $Q = I \times t = 0.5 \times 10 = 5 \text{ C}$

Example 3 : What is the time taken for 24 C of charge to flow if the current is 2 A ?

Solution : $t = \frac{Q}{I} = \frac{24}{2} = 12 \text{ s}$

Practice Questions :

- If 8 C of charge flows through a wire in 4 s, what is the current ?
(a) 1 A (b) 2 A (c) 4 A (d) 8 A
- How much charge flows in 5 min through a wire if current is 3 A ?
(a) 15 C (b) 300 C (c) 600 C (d) 900 C

Effect of Current

2. Electric Potential

1. Meaning and Definition

- Electric potential at a point is the amount of electric potential energy possessed by a unit positive charge placed at that point.
- It is denoted by V .
- Electric potential is a scalar quantity.
- SI unit : volt (V).
- 1 volt = 1 joule per coulomb ($1 \text{ V} = 1 \text{ J/C}$).
- It depends on the position in an electric field.

Electric potential due to a point charge :

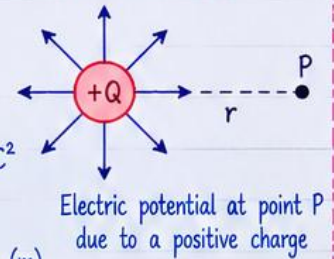
$$V = \frac{kQ}{r}$$

where,

$$k = \frac{1}{4\pi\epsilon_0} = 9 \times 10^9 \text{ N m}^2/\text{C}^2$$

Q = charge (C)

r = distance from the charge (m)



2. Electric Potential Energy

- When a charge is placed in an electric field, it possesses electric potential energy (U).
- Electric potential is the potential energy per unit charge.

$$V = \frac{U}{q} \quad \begin{cases} V = \text{electric potential (V)} \\ U = \text{electric potential energy (J)} \\ q = \text{charge (C)} \end{cases}$$

Example 1 :

A charge of $2 \mu\text{C}$ is placed at a point where the potential is 100 V. Find the electric potential energy.

Given : $V = 100 \text{ V}$, $q = 2 \mu\text{C} = 2 \times 10^{-6} \text{ C}$

Formula : $U = qV$

Solution : $U = 2 \times 10^{-6} \times 100$
 $= 2 \times 10^{-4} \text{ J}$

3. Work Done and Electric Potential

- The work done in bringing a charge q from infinity to a point in an electric field is equal to the electric potential energy of the charge.
- Thus, electric potential at a point is also defined as the work done per unit positive charge in bringing it from infinity to that point.

$$V = \frac{W}{q} \quad \begin{cases} W = \text{work done (J)} \\ q = \text{charge (C)} \\ V = \text{electric potential (V)} \end{cases}$$

Example 2 :

If 5 J of work is done in bringing a charge of 10 mC from infinity to a point, what is the electric potential at that point?

Given : $W = 5 \text{ J}$, $q = 10 \text{ mC} = 0.01 \text{ C}$

Formula : $V = \frac{W}{q}$

Solution : $V = \frac{5}{0.01} = 500 \text{ V}$

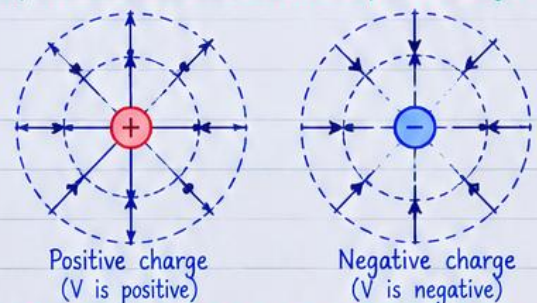
Note :

- Electric potential is positive for a positive charge and negative for a negative charge.
- At infinity, electric potential is taken as zero ($V=0$).

4. Equipotential Surface

- A surface on which the electric potential is the same at all points is called an equipotential surface.
- No work is done in moving a charge along an equipotential surface because the potential does not change.
- Equipotential surfaces are always perpendicular to the electric field lines.

Equipotential surfaces around a point charge :



5. Key Points

- Electric potential is a scalar quantity.
- It is measured in volt (V).
- It depends on the distance and magnitude of charge.
- It is positive near a positive charge and negative near a negative charge.
- Potential is zero at infinity.

Formula for potential due to a point charge :

- $V = \frac{kQ}{r}$
- $k = 9 \times 10^9 \text{ N m}^2/\text{C}^2$
- If Q is +ve, V is +ve
- If Q is -ve, V is -ve

Effect of Current

3. Potential Difference (Voltage)

1. Meaning and Definition

- The potential difference between two points in an electric field is the work done per unit positive charge in moving a charge from one point to the other.
- It is denoted by V or ΔV .
- SI unit : volt (V).
- $1 \text{ V} = 1 \text{ joule per coulomb}$ ($1 \text{ V} = 1 \text{ J/C}$).

$$V = \frac{W}{Q} \quad \begin{cases} V = \text{potential difference (V)} \\ W = \text{work done (J)} \\ q = \text{charge (C)} \end{cases}$$

Potential difference between two points A and B :



V_{AB} = Work done in moving 1 C charge from A to B.

$$V_{AB} = \frac{W_{AB}}{Q}$$

2. Relation with Electric Potential

- Electric potential at a point is the potential energy per unit charge at that point with respect to a reference point (usually taken at infinity).
- Potential difference between two points A and B is the difference of their electric potentials.

$$V_{AB} = V_A - V_B$$

Example 1 :

The electric potential at point A is 20 V and at point B is 5 V. Find the potential difference between A and B.

Given : $V_A = 20 \text{ V}$, $V_B = 5 \text{ V}$

Formula : $V_{AB} = V_A - V_B$

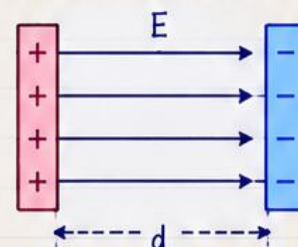
Solution : $V_{AB} = 20 - 5 = 15 \text{ V}$

3. Potential Difference in a Uniform Electric Field

- In a uniform electric field, the potential difference between two points separated by distance d along the field is given by :

$$V = E d \quad \begin{cases} V = \text{potential difference (V)} \\ E = \text{electric field strength (V/m)} \\ d = \text{distance (m)} \end{cases}$$

Uniform electric field between two plates :



Example 2 : The electric field between two parallel plates is $5 \times 10^3 \text{ V/m}$. The separation between the plates is 0.02 m. Find the potential difference between the plates.

Given : $E = 5 \times 10^3 \text{ V/m}$, $d = 0.02 \text{ m}$

Formula : $V = E d$ Solution : $V = 5 \times 10^3 \times 0.02 = 100 \text{ V}$

Note :

- Potential is the property of a single point, while potential difference is the difference in potential between two points.
- Potential difference can be measured with a voltmeter.

4. Sources of Potential Difference

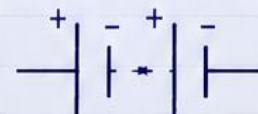
- A cell or battery maintains a potential difference between its two terminals by chemical action.
- The positive terminal is at higher potential and the negative terminal is at lower potential.
- The potential difference is equal to the work done by the cell in moving a unit positive charge from the negative to the positive terminal inside the cell.

Symbol and diagram of a cell :



Longer line : +ve terminal
Shorter line : -ve terminal

Symbol of a battery :



Combination of two or more cells.

Effect of Current

4

4. Ohm's Law

1. Statement of Ohm's Law

- At a constant temperature, the current flowing through a conductor is directly proportional to the potential difference across its ends.
- Mathematically,

$$V = IR \quad \begin{cases} V = \text{potential difference (V)} \\ I = \text{current (A)} \\ R = \text{resistance } (\Omega) \end{cases}$$

Meaning :

- If the potential difference is increased, the current also increases in the same ratio, provided the temperature remains constant.
- The V - I ratio (V/I) is constant for a conductor.

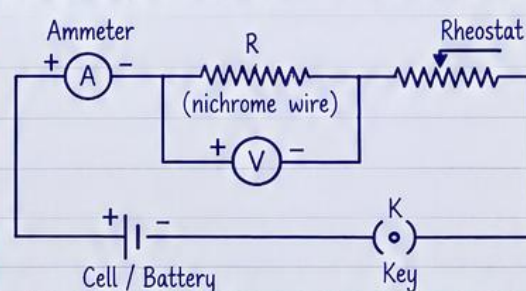
$$R = \frac{V}{I}$$

$\rightarrow$ R is constant (at constant temperature)

2. Experimental Verification

- A resistor (nichrome wire) is connected in series with a battery, key, rheostat and ammeter.
- A voltmeter is connected in parallel with the resistor.
- The current is changed by using a rheostat.
- Ammeter and voltmeter readings are noted and a V - I graph is plotted.

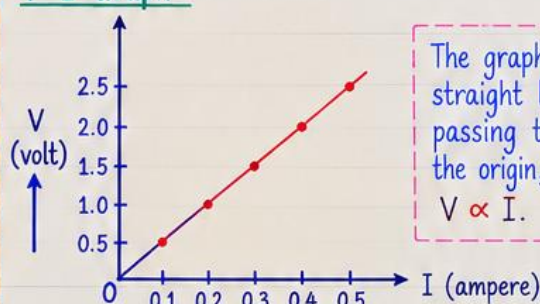
Circuit diagram for verification of Ohm's law :



3. Observations

S. No.	Potential difference V (volt)	Current I (ampere)	V/I (ohm)
1.	0.5	0.1	5
2.	1.0	0.2	5
3.	1.5	0.3	5
4.	2.0	0.4	5
5.	2.5	0.5	5

V-I Graph :



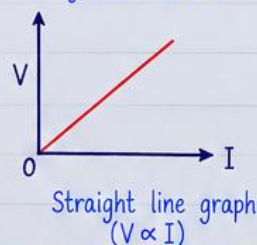
The graph is a straight line passing through the origin, showing $V \propto I$.

4. Limitations of Ohm's Law

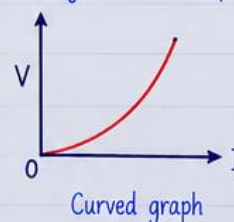
- It is valid only when physical conditions like temperature, pressure etc. remain constant.
- It is not valid for non-ohmic conductors such as filament lamp, diode, transistor etc.
- At very high temperatures, the proportionality between V and I may not hold.

Ohmic and Non-Ohmic Conductors :

Ohmic conductor (e.g. metal wire)



Non-ohmic conductor (e.g. filament lamp)



5. Example

A current of 0.5 A flows through a resistor of 10Ω . Find the potential difference across it.

Given : $I = 0.5 \text{ A}$, $R = 10 \Omega$

Formula : $V = IR$

Solution : $V = 0.5 \times 10 = 5 \text{ V}$

Another Example

The potential difference across a conductor is 12 V and the current is 3 A. Calculate the resistance.

Given : $V = 12 \text{ V}$, $I = 3 \text{ A}$

Formula : $R = \frac{V}{I}$

Solution : $R = \frac{12}{3} = 4 \Omega$

5. Resistance and Resistivity

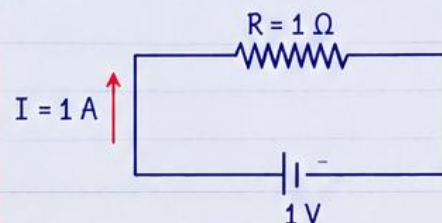
1. Electric Resistance

- The property of a conductor which opposes the flow of electric current through it is called electric resistance.
- It is denoted by R .
- SI unit : ohm (Ω).
- 1 ohm is the resistance of a conductor through which 1 A current flows when the potential difference across it is 1 V.

$$R = \frac{V}{I} \quad \begin{cases} R = \text{resistance } (\Omega) \\ V = \text{potential difference (V)} \\ I = \text{current (A)} \end{cases}$$

Physical meaning :

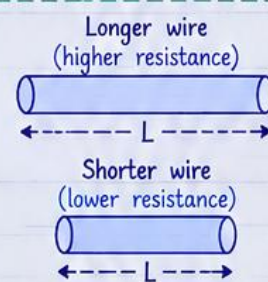
If a potential difference of 1 V is applied across a conductor and the current flowing through it is 1 A, then its resistance is 1 Ω .



2. Factors Affecting Resistance

The resistance of a conductor depends on :

- Length (L)** : $R \propto L$ (longer wire $\rightarrow$ higher resistance)
- Cross-sectional area (A)** : $R \propto \frac{1}{A}$ (thicker wire $\rightarrow$ lower resistance)
- Nature of material** : different materials have different resistances.
- Temperature (T)** : for metals, resistance increases with rise in temperature.



3. Resistivity

- The resistance of a conductor depends on its material. This property of a material is called resistivity (ρ).
- It is denoted by ρ (rho).
- SI unit : ohm metre ($\Omega \text{ m}$).
- Resistance of a uniform wire is given by :

$$R = \frac{\rho L}{A} \quad \begin{cases} \rho = \text{resistivity } (\Omega \text{ m}) \\ L = \text{length of conductor (m)} \\ A = \text{cross-sectional area (m}^2\text{)} \\ R = \text{resistance } (\Omega) \end{cases}$$

Derivation :

Resistance is directly proportional to length (L) and inversely proportional to cross-sectional area (A).

$$R \propto L \quad \text{and} \quad R \propto \frac{1}{A}$$

$$R \propto \frac{L}{A} \Rightarrow R = \frac{\rho L}{A}$$

Unit of resistivity :

$$\rho = \Omega \text{ m}$$

1 $\Omega \text{ m}$ = resistance of a wire of length 1 m and area 1 m^2 .

4. Resistivity of Some Materials

Material	Resistivity ($\Omega \text{ m}$)	Material	Resistivity ($\Omega \text{ m}$)
Silver	1.6×10^{-8}	Iron	1.0×10^{-7}
Copper	1.7×10^{-8}	Nichrome	1.1×10^{-6}
Aluminium	2.8×10^{-8}	Manganin	4.4×10^{-6}
Tungsten	5.6×10^{-8}	Rubber	$\sim 10^{13}$

5. Numerical Examples

Example 1 : A wire of length 2 m and cross-sectional area $1 \times 10^{-6} \text{ m}^2$ has a resistivity of $2.5 \times 10^{-8} \Omega \text{ m}$. Find its resistance.

Given : $\rho = 2.5 \times 10^{-8} \Omega \text{ m}$
 $L = 2 \text{ m}$
 $A = 1 \times 10^{-6} \text{ m}^2$

Formula : $R = \frac{\rho L}{A}$

Solution : $R = \frac{2.5 \times 10^{-8} \times 2}{1 \times 10^{-6}}$
 $= 5 \times 10^{-2} \Omega = 0.05 \Omega$

Example 2 : The resistance of a wire is 4 Ω . Its length is 1 m and its cross-sectional area is $2 \times 10^{-6} \text{ m}^2$. Find the resistivity.

Given : $R = 4 \Omega$
 $L = 1 \text{ m}$
 $A = 2 \times 10^{-6} \text{ m}^2$

Formula : $\rho = \frac{R A}{L}$

Solution : $\rho = \frac{4 \times 2 \times 10^{-6}}{1}$
 $= 8 \times 10^{-6} \Omega \text{ m}$

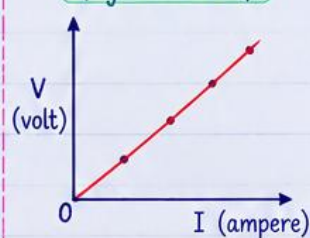
6. Ohm's Law Applications

1. Ohmic and Non-Ohmic Conductors

- Conductors which obey Ohm's law ($V \propto I$) at constant temperature are called ohmic conductors.
- They have a constant resistance and give a straight line V-I graph.
- Examples:** metals like copper, aluminium, nichrome etc.
- Conductors which do not obey Ohm's law are called non-ohmic conductors.
- They do not have a constant resistance and give a curved V-I graph.
- Examples:** filament lamp, diode, transistor, electrolytes etc.

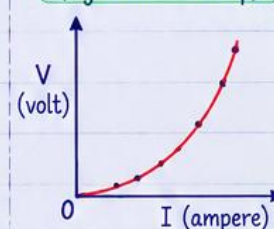
V-I graphs :

Ohmic conductor
(e.g. metal wire)



$V \propto I$
(straight line graph)
Resistance is constant.

Non-ohmic conductor
(e.g. filament lamp)

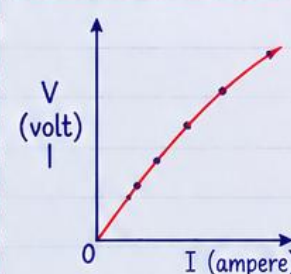


V is not directly proportional to I
(curved graph)
Resistance is not constant.

2. Comparison between Ohmic and Non-Ohmic Conductors

Property	Ohmic Conductor	Non-Ohmic Conductor
Ohm's law	Obeys Ohm's law	Does not obey Ohm's law
V-I graph	Straight line	Curved line
Resistance	Constant (at constant temperature)	Not constant
Examples	Copper, aluminium, nichrome	Filament lamp, diode, transistor, electrolyte
Behaviour	$V \propto I$	V not proportional to I

V-I characteristic of a filament lamp :

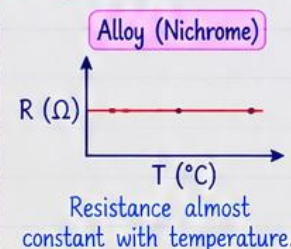
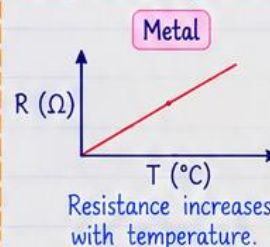


As current increases, the filament gets hot and its resistance increases, so the graph is curved.

3. Temperature Effect on Resistance

- For most metals, resistance increases with rise in temperature.
- For alloys like nichrome, the change in resistance with temperature is very small, so they are used in heating devices.

Graphs showing effect of temperature :



4. Practical Applications

- Ohmic conductors are used in circuits where constant resistance is required.
- Non-ohmic conductors are used in devices like bulbs, diodes and transistors.
- Nichrome is used in heaters because it has high resistance and can withstand high temperature.
- Electrical appliances are designed considering their resistance and power rating.

Examples of non-ohmic devices :



Filament lamp
(resistance increases with temperature)



Diode
(conducts current in one direction)



Transistor
(non-linear V-I characteristic)

5. Mixed Examples

Example 1 : A copper wire has a resistance of $10\ \Omega$. If the potential difference across it is $5\ \text{V}$, find the current.

Given : $R = 10\ \Omega$, $V = 5\ \text{V}$

Formula : $I = \frac{V}{R}$

Solution : $I = \frac{5}{10} = 0.5\ \text{A}$

Example 2 : A current of $2\ \text{A}$ flows through a resistor of $8\ \Omega$. Find the potential difference across it.

Given : $I = 2\ \text{A}$, $R = 8\ \Omega$

Formula : $V = IR$

Solution : $V = 2 \times 8 = 16\ \text{V}$

Example 3 : A wire of resistance $4\ \Omega$ carries a current of $0.5\ \text{A}$. Find the power dissipated.

Given : $R = 4\ \Omega$, $I = 0.5\ \text{A}$

Formula : $P = I^2 R$

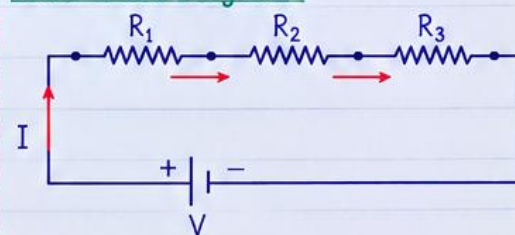
Solution : $P = (0.5)^2 \times 4$
 $= 0.25 \times 4 = 1\ \text{W}$

7. Series Combination of Resistors

1. Introduction

- Resistors are said to be in series when they are connected one after the other in a single path so that the same current flows through each resistor.
- The current remains the same in all the resistors but the potential difference gets distributed among them.

Series circuit diagram :



2. Equivalent Resistance

- If R_1 , R_2 and R_3 are connected in series, the equivalent resistance (R_s) is the sum of individual resistances.

$$R_s = R_1 + R_2 + R_3 + \dots + R_n$$

For two resistors in series :

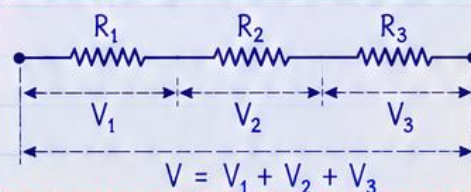


$$R_s = R_1 + R_2$$

3. Potential Difference in Series

- The total potential difference across the series combination is equal to the sum of potential differences across each resistor.
- $V = V_1 + V_2 + V_3 + \dots + V_n$

Potential difference across each resistor :



4. Current in Series

- The current through each resistor is the same.
- $I = I_1 = I_2 = I_3 = \dots = I_n$

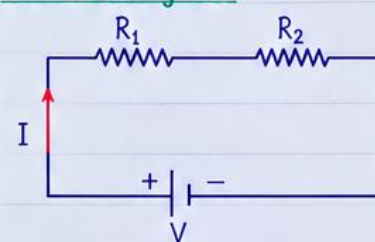
Key Points :

- Same current flows through all resistors.
- Total resistance is the sum of individual resistances.
- Potential difference is divided among the resistors.
- If more resistors are added in series, the total resistance increases and the current decreases for the same voltage.

5. Derivation of Equivalent Resistance (Two Resistors)

- Let two resistors R_1 and R_2 be connected in series across a battery of potential difference V .
- Current through each resistor = I .
- Potential difference across R_1 : $V_1 = I R_1$
- Potential difference across R_2 : $V_2 = I R_2$
- Total potential difference : $V = V_1 + V_2 = I R_1 + I R_2 = I(R_1 + R_2)$
- If R_s is the equivalent resistance, then $V = I R_s$
- So, $I R_s = I(R_1 + R_2) \Rightarrow R_s = R_1 + R_2$

Derivation diagram :



$$R_s = R_1 + R_2$$

6. Numerical Examples

Example 1 :

Three resistors of $2\ \Omega$, $3\ \Omega$ and $5\ \Omega$ are connected in series. Find the equivalent resistance.

Given : $R_1 = 2\ \Omega$, $R_2 = 3\ \Omega$, $R_3 = 5\ \Omega$

Formula : $R_s = R_1 + R_2 + R_3$

Solution : $R_s = 2 + 3 + 5 = 10\ \Omega$

Example 2 :

Two resistors of $4\ \Omega$ and $6\ \Omega$ are connected in series across a $12\ \text{V}$ battery. Find (i) total resistance (ii) current in the circuit (iii) potential difference across each resistor.

Given : $R_1 = 4\ \Omega$, $R_2 = 6\ \Omega$, $V = 12\ \text{V}$

Solution : (i) $R_s = 4 + 6 = 10\ \Omega$

(ii) $I = \frac{V}{R_s} = \frac{12}{10} = 1.2\ \text{A}$

(iii) $V_1 = I R_1 = 1.2 \times 4 = 4.8\ \text{V}$
 $V_2 = I R_2 = 1.2 \times 6 = 7.2\ \text{V}$

Effect of Current

8. Series Circuit Numericals

1. Example 1 : Find equivalent resistance and total current

Three resistors of $2\ \Omega$, $4\ \Omega$ and $6\ \Omega$ are connected in series with a 12 V battery. Find (i) equivalent resistance (ii) total current.

Given : $R_1 = 2\ \Omega$, $R_2 = 4\ \Omega$, $R_3 = 6\ \Omega$, $V = 12\text{ V}$

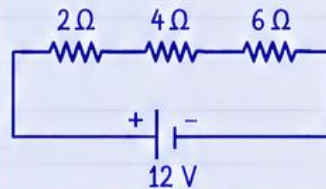
To find : (i) R_s (ii) I

Solution :

$$(i) R_s = R_1 + R_2 + R_3 \\ = 2 + 4 + 6 = 12\ \Omega$$

$$(ii) I = \frac{V}{R_s} = \frac{12}{12} = 1\text{ A}$$

Circuit diagram :



Formula for Series Circuit :

- $R_s = R_1 + R_2 + R_3 + \dots + R_n$
- $I = \frac{V}{R_s}$
- Voltage drop across each resistor : $V_1 = IR_1$, $V_2 = IR_2$, $V_3 = IR_3$
- $V = V_1 + V_2 + V_3$

Key Points :

- Same current flows through all resistors in series.
- Total resistance is the sum of all resistances.
- Voltage divides in proportion to resistance.
- $V = V_1 + V_2 + V_3$

2. Example 2 : Find voltage drop across each resistor

Three resistors $3\ \Omega$, $5\ \Omega$ and $7\ \Omega$ are connected in series with an 18 V battery. Find the current in the circuit and the voltage drop across each resistor.

Given : $R_1 = 3\ \Omega$, $R_2 = 5\ \Omega$, $R_3 = 7\ \Omega$, $V = 18\text{ V}$

Solution :

$$R_s = 3 + 5 + 7 = 15\ \Omega$$

$$I = \frac{V}{R_s} = \frac{18}{15} = 1.2\text{ A}$$

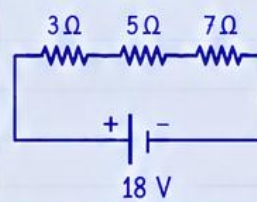
$$V_1 = IR_1 = 1.2 \times 3 = 3.6\text{ V}$$

$$V_2 = IR_2 = 1.2 \times 5 = 6.0\text{ V}$$

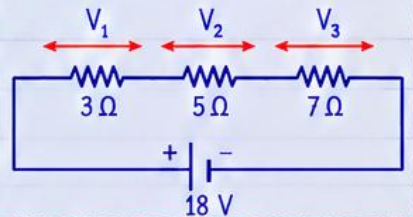
$$V_3 = IR_3 = 1.2 \times 7 = 8.4\text{ V}$$

$$\text{Check : } 3.6 + 6.0 + 8.4 = 18\text{ V}$$

Circuit diagram :



Voltage across resistors :



3. Example 3 : Find unknown resistance

Two resistors of $4\ \Omega$ and an unknown resistance R are connected in series with a 9 V battery. If the current in the circuit is 1.5 A , find the value of R .

Given : $R_1 = 4\ \Omega$, $R_2 = R$, $V = 9\text{ V}$, $I = 1.5\text{ A}$

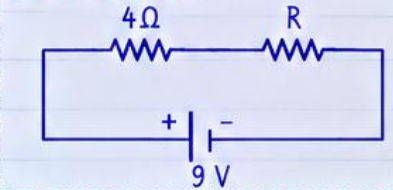
Solution :

$$R_s = \frac{V}{I} = \frac{9}{1.5} = 6\ \Omega$$

$$R_s = R_1 + R_2 \Rightarrow 6 = 4 + R$$

$$R = 6 - 4 = 2\ \Omega$$

Circuit diagram :



4. Example 4 : Multi-step problem

A 24 V battery is connected to three resistors in series. $R_1 = 2\ \Omega$, $R_2 = 4\ \Omega$ and $R_3 = 6\ \Omega$. Find (i) total current (ii) voltage across each resistor (iii) If the $6\ \Omega$ resistor is replaced by a $10\ \Omega$ resistor, find the new current.

(i) Original circuit :

$$R_s = 2 + 4 + 6 = 12\ \Omega$$

$$I = \frac{24}{12} = 2\text{ A}$$

$$V_1 = 2 \times 2 = 4\text{ V}$$

$$V_2 = 2 \times 4 = 8\text{ V}$$

$$V_3 = 2 \times 6 = 12\text{ V}$$

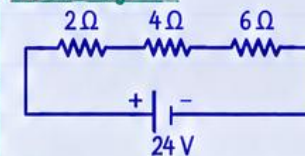
$$\text{Check : } 4 + 8 + 12 = 24\text{ V}$$

(ii) New circuit ($R_3 = 10\ \Omega$) :

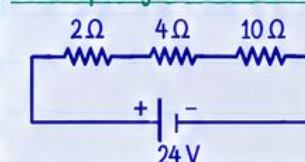
$$R_s = 2 + 4 + 10 = 16\ \Omega$$

$$I = \frac{24}{16} = 1.5\text{ A}$$

Circuit diagram :



After replacing $6\ \Omega$ with $10\ \Omega$:



Common Mistakes :

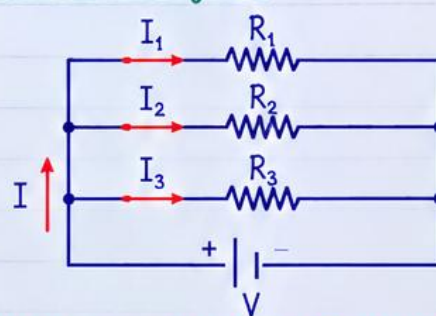
1. Using parallel formula instead of series formula.
2. Forgetting to add all resistances in series.
3. Incorrect unit conversions (Ω , V , A).
4. Not checking if the sum of voltage drops equals the supply voltage.
5. Arithmetic errors in addition or division.
6. Confusing current (I) with voltage (V).

9. Parallel Combination of Resistors

1. Introduction

- Resistors are said to be in parallel when their two ends are connected across the same two points.
- Each resistor has the same potential difference (voltage) across it.
- The current divides into different branches depending on the resistance of each branch.
- Parallel combination is used in household wiring so that each appliance gets the same voltage.

Parallel circuit diagram :

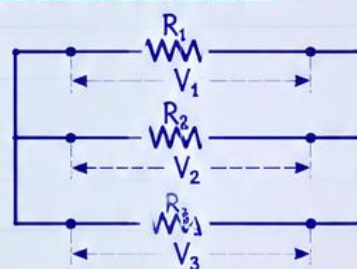


2. Potential Difference in Parallel

- The potential difference across each resistor is the same and is equal to the supply voltage.

$$V = V_1 = V_2 = V_3$$

Voltage across each resistor :



3. Current Division in Parallel

- The total current is equal to the sum of currents in the different branches.

$$I = I_1 + I_2 + I_3$$

- The current in each branch is inversely proportional to its resistance.

$$I_1 : I_2 : I_3 = \frac{1}{R_1} : \frac{1}{R_2} : \frac{1}{R_3}$$

Key Points :

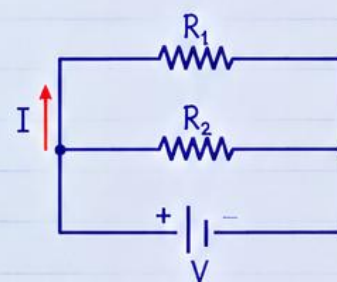
- Voltage is same across all resistors.
- Current divides into different branches.
- Branch with smaller resistance carries larger current.
- Total current is sum of branch currents.
- Equivalent resistance in parallel is always smaller than the smallest individual resistance.

4. Derivation of Equivalent Resistance (Two Resistors)

- Let two resistors R_1 and R_2 be connected in parallel across a battery of potential difference V .
- Current through R_1 : $I_1 = V/R_1$
- Current through R_2 : $I_2 = V/R_2$
- Total current : $I = I_1 + I_2 = V/R_1 + V/R_2$
- If R_p is the equivalent resistance, then $I = V/R_p$

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$$

Parallel combination of two resistors :



5. General Formula

- For n resistors in parallel,

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots + \frac{1}{R_n}$$

6. Numerical Example

Example : Two resistors of $4\ \Omega$ and $6\ \Omega$ are connected in parallel. Find the equivalent resistance.

Given : $R_1 = 4\ \Omega$, $R_2 = 6\ \Omega$

Formula : $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2}$

Solution : $\frac{1}{R_p} = \frac{1}{4} + \frac{1}{6} = \frac{3}{12} + \frac{2}{12} = \frac{5}{12}$
 $R_p = \frac{12}{5} = 2.4\ \Omega$

Another Example : Three resistors of $2\ \Omega$, $3\ \Omega$ and $6\ \Omega$ are connected in parallel. Find the equivalent resistance.

Given : $R_1 = 2\ \Omega$, $R_2 = 3\ \Omega$, $R_3 = 6\ \Omega$

Formula : $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

Solution : $\frac{1}{R_p} = \frac{1}{2} + \frac{1}{3} + \frac{1}{6} = \frac{3}{6} + \frac{2}{6} + \frac{1}{6} = \frac{6}{6}$
 $R_p = 1\ \Omega$

10. Numerical Examples (Parallel Combination)1. Problem 1 : Equivalent Resistance

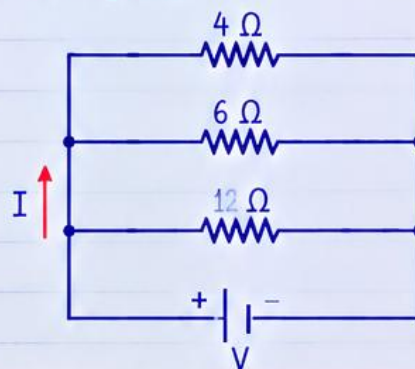
- Find the equivalent resistance of three resistors $4\ \Omega$, $6\ \Omega$ and $12\ \Omega$ connected in parallel.

Given : $R_1 = 4\ \Omega$, $R_2 = 6\ \Omega$, $R_3 = 12\ \Omega$

Formula :
$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Solution :
$$\begin{aligned}\frac{1}{R_p} &= \frac{1}{4} + \frac{1}{6} + \frac{1}{12} \\ &= \frac{3}{12} + \frac{2}{12} + \frac{1}{12} \\ &= \frac{6}{12} = \frac{1}{2} \\ R_p &= 2\ \Omega\end{aligned}$$

Circuit diagram :



Current division :

Current in each branch : $I_1 = \frac{V}{R_1}$, $I_2 = \frac{V}{R_2}$, $I_3 = \frac{V}{R_3}$

$$I_1 : I_2 : I_3 = \frac{1}{R_1} : \frac{1}{R_2} : \frac{1}{R_3}$$

2. Problem 2 : Current in each branch

- Three resistors $2\ \Omega$, $4\ \Omega$ and $8\ \Omega$ are connected in parallel across a $12\ \text{V}$ battery. Find the current through each resistor and total current.

Given : $R_1 = 2\ \Omega$, $R_2 = 4\ \Omega$, $R_3 = 8\ \Omega$, $V = 12\ \text{V}$

Solution :
$$\begin{aligned}I_1 &= \frac{V}{R_1} = \frac{12}{2} = 6\ \text{A} \\ I_2 &= \frac{V}{R_2} = \frac{12}{4} = 3\ \text{A} \\ I_3 &= \frac{V}{R_3} = \frac{12}{8} = 1.5\ \text{A}\end{aligned}$$

Total current :

$$\begin{aligned}I &= I_1 + I_2 + I_3 \\ &= 6 + 3 + 1.5 \\ &= 10.5\ \text{A}\end{aligned}$$

Check using equivalent resistance :

$$\begin{aligned}\frac{1}{R_p} &= \frac{1}{2} + \frac{1}{4} + \frac{1}{8} \\ &= \frac{4}{8} + \frac{2}{8} + \frac{1}{8} \\ &= \frac{7}{8} \Rightarrow R_p = \frac{8}{7}\ \Omega \\ I &= \frac{V}{R_p} = \frac{12 \times 8}{7} = 12 \times \frac{7}{8} \\ &= 10.5\ \text{A} \quad \checkmark\end{aligned}$$

3. Problem 3 : Unknown Resistor

- Two resistors $3\ \Omega$ and R are connected in parallel. The equivalent resistance is $1.5\ \Omega$. Find the value of R .

Given : $R_1 = 3\ \Omega$, $R_2 = R$, $R_p = 1.5\ \Omega$

Solution :
$$\begin{aligned}\frac{1}{R_p} &= \frac{1}{R_1} + \frac{1}{R_2} \\ \frac{1}{1.5} &= \frac{1}{3} + \frac{1}{R} \\ \frac{2}{3} &= \frac{1}{3} + \frac{1}{R} \Rightarrow \frac{1}{R} = \frac{2}{3} - \frac{1}{3} = \frac{1}{3} \\ R &= 3\ \Omega\end{aligned}$$

Key Points :

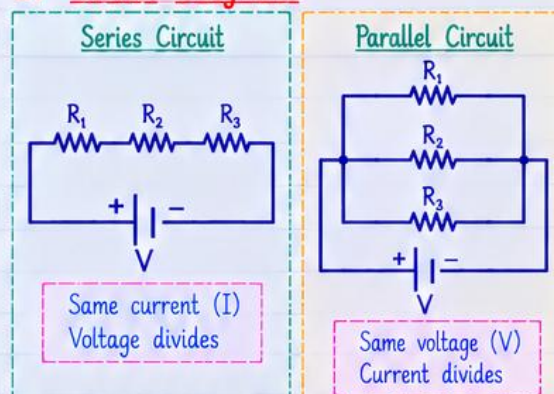
- Voltage is same across all resistors in parallel.
- Current divides inversely proportional to resistance.
- Equivalent resistance in parallel is always less than the smallest resistor.
- Total current is the sum of currents in all branches.
- Parallel combination is used in household wiring so that each appliance gets the same voltage.

11. Series vs Parallel Combination of Resistors

1. Key Differences

Property	Series Combination	Parallel Combination
Connection	End to end	Across the same two points
Equivalent resistance	$R_s = R_1 + R_2 + R_3 + \dots$	$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$
Current	Same through all resistors ($I_1 = I_2 = I_3$)	Divides in different branches ($I = I_1 + I_2 + I_3$)
Voltage	Divides among resistors ($V = V_1 + V_2 + V_3$)	Same across each branch ($V_1 = V_2 = V_3 = V$)
If one resistor is removed	Whole circuit breaks	Other branches keep working
Equivalent resistance value	Greater than any individual resistance	Smaller than the smallest individual resistance
Common use	Voltage division, appliances in series (rare)	Household wiring, multiple appliances, current division

2. Circuit Diagrams



3. Important Formulas

Series :

- $R_s = R_1 + R_2 + R_3 + \dots$
- $I_1 = I_2 = I_3 = I$
- $V = V_1 + V_2 + V_3$
- $V_k = IR_k$

Parallel :

- $\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \dots$
- $V_1 = V_2 = V_3 = V$
- $I = I_1 + I_2 + I_3$
- $I_k = \frac{V}{R_k}$

4. Example 1 : Compare current and voltage distribution

- Two resistors $4\ \Omega$ and $6\ \Omega$ are connected (i) in series (ii) in parallel to a 12 V battery. Find the current and voltage across each resistor in both cases.

(i) Series combination :

Given : $R_1 = 4\ \Omega$, $R_2 = 6\ \Omega$, $V = 12\text{ V}$

Solution :

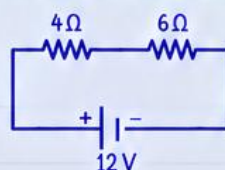
$$R_s = 4 + 6 = 10\ \Omega$$

$$I = \frac{V}{R_s} = \frac{12}{10} = 1.2\text{ A}$$

$$\text{Voltage across } 4\ \Omega : V_1 = IR_1 = 1.2 \times 4 = 4.8\text{ V}$$

$$\text{Voltage across } 6\ \Omega : V_2 = IR_2 = 1.2 \times 6 = 7.2\text{ V}$$

Check : $V_1 + V_2 = 4.8 + 7.2 = 12\text{ V} \checkmark$



(ii) Parallel combination :

Given : $R_1 = 4\ \Omega$, $R_2 = 6\ \Omega$, $V = 12\text{ V}$

Solution :

$$\frac{1}{R_p} = \frac{1}{4} + \frac{1}{6} = \frac{3}{12} + \frac{2}{12} = \frac{5}{12}$$

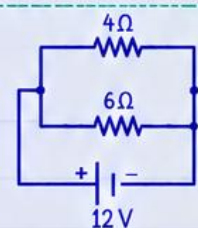
$$R_p = \frac{12}{5} = 2.4\ \Omega$$

$$\text{Current from battery : } I = \frac{V}{R_p} = \frac{12}{2.4} = 5\text{ A}$$

$$\text{Branch currents : } I_1 = \frac{V}{R_1} = \frac{12}{4} = 3\text{ A}$$

$$I_2 = \frac{V}{R_2} = \frac{12}{6} = 2\text{ A}$$

Check : $I_1 + I_2 = 3 + 2 = 5\text{ A} \checkmark$



5. Example 2 : Mixed series-parallel circuit

- In the given circuit, a $4\ \Omega$ resistor is in series with a parallel combination of $6\ \Omega$ and $3\ \Omega$. A 12 V battery is connected. Find (i) total current (ii) current through each resistor (iii) voltage across each resistor.

Solution :

Step 1 : Find equivalent of parallel part ($6\ \Omega$ and $3\ \Omega$)

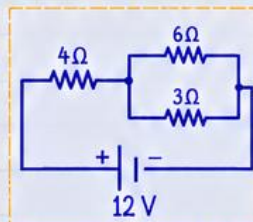
$$\frac{1}{R_p} = \frac{1}{6} + \frac{1}{3} = \frac{1}{6} + \frac{2}{6} = \frac{3}{6} \Rightarrow R_p = 2\ \Omega$$

Step 2 : Total resistance

$$R_{\text{total}} = 4 + 2 = 6\ \Omega$$

Step 3 : Total current from battery

$$I = \frac{V}{R_{\text{total}}} = \frac{12}{6} = 2\text{ A}$$



Step 4 : Voltages

$$\text{Voltage across } 4\ \Omega : V_1 = I \times 4 = 2 \times 4 = 8\text{ V}$$

$$\text{Voltage across parallel part : } V_p = 12 - 8 = 4\text{ V}$$

(Same across $6\ \Omega$ and $3\ \Omega$)

Step 5 : Currents in parallel branch

$$I_6 = \frac{V_p}{6} = \frac{4}{6} = 0.67\text{ A}$$

$$I_3 = \frac{V_p}{3} = \frac{4}{3} = 1.33\text{ A}$$

Check : $0.67 + 1.33 = 2\text{ A} \checkmark$

6. Practical Applications

- Series** : Used in decorative lights, old-style appliances, voltage dividers, fuses and current limiting.
- Parallel** : Used in household wiring so all appliances get the same voltage and work independently.

7. Common Mistakes

- Using parallel formula for series and vice versa.
- Forgetting to add all resistances in series.
- Assuming same current in parallel branches.
- Not checking if voltage drops add to the supply voltage.
- Arithmetic/units errors (Ω , V, A).

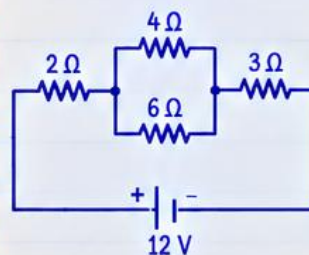
12. Applications of Resistor Combinations

1. Circuit Analysis : Steps

- Identify series and parallel combination in the circuit.
- Simplify step by step to find the equivalent resistance.
- Find total current using $I = \frac{V}{R_{eq}}$.
- Find current and voltage across each resistor.
- Check your answer using basic rules (KVL / KCL at simple level).

Example 1 : Series-Parallel Circuit Analysis

Find the current through each resistor and voltage drop across each resistor in the given circuit.



Solution :

$$R_p = \frac{4 \times 6}{4 + 6} = \frac{24}{10} = 2.4 \Omega$$

$$R_{eq} = 2 + 2.4 + 3 = 7.4 \Omega$$

$$\text{Total current : } I = \frac{12}{7.4} = 1.62 \text{ A}$$

$$\text{Voltage across } 2 \Omega : V_1 = 1.62 \times 2 = 3.24 \text{ V}$$

$$\text{Voltage across parallel part : } V_p = 1.62 \times 2.4 = 3.89 \text{ V}$$

$$\text{Voltage across } 3 \Omega : V_3 = 1.62 \times 3 = 4.86 \text{ V}$$

$$\text{Currents in parallel :}$$

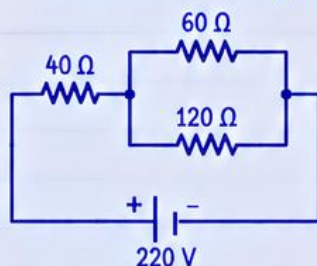
$$I_4 = \frac{3.89}{4} = 0.97 \text{ A}$$

$$I_6 = \frac{3.89}{6} = 0.65 \text{ A}$$

$$\text{Check : } 3.24 + 3.89 + 4.86 = 11.99 \text{ V} \approx 12 \text{ V} \checkmark$$

2. Example 2 : Household Circuit Analysis

- In a home, a 220 V supply is given to a circuit where a 40 Ω bulb is in series with a parallel combination of two appliances of 60 Ω and 120 Ω. Find the total current and the current through each appliance.



Solution :

$$R_p = \frac{60 \times 120}{60 + 120} = \frac{7200}{180} = 40 \Omega$$

$$R_{eq} = 40 + 40 = 80 \Omega$$

$$\text{Total current : } I = \frac{220}{80} = 2.75 \text{ A}$$

$$\text{Voltage across parallel part : } V_p = 2.75 \times 40 = 110 \text{ V}$$

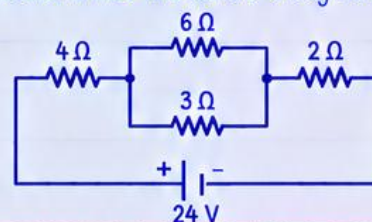
$$\text{Current in } 60 \Omega : I_1 = \frac{110}{60} = 1.83 \text{ A}$$

$$\text{Current in } 120 \Omega : I_2 = \frac{110}{120} = 0.92 \text{ A}$$

$$\text{Check : } 1.83 + 0.92 = 2.75 \text{ A} \checkmark$$

3. Example 3 : Mixed Combination (Challenging)

- Find the equivalent resistance and total current in the circuit shown. Also find current through 6 Ω resistor.



Solution :

$$R_p = \frac{6 \times 3}{6 + 3} = \frac{18}{9} = 2 \Omega$$

$$R_{eq} = 4 + 2 + 2 = 8 \Omega$$

$$\text{Total current : } I = \frac{24}{8} = 3 \text{ A}$$

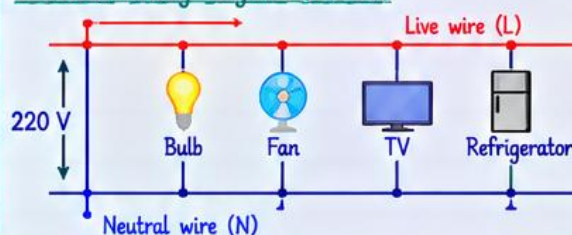
$$\text{Voltage across parallel part : } V_p = 3 \times 2 = 6 \text{ V}$$

$$\text{Current through } 6 \Omega : I_6 = \frac{6}{6} = 1 \text{ A} \checkmark$$

4. Household Wiring Principles (Relevant Concepts)

- In household wiring, appliances are connected in parallel across the main supply (usually 220 V).
- Each appliance gets the same voltage.
- Appliances work independently (switching one OFF does not affect others).
- Series connection is rarely used in home circuits because voltage divides and appliances will not get full supply.

Household wiring diagram (Parallel)



5. Conceptual Questions

Q1. Why are household appliances connected in parallel and not in series?

Ans : In parallel, each appliance gets the full supply voltage (220 V) and they work independently. In series, voltage divides and if one appliance fails, all stop working.

Q2. If two identical resistors are connected (i) in series (ii) in parallel, which combination has greater equivalent resistance?

Ans : Series combination has greater equivalent resistance ($R_s = 2R$) while parallel has smaller equivalent resistance ($R_p = \frac{R}{2}$).

6. Multiple Choice Questions (MCQs)

Q1. Three resistors 2 Ω, 4 Ω and 6 Ω are connected in parallel. The equivalent resistance is :
(A) 12 Ω (B) 6 Ω (C) 1 Ω (D) 2 Ω

Ans : (C) 1 Ω

$$\text{Explanation : } \frac{1}{R} = \frac{1}{2} + \frac{1}{4} + \frac{1}{6} = \frac{11}{12} \Rightarrow R = \frac{12}{11} \times 1 \Omega$$

Q2. In a series circuit, which of the following is same for all resistors?

(A) Voltage (B) Current (C) Resistance (D) Power

Ans : (B) Current

Explanation : Same current flows through all resistors in series.

Q3. A 6 Ω resistor is connected in parallel with a 3 Ω resistor. The current through 6 Ω resistor is 1 A. The current through 3 Ω resistor will be : (A) 0.5 A (B) 1 A (C) 2 A (D) 3 A

Ans : (C) 2 A

Explanation : In parallel, voltage is same so current $\propto \frac{1}{R}$.

$$I_3 = \left(\frac{R_6}{R_3} \right) \times I_6 = \left(\frac{6}{3} \right) \times 1 = 2 \text{ A}$$

13. Electric Power

1. Introduction

- Electric power is the rate at which electrical energy is converted into other forms of energy (heat, light, sound, etc.).
- It tells us how quickly electrical energy is used in a circuit.

2. Definition and SI Unit

- Electric power (P) is the work done per unit time by the electric current.
- SI unit of power is watt (W).
- 1 watt is the power when 1 joule of work is done in 1 second.

$$1 \text{ W} = 1 \text{ J/s}$$

- Other units : kilowatt (kW), $1 \text{ kW} = 1000 \text{ W}$

Examples of electrical appliances and their power ratings :



LED Bulb
(9 W)



Fan
(70 W)



Television
(100 W)



Room Heater
(1000 W)

A higher wattage appliance consumes electrical energy faster.

3. Relationship between Power, Voltage and Current

- The electrical energy (W) supplied to a device is given by : $W = V \times Q$

where V = potential difference (volts)

Q = charge (coulombs)

Power is the rate of doing work :

$$P = \frac{W}{t} = \frac{VQ}{t} = V \left(\frac{Q}{t} \right) = VI$$

Hence, $P = VI$

4. Other Useful Forms of Power

- Using Ohm's law ($V = IR$),

$$P = VI = I(IR) = I^2R$$

$$P = VI = \frac{V^2}{R}$$

- So, power can be calculated using any of the following formulas :

$$P = VI \quad \text{or} \quad P = I^2R \quad \text{or} \quad P = \frac{V^2}{R}$$

5. Derivation of $P = VI$

- Work done in moving a charge Q through a potential difference V is $W = VQ$.
- Power is work done per unit time :

$$P = \frac{W}{t} = \frac{VQ}{t}$$

But, $\frac{Q}{t} = I$ (current)

Therefore, $P = VI$

6. Numerical Examples

Example 1 : Calculate power

A bulb is connected to a 12 V supply and it draws a current of 0.5 A. Find the power consumed by the bulb.

Given : $V = 12 \text{ V}$, $I = 0.5 \text{ A}$

Solution : $P = VI = 12 \times 0.5 = 6 \text{ W}$

$$\text{Power} = 6 \text{ W}$$

Example 2 : Using $P = I^2R$

A heater of resistance 20Ω is connected to a 230 V supply. Find the power consumed.

Given : $V = 230 \text{ V}$, $R = 20 \Omega$

$$\begin{aligned} \text{Solution : } P &= \frac{V^2}{R} = \frac{(230)^2}{20} \\ &= \frac{52900}{20} = 2645 \text{ W} \end{aligned}$$

$$\text{Power} = 2645 \text{ W} (\approx 2.65 \text{ kW})$$

Example 3 : Using $P = I^2R$

A device draws a current of 2 A and has a resistance of 10Ω . Find the power.

Given : $I = 2 \text{ A}$, $R = 10 \Omega$

$$\begin{aligned} \text{Solution : } P &= I^2R = (2)^2 \times 10 \\ &= 4 \times 10 = 40 \text{ W} \end{aligned}$$

$$\text{Power} = 40 \text{ W}$$

Example 4 : Using $P = \frac{V^2}{R}$

A lamp of 100Ω resistance is connected to a 220 V supply. Find the power consumed.

Given : $V = 220 \text{ V}$, $R = 100 \Omega$

$$\begin{aligned} \text{Solution : } P &= \frac{V^2}{R} = \frac{(220)^2}{100} \\ &= \frac{48400}{100} = 484 \text{ W} \end{aligned}$$

$$\text{Power} = 484 \text{ W}$$

Example 5 : Finding current from power

A device is rated 60 W when connected to a 12 V supply. Find the current drawn.

Given : $P = 60 \text{ W}$, $V = 12 \text{ V}$

$$\begin{aligned} \text{Solution : } P &= VI \Rightarrow I = \frac{P}{V} \\ I &= \frac{60}{12} = 5 \text{ A} \end{aligned}$$

$$\text{Current} = 5 \text{ A}$$

7. Key Points

- Electric power is the rate of conversion of electrical energy.
- SI unit is watt (W).
- $P = VI$, $P = I^2R$, $P = \frac{V^2}{R}$.
- Higher power means more energy is consumed per second.
- Used to compare the energy consumption of electrical appliances.
- $1 \text{ kW} = 1000 \text{ W}$.

Effect of Current

14. Relations Between P, V, I and R

1. Basic Relations

- Electric power (P) is the rate of doing work in an electric circuit.
- Potential difference (V) provides the energy to move charges.
- Current (I) is the rate of flow of charge.
- Resistance (R) opposes the flow of current.
- These four quantities are related through Ohm's law and the definition of power.

$$\text{Ohm's law : } V = IR$$

$$\text{Electric power : } P = VI$$

2. Derivation of Formulas

$$\text{We know, } P = VI \quad \dots (1)$$

$$\text{Using Ohm's law, } V = IR$$

$$\text{Put } V = IR \text{ in (1) :}$$

$$P = I (IR) = I^2 R \quad \dots (2)$$

$$\text{From Ohm's law, } I = \frac{V}{R}$$

$$\text{Put } I = \frac{V}{R} \text{ in (1) :}$$

$$P = V \left(\frac{V}{R} \right) = \frac{V^2}{R} \quad \dots (3)$$

$$\text{Hence, } P = VI = I^2 R = \frac{V^2}{R}$$

3. When to Use Each Formula ?

- Use $P = VI$ when voltage (V) and current (I) are given.
- Use $P = I^2 R$ when current (I) and resistance (R) are given.
- Use $P = \frac{V^2}{R}$ when voltage (V) and resistance (R) are given.
- All three formulas are equivalent and give the same power.

4. Unit of Power

- SI unit of power is watt (W).
- $1 \text{ W} = 1 \text{ J/s} = 1 \text{ V} \times 1 \text{ A}$
- Common larger unit : kilowatt (kW)

$$1 \text{ kW} = 1000 \text{ W}$$

5. Numerical Examples

(a) Using $P = VI$

Example 1 : A bulb is connected to a 12 V supply and draws a current of 0.5 A. Find the power consumed.

$$\text{Given : } V = 12 \text{ V, } I = 0.5 \text{ A}$$

$$\begin{aligned} \text{Solution : } P &= VI \\ &= 12 \times 0.5 \\ &= 6 \text{ W} \end{aligned}$$

$$\text{Power} = 6 \text{ W}$$

(b) Using $P = I^2 R$

Example 2 : A heater of resistance 20Ω draws a current of 3 A. Find the power consumed.

$$\text{Given : } I = 3 \text{ A, } R = 20 \Omega$$

$$\begin{aligned} \text{Solution : } P &= I^2 R \\ &= (3)^2 \times 20 \\ &= 9 \times 20 \\ &= 180 \text{ W} \end{aligned}$$

$$\text{Power} = 180 \text{ W}$$

(c) Using $P = \frac{V^2}{R}$

Example 3 : A device of resistance 50Ω is connected to a 100 V supply. Find the power consumed.

$$\text{Given : } V = 100 \text{ V, } R = 50 \Omega$$

$$\begin{aligned} \text{Solution : } P &= \frac{V^2}{R} \\ &= \frac{(100)^2}{50} \\ &= \frac{10000}{50} \\ &= 200 \text{ W} \end{aligned}$$

$$\text{Power} = 200 \text{ W}$$

6. More Examples (Different situations)

(a) Finding current when power and voltage are given

Example 4 : A device is rated 60 W and connected to a 12 V supply. Find the current drawn.

$$\text{Given : } P = 60 \text{ W, } V = 12 \text{ V}$$

$$\begin{aligned} \text{Solution : } P &= VI \Rightarrow I = \frac{P}{V} \\ &= \frac{60}{12} = 5 \text{ A} \end{aligned}$$

$$\text{Current} = 5 \text{ A}$$

(b) Finding resistance when power and current are given

Example 5 : A motor takes a current of 4 A and consumes 256 W of power. Find its resistance.

$$\text{Given : } P = 256 \text{ W, } I = 4 \text{ A}$$

$$\begin{aligned} \text{Solution : } P &= I^2 R \Rightarrow R = \frac{P}{I^2} \\ &= \frac{256}{(4)^2} = \frac{256}{16} = 16 \Omega \end{aligned}$$

$$\text{Resistance} = 16 \Omega$$

(c) Finding voltage when power and resistance are given

Example 6 : A resistor of 10Ω dissipates 40 W of power. Find the voltage across it.

$$\text{Given : } P = 40 \text{ W, } R = 10 \Omega$$

$$\begin{aligned} \text{Solution : } P &= \frac{V^2}{R} \Rightarrow V = \sqrt{PR} \\ &= \sqrt{40 \times 10} \\ &= \sqrt{400} = 20 \text{ V} \end{aligned}$$

$$\text{Voltage} = 20 \text{ V}$$

15. Power Dissipation Due to Current

1. Joule's Law of Heating

- When an electric current flows through a resistance, electrical energy is converted into heat energy due to collisions of electrons with atoms of the conductor.
- This heating effect is known as Joule heating.
- The amount of heat produced is given by :

$$H = I^2 R t$$

where, H = heat produced (joule)
 I = current (ampere)
 R = resistance (ohm)
 t = time (second)

2. Derivation of Joule's Law

Electrical energy supplied in time t :

$$W = VIt \quad \dots(1)$$

Using Ohm's law, $V = IR$

$$\text{So, } W = (IR) I t \\ = I^2 R t \quad \dots(2)$$

Since this electrical energy is converted into heat energy,

$$H = I^2 R t$$

3. Relation with Power

Power is the rate of heat production :

$$P = \frac{H}{t}$$

Using $H = I^2 R t$,

$$P = I^2 R$$

Also, using $V = IR$,

$$P = VI = \frac{V^2}{R}$$

Hence,

$$H = Pt = I^2 R t$$

4. Conversion of Electrical Energy to Heat

- The electric energy supplied to a circuit is converted into heat energy in a resistor.
- Electrical energy (in joule) : $E = VIt$
- Since heat produced is equal to electrical energy supplied,

$$H = E = VIt = I^2 R t = \frac{V^2}{R} t$$

- In practical appliances, this heat is used for useful heating (e.g. kettle, heater, iron).

5. Heating Appliances



Room Heater
(High power
1000-2000 W)



Electric Iron
(750-1500 W)



Electric Kettle
(1000-2000 W)



Immersion Rod
(1000-1500 W)

These appliances have high resistance and draw significant current. Electrical energy is mainly converted into heat energy which is used for heating purposes.

6. Numerical Examples

(a) Heat produced in a resistor

A current of 2 A flows through a resistance of 5Ω for 10 minutes. Find the heat produced.

Given : $I = 2 \text{ A}$, $R = 5 \Omega$
 $t = 10 \text{ min} = 600 \text{ s}$

$$\text{Solution : } H = I^2 R t \\ = (2)^2 \times 5 \times 600 \\ = 4 \times 5 \times 600 \\ = 12000 \text{ J}$$

$$\text{Heat produced} = 12000 \text{ J}$$

(b) Electrical energy consumed

An electric iron of 1000 W is used for 30 minutes. Find the electrical energy consumed (in joule and kilowatt-hour).

Given : $P = 1000 \text{ W}$, $t = 30 \text{ min}$
 $= 1800 \text{ s}$

$$\text{Solution : } E = Pt = 1000 \times 1800 \\ = 1,800,000 \text{ J} \\ = 1.8 \times 10^6 \text{ J}$$

$$\text{In kWh : } 1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$$

$$E = \frac{1.8 \times 10^6}{3.6 \times 10^2} \\ = 0.5 \text{ kWh}$$

$$\text{Energy consumed} = 1.8 \times 10^6 \text{ J} \\ = 0.5 \text{ kWh}$$

(c) Find current from power rating

A 2000 W room heater is connected to a 220 V supply. Find the current drawn and the heat produced in 5 minutes.

Given : $P = 2000 \text{ W}$, $V = 220 \text{ V}$
 $t = 5 \text{ min} = 300 \text{ s}$

$$\text{Solution : } P = VI \Rightarrow I = \frac{P}{V} \\ = \frac{2000}{220} = 9.09 \text{ A}$$

$$\text{Heat produced : } H = Pt \\ = 2000 \times 300 \\ = 600000 \text{ J} \\ = 6 \times 10^5 \text{ J}$$

$$\text{Current} = 9.09 \text{ A} \\ \text{Heat produced} = 6 \times 10^5 \text{ J}$$

7. Key Points

- Joule's law of heating : $H = I^2 R t$.
- Electrical energy is converted into heat energy in a resistor.
- Power is the rate of heat production : $P = I^2 R = VI = \frac{V^2}{R}$.
- Heating appliances have high power ratings.
- Unit of energy : joule (J) or kilowatt-hour (kWh).
- $1 \text{ kWh} = 3.6 \times 10^6 \text{ J}$.

8. Important Applications

- Room heaters, electric irons, electric kettles, immersion rods, toasters and geysers.
- Fuses work on heating effect (melting due to high current).
- Electrical heating is used in industrial furnaces and ovens.
- Used in devices where heat energy is the desired output.

16. Magnetic Field

1. Meaning of Magnetic Field

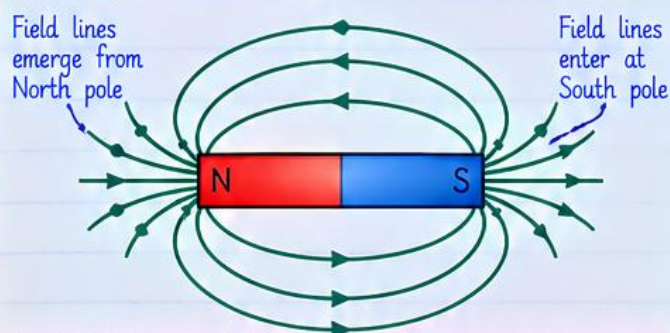
- The region around a magnet or a current carrying conductor where a magnetic force is experienced by a magnetic material (like iron filings, magnetic needle) is called a magnetic field.
- It is a vector field, represented by magnetic field lines.

It is a region in which a north pole of a test magnet experiences a force.

2. Magnetic Field Lines

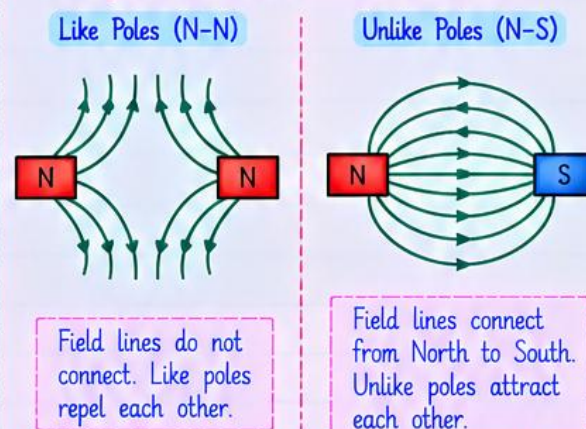
- Magnetic field lines are imaginary lines used to represent a magnetic field.
- They show the direction and relative strength of the magnetic field.
- They do not actually exist, but help us to visualise the magnetic field.

3. Diagram: Bar Magnet



Magnetic field lines are closed curves. Outside the magnet, they go from North pole to South pole and inside the magnet, they go from South pole to North pole.

4. Diagram: Field Lines Around Poles



5. Direction of Magnetic Field

- The direction of magnetic field at a point is the direction of force experienced by a north pole placed at that point.
- Outside the magnet : from North to South.
- Inside the magnet : from South to North.

6. Strength of Magnetic Field

- The strength of a magnetic field is indicated by the closeness (density) of field lines.
- Where field lines are closer, the field is stronger.
- Where field lines are farther apart, the field is weaker.

Stronger field
(lines closer)



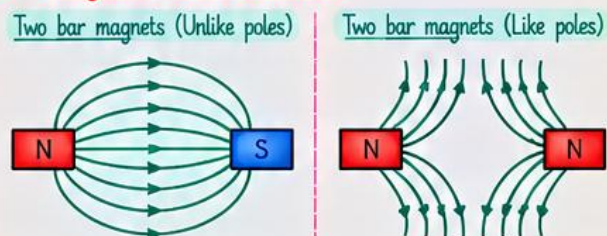
Weaker field
(lines farther)



7. Properties of Magnetic Field Lines

- Magnetic field lines are closed continuous curves.
- Outside the magnet, they go from North pole to South pole and inside the magnet, from South pole to North pole.
- The tangent to a field line at any point gives the direction of the magnetic field at that point.
- Field lines never intersect each other.
- The closeness (density) of field lines represents the strength of the magnetic field.
- No two magnetic field lines can be parallel at the same point.

8. Magnetic Field Patterns



9. Diagram Based Questions

(a) Identify the poles



Q. A bar magnet is placed with its magnetic field lines as shown. Identify the poles A and B.

Ans: A - North pole, B - South pole.

(b) Direction of field line



Q. What is the direction of magnetic field at point P shown in the figure?

Ans: The direction is along the tangent to the field line at P (in the direction of arrow).

(c) Strength of magnetic field



Q. In which region (A or B) is the magnetic field stronger?

Ans: Region A is stronger because the field lines are closer.

17. Magnetic Field Due to Current-Carrying Conductors

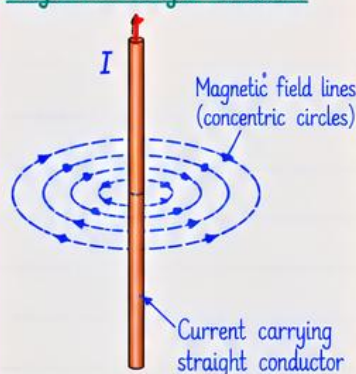
1. Straight Current-Carrying Conductor

- A straight conductor carrying current produces concentric circular magnetic field lines around it.
- The direction of field lines is given by Right-Hand Thumb Rule.
- The strength of magnetic field at a distance r from the conductor is :

$$B = \frac{\mu_0 I}{2\pi r}$$

where, $\mu_0 = 4\pi \times 10^{-7} \text{ Tm A}^{-1}$
 I = current (A)
 r = distance from the conductor (m)
 B = magnetic field (tesla, T)

Diagram : Straight Conductor



Right-Hand Thumb Rule



Hold the conductor in your right hand with thumb in the direction of current. The curled fingers give the direction of magnetic field lines.

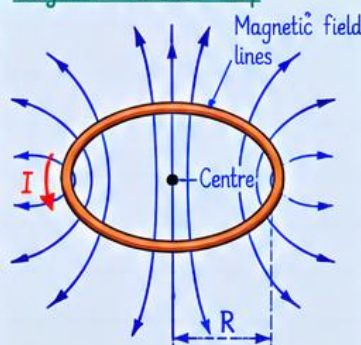
2. Circular Current-Carrying Loop

- A circular loop carrying current produces a magnetic field along its axis.
- The field is maximum at the centre of the loop.
- Magnitude of magnetic field at the centre of a circular loop of radius R is :

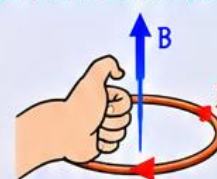
$$B = \frac{\mu_0 I}{2R}$$

where, $\mu_0 = 4\pi \times 10^{-7} \text{ Tm A}^{-1}$
 I = current (A)
 R = radius of the loop (m)

Diagram : Circular Loop



Direction of Field (Loop)



Curl the fingers of your right hand in the direction of current. Your thumb gives the direction of magnetic field along the axis of the loop.

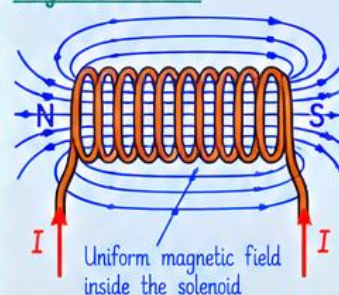
3. Current-Carrying Solenoid

- A solenoid is a long cylindrical coil with many closely spaced turns of wire.
- It produces a strong and nearly uniform magnetic field inside, similar to a bar magnet.
- Magnetic field inside a long solenoid is :

$$B = \mu_0 n I$$

where, $\mu_0 = 4\pi \times 10^{-7} \text{ Tm A}^{-1}$
 n = number of turns per unit length (turns/m)
 I = current (A)

Diagram : Solenoid



Field Pattern (Solenoid)

- Inside : field is strong and nearly uniform (parallel lines).
- Outside : field is weak and spreads out (like a bar magnet).

4. Factors Affecting Magnetic Field Strength

- Magnitude of current (I) : Higher current $\rightarrow$ stronger field.
- Distance from conductor (r) : Field decreases with distance ($B \propto \frac{1}{r}$).
- Number of turns (n) in a solenoid : More turns $\rightarrow$ stronger field.
- Shape and size of conductor : e.g. loop radius, solenoid length.
- Medium around the conductor : Field is stronger in materials with higher magnetic permeability.

5. Applications

- Electromagnets : Used in electric bells, cranes, relays and magnetic locks.
- Electric motors : Current-carrying coils produce magnetic field and experience force.
- Generators : Rotating coils in a magnetic field produce current.
- Solenoids : Used in automated doors, valves and switches.
- Loudspeakers : Current in a coil produces magnetic field and moves the cone.
- Magnetic field sensors : Used in measuring devices.

6. Numerical Example (Straight Conductor)

A straight conductor carries a current of 5 A. Find the magnetic field at a point 0.1 m from the conductor.

Given : $I = 5 \text{ A}$, $r = 0.1 \text{ m}$

$$\text{Solution : } B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \times 10^{-7} \times 5}{2\pi \times 0.1} = 1.0 \times 10^{-5} \text{ T}$$

$$B = 1.0 \times 10^{-5} \text{ T}$$

7. Numerical Example (Circular Loop)

A circular loop of radius 0.2 m carries a current of 3 A. Find the magnetic field at its centre.

Given : $I = 3 \text{ A}$, $R = 0.2 \text{ m}$

$$\text{Solution : } B = \frac{\mu_0 I}{2R} = \frac{4\pi \times 10^{-7} \times 3}{2 \times 0.2} = 9.42 \times 10^{-6} \text{ T}$$

$$B = 9.42 \times 10^{-6} \text{ T}$$

8. Numerical Example (Solenoid)

A solenoid has 800 turns in 0.4 m length and carries a current of 2 A. Find the magnetic field inside the solenoid.

Given : $n = \frac{800}{0.4} = 2000 \text{ turns/m}$, $I = 2 \text{ A}$

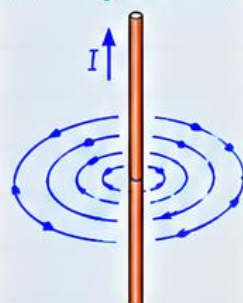
$$\text{Solution : } B = \mu_0 n I = 4\pi \times 10^{-7} \times 2000 \times 2 = 5.03 \times 10^{-3} \text{ T}$$

$$B = 5.03 \times 10^{-3} \text{ T}$$

18. Magnetic Field Applications

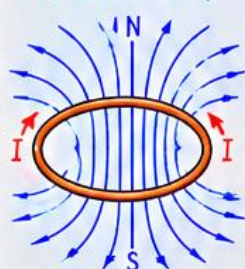
1. Field-Pattern Comparisons

(a) Straight Conductor



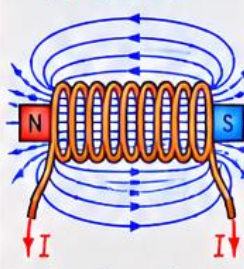
Field lines are concentric circles on the conductor.

(b) Circular Loop



Field lines resemble those of a bar magnet. Inside the loop, field is strong and nearly uniform.

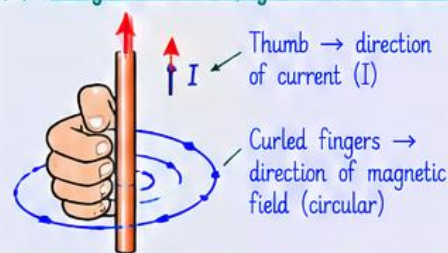
(c) Solenoid



Inside a long solenoid, field lines are straight, parallel and closely spaced (nearly uniform field). Outside, pattern is like a bar magnet.

2. Direction-Finding Examples

(a) Straight Conductor (Right-Hand Thumb Rule)



Thumb → direction of current (I)

Curled fingers → direction of magnetic field (circular)

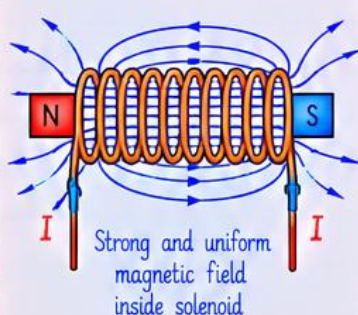
(b) Circular Loop (Right-Hand Rule)



N (field direction)

Curl fingers in direction of current. Thumb gives direction of magnetic field along the axis (North pole).

3. Solenoid as an Electromagnet



Strong and uniform magnetic field inside solenoid

Why is a solenoid a good electromagnet ?

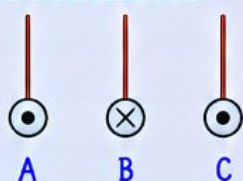
- Produces a strong and nearly uniform magnetic field inside.
- Field strength can be increased by increasing current, number of turns or using a soft iron core.
- Polarity can be changed by reversing the current.

4. Applications of Magnetic Fields

- **Electromagnets** : Used in electric bells, cranes, relays, magnetic locks and scrapyards.
- **Electric motors** : Current-carrying coils in a magnetic field experience a torque and rotate.
- **Generators** : Rotating coils in a magnetic field induce an emf (basis of electricity generation).
- **Solenoids** : Used in automated doors, valves and switches.
- **Magnetic sensors** : Used in position and speed measurement (e.g. in vehicles).
- **Loudspeakers** : A current-carrying coil in a magnetic field moves the cone to produce sound.

5. Diagram Interpretation Questions

(a) Identify the magnetic field pattern and find the direction.

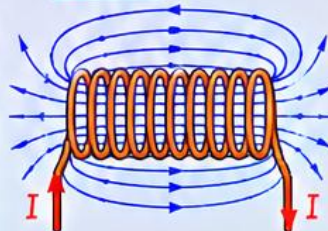


Q1. Find the direction of magnetic field at point P due to each wire.

Ans :

- A : Anticlockwise (out of page)
- B : Clockwise (into the page)
- C : Anticlockwise (out of page)

(b) Determine the poles and direction of field lines.



Q2. Which end is North pole ?

Ans :

- Left end → North pole.
- Right end → South pole.
- Field lines inside are from left to right.

6. Conceptual MCQs

Q1. The magnetic field lines around a straight current-carrying conductor are :

- (a) straight lines (b) concentric circles
(c) parallel lines (d) radial lines

Ans : (b) concentric circles

Q2. The inside of a long solenoid behaves like :

- (a) a bar magnet (b) a straight conductor
(c) a uniform magnetic field (d) a circular loop

Ans : (c) a uniform magnetic field

Q3. By reversing the direction of current in a solenoid, what happens ?

- (a) Field strength increases (b) No change
(c) Polarity is reversed (d) Field becomes zero

Ans : (c) Polarity is reversed

Q4. Which device uses a strong magnetic field produced by a current-carrying coil to move a cone ?

- (a) Generator (b) Loudspeaker
(c) Electromagnet (d) Transformer

Ans : (b) Loudspeaker

7. Important Points

- Field patterns help us visualise the magnetic field and its strength.
- Direction of the field is determined by the Right-Hand Thumb Rule.
- A solenoid produces a strong and uniform magnetic field and acts like a bar magnet.
- Increasing current or number of turns increases the field strength.
- Magnetic fields have many practical applications in everyday devices.

19. Force on a Current-Carrying Conductor

1. Meaning

- A current-carrying conductor placed in a magnetic field experiences a mechanical force.
- This force is due to the interaction between the magnetic field and the moving charges (current) in the conductor.
- The direction of force, its magnitude and the motion of the conductor depend on the direction of current, magnetic field and length of the conductor inside the field.

2. Formula for Force

$$F = BIL \sin \theta$$

where,

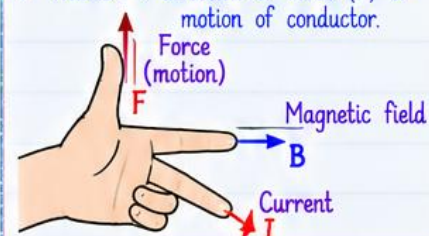
- F = force on conductor (N)
 B = magnetic field (tesla, T)
 I = current in conductor (A)
 L = length of conductor in magnetic field (m)
 θ = angle between direction of current and magnetic field (degree)

Maximum force : $F_{\max} = BIL$
(when $\theta = 90^\circ$)

Minimum force : $F = 0$
(when $\theta = 0^\circ$)

3. Direction of Force

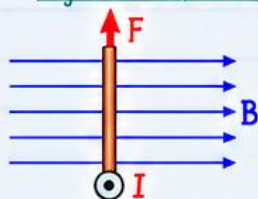
- The direction of force is given by Fleming's Left-Hand Rule.
- Stretch the thumb, forefinger and middle finger of your left hand mutually perpendicular to each other.
- Forefinger $\rightarrow$ direction of magnetic field (B)
- Middle finger $\rightarrow$ direction of current (I)
- Thumb $\rightarrow$ direction of force (F) or motion of conductor.



Fleming's Left-Hand Rule

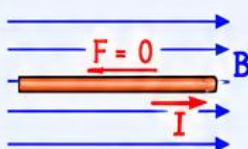
4. Special Cases

(a) Conductor perpendicular to magnetic field ($\theta = 90^\circ$)



$$F = BIL \text{ (maximum)}$$

(b) Conductor parallel to magnetic field ($\theta = 0^\circ$)



$$F = 0 \text{ (minimum)}$$

(c) Conductor at an angle θ



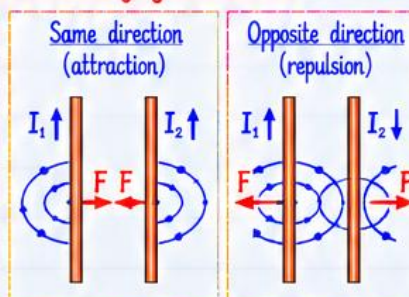
$$F = BIL \sin \theta$$

5. Factors Affecting Force

- Magnetic field strength (B) : Greater B $\rightarrow$ greater force.
- Current (I) : Higher current $\rightarrow$ greater force.
- Length of conductor (L) : Longer length inside the field $\rightarrow$ greater force.
- Angle (θ) : Force depends on $\sin \theta$. Maximum at 90° , zero at 0° .

6. Interaction Between Two Parallel Current-Carrying Conductors

- Two parallel current-carrying conductors experience a force due to the magnetic field produced by each other.
- If currents are in the same direction $\rightarrow$ attractive force.
- If currents are in opposite directions $\rightarrow$ repulsive force.



7. Applications

- Electric motors** : A current-carrying coil in a magnetic field experiences a force, producing rotation.
- Moving coil galvanometer** : Deflection due to force on a current-carrying coil.
- Loudspeakers** : A current-carrying coil in a magnetic field moves the cone to produce sound.
- Generators** : Mechanical motion in a magnetic field induces current (reverse application of the same principle).

8. Numerical Examples

(a) Calculate the force

A straight conductor of length 0.2 m carries a current of 5 A. It is placed perpendicular to a magnetic field of 0.3 T. Find the force on the conductor.

Given : $B = 0.3 \text{ T}$, $I = 5 \text{ A}$
 $L = 0.2 \text{ m}$, $\theta = 90^\circ$

Solution : $F = BIL \sin \theta$
 $= 0.3 \times 5 \times 0.2 \times 1$
 $= 0.3 \text{ N}$

$$F = 0.3 \text{ N}$$

(b) Find the current

A conductor of length 0.5 m is placed at right angles to a magnetic field of 0.4 T. If it experiences a force of 0.6 N, find the current in it.

Given : $F = 0.6 \text{ N}$, $B = 0.4 \text{ T}$
 $L = 0.5 \text{ m}$, $\theta = 90^\circ$

Solution : $F = BIL$
 $I = \frac{F}{BL}$
 $= \frac{0.6}{0.4 \times 0.5}$
 $= 3 \text{ A}$

$$I = 3 \text{ A}$$

(c) Conductor at an angle

A conductor of length 0.4 m carries a current of 2 A. It is placed in a magnetic field of 0.5 T at an angle of 30° with the field. Find the force.

Given : $B = 0.5 \text{ T}$, $I = 2 \text{ A}$
 $L = 0.4 \text{ m}$, $\theta = 30^\circ$

Solution : $F = BIL \sin \theta$
 $= 0.5 \times 2 \times 0.4 \times \sin 30^\circ$
 $= 0.5 \times 2 \times 0.4 \times 0.5$
 $= 0.2 \text{ N}$

$$F = 0.2 \text{ N}$$

20. Fleming's Left-Hand Rule

1. Statement

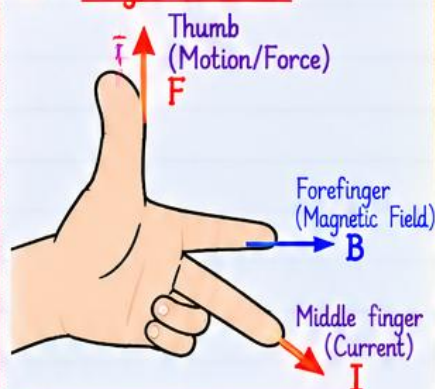
- Fleming's Left-Hand Rule is used to find the direction of force (motion) on a current-carrying conductor placed in a magnetic field.
- If we stretch the thumb, forefinger and middle finger of the left hand mutually perpendicular to each other, then:

Forefinger → direction of Magnetic Field (B)

Middle finger → direction of Current (I)

Thumb → direction of Force (F) or Motion

2. Finger Positions



Fleming's Left-Hand Rule

Important Points

- Use left hand (not right hand).
- Thumb gives the direction of force or motion.
- Forefinger gives the direction of magnetic field (from North to South).
- Middle finger gives the direction of current (from positive to negative).
- The three fingers are mutually perpendicular to each other.

3. Relationship between F, B and I

- A current-carrying conductor placed in a magnetic field experiences a force.
- Direction of force is given by Fleming's Left-Hand Rule.
- Magnitude of force is :

$$F = BIL \sin \theta$$

where, F = force on conductor (N)
 B = magnetic field (tesla, T)
 I = current in conductor (A)
 L = length of conductor in magnetic field (m)
 θ = angle between current and magnetic field (degree)

4. Direction-Finding Examples

(a) Conductor moving upwards

A current-carrying conductor is placed in a magnetic field as shown. Find the direction of force (motion).

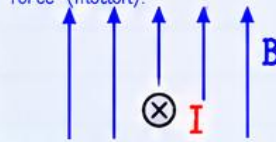


Using Fleming's left-hand rule :
 Forefinger → right (B)
 Middle finger → up (I)
 Thumb → out of page (F)

Force is out of the page (towards you).

(b) Conductor moving into the page

A current-carrying conductor is placed in a magnetic field as shown. Find the direction of force (motion).



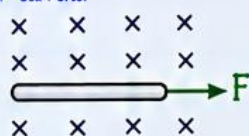
Using Fleming's left-hand rule :
 Forefinger → up (B)
 Middle finger → into page (I)
 Thumb → left (F)

Force is towards left.

5. More Examples

(a) Find direction of current

A conductor experiences a force towards right when placed in a magnetic field directed into the page. Find the direction of current.

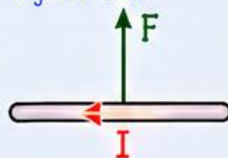


Using left-hand rule :
 Thumb → right (F)
 Forefinger → into page (B)
 Middle finger → down (I)

Current is downwards.

(b) Find direction of magnetic field

A conductor carries current towards left and experiences a force upwards. Find the direction of magnetic field.



Using left-hand rule :
 Thumb → up (F)
 Middle finger → left (I)
 Forefinger → out of page (B)

Magnetic field is out of the page (towards you).

6. Applications

- Electric Motors** : A current-carrying coil placed in a magnetic field experiences a force, producing rotational motion.
- Moving Coil Galvanometer** : A current-carrying coil moves in a magnetic field, used for detecting small currents.
- Loudspeakers** : A current-carrying coil moves in a magnetic field, causing the cone to move and produce sound.
- Electric Generators** : Based on the reverse principle (motion induces current), but the force concept helps in understanding torque.
- Magnetic Levitation and Modern Devices** : Used in various devices where force is produced on current-carrying conductors.

7. Key Points

- Fleming's Left-Hand Rule gives the direction of force on a current-carrying conductor.
- Left hand is used (unlike Fleming's Right-Hand Rule).
- Thumb → force (F), Forefinger → magnetic field (B), Middle finger → current (I).
- The three are mutually perpendicular.
- Used mainly in motors and devices where a current-carrying conductor experiences a force in a magnetic field.
- Direction of force reverses if current or magnetic field direction is reversed.
- Maximum force occurs when conductor is perpendicular to the magnetic field ($\theta = 90^\circ$).

21. Electromagnetic Induction

1. Meaning

- Electromagnetic induction is the phenomenon of producing an induced electric current in a conductor when the **magnetic flux** linked with it **changes**.
- The current produced is called **induced current** and the emf produced is called **induced emf**.

2. Cause of Induction

- An induced current is produced when there is a **change in magnetic flux** linked with a conductor.
- The magnetic flux can change due to :
 - Relative motion between magnet and coil.
 - Change in strength of magnetic field.
 - Change in area of the coil.
 - Change in orientation of the coil in a magnetic field.

Magnetic Flux (Φ)

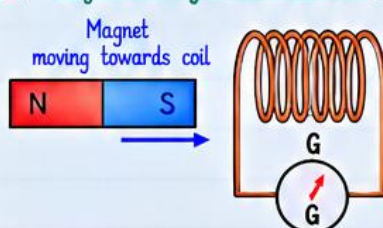
Magnetic flux is the total magnetic field passing through a given area.

$$\Phi = B A \cos \theta$$

where, B = magnetic field
 A = area of coil
 θ = angle between B and normal to area

3. Experimental Demonstrations

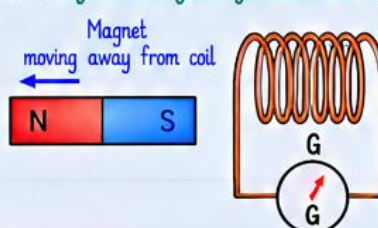
(a) Magnet moving towards the coil



Observation :

- A momentary current is induced in the coil.
- The galvanometer shows a deflection in one direction.

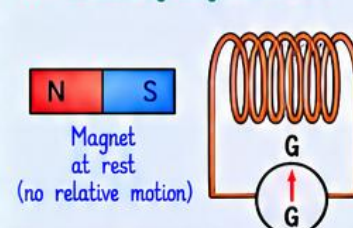
(b) Magnet moving away from the coil



Observation :

- A momentary current is induced in the coil.
- The galvanometer shows a deflection in the opposite direction compared to (a).

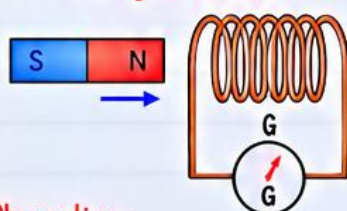
(c) Stationary magnet and coil



Observation :

- No induced current is produced in the coil.
- The galvanometer shows no deflection.

4. Reversing the Poles

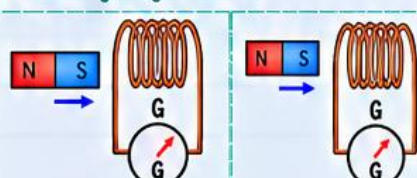


Observation :

- If the south pole is moved towards the coil instead of the north pole, the direction of induced current is reversed.
- The galvanometer shows a deflection in the opposite direction.

5. Faster or Slower Motion

(a) Moving magnet faster



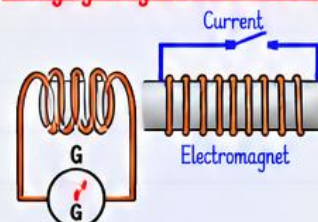
Observation :

- Deflection is larger, induced current is stronger.

Observation :

- Deflection is smaller, induced current is weaker.

6. Changing Magnetic Field Strength

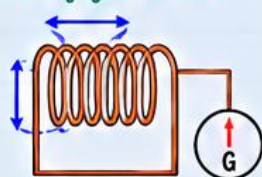


Observation :

- When the current in the electromagnet is changed, the magnetic field around it changes.
- A momentary induced current is produced in the nearby coil.

7. Changing Area or Orientation

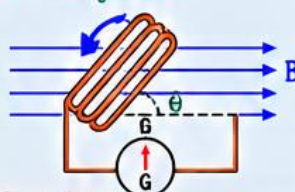
(a) Changing area of coil



Observation :

- When the area of the coil is increased or decreased, the magnetic flux changes and an induced current is produced.

(b) Rotating the coil



Observation :

- When the coil is rotated in a magnetic field, the angle θ changes, so the magnetic flux changes and an induced current is produced.

8. Important Points

- Induced current is produced only when the magnetic flux linked with the conductor changes.
- The direction of induced current depends on whether the flux is increasing or decreasing.
- Faster change in magnetic flux produces a larger induced current.
- If there is no change in magnetic flux, no induced current is produced.
- The induced current exists only as long as the magnetic flux is changing (it is momentary).

22. Induced Potential Difference (Induced EMF)

1. Meaning

- When the magnetic flux linked with a coil changes, an emf (potential difference) is induced in the coil. This emf is called **induced emf**.
- If the circuit is closed, an induced current also flows, which is called **induced current**.

Symbol : E or $\mathcal{E}$
SI unit : volt (V)

2. Causes of Induced EMF

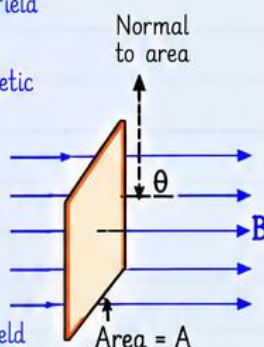
- Induced emf is produced when there is a change in magnetic flux linked with a coil.
- The magnetic flux can change due to :
 - Change in strength of magnetic field (B).
 - Change in area (A) of the coil.
 - Change in orientation (θ) of the coil.
 - Relative motion between the magnet and the coil (e.g. moving magnet or moving coil).

3. Magnetic Flux

- Magnetic flux is the total magnetic field passing through a given area.
- For a uniform magnetic field, magnetic flux (Φ) is given by :

$$\Phi = B A \cos \theta$$

where, B = magnetic field (tesla, T)
 A = area of the coil (m^2)
 θ = angle between magnetic field and normal to the area (degree)



4. Faraday's Law of Electromagnetic Induction

- The magnitude of induced emf in a coil is equal to the rate of change of magnetic flux linked with the coil.

$$E = -N \frac{d\Phi}{dt}$$

where, E = induced emf (V)
 N = number of turns in the coil
 Φ = magnetic flux (Wb)
 t = time (s)

- The negative sign ($-$) shows the direction of induced emf (given by Lenz's law).
- If Φ changes uniformly, then

$$E = -N \frac{\Phi_2 - \Phi_1}{t_2 - t_1}$$

5. Factors Affecting Induced EMF

- Number of turns (N)** : More turns $\rightarrow$ larger induced emf.
- Rate of change of flux ($\frac{d\Phi}{dt}$)** : Faster change $\rightarrow$ larger induced emf.
- Magnetic field strength (B)** : Stronger field $\rightarrow$ larger change in flux $\rightarrow$ larger emf.
- Area of the coil (A)** : Larger area $\rightarrow$ larger flux $\rightarrow$ larger emf.
- Angle of the coil (θ)** : Change in orientation alters the flux $\rightarrow$ induces emf.

6. Numerical Example 1 (Change in Magnetic Field)

A coil of 200 turns and area 0.02 m^2 is placed in a magnetic field which changes from 0.1 T to 0.5 T in 0.4 s . The plane of the coil is perpendicular to the field. Find the induced emf.

Given : $N = 200$, $A = 0.02 \text{ m}^2$
 $B_1 = 0.1 \text{ T}$, $B_2 = 0.5 \text{ T}$, $t = 0.4 \text{ s}$
 $\theta = 0^\circ$ ($\cos \theta = 1$)

Solution : $\Phi_1 = B_1 A = 0.1 \times 0.02 = 0.002 \text{ Wb}$
 $\Phi_2 = B_2 A = 0.5 \times 0.02 = 0.01 \text{ Wb}$

$$E = N \frac{(\Phi_2 - \Phi_1)}{t}$$

$$= 200 \times \frac{(0.01 - 0.002)}{0.4}$$

$$= \frac{200 \times 0.008}{0.4} = 4 \text{ V}$$

$$E = 4 \text{ V}$$

7. Numerical Example 2 (Change in Area)

A rectangular coil of 100 turns is placed in a uniform magnetic field of 0.3 T . Its area changes from 0.01 m^2 to 0.05 m^2 in 0.2 s . The plane of the coil is perpendicular to the field. Find the induced emf.

Given : $N = 100$, $B = 0.3 \text{ T}$
 $A_1 = 0.01 \text{ m}^2$, $A_2 = 0.05 \text{ m}^2$, $t = 0.2 \text{ s}$

Solution : $\Phi_1 = B A_1 = 0.3 \times 0.01 = 0.003 \text{ Wb}$
 $\Phi_2 = B A_2 = 0.3 \times 0.05 = 0.015 \text{ Wb}$

$$E = N \frac{(\Phi_2 - \Phi_1)}{t}$$

$$= 100 \times \frac{(0.015 - 0.003)}{0.2}$$

$$= \frac{100 \times 0.012}{0.2} = 6 \text{ V}$$

$$E = 6 \text{ V}$$

8. Numerical Example 3 (Change in Orientation)

A coil of 50 turns and area 0.04 m^2 is placed in a uniform magnetic field of 0.2 T . The coil is rotated from $\theta = 0^\circ$ to $\theta = 90^\circ$ in 0.5 s . Find the induced emf.

Given : $N = 50$, $A = 0.04 \text{ m}^2$, $B = 0.2 \text{ T}$
 $\theta_1 = 0^\circ$, $\theta_2 = 90^\circ$, $t = 0.5 \text{ s}$

Solution : $\Phi_1 = B A \cos 0^\circ = 0.2 \times 0.04 \times 1 = 0.008 \text{ Wb}$
 $\Phi_2 = B A \cos 90^\circ = 0.2 \times 0.04 \times 0 = 0 \text{ Wb}$

$$E = N \frac{(\Phi_2 - \Phi_1)}{t}$$

$$= 50 \times \frac{(0 - 0.008)}{0.5}$$

$$= \frac{-0.4}{0.5} = -0.8 \text{ V}$$

$$E = 0.8 \text{ V}$$

(magnitude)

23. Induced Current and Lenz's Law

1. Induced Current

- When an emf is induced in a closed circuit, a current flows in the circuit. This current is called **induced current**.
- It is produced only when there is a change in magnetic flux linked with the circuit.
- The induced current exists only for the time during which the magnetic flux is changing.

2. Lenz's Law

- The direction of induced current is such that it produces a magnetic field which **opposes** the cause (change in magnetic flux) that produces it.
- It is a statement of the law of conservation of energy (the induced current always acts against the change).

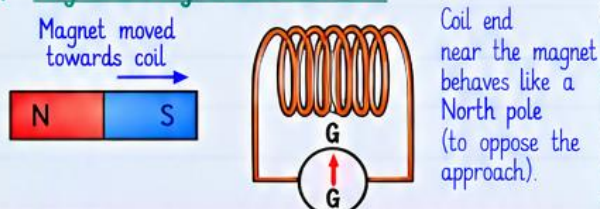
"The induced current is in such a direction that it opposes the change in magnetic flux that produces it."

3. Effect of Relative Motion

- If a magnet is moved towards a coil, the magnetic flux through the coil **increases** and an induced current is produced in a direction that **opposes** this increase.
- If the magnet is moved away from the coil, the flux decreases and the induced current is in a direction that opposes this decrease.
- If there is no relative motion (or no change in flux), no induced current is produced.

4. Direction of Induced Current (Examples)

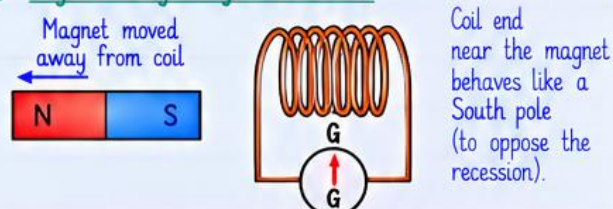
(a) Magnet moving towards the coil



Observation :

- A momentary induced current flows.
- The near face of the coil becomes a North pole (to repel the approaching North pole).
- Galvanometer shows a deflection in one direction.

(b) Magnet moving away from the coil

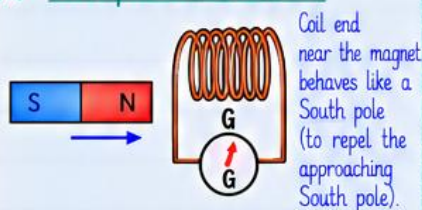


Observation :

- A momentary induced current flows (in opposite direction to case (a)).
- The near face of the coil becomes a South pole (to attract the receding North pole).
- Galvanometer shows a deflection in the opposite direction.

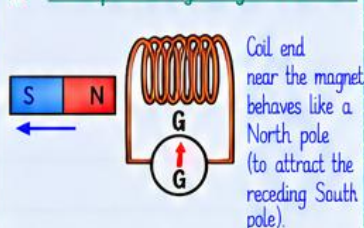
5. Effect of Direction of Motion

(a) South pole towards the coil



Induced current is in a direction opposite to that in case of North pole approaching.

(b) South pole moving away from the coil



Induced current is opposite to that when South pole approaches (and same as North pole approaching).

6. Relationship between Induced EMF and Current

- Induced emf (E) is related to the rate of change of magnetic flux by Faraday's law :

$$E = -N \frac{d\Phi}{dt}$$

- If the coil has resistance R , the induced current is given by Ohm's law :

$$I = \frac{E}{R} = -\frac{1}{R} N \frac{d\Phi}{dt}$$

- Larger induced emf or smaller resistance produces a larger induced current.

7. Worked Conceptual Examples

(a) Which way will current flow ?

A North pole of a bar magnet is moved towards a coil. Which face of the coil becomes North or South and what is the direction of induced current (seen from the magnet side)?

Solution :

- Flux increases, so the coil must oppose the increase.
- Near face becomes North pole.
- Induced current (seen from magnet side) is anticlockwise.

(b) No current condition

A magnet is held at rest inside a coil. Will there be an induced current?

Solution :

- There is no change in magnetic flux (θ , area and field are constant).
- Hence, no induced emf and no induced current.
- A current flows only when the magnet (or coil) is moved or the field strength is changed.

8. Applications

- Electric generators** : Mechanical energy is converted into electrical energy using electromagnetic induction.
- Transformers** : Changing current in primary coil induces current in secondary coil (used in power transmission).
- Dynamos and alternators** : Based on induction principle.
- Induction cooktops** : Eddy currents are induced in metal utensils, producing heat.
- Metal detectors** : Motion of metal changes the magnetic field and induces current in a coil.
- Energy harvesting devices** : Use induced current from motion to generate electricity.

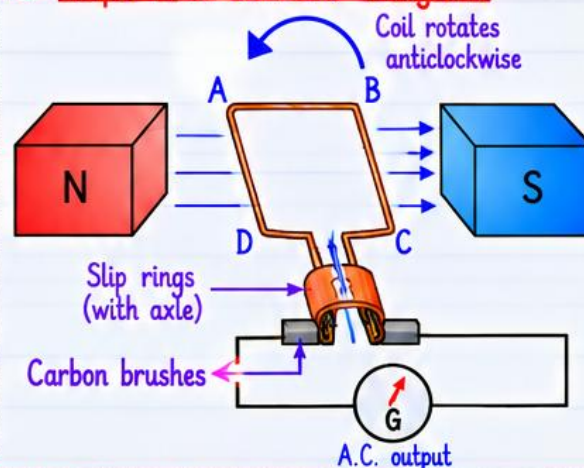
24. Electromagnetic Induction Applications

1. Generator Principle

- A generator works on the principle of electromagnetic induction.
- When a coil is rotated in a magnetic field, the magnetic flux linked with the coil changes continuously and an induced emf is produced.
- This converts mechanical energy into electrical energy.
- If the coil has N turns and area A and rotates with angular speed ω in a uniform magnetic field B , then the induced emf is :

$$E = NBA\omega \sin \omega t$$

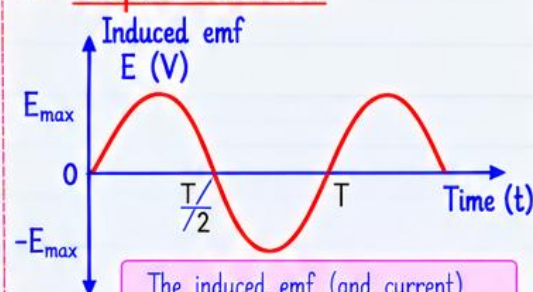
2. Simple A.C. Generator (Diagram)



3. Working of an A.C. Generator

- A rectangular coil ABCD is rotated with uniform angular speed ω in a uniform magnetic field.
- The magnetic flux linked with the coil changes continuously.
- According to Faraday's law, an induced emf is produced.
- The ends of the coil are connected to slip rings which maintain continuous contact with carbon brushes.
- The induced emf (and current) changes direction after every half rotation, so the output is alternating current (AC).

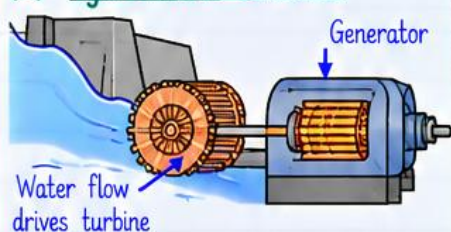
4. Output Waveform



The induced emf (and current) changes direction after every half rotation, producing alternating current (AC).

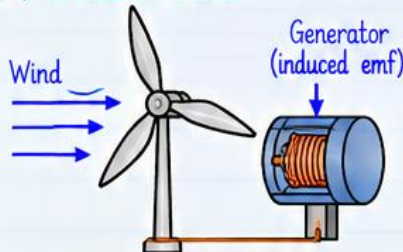
5. Practical Examples

(a) Hydroelectric Generator



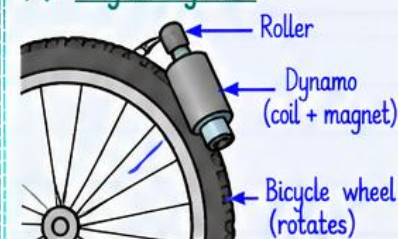
- Kinetic energy of flowing water rotates the turbine.
- The rotating coil in a magnetic field produces induced emf.
- Used in hydroelectric power plants.

(b) Wind Generator



- Wind rotates the blades.
- The rotating coil produces induced emf.
- Used in wind power plants.

(c) Bicycle Dynamo



- Rotation of the wheel rotates the dynamo.
- Induced emf is produced due to changing magnetic flux.
- Used to power small lamps.

6. Important Points

- 1 A generator converts mechanical energy into electrical energy using electromagnetic induction.
- 2 The induced emf is produced only when the magnetic flux linked with the coil changes.
- 3 The magnitude of induced emf depends on N , B , A and ω .
- 4 The direction of induced current reverses after every half rotation (AC).
- 5 Larger angular speed or magnetic field strength produces larger induced emf.

7. Exam-Style Questions

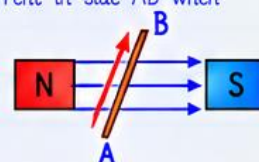
Q1. A rectangular coil of 100 turns and area 0.02 m^2 rotates with angular speed 50 rad s^{-1} in a uniform magnetic field of 0.4 T . Find the maximum induced emf.

Sol: $E_{\text{max}} = NBA\omega$
 $= 100 \times 0.4 \times 0.02 \times 50$
 $= 40 \text{ V}$

$E_{\text{max}} = 40 \text{ V}$

Q2. The diagram shows a coil rotating in a magnetic field. State the direction of induced current in side AB when the coil moves as shown.

Sol: Using Fleming's right-hand rule, current in AB is from A to B.



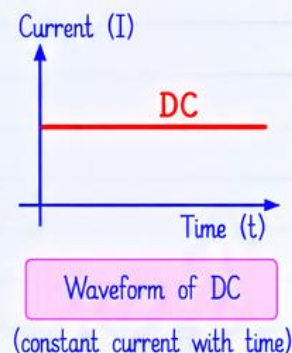
25. Direct Current (DC)

1. Definition

- Direct Current (DC) is an electric current that flows in **one direction only** through a conductor.
- In DC, the direction of current does not change with time.
- The magnitude of current may be constant (steady DC) or may vary but the direction remains the same.

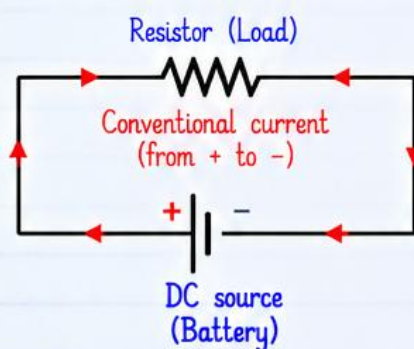
2. Characteristics of DC

- Flows in one direction only.
- Has a constant polarity (positive and negative terminals remain fixed).
- Produces a steady current (magnitude may be constant or variable).
- Can be stored easily using batteries.
- Mainly used in electronic devices and circuits.



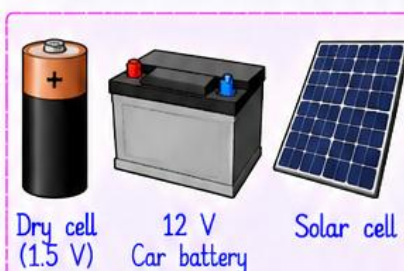
3. Direction of Current in DC Circuit

- Conventional current flows from the positive terminal to the negative terminal of the source.
- Electron flow is from the negative terminal to the positive terminal (opposite to conventional current).



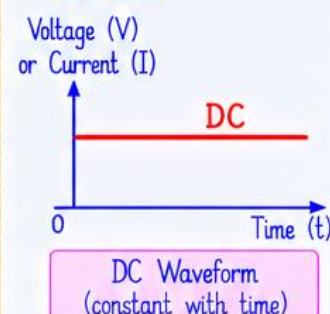
4. Sources of DC

- Cells and batteries (e.g., 1.5 V dry cell, 12 V car battery).
- DC power supply units.
- Solar cells (photovoltaic cells).
- DC generators (dynamo).
- Rectifiers (convert AC to DC).

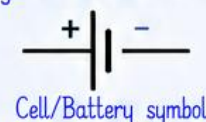


5. Waveform and Symbols

- DC has a straight line waveform parallel to the time axis.



- Symbol for DC source :



6. Practical Applications of DC

- Used in electronic circuits (mobile phones, laptops, TVs, etc.).
- Used in battery-powered devices (torch, calculator, remote control).
- Used in electric vehicles and car electrical systems.
- Used in charging of batteries.
- Used in DC motors (to produce rotational motion).
- Used in solar power systems.



7. Comparison of DC and AC

Feature	Direct Current (DC)	Alternating Current (AC)
Direction	Flows in one direction only	Changes direction periodically
Magnitude	Constant (steady)	Varies with time (sinusoidal)
Waveform	Straight line	Sinusoidal wave
Frequency	Zero frequency	50 Hz (in India)
Sources	Cells, batteries, solar cells, DC generators	Alternators (AC generators) mains supply
Common uses	Electronic devices, battery-powered devices, DC motors	Domestic supply, large-scale power transmission
Storage	Can be stored in batteries	Cannot be stored directly

8. Example (Numerical)

A battery provides a constant voltage of 6 V across a resistor of 3 Ω . Find the current in the circuit.

Given : $V = 6 \text{ V}$
 $R = 3 \Omega$

Solution : Using Ohm's law,

$$I = \frac{V}{R} = \frac{6}{3} = 2 \text{ A}$$

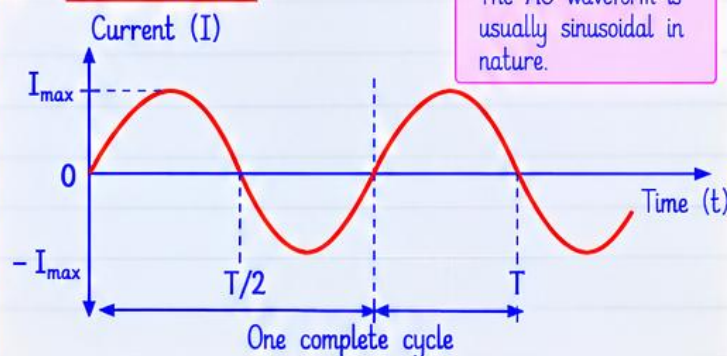
$$I = 2 \text{ A}$$

26. Alternating Current (AC)

1. Definition

- Alternating Current (AC) is an electric current that **changes its direction periodically** with time.
- In AC, the magnitude of current also varies with time in a regular manner (usually sinusoidal).
- The direction of current reverses after every half cycle.

2. AC Waveform



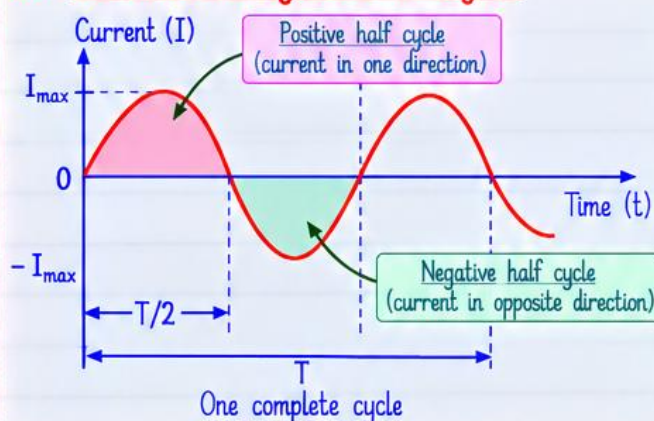
3. Main Characteristics

- ① Direction of current changes periodically.
- ② Magnitude of current varies with time (follows a sinusoidal waveform).
- ③ Has a time period (T) and frequency (f).
- ④ Average current over one complete cycle is zero.
- ⑤ Widely used for power supply and electricity transmission.

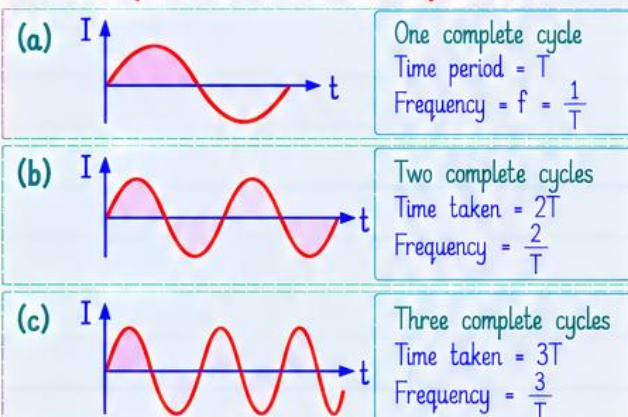
4. Time Period and Frequency

- **Time Period (T)** : Time taken to complete one full cycle.
- Unit : second (s)
- **Frequency (f)** : Number of cycles per second.
- Unit : hertz (Hz)
- Relationship : $f = \frac{1}{T}$ or $T = \frac{1}{f}$
- If frequency is 50 Hz, it means 50 cycles are completed in 1 second.
- For 50 Hz, the time period is : $T = \frac{1}{50} = 0.02 \text{ s}$ (20 ms)

5. Positive and Negative Half Cycles



6. Examples of Waveform Interpretation



7. Numerical Example 1 (Find Time Period)

An AC source has a frequency of 50 Hz. Find its time period.

Given : $f = 50 \text{ Hz}$

Solution : $T = \frac{1}{f} = \frac{1}{50} = 0.02 \text{ s}$ $T = 0.02 \text{ s}$
 $= 20 \text{ ms}$

8. Numerical Example 2 (Find Frequency)

The time period of an AC is 0.01 s. Find its frequency.

Given : $T = 0.01 \text{ s}$

Solution : $f = \frac{1}{T} = \frac{1}{0.01} = 100 \text{ Hz}$ $f = 100 \text{ Hz}$

9. Numerical Example 3 (Cycles in Given Time)

An AC supply has a frequency of 50 Hz. How many cycles are completed in 2 seconds?

Given : $f = 50 \text{ Hz}$, $t = 2 \text{ s}$

Solution : Number of cycles (N) = $f \times t = 50 \times 2 = 100 \text{ cycles}$
 $N = 100 \text{ cycles}$

10. Important Points

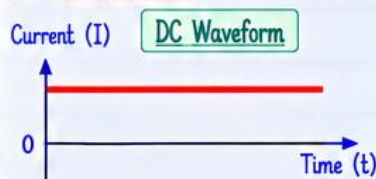
- In one time period, current completes one full cycle (positive half cycle + negative half cycle).
- Frequency in India is 50 Hz.
- AC can be easily stepped up or stepped down using transformers, which makes it suitable for long-distance power transmission.

27. AC vs DC

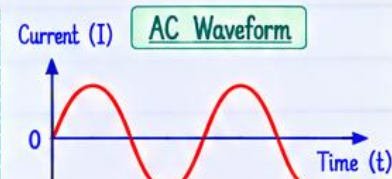
1. Meaning

- **Direct Current (DC)** : A current which flows only in one direction and has constant magnitude with time.
- **Alternating Current (AC)** : A current which changes its direction and magnitude periodically with time.

2. Waveforms



DC : Constant value
(does not change with time)



AC : Changes with time
(alternates direction)

3. AC vs DC : Detailed Comparison

S. No.	Parameter	Direct Current (DC)	Alternating Current (AC)
1	Direction	Flows only in one direction	Changes direction periodically
2	Magnitude	Constant	Varies with time (usually sinusoidal)
3	Waveform	Straight line	Sine wave
4	Frequency	Zero (0 Hz)	Non-zero (in India 50 Hz)
5	Source	Batteries, DC power supply, solar cells	Alternator, power grid (mains), AC generator
6	Transmission	Not suitable for long distance	Suitable for long distance (can be stepped up/down using transformer)
7	Conversion	Can be converted to AC using inverter	Can be converted to DC using rectifier
8	Common Uses	Mobile chargers, electronics, electric vehicles	Homes, industries, appliances, power distribution

4. Frequency of AC

- Frequency (f) is the number of complete cycles in one second.
- SI unit : hertz (Hz)

$$f = \frac{1}{T}$$

where, f = frequency (Hz)
T = time period (s)

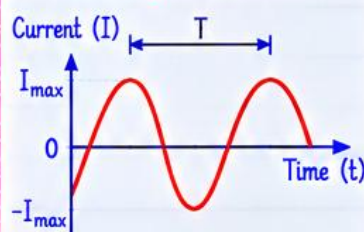
- In India, the mains supply frequency is 50 Hz.

Example : If 100 cycles are completed in 2 seconds, find the frequency.

Solution :

$$f = \frac{\text{Number of cycles}}{\text{time}} = \frac{100}{2} = 50 \text{ Hz}$$

5. Reading Waveforms



- The current starts from zero, increases to maximum positive value, decreases to zero, becomes negative, reaches maximum negative value and again comes to zero. This completes one cycle.
- Time taken for one cycle = T (time period).
Frequency $f = \frac{1}{T}$

6. Advantages

Advantages of DC

- Simple and constant supply.
- Safe for low-voltage devices.
- Used in electronic circuits and battery-operated devices.
- No frequency-related issues.

Advantages of AC

- Can be easily stepped up or down using transformers.
- Suitable for long-distance transmission.
- Widely used in homes, industries and power distribution.
- Generators can produce AC easily and economically.

7. Uses

Uses of DC	Uses of AC
• Mobile phones and laptops • Batteries and solar panels • Electronic circuits (TV, computer) • Electric vehicles : • DC motors in small devices	• Household supply (fans, lights) • Industrial machinery • Power transmission and distribution • AC motors (in pumps, compressors) • Home appliances (refrigerator, washing machine, etc.)

8. Important Points

- ① DC has zero frequency, AC has non-zero frequency.
- ② AC can be easily converted to higher or lower voltage using a transformer; DC cannot.
- ③ AC is preferred for long-distance transmission due to lower power loss.
- ④ Many electronic devices require DC, so AC is first converted to DC using a rectifier.
- ⑤ The standard mains supply in India is 230 V, 50 Hz (AC).

9. Conceptual and Numerical Questions

Q1. A coil produces 150 cycles in 3 seconds. Calculate the frequency.

Sol: $f = \frac{\text{Number of cycles}}{\text{time}} = \frac{150}{3} = 50 \text{ Hz}$

Q2. The time period of an AC source is 0.02 s. Find its frequency.

Sol: $f = \frac{1}{T} = \frac{1}{0.02} = 50 \text{ Hz}$

Q3. State whether the following are AC or DC :
(a) Battery (b) Mains supply (c) Solar cell
(d) Mobile charger output (e) Generator

Sol: (a) DC (b) AC (c) DC (d) DC (e) AC

Q4. The waveform shown below represents a current. Identify whether it is AC or DC and give a reason.



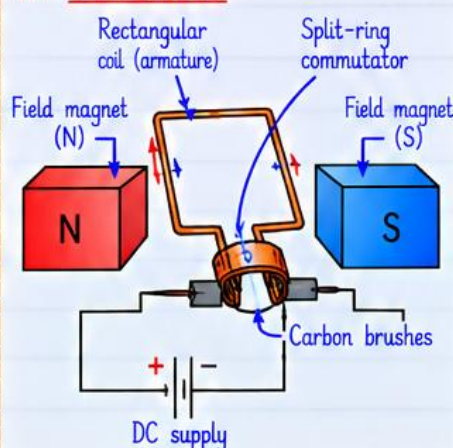
Sol: DC, because the current is constant and does not change with time.

28. Electric Motor

1. Principle

- An electric motor works on the principle that a **current-carrying conductor** placed in a **magnetic field** experiences a **force**.
- When a rectangular coil is placed in a magnetic field and current is passed through it, forces on its two sides are in **opposite directions**, producing a **torque** that **rotates the coil**.

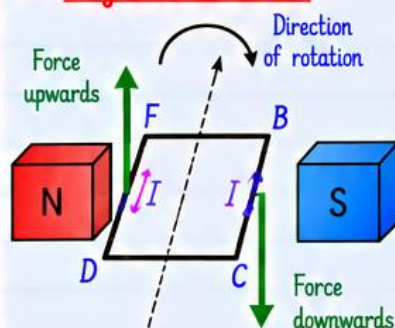
2. Construction



3. Working

- When current flows through the coil, the two parallel sides experience **equal and opposite forces** due to the magnetic field.
- These forces form a couple producing a **torque**, which **rotates** the coil.
- After every half rotation, the **split-ring commutator** reverses the current in the coil.
- The direction of force also reverses, so the coil continues to rotate in the same direction.

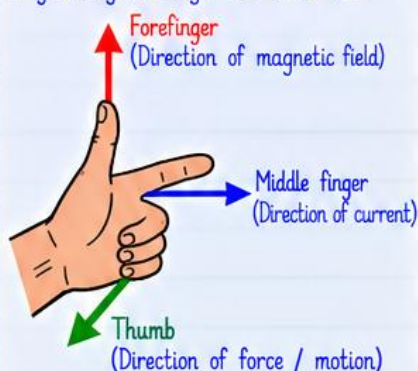
4. Diagram with Forces



Side AB experiences an upward force and side CD experiences a downward force, forming a couple which rotates the coil.

5. Fleming's Left-Hand Rule

The direction of force on a current-carrying conductor in a magnetic field is given by Fleming's left-hand rule.



6. Energy Conversion

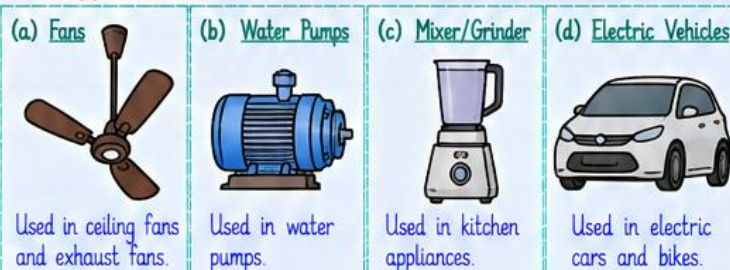
- Electric motor converts **electrical energy** into **mechanical energy**.
- The electrical energy supplied to the motor is converted into rotational **kinetic energy** of the coil/armature.

Electrical Energy
 $\Rightarrow$
 Mechanical Energy
 (rotation)

7. Advantages

- Simple construction and easy to operate.
- High efficiency.
- Can provide continuous rotary motion.
- Widely used in home appliances, industries and vehicles.
- Available in different sizes and power ratings.

8. Applications



9. Important Points

- A current-carrying conductor in a magnetic field experiences a force.
- In a motor, the coil experiences a torque due to a pair of equal and opposite forces.
- Split-ring commutator reverses the current after every half rotation.
- Direction of force is given by Fleming's left-hand rule.
- Electric motor converts electrical energy into mechanical energy.

10. Conceptual Questions

Q1. Why does a current-carrying coil rotate in a magnetic field?

Ans: The two parallel sides of the coil experience equal and opposite forces, forming a couple (torque), which rotates the coil.

Q2. What is the function of a split-ring commutator in a DC motor?

Ans: It reverses the direction of current in the coil after every half rotation so that the coil continues to rotate in the same direction.

Q3. Which rule is used to find the direction of force in a motor?

Ans: Fleming's left-hand rule.

Q4. Convert the following energy.

Ans: Electrical energy $\rightarrow$ Mechanical energy (rotation).

Q5. State two applications of electric motor.

Ans: (i) Ceiling fans (ii) Water pumps, Mixer/Grinder, Electric vehicles, etc.

Q6. Why is DC supply used in a simple electric motor?

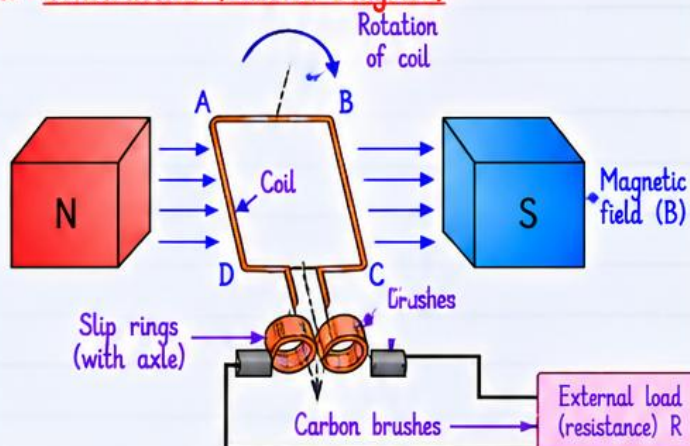
Ans: Because the split-ring commutator works with DC to reverse current every half rotation and maintain continuous rotation.

29. Electric Generator

1. Principle

- A generator works on the principle of **electromagnetic induction**.
- When a coil rotates in a magnetic field, the **magnetic flux** linked with the coil **changes continuously**, so an **induced emf** is produced in the coil.
- If the coil is connected to an external circuit, an induced current flows.

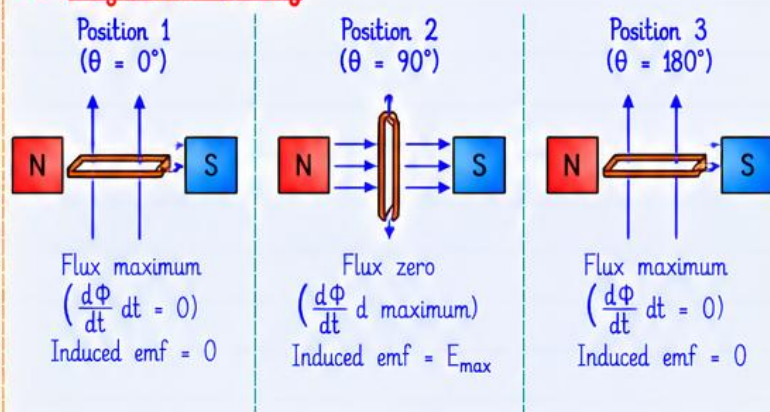
2. Construction (Labeled Diagram)



3. Working

- A rectangular coil ABCD is rotated with angular speed ω in a uniform magnetic field.
- As the coil rotates, the magnetic flux linked with the coil changes continuously.
- An emf is induced in the coil (according to Faraday's law) and direction is given by Fleming's right-hand rule.
- The ends of the coil are connected to slip rings which rotate with the coil. Carbon brushes maintain contact with the slip rings.
- The induced emf (and current) changes direction every half rotation, so the output is alternating current (AC).

4. Diagram of Working



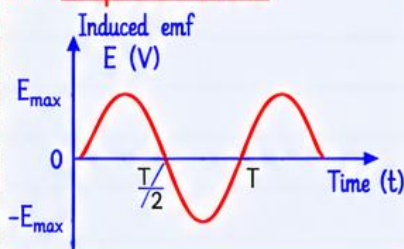
5. Induced EMF in a Rotating Coil

If a coil of N turns and area A rotates with angular speed ω in a magnetic field B , the induced emf is :

$$E = NBA\omega \sin \omega t$$

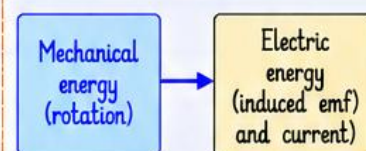
- Maximum emf : $E_{\text{max}} = NBA\omega$
- The induced emf varies sinusoidally with time.

6. Output Waveform



The generator produces an alternating current (AC) output.

7. Energy Conversion



- A generator converts mechanical energy into electrical energy using electromagnetic induction.

8. Generator vs Motor (Comparison)

Feature	Electric Generator	Electric Motor
Principle	Electromagnetic induction (change in flux produces emf)	Force on current-carrying conductor (motor effect)
Input	Mechanical energy (rotation)	Electrical energy (current supply)
Output	Electrical energy (induced emf and current)	Mechanical energy (rotation)
Rule used	Fleming's right-hand rule (for direction of induced current)	Fleming's left-hand rule (for direction of force)
Device parts	Slip rings, carbon brushes	Commutator (in D.C. motor)
Type of output	Alternating current (AC)	Rotational motion (mechanical)

9. Applications

Generators are used in :

- Power plants (thermal, hydro, nuclear)
- Wind energy systems
- Diesel generators (backup supply)
- Automobiles (alternator for charging battery)
- Bicycle dynamo
- Small portable generators

10. Important Points

- A generator requires mechanical energy to rotate the coil.
- It works on electromagnetic induction.
- The output is AC (alternating current).
- Larger magnetic field strength, area of coil, number of turns and angular speed produce larger induced emf.
- It converts mechanical energy into electrical energy.

30. Integrated Revision

1. Potential Difference and Ohm's Law

Q1. A current of 2 A flows through a resistor of 10 Ω . Find the potential difference across it.

Sol : $V = IR$
 $= 2 \times 10$
 $= 20 \text{ V}$

$V = 20 \text{ V}$

Q2. The potential difference across a conductor is 12 V and the current is 3 A. Find its resistance.

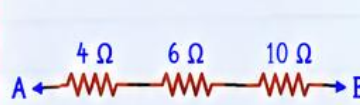
Sol : $R = \frac{V}{I} = \frac{12}{3} = 4 \Omega$

$R = 4 \Omega$

2. Resistor Combinations

Q3. Find the equivalent resistance between A and B.

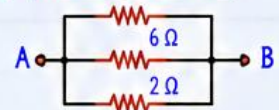
(a) Series combination:



$R_{eq} = 4 + 6 + 10 = 20 \Omega$

$R_{eq} = 20 \Omega$

(b) Parallel combination:



$\frac{1}{R_{eq}} = \frac{1}{6} + \frac{1}{2} + \frac{1}{2}$
 $= \frac{1+2+3}{6} = \frac{6}{6}$

$R_{eq} = 1 \Omega$

3. Electric Power

Q4. A 60 W bulb is operated at 220 V. Find the current drawn.

Sol : $P = VI \Rightarrow I = \frac{P}{V} = \frac{60}{220} = 0.27 \text{ A}$

$I = 0.27 \text{ A}$

Q5. A heater of 100 Ω is connected to a 200 V supply. Find the power.

Sol : $P = \frac{V^2}{R} = \frac{(200)^2}{100} = \frac{40000}{100}$

$P = 400 \text{ W}$

4. AC Frequency and Time Period

Q6. An AC source has a time period of 0.02 s. Find its frequency.

Sol : $f = \frac{1}{T} = \frac{1}{0.02} = 50 \text{ Hz}$

$f = 50 \text{ Hz}$

Q7. Find the time period of an AC supply with a frequency of 60 Hz.

Sol : $T = \frac{1}{f} = \frac{1}{60} = 0.0167 \text{ s}$

$T = 0.0167 \text{ s}$

5. Electromagnetic Induction

Q8. A coil of 500 turns has a magnetic flux change from 0.02 Wb to 0.08 Wb in 0.1 s. Find the induced emf.

Sol : $E = N \left(\frac{\Delta \Phi}{\Delta t} \right)$
 $= 500 \frac{(0.08 - 0.02)}{0.1}$
 $= \frac{500 \times 0.06}{0.1} = 300 \text{ V}$

$E = 300 \text{ V}$

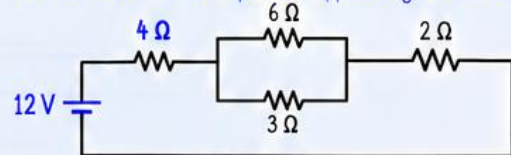
6. Motor vs Generator (Conceptual)

Q9. State two differences between an electric motor and an electric generator.

Ans :	Electric Motor	Electric Generator
Energy conversion	Electrical $\rightarrow$ Mechanical	Mechanical $\rightarrow$ Electrical
Working principle	Force on current-carrying conductor	Electromagnetic induction
Input	Electrical energy (current supply)	Mechanical energy (rotation)
Output	Rotational motion	Electrical energy (induced emf)

7. Mixed Numerical

Q10. In the given circuit, find (i) total resistance (ii) total current (iii) power supplied by the source.



Sol : (i) $R_{parallel} = \frac{6 \times 3}{6 + 3} = \frac{18}{9} = 2 \Omega$

$R_{total} = 4 + 2 + 2 = 8 \Omega$

$R_{total} = 8 \Omega$

(ii) $I = \frac{V}{R} = \frac{12}{8} = 1.5 \text{ A}$

$I = 1.5 \text{ A}$

(iii) $P = VI = 12 \times 1.5 = 18 \text{ W}$

$P = 18 \text{ W}$

8. Syllabus Based MCQs

Q1. The SI unit of electric potential difference is :

- (a) ampere (b) ohm
(c) volt (d) joule

Ans : (c) volt

Explanation : Potential difference is measured in volt (V).

Q3. A device that converts mechanical energy into electrical energy is :

- (a) electric motor (b) generator
(c) transformer (d) electric heater

Ans : (b) generator

Explanation : A generator works on electromagnetic induction.

Q2. Which of the following is used to increase current in a circuit ?

- (a) increase resistance
(b) decrease resistance
(c) decrease potential difference
(d) increase length of wire

Ans : (b) decrease resistance

Explanation : From Ohm's law $I = \frac{V}{R}$. Decreasing R increases I.

Q4. The frequency of AC supply in India is :

- (a) 25 Hz (b) 50 Hz
(c) 60 Hz (d) 100 Hz

Ans : (b) 50 Hz

Explanation : The standard mains supply frequency in India is 50 Hz.

Q5. The direction of induced current in a coil is given by :

- (a) Ohm's law
(b) Fleming's left-hand rule
(c) Fleming's right-hand rule
(d) Lenz's law

Ans : (d) Lenz's law

Explanation : Lenz's law gives the direction of induced current.

Q6. Which of the following produces alternating current (AC) ?

- (a) battery (b) solar cell
(c) generator (d) dry cell

Ans : (c) generator

Explanation : A generator produces AC due to continuous change in magnetic flux.

9. Key Takeaways

① $V = IR$ and $P = VI = I^2 R = \frac{V^2}{R}$

② Series : $R_{eq} = R_1 + R_2 + \dots$
 Parallel : $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \dots$

③ AC : $f = \frac{1}{T}$ (in India $f = 50 \text{ Hz}$)

④ Induced emf : $E = N \frac{\Delta \Phi}{\Delta t}$
 $E = N B A \omega \sin \omega t$

⑤ Motor : Electrical $\rightarrow$ Mechanical
 Generator : Mechanical $\rightarrow$ Electrical