Chapter = 13

"Current Electricity"

Electric Current:

The amount of charge passing through the conducting material in unit time is called electric current.

Mathematically:

Let q is the amount of charge passing through the cross section of a conductor in time t. The electric current I can be expressed mathematically as

$$\boxed{I = \frac{q}{t}}$$

The S.I unit of electric current is Amperes and it is equal to Coulomb/second.

Electronic Current:

It is the current in the direction of motion of electron flowing in conductor under the influence of a potential source. Its direction is from negative to positive.

Conventional Current:

It is the current in the direction in which positive charges would have been flown in conductor under the influence of a potential source. Its direction is from positive to negative.

Ohm's Law:

Significance:

It is an empirical law discovered by Georg Simon Ohm in 1827. It is fundamental law in electrical and electronics.

Statement:

"The current passing through a conductor is directly proportional to the potential difference applied across the conductor keeping the other physical factors constant such as resistance and temperature."

Mathematically:

If I is the current passing through a conductor and V is the voltage dropped across it then mathematically Ohm's law can be expressed as

$$V \propto I$$

$$V = (constant)I$$

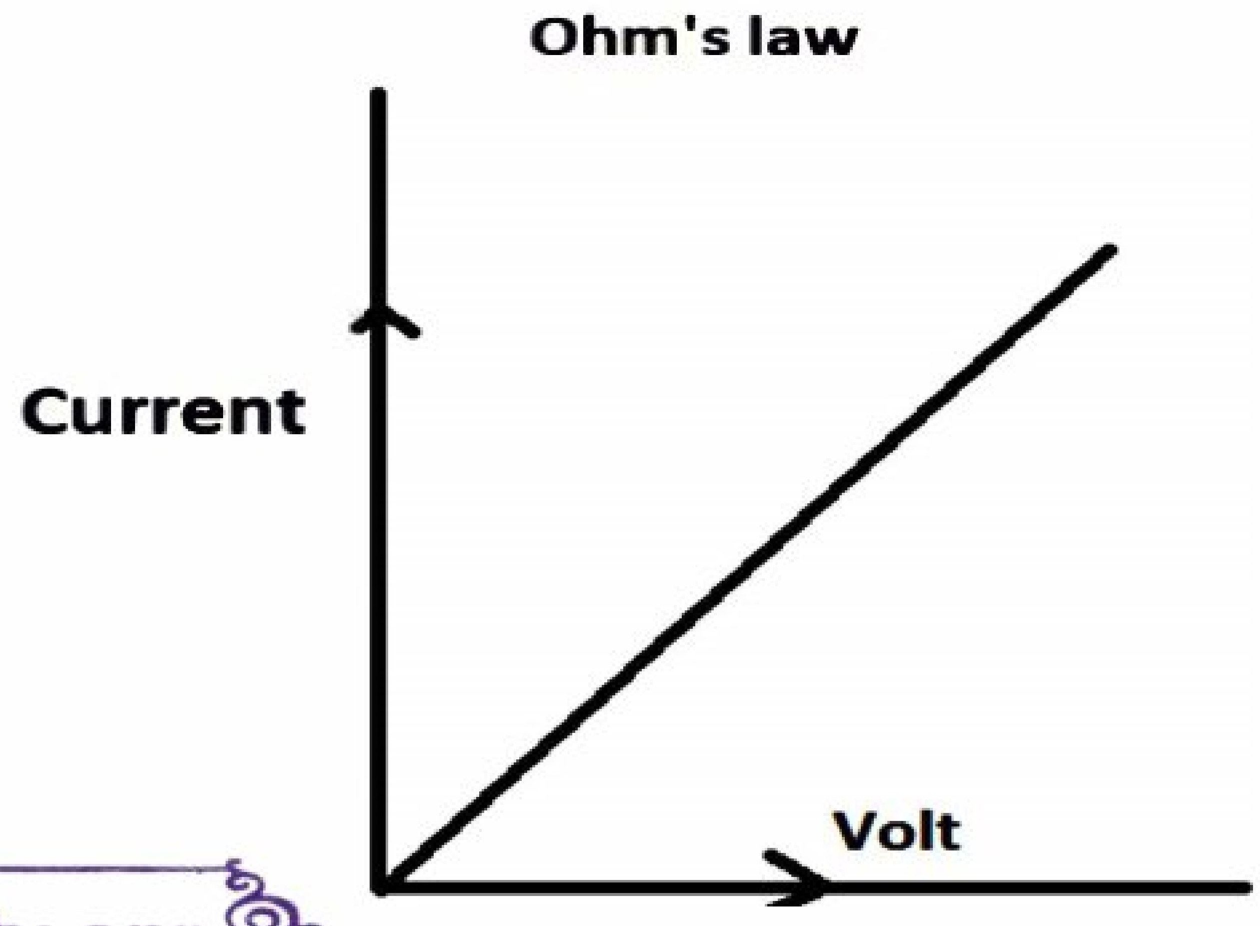
Here, Constant = R = Resistance of conductor

$$V = (R)I$$

$$\boldsymbol{V = IR}$$

Graphical representation:

The graph between the voltage and current is shown in figure.



Resistance:

The opposition to the flow of charge is called resistance. The S.I unit of resistance is ohm (Ω)

Conductance:

The reciprocal of the resistance is called conductance. It is the facility to the flow of charge.

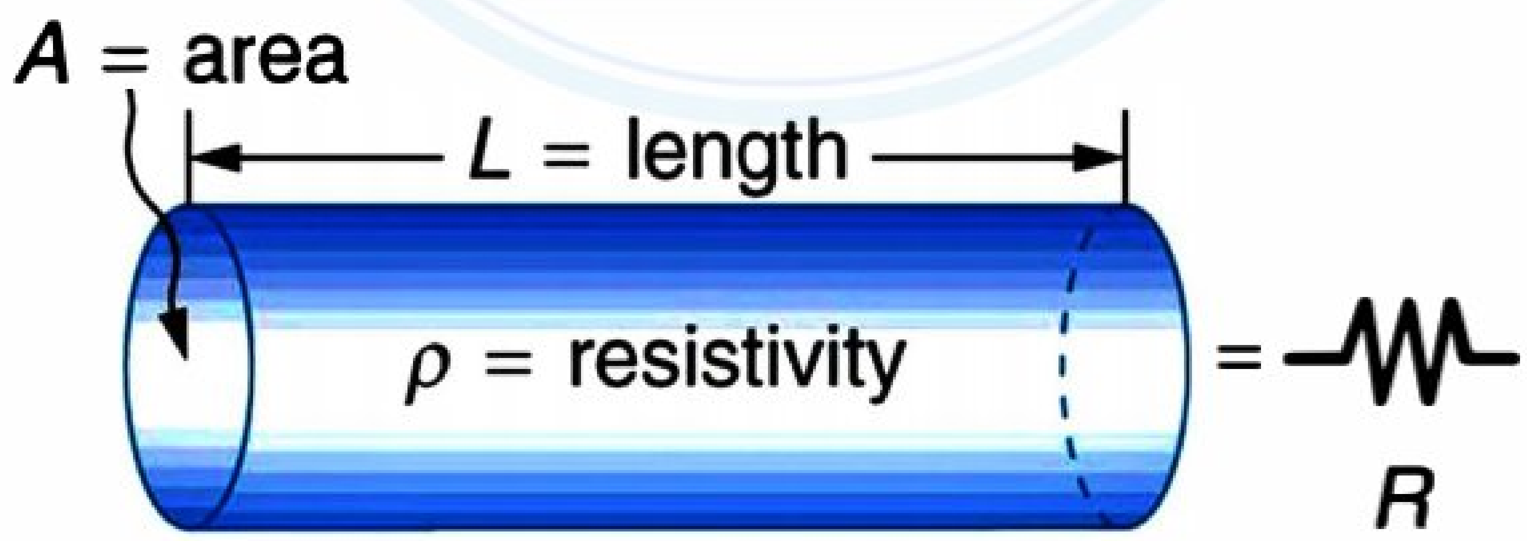
Resistivity:

Resistance per unit length per unit cross sectional area of material is called Resistivity or specific resistance.

$$\boxed{\rho = \frac{RA}{L}}$$

Derivation:

Resistance of the conductor depends upon the dimensions of the conductor such as length and cross-sectional area. To determine the expression for the resistivity of the conductor suppose that we have conductor of length 'L' and area of cross-section 'A'.



It is found that the resistance of conductor increases with increasing length and decreases when area of cross-section is increased i.e.

$$R \propto L$$

$$R \propto \frac{1}{A}$$

Combining above expression, we have

$$R \propto \frac{L}{A}$$

$$\boxed{R = \frac{\rho L}{A}}$$

Here ρ is called resistivity or Specific resistance and can be expressed as.

$$\boxed{\rho = \frac{RA}{L}}$$

The S.I unit of Specific resistance or resistivity is Ohm-meter ($\Omega . m$).

Q. Explain the effect of temperature on resistance.

Dependence of Resistance on temperature:

The resistance in flow of electric current is due to the collision of electrons with the ions or atoms of the metal (solid). The electrical resistance of metals increases with the increase in temperature. As the temperature of a body increases its atoms or molecules start vibrating with the higher amplitude and the probability of collision of electrons with the ions or atoms increases which ultimately affect the drift velocity of free electrons for a given applied voltage. This causes the increase in resistance of material and hence with rising the temperature, the decrease in drift velocity is attributed to the decrease in the electric current or increase in the resistance for a given applied voltage.

Q. Derive the expression for the effect of temperature on the resistance of a conductor.

Derivation:

Let R_o is the resistance of a material (metal) at temperature T_1 and if the temperature of metal is changed to T_2 the final resistance of the material will changed to R_t. Therefore,

Change in resistance, $\Delta R = R_t - R_o$

Change in temperature, $\Delta T = T_2 - T_1$

Experimentally it is found that the change in resistance (ΔR) is directly proportional to the original resistance R_o and temperature difference ΔT

$$\Delta R \propto R_o$$

$$\Delta R \propto \Delta T$$

$$\Delta R \propto R_o \Delta T$$

$$\Delta R = \alpha R_o \Delta T$$

$$\boldsymbol{\alpha = \frac{\Delta R}{R_o \Delta T}}$$

Here α is called the temperature co-efficient of resistance and it is defined as

"Change in resistance per unit original resistance per unit change in temperature is called temperature co-efficient of resistance."

Positive Temperature Coefficient:

When resistance increases with the increase in temperature as in case of metals, then temperature coefficient is positive.

Negative Temperature Coefficient:

When resistance decreases with the increase in temperature as in case of semiconductor, then temperature coefficient is negative.

Final Resistance:

Since

$$\Delta R = \alpha R_o \Delta T$$

As we know that

$$\Delta R = R_t - R_o$$

We get

$$R_t - R_o = \alpha R_o \Delta T$$

$$R_T = R_o + \alpha R_o \Delta T$$

$$\boldsymbol{R_T = R_o(1 + \alpha \Delta T)}$$

In terms of resistivity

As we know that resistance is directly proportional to resistivity therefore,

$$\boldsymbol{\rho_T = \rho_o(1 + \alpha \Delta T)}$$

Combination of Resistance:

Series Combination of Resistors:

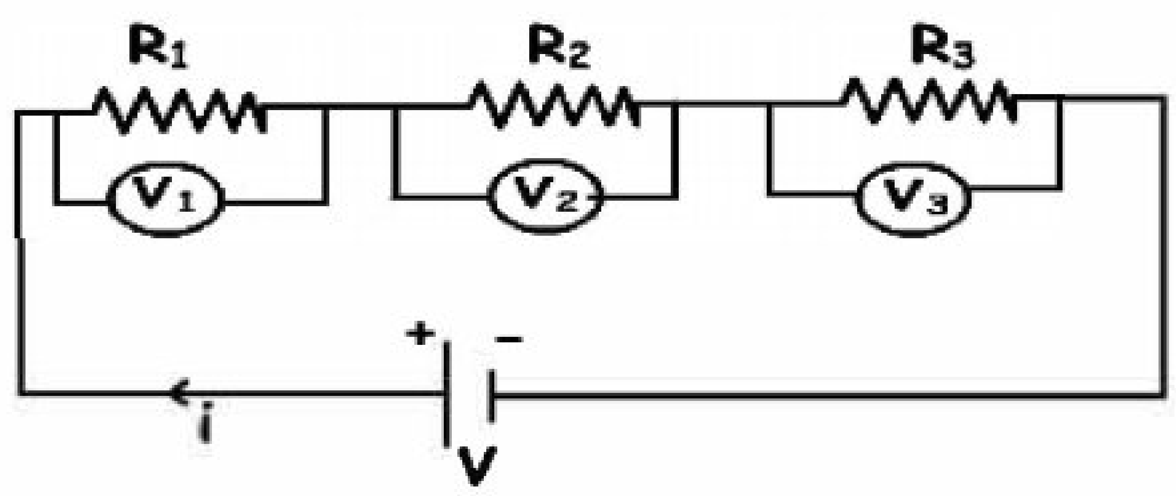
When resistances are connected end to end, then this kind of arrangement is called series combination of resistors.

Current and Voltage in series combination:

In series combination of resistors there is only one path for the flow of electric current. Electric current passing through each resistor is same. The sum of potential differences across the resistors is equal to the total potential difference applied across the combination.

Derivation for Equivalent Resistance

Consider three resistances R_1, R_2 and R_3 connected to one another in series circuit as shown below.



Let the circuit is connected to a power supply of voltage 'V' and an electric current 'I' is passing through the circuit. Let

Potential difference across R_1 is V_1
Potential difference across R_2 is V_2

Potential difference across R_3 is V_3

The sum of these Potential differences is equal to 'V'.

$V = V_1 + V_2 + V_3$ ---------------------- (1)

According to Ohm's law

$V = IR$
$V_1 = I_1R_1$ $V_2 = I_2R_2$ $V_3 = I_3R_3$

Substituting these values in equation (1), we have

$IR_E = IR_1 + IR_2 + IR_3$

$IR_E = I(R_1 + R_2 + R_3)$

$\boldsymbol{R_E = R_1 + R_2 + R_3}$

Conclusion:

1. In series combination the equivalent resistance is the sum of the individual resistances.
2. Equivalent resistance is greater than largest resistance connected in series.

Parallel Combination of Resistors:

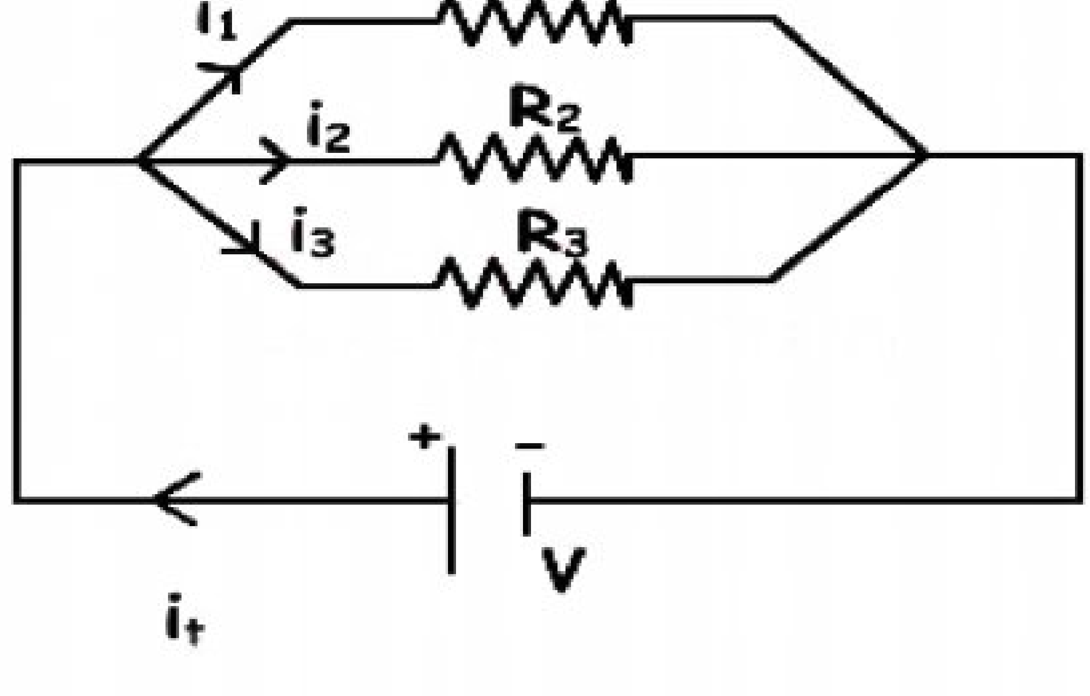
When resistors are connected to the same terminals of the battery, then this kind of arrangement is called parallel combination of resistances.

Current and voltage in parallel combination:

In parallel combination of resistors there is more than one path for the flow of electric current. Electric current passing through each resistor is different and it depends upon the value of resistance. Potential difference across each resistor is the same.

Derivation for Equivalent Resistance

Consider three resistances R_1, R_2 and R_3 connected to the same terminals of battery as shown in figure below



Let the circuit is connected to a power supply of voltage 'V' and an electric current 'I' is passing through the circuit.

Electric current passing through R_1 is I_1
Electric current passing through R_2 is I_2
Electric current passing through R_3 is I_3

The sum of all three currents is equal to 'I'.

$$\boldsymbol{I = I_1 + I_2 + I_3} \text{----------------} \textbf{(1)}$$

According to Ohm's law

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

$$I_1 = \frac{V_1}{R_1},\ I_2 = \frac{V_2}{R_2},\ I_3 = \frac{V_3}{R_3}$$

substituting all these values in equation (1), we have

$$\frac{V}{R_E} = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}$$

Since in parallel combination potential difference across each resistor is same i.e.

$$V = V_1 = V_2 = V_3$$

$$\frac{V}{R_E} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\boldsymbol{\frac{1}{R_E} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

Equivalent resistance of circuit is always smaller than any of the resistance connected parallel in the circuit.

Conclusion:

1. The reciprocal of the equivalent resistance is the sum of the reciprocals of the individual resistances.
2. The equivalent resistance is less than the smallest resistance in combination.

Power Dissipation in Resistors:

The power dissipated as heat when electric current is passing through the resistor is called power dissipation in resistor.

Explanation:

When an electric current passes through a conductor, some useful electrical energy is dissipated in the form of heat energy. This loss of electrical energy is due to the collision of charges with the atoms of conductor. Loss of electrical energy in unit time is referred to as "power dissipation in resistor".

Unit:

Its unit is Watt (W) which is equivalent to Joule per second (J/s).

Mathematically:

The work done in transferring charge 'q' to the resistor is given by

$$W = qV$$

Power is defined as Work done per unit time

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

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

Since

$$I = \frac{q}{t}$$

$$\boxed{P = VI} — (1)$$

Using Ohms law $V = IR$

$$P = (IR)I$$

$$\boldsymbol{P = I^2R — (2)}$$

Again using Ohm's Law

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

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

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

$$\boxed{P = \frac{V^2}{R}} — (3)$$

Combining equation (1), (2) and (3)

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

Heat energy in resistor:

If a current "I" flows steadily through a resistor "R" for time "t" then, total heat energy supplied through the resistor "R" is given by

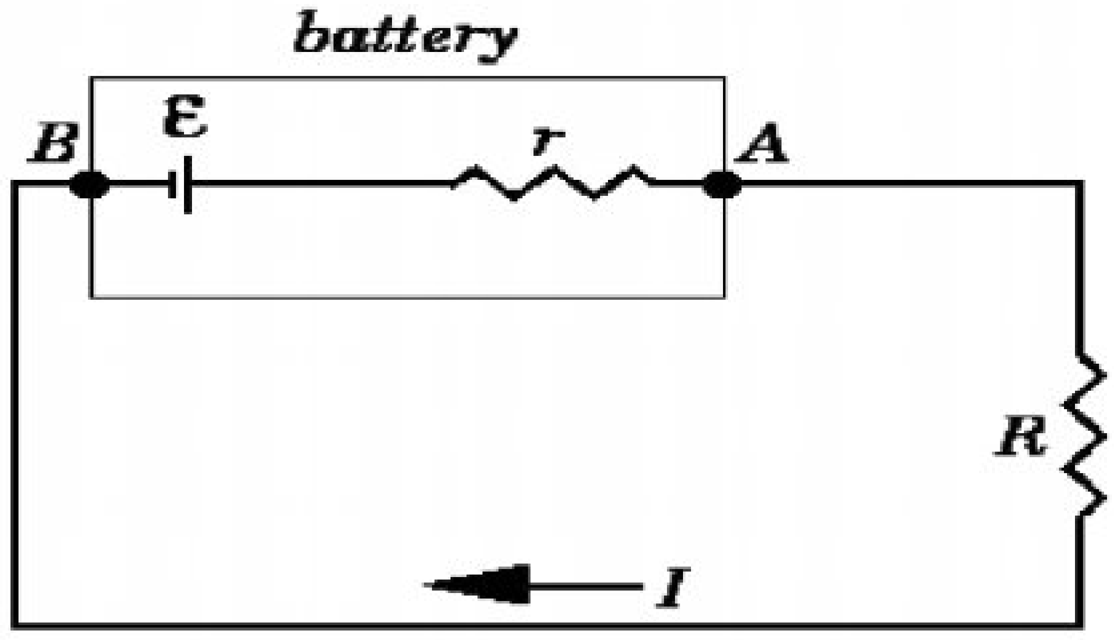
Heat energy = Power dissipated x time

$$H = (I^2R)\,(t)$$

$$\boldsymbol{H = I^2Rt}$$

Electromotive Force (E.M.F):

The potential difference exists between the two terminals of a battery when it is not connected in external circuit is called electromotive force.



Mathematically:

Suppose a battery of electromotive force 'E' is connected to external resistor 'R' and let 'r' is the internal resistance of battery as shown in figure.

Using Ohm's law

Voltage of source = Current x Resistance in circuit

$$E = I(r + R)$$

$$E = Ir + IR$$

Here

$V = IR =$ Potential difference across external resistor

$$\boldsymbol{E = Ir + V}$$

Here E is the E.M.F. of the battery and r is the internal resistance of battery and I is the Maximum current that a battery can provide.