

Chapter =13

Current Electricity

**Electric Current:**

Amount of charge passing through the cross-section area of a conductor in a unit time is defined as the electric current

Mathematically:

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

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

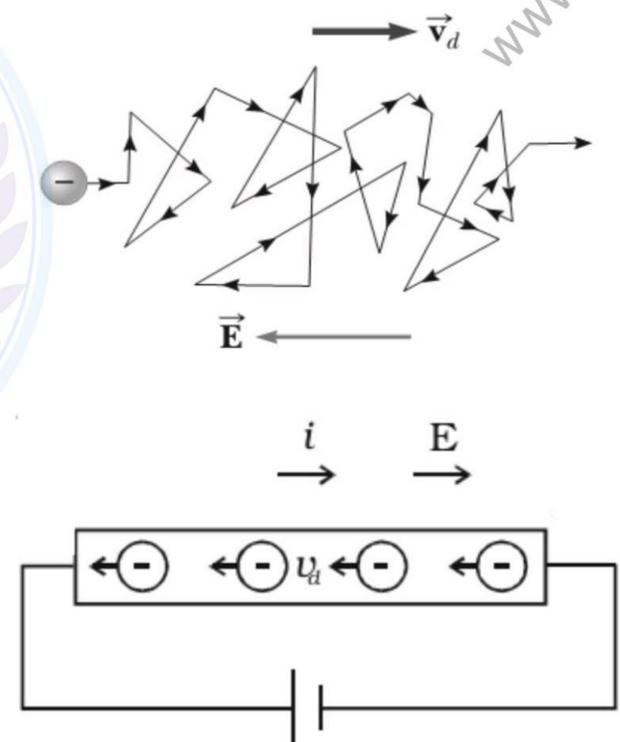
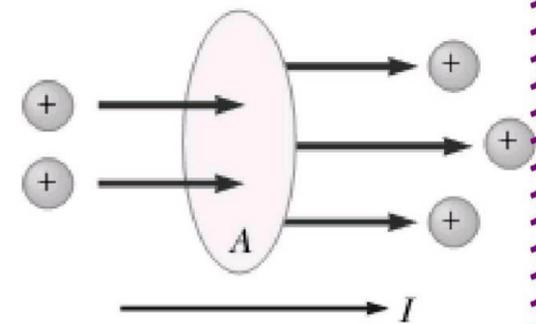
The S.I unit of electric current is Amperes and it may be defined as

Electric current is a fundamental quantity and the unit of electric charge Coulomb is defined in terms of electric current as

"It is the amount of charge that passes through the cross-sectional area of a conductor in 1 second if the current passing through the conductor is 1 ampere."

Explanation:

In normal condition the free electrons in a metal conductor are in continuous random motion identical to the motion of the molecules of an ideal gas. For each electron moving in a particular direction there is another electron moving in the opposite direction hence net current is zero. Now if an external electric field is applied across the conductor through a battery (or any other source) the electrons are attracted toward the positive terminal of the battery and drift toward the positive terminal with velocity v_d . Now as all the electrons are moving in the same direction there is a net charge flow through the conductor, hence developing an Electric Current.



Types of Current:

On the basis of direction, the electrical current has two types



- **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:

"Voltage developed across a conductor is directly proportional to the current passing through it keeping the other physical factors constant."

OR

"Current passing through a conductor is directly proportional to the voltage applied across it keeping the other physical factors constant."

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

$$V \propto I$$

$$kV = I \quad \text{--- (1)}$$

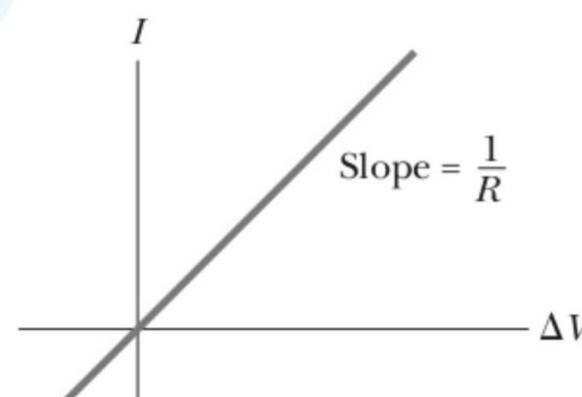
Here k is the conductance of the given material wire. The resistance R of wire is defined as the reciprocal of the conductance

$$R = \frac{1}{k}$$

Equation (1) becomes

$$\boxed{V = IR}$$

R is called resistance of the given material.



Limitations of Ohm's Law:

The limitations of Ohm's law are,



- 1) Dimensions of conductor must be same
- 2) Temperature of conductor must be same
- 3) It holds only for metallic conductor

Graphical representation:

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

Resistance:

The opposition the flow of Electric current is called Resistance

Explanation:

Phenomena of resistance can be explained as:

If an external electric field is applied across the conductor through a battery (or any other source) the electrons are attracted toward the positive terminal of the battery and drift toward the positive terminal, with drift velocity v_d . These electrons in their way toward the positive terminal of the battery collide with the vibrating atoms of material and lose energy this lost in energy causes difficulty to the electron in reaching the positive terminal.

Factor affecting Resistance:

Electrical Resistance depends upon following factors.

- Dimensions of conductors (length area of Cross section).
- Temperature.
- Stress and strain.

The S.I unit of Resistance is Ohm which is equivalent to volt per meter represented by Greek letter capital Omega (Ω).

Resistivity:

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

Explanation:

Resistance of the conductor depends upon the dimensions of the conductor as

- Length of conductor (L). Higher the length higher the resistance.
- Cross-sectional Area of conductor (A). Higher the cross-sectional lower the resistance.

Mathematically it can be expressed as

$$R \propto L$$

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

Combining above expression

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

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

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

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

The S.I unit of Specific resistance or resistivity is **Ohmmeter** ($\Omega \cdot m$).

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). 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 causes the increase in resistance of material.

Mathematically:

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

The change in resistance (ΔR) is directly proportional to the original resistance

$$\Delta R \propto R_o$$

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

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

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



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

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

Temperature co-efficient of resistance could be positive or negative. Temperature co-efficient of metallic resistances is always positive. Whereas the Co-efficient of Semiconductor materials could be negative or positive depending on temperature range negative.

Final resistance R_T is can be written as

$$R_T = R_o + \Delta R$$

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

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



In Terms of Resistivity:

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

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

Combination of Resistance:

Series Combination of Resistor:

In series combination of resistors there is only one path for the flow of electric current.

Electric current passing through each resistor is same.

Potential difference across each resistor is different and it depends upon the value or resistance.

Expression 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.

Potential difference across R_1 is V_1

Potential difference across R_2 is V_2

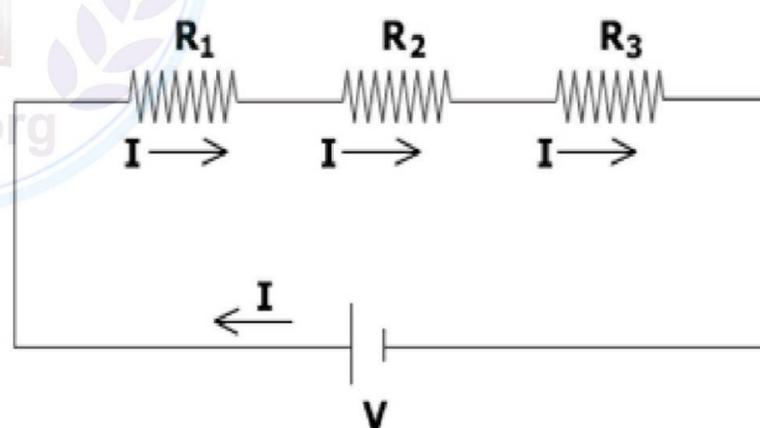
Potential difference across R_3 is V_3

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

$$V = V_1 + V_2 + V_3$$

According to Ohm's law $V = IR$

$$IR_e = IR_1 + IR_2 + IR_3$$



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

$$R_e = R_1 + R_2 + R_3$$

Hence, equivalent resistance of circuit is always greater than any of the resistance connected in series in the circuit.



Parallel Combination of Resistors

In parallel combination of resistors there is more than only 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.

Expression for Equivalent Resistance

Consider three resistances R_1 , R_2 and R_3 connected to one another in parallel circuit 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'.

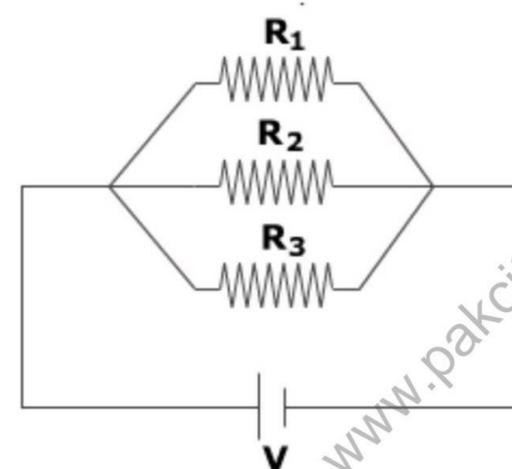
$$I = I_1 + I_2 + I_3$$

According to Ohm's law $I = \frac{V}{R}$

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

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

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

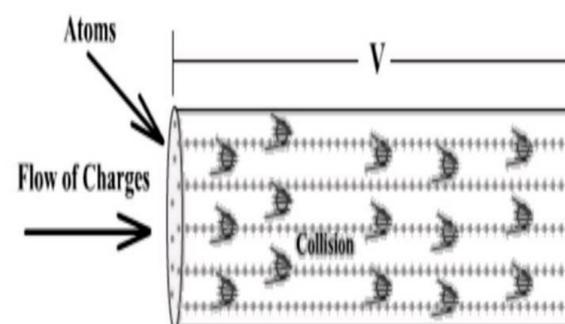


Power Deception in Resistors:

When current flows in a conductor then a part of electrical energy appears in the form of heat energy which is known as Power Deception in Resistor.

Explanation:

When an electric current pass 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

Power is defined as Work done per unit time

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

Since

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

$$W = qV$$

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

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

$$\boxed{P = VI} \text{--- (1)}$$

Using Ohms law $V = IR$

$$\begin{aligned} P &= (IR)I \\ P &= I^2R \text{--- (2)} \end{aligned}$$

Again, using Ohm's Law $I = \frac{V}{R}$

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

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



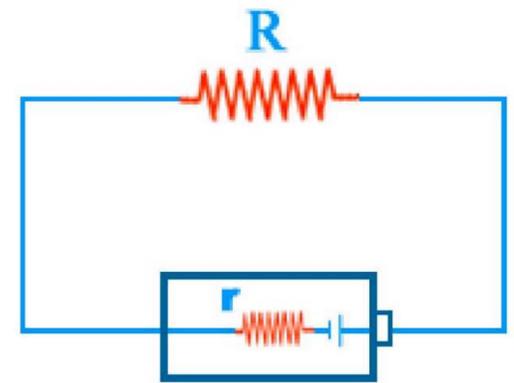
$$\boxed{P = \frac{V^2}{R}} \text{--- (3)}$$

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

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

INTERNAL RESISTANCE:

“When current passes through a source of potential difference, such as a battery, then it experiences some opposition within the source this opposition in the flow of current is called internal resistance.”

**Electromotive Force:**

Work done per unit charge by the potential source is called Electromotive force it is equal to the open terminal voltage of a Voltage Source is called Electro Motive force.

Mathematically:

$$E = Ir$$

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.

If we connect the battery across resistance R the potential dropped V across R can be written as Find out as

$$E = Ir + V$$

$$E = Ir + IR$$

Current in the circuit can be written as

$$I = \frac{E}{R + r}$$

Now if the battery is lost the Electrical energy and it is charging by an external source

$$V = E + Ir$$

TERMINAL VOLTAGE:

“The potential difference appears at the two terminals of a source in the presence of internal resistance and a current is passing through it, is called terminal voltage.”

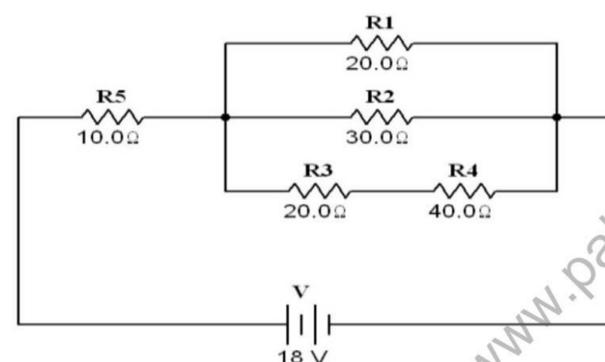
$$V = E - Ir$$

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ELECTROMOTIVE FORCE	POTENTIAL DIFFERENCE
The term e.m.f is used for a device which produces electricity e.g cell, battery, and generator.	The term potential difference is used for a device which uses electricity e.g. filament, speaker, and fan.
A source of electricity changes other forms of energy into electric energy.	A device which uses electricity changes electric energy into other forms of energy.
Formula: $E =$	Formula: $V =$ 
Unit: Volt	Unit: Volt
The emf of a source is 1V if it changes 1J of energy from other forms into electric form for every 1C charge flowing through it.	The potential difference across a device is 1V if it changes 1J of energy from electric form into other forms for every 1C charge flowing through it.

CHAPTER-13**NUMERICALS FROM PAST PAPERS****1995**

- Q.3(c)** A platinum wire of diameter 0.2mm is wound to make a resistor of 4 Ω . How long a wire is needed for this purpose? ($\rho = 11 \times 10^{-8} \Omega \text{m}$)
(1.1424m)

**1996**

- Q.4(c)** The resistance of a copper wire is 1.27 Ω at 20 $^{\circ}\text{C}$. Find its resistance at 0 $^{\circ}\text{C}$ and at 100 $^{\circ}\text{C}$. The temperature coefficient of resistivity of copper is $\alpha = 0.0039^{\circ}\text{C}^{-1}$ (1.178 Ω , 1.637 Ω)

2000

- Q.4(d)** You are given three resistors each of 2 ohms. How would you arrange these resistors to obtain the equivalent resistances of (i) 1.33 ohms (ii) 3 ohms (iii) 6 ohms? Also prove the result mathematically.

2001

- Q.3(d)** Find the equivalent resistance and the current through R_3 & R_4 . Given $R_1 = 20\Omega$, $R_2 = 30\Omega$, $R_3 = 20\Omega$, $R_4 = 40\Omega$, $R_5 = 10\Omega$
(20 Ω , 15A)

2002 (Pre Med. group)

Q.6(d) A battery of 24V is connected to a 10Ω load and current of 2.2 amp is drawn; find the internal resistance of the battery and its terminal voltage. **(0.9 Ω , 22V)**

2002 (Pre Engg. group)



Q.3(d) The resistance of a tungsten wire used in a filament of a 60-watt bulb is 240Ω when the bulb is hot at a temperature of 2020°C , what would you estimate its resistance at 20°C ? (The temperature coefficient of tungsten $\alpha 0.0046/^\circ\text{C}$) **(25.4 Ω)**

2003 (Pre Med. group)

Q.3(d) Find the equivalent resistance in the given circuit, current I and potential difference between 'a' and 'b':

$$R_1 = 5\Omega, R_2 = 2\Omega, R_3 = 3\Omega, R_4 = 6\Omega, V = 6 \text{ volts} \quad \mathbf{(1A, 5V, 6\Omega)}$$

2003 (Pre Engg. group)

Q.3. (d) A 50-ohm resistor is to be wound with platinum wire, 0.1 mm in diameter. How much wire is needed ($\rho = 11 \times 10^{-8} \Omega\text{-m}$)? **(3.57 m)**

2005

Q.6. (d) Two resistances of 10Ω and 50Ω are connected in series with a 6-volt battery. Calculate:

- The charges drawn from the battery per minute
- The power dissipated in 10Ω resistance. **(6C, 0.1W)**

2006

Q.4. (d) A 50-ohm resistor is required from a copper wire, 0.2 mm in diameter. What is the length of the wire needed? ($\rho = 1.6 \times 10^{-8} \Omega\text{-m}$) **(98.125m)**

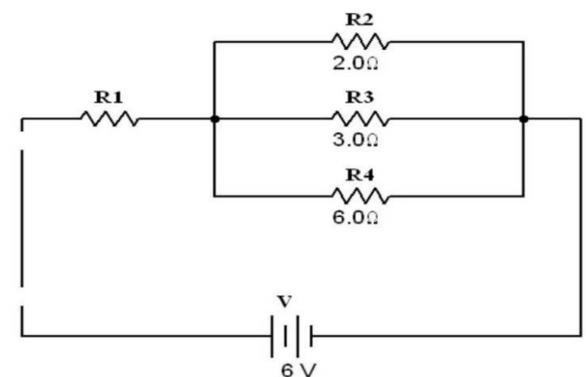
2008

Q.3. (d) A rectangular block of iron has the dimensions $1.2\text{cm} \times 1.2\text{cm} \times 15\text{cm}$.

(i) What is the resistance of the opposite square ends?

(ii) What is the resistance between two of the rectangular faces?

(The resistivity for iron at room temperature is 9.6×10^{-8} —



$8\Omega\text{m}$) ($1 \times 10^{-7}\Omega$, $6.4 \times 10^{-8}\Omega$)

2009

Q.6. (d) In the given diagram $R_1 = R_2 = 4 \Omega$ and $R_3 = 6\Omega$. Calculate the current in the 6Ω resistor.

(0.37A)



2010

Q.2. (xi) A water heater that will deliver 1 kg of water per minute is required. The water is supplied at 20°C and an output temperature of 80°C is desired. What should be the resistance of the heating element in water if the line voltage is 220V? (Sp. Heat of water = 4200 J/kg K).

(11.52 Ω)

2011

Q.2. (x) A rectangular bar of iron is 2 cm x 2 cm in cross –section and 20 cm long. What is the resistance of the bar at 500°C if $\rho = 11 \times 10^{-8}\Omega\text{-m}$ and $\alpha = 0.0052\text{K}^{-1}$?

($1.98 \times 10^{-4}\Omega$)

2012 You are given three resistors each of 2Ω . How would you arrange these to obtain equivalent resistance of: (a) 1.33Ω (b) 3Ω (c.) 6Ω . Verify the results mathematically?

2013 Two resistors of 5Ω and 2Ω are connected in parallel with a 9V battery. Calculate the current and power dissipated in each resistance.

2014

Q2(ii) A rectangular bar of iron is 2 cm X 2cm in cross section an 20 cm long. What will be its resistance at 500°C ? If $\alpha = 0.0052 \text{ K}^{-1}$ and $\rho = 11 \times 10^{-8}\Omega\text{m}$

2015

Q2(vii) A 50-ohm resistor is to be wound with platinum wire, 0.1 mm in diameter. How much wire is needed ($\rho = 11 \times 10^{-8} \Omega\text{m}$)?

(3.57 m)