CHAPTER-6
CURRENT ELECTRICITY

Topic-1 Current, E.M.F., Resistance and Ohm's Law

Concepts covered: Ohm's Law, emf, Potential difference, Resistance

Revision Notes

- A sustained electric current flows through a conductor only when it is connected to a source of emf.
- The electric current, in a given conductor is simply the rate of flow of charge across its cross section. Thus,

$$I = Q/t$$

- The unit of current is **ampere** (A). We have

$$\mathbf{1\ A = 1\ Coulomb\ per\ second = 1\ Cs^{-1}}$$

- The current, flowing through a wire, is said to be one ampere when one Coulomb of charge flows across its cross-section in one second.
- Potential is the electrical state of a conductor which determines the direction of flow of charge when two conductors are either kept in contact or joined by a metallic wire. The potential at a point is defined as the amount of work done in bringing a unit positive charge from infinity to that point. The potential difference (p.d.) between two points is simply the work done in transporting a positive charge of one Coulomb from the first point to the second point. $W = QV$
- The unit of potential difference is **Volt** (V). We have 1 volt = 1 joule per Coulomb = 1 JC^{-1}. The potential difference between two points equals one volt if the work done in transporting a charge of one coulomb between these points equals one joule.
- **Electromotive Force:** When no current is drawn from a cell, then the potential difference between the terminals of the cell is called electromotive force. It is denoted by ε. Its unit is Volt. The electromotive force of a cell depends upon

  (i) the material of the electrodes. **(ii)** the electrolyte used in the cells.
- **According to Ohm's Law :**

  The current flowing through a given conductor is directly proportional to the potential difference across its ends, provided the physical conditions of the conductor (*e.g.*, its length, its area of cross-section, its temperature, etc.) remain constant.

  The resistance of a conductor equals the ratio of the potential difference across its ends to the current flowing through it. Thus, the resistance of the conductor is numerically equal to the potential difference across its ends when unit current flows through it.

$$R = V/I \text{ or } V = IR \text{ or } I = V/R$$

- The obstruction offered to the flow of current by the conductor (or wire) is called its resistance. The unit of resistance is **ohm** (Ω). A conductor has a resistance of one ohm when a potential difference of one volt across its ends causes a current of one ampere to flow through it.
- The resistance associated with the electrolyte of a cell—within its electrodes—is known as the **internal resistance** of the cell.
- When a cell of emf ε or E, and internal resistance r, is connected across an external resistance R, current flows through the circuit, which is given by $I = E/(R + r)$

  and V = 'p.d.' across $V = IR$
- The internal resistance of a cell depends on

  (i) the nature, concentration and temperature of its electrolyte.

  (ii) the surface area of the ('dipped within the electrolyte' part) electrodes.

  (iii) the distance between the electrodes.
- An increase in the surface area of the electrodes causes the internal resistance to decrease, whereas an increase in the distance between the electrodes causes the internal resistance to increase. Internal resistance decreases with increasing temperature or concentration of an electrolyte.

- **Factors Affecting the Resistance of a Conductor**

  The electrical resistance of a conductor depends on the following factors :

  (i) Length of the conductor : The resistance of a conductor R is directly proportional to its length l

  i.e., $$R \propto l$$

  $\therefore$ When the length of a wire is doubled or halved, then its resistance also gets doubled or halved respectively.

  (ii) Area of cross-section of the conductor : The resistance of a conductor R is inversely proportional to its area of cross-section A.

  i.e., $$R \propto \frac{1}{A}$$

  $\therefore$ When the area of cross-section of wire is doubled, its resistance gets halved and if area of cross-section of wire is halved, its resistance will get doubled.

  (iii) Nature of the material of the conductor : The resistance of a conductor depends on the nature of the material of which it is made of. Some materials have low resistance whereas others have high resistance.

  (iv) Effects of temperature :

  (a) Resistance of a conductor increases linearly with increase in temperature.

  (b) Resistance of a semiconductor decreases with increase in temperature.

  (c) Resistance of insulators (non-conductor) decreases with increase in temperature.

  (d) Resistance of electrolytes decreases with increase in temperature.

  From the above relation (i) and (ii), we can write $R \propto \frac{1}{A}$ or $R = \rho \frac{l}{A}$ where, ρ is the constant of proportionality called resistivity or specific resistance of the conductor.

- **Ohmic and non-ohmic resistor :**

  The conductor which obeys Ohm's law is called ohmic resistor (or linear resistance), *e.g.,* Silver, nichrome, copper, iron, etc. The graph of V vs I is a straight line. The conductor which does not obey Ohm's law is known as non-ohmic resistor for non-linear resistance) *e.g.,* Triode valve, junction diode, transistor, etc. The graph of V vs I is a curved line.

- **Superconductor :** It is a substance of zero resistance at a very low temperature. *e.g.,* Mercury, niobium, etc.
- Resistivity of a material is the resistance of a wire of that material of a unit length and unit area of cross section.
- **Difference between ohmic and non-ohmic resistor :**

S. No.	Ohmic resistor	Non-ohmic resistor
1.	It obeys Ohm's law. i.e., V/I is constant for all values of V or I.	It does not obey the Ohm's law i.e., V/I is not the same for all values V or I.
2.	The graph for potential difference (V) versus current (I) is a straight line.	The graph for potential difference (V) versus current (I) is not a straight line.
3.	The slope of V–I graph is same at all values of V or I at a given temperature.	The slope of V–I graph is different at different values of V or I at a given temperature.
	Examples : All metallic conductors such as silver, iron, copper, nichrome, electrolyte with suitable electrodes, etc.	*Examples*: Junction diode, diode valve, transistor, filament of a bulb, etc.

- **Difference between resistance and resistivity :**

S. No.	Resistance	Resistivity
1.	Resistance of a conductor is the obstruction offered by the conductor in the flow of current through it. It is measured by the potential difference needed across the conductor to flow one ampere current through it. $\left(R = \frac{V}{I}\right)$	It is the property of the conductor due to which it offers resistance to the flow of current through it. It is measured by the resistance offered by 1 m length of wire of that material of area of cross-section 1 m^2. $\left(\rho = \frac{RA}{l}\right)$
2.	The resistance of a conductor depends upon its material, temperature, length and area of cross section	The resistivity of a conductor depends only on its material and temperature but not on its shape and size.
3.	Its SI unit is ohm (or Ω).	Its SI unit is ohm metre (or Ω m).

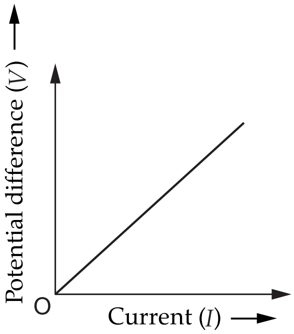
- The p.d. of a cell is defined as the energy spent (or the work done) per unit charge in taking a positive charge around the complete circuit of the cell (i.e., in the circuit outside the cell as well as in the electrolyte inside the cell).

- When no current is drawn from a cell i.e., when the cell is in open circuit, the potential difference between the terminals of the cell is called its electromotive force or *(e.m.f.)*.
- When current is drawn from a cell i.e., when the cell is in a closed circuit, the potential difference between the electrodes of the cell is known as its terminal voltage.
- The terminal voltage of a cell is defined as the work done per unit charge in carrying a positive charge around the circuit across the terminals of the cells.
- **Difference between E.M.F. and the terminal voltage of cells :**

S. No.	E.m.f. of cell	Terminal voltage of cell
1.	It is measured by the amount of work done in moving a unit positive charge in the complete the circuit inside and outside the cell.	It is measured by the amount of work done in moving a unit positive charge in the circuit outside the cell.
2.	It is the characteristic of the cell, i.e.,. it does not depend on the amount of current drawn from the cell.	It depends on the amount of current drawn from the cell. More the current is drawn from the cell, less is the terminal voltage.
3.	It is equal to the terminal voltage when cell is not in use, while greater than the terminal voltage when a cell is in use.	It is equal to the e.m.f. of the cell when the cell is not in use, while less than the e.m.f when the cell is in use.

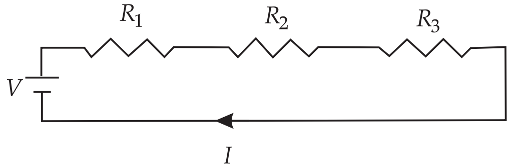
- When the resistance of the combination is to be increased, they are connected in series and when the resistance of the combination is to be decreased, in order to pass a heavy current in the circuit, they are connected in parallel.
- ***V-I* graph :**

  The below graph gives the graphical representation of Ohm's law where the slope of *V-I* graph gives the resistance of the conductor.



- **Combination of resistors in series :**

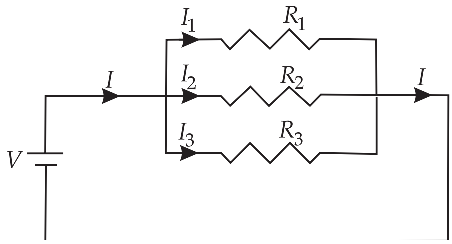
  Three resistors R_1, R_2 and R_3 are connected in series. The same current I, flows through all the three resistors but the potential across each resistor is different and let it be V_1, V_2 and V_3 respectively.



$$V = V_1 + V_2 + V_3$$
$$= IR_1 + IR_2 + IR_3 \text{(Using Ohm's law, } V = IR \text{)}$$
$$IR_{eq} = I(R_1 + R_2 + R_3)$$
$$R_{eq} = R_1 + R_2 + R_3$$

So, the equivalent resistance in a series combination is the sum of all resistances.

- **Combination of resistors in parallel :**



Three resistors R_1, R_2 and R_3 are connected in parallel. The same potential difference, V exist through all the three resistors but the current across each resistor is different and let it be I_1, I_2 and I_3 respectively.

Net current, $I = I_1 + I_2 + I_3$

$$\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \text{ (Using Ohm's law, } I = \frac{V}{R}\text{)}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

So, the reciprocal of equivalent resistance in a parallel combination is equal to the sum of reciprocal of individual resistances.

- The following two facts are to be noted about the series combination.
  - **(i)** The current has a single path for its flow. Hence, the same current passes through each resistor, so the potential difference across any resistor is directly proportional to its resistance.
  - **(ii)** The potential difference across the entire circuit is equal to the sum of potential differences across the individual resistor, *i.e.*,

$$V = V_1 + V_2 + V_3 \ldots.$$

- The following two points are to be noted about the parallel combination.
  - **(i)** The potential difference across each resistor is the same (say $V_1 = V_2 = V_3$) which is equal to the potential difference across the terminals of the battery (or source).
  - **(ii)** The main current I from the battery divides itself in different arms. The low resistance arm allows more current and the high resistance arm allows less current, *i.e.*, the current in a resistor is inversely proportional to its resistance. The sum of currents $I_1\ I_2\ I_3$ ... in the separate branches of the parallel circuit is equal to the current I drawn from the source *i.e.*, $I = I_1 + I_2 + I_3 + \ldots$

Mnemonics

Concept: Equivalent resistance of series and parallel combination of resistors.

Mnemonics: **S**unny **A**rrived **D**adar and **P**ari **Ar**rived **R**ajasthan.

Interpretation:

S : Series Combination

A : Add

D : Directly

P : Parallel combination

A : Add

R : Reciprocals

(For series combination of resistors: $R_{EQ} = R_1 + R_2 + R_3 + \ldots\ldots..$

For parallel combination of resistors: $1/R_{EQ} = 1/R_1 + 1/R_2 + 1/R_3 + \ldots\ldots\ldots$)

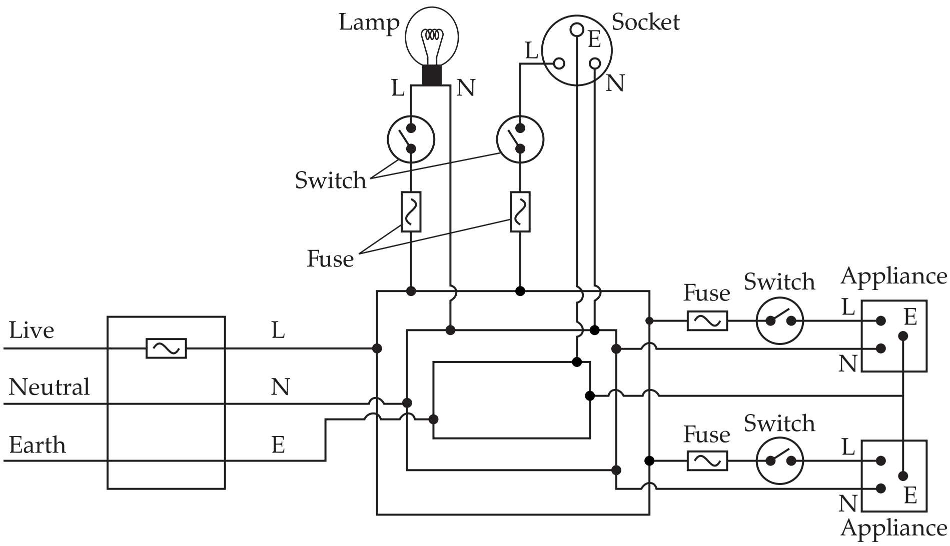
Topic-2

Electric Power and Energy, Fuse, Household Circuit

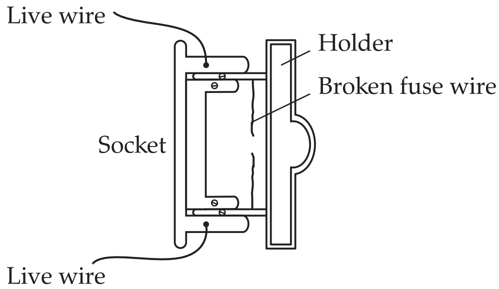
Concepts covered: Electrical power, Electrical energy, Household circuits, Safety precaution

Revision Notes

- In India, electric power for domestic use is supplied with alternating current (a.c.) at a frequency of 50 Hz with a (rms) potential difference of 220 V between the phase (or live) wire and the neutral wire.
- The neutral and the earth wires of the local sub-station are usually connected together so that the neutral wire is at the same potential as the earth. The live or the phase wire is then at a potential of 220 V (rms) with respect to either the neutral or the earth wire.
- We use two systems for domestic wiring – the tree system and ring system. Of the two, the ring system is more popular because of its several advantages. It is shown as



* **Advantages of the ring system :** The ring system has the following advantages :
  (i) In the ring system, the current from mains can reach to an individual appliance through two separate paths. Thus each appliance gets connected to the mains effectively through a thick wire. Therefore, the wire required for the main ring is of a lower current carrying capacity than that which would be required for a direct connection to the mains. This reduces the cost of wiring considerably.
  (ii) Each appliance has a separate fuse. Therefore if due to some fault, the fuse of one appliance burns, it does not affect the other appliances.



  (iii) In this system, all the plugs and sockets of the same size can be used, but each socket should have its own fuse of rating suitable for the appliance to be connected with it.
  (iv) While installing a new appliance in a room, a new line up to the distribution box is not required, but it can be directly connected to the ring circuit in that room. The care is taken that the total current drawn from the mains in the ring circuit does not exceed the rating of the main fuse (viz. 30 A).
* **Connection of all appliances (bulb, fan, socket, etc.) with the mains :**
  We note that all the electrical appliances (say, bulbs, fans, sockets, etc) are connected in parallel at the mains, each with a separate switch and a separate fuse connected in the live wire.
* **Advantages of connecting the appliances in parallel :**
  (i) Each appliance gets connected to 220 V supply (= its voltage rating) for its normal working.
  (ii) Each appliance works independently without being affected by the status of the other appliance being switched on or off.
* **Disadvantages of connecting the appliances in series :**
  (i) The voltage of source gets divided in all the appliances connected in series, in a ratio of their resistances, so each appliance does not operate at its rated voltage.
  (ii) On connecting one more appliance in the same circuit, the resistance of the circuit will increase. Hence, it will reduce the current in the circuit, so each appliance will get less power.
  (iii) All appliances connected in series operate simultaneously. None of the appliances can be operated independently. If one appliance is switched off or not operated, no other appliance connected with it in series will then operate.
* Electrical energy is very important in our day-to-day life. This is because of the case with which it can be converted into other forms of energy.

- The flow of an electrical current through a conductor produces heat. The heating effect associated with a current is expressed by Joule's Law, according to which

$$H = I^2 Rt = V^2 t/R = IVt.$$

- The electrical power of a given device is simply the rate at which electrical energy is being consumed by it.
- We have $P = IV = I^2R = V^2/R$
- The resistance R (in ohm) of a device of power P watt, working at an applied p.d. of V volt, is given by

$$R = V^2/P \text{ ohm}.$$

- 1 watt is the electric power consumed when a current of 1 ampere flows through a circuit having a potential difference of 1 volt.
- We need both **conductors** (materials which let electricity flow through them easily) and **insulators** (materials which do not (easily) let electric current flow through them) for safe and proper use of electrical energy.
- All electric circuits (closed conducting paths used for ensuring flow of electric current) need :
  (i) a source of electricity (cell, battery, generator, 'mains', etc.)
  (ii) conducting wires or conductors for providing a path for the flow of current and
  (iii) a switch or a key for switching 'ON' and 'OFF' electric energy as per our requirements.
- **SI Units :**

S. No.	Physical Quantity	SI Unit	
		Name	**Symbol**
1.	Current	ampere	A
2.	Voltage	volt	V
3.	Resistance	ohm	Ω
4.	Heat energy/Electric energy	joule	J
5.	Electric power	watt	W

By the definition of potential difference, work needed to move a charge Q through a potential difference V is

$$W = QV$$

But $Q = I \times t$

$$W = VIt$$

Using Ohm's law, $W = I^2 Rt = (V^2/R)\, t$

- The unit often used for estimating the consumption of electrical energy is the kilowatt hour (kWh). One **kilowatt-hour** (kWh) is the electrical energy consumed by an electrical appliance of power 1 kW when it is used for 1 hour.

$$1 \text{ kWh} = 1000 \text{ W} \times 3600 \text{ s}$$
$$= 3.6 \times 10^6 \text{ J}$$

- **Electrical energy consumed by appliance** (in kWh) = power (in kW) × time (in h)

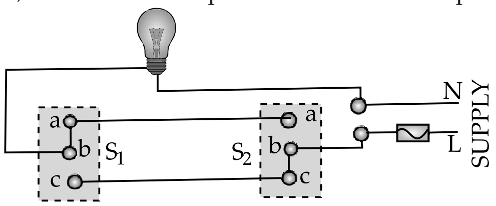
$$= \text{power (in watt)} \times \text{time (in hour)} \times 10^3$$
$$= V \text{ (volt)} \times I \text{ (in ampere)} \times t \text{ (hour)} \times 10^3$$

- **Cost of electricity** = Electrical energy in kWh × cost per kWh
- **Colour coding of wires in a cable :**

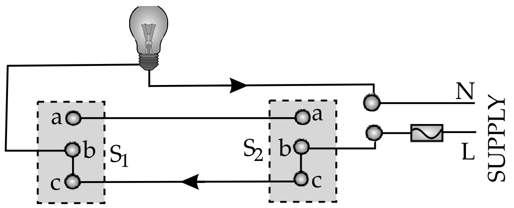
Wire	Colour	
	old convention	**new convention**
Live	Red	Brown
Neutral	Black	Light blue
Earth	Green	Green or Yellow

- A fuse is a safety device which limits the flow of current in a circuit and thus protecting the device from being damaged.
- Fuse is made up of material having low melting point.
- A switch is an ON/OFF device which is connected in a circuit to the live wire.
- Earthing protects the appliance and the user from getting damaged /hazardous shock due to excessive current. If excess current flows due to short circuit in electrical appliance, it passes through the earth wire to the earth. In local earthing, the earth connection at a meter is connected to a thick copper wire, which is buried deep in the earth and its ends are connected to a copper plate surrounded by a mixture of charcoal and salt. The thick copper wire is covered by a hollow pipe and water is poured into the pipe from time to time to provide a conducting layer between the plate and the ground.

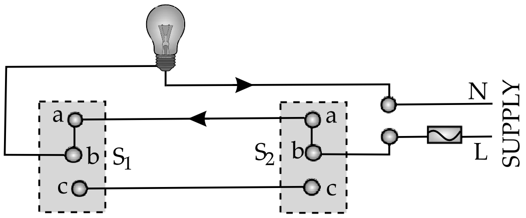
- Staircase wiring or dual control switch has two pathways for making the switch ON/OFF. The following diagrams illustrate a dual switch with two switches S_1 and S_2. The circuit can be switched on either using switch S_1 or S_2. When the connection ba is changed to bc, the circuit is completed and the switch operates by S_1 whereas when the connection bc is changed to ab, the circuit is completed and the switch operates by S_2.



(a) Bulb OFF

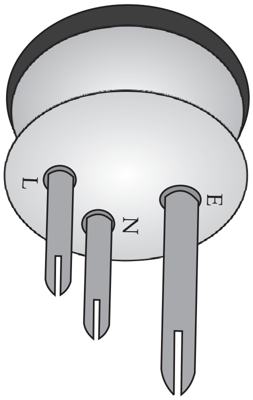


(b) Bulb ON through switch S_1

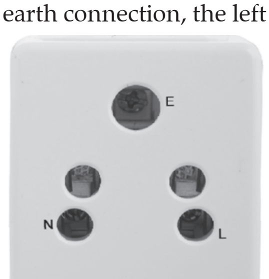


(c) Bulb ON through switch S_2

- Three pin plug has three pins – the top pin is for earth (E), the left pin is for live (L) and the right pin is for neutral (N).The earth pin is made longer and thicker so that firstly earth connection is made and if the device is faulty then after live connection is made, the current passes to the earth through earth wire.



- A socket is fixed in the board of the circuit so that plug can be inserted. It has three holes which have a hollow metallic tube. The upper bigger hole is for earth connection, the left is for neutral and right for a live wire.



- Safety precautions while using electricity :
  (i) Never touch the appliance with wet hands.

(ii) The wires carrying current should be having higher capacity than the total current which would flow when all the appliances are switched on.
(iii) Each appliance must be provided with a fuse and earthing.
(iv) The insulation of wires should be of good quality and that should be checked from time to time.
(v) Local earthing should be done near kWh meter.

Mnemonics

Concept: Joule's law of electrical heating.
Mnemonics: **H**e **P**refers to **C**ome to **S**chool at **R**ight **T**ime.
Interpretation:
H : Heat
P : Proportional to
C : Current
S : Square
R : Resistance
T : Time

$H \propto I^2RT$

Heat generated is proportional to (i) square of current, (ii) resistance of the conductor and (iii) time of current flow.

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