16. Electrical Energy

- There are two types of charges: positive charge, i.e., the charge that a glass rod acquires when rubbed with silk and negative charge, i.e., the charge which an ebonite rod acquires when rubbed with flannel.
- Like charges repel each other while opposite charges attract each other.
- The force of attraction (or repulsion) between two charged particle is given by Coulomb's law, according to which the interaction force between two charged particles is directly proportional to the product of charges and inversely proportional to the square of the distance separating them, i.e., $F = \frac{1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r^2}$, where $\frac{1}{4\pi\varepsilon_0}$ is a constant of proportionality and its value for charges placed in vacuum (or air) is 9×10^9 Nm^2C^{-2}.
- If we try to bring a small charge 'q' close to an already exiting similar charge, Q, called source charge, it experiences a force of repulsion. Hence work is to be done to bring it to any point at a distance from the source charge which is stored up as electrostatic potential energy. The electrostatic potential energy of the system of these two charges is given by:

$$U = \frac{1}{4\pi\varepsilon_0}\frac{Qq}{r}$$

- Potential energy per Coulomb of charge is called potential. Thus potential $\phi = \frac{U}{q} = \frac{1}{4\pi\varepsilon_0}\frac{Q}{r}$ is a function of position. Potential difference between two points in the surroundings of a source charge is given by:

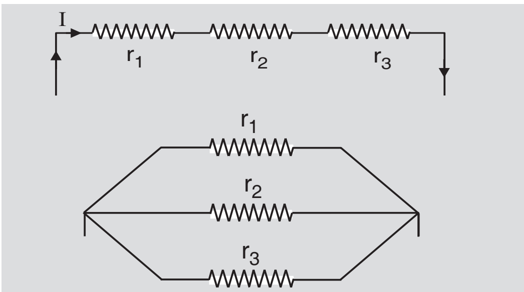
$$V = \phi_B - \phi_A = \frac{1}{4\pi\varepsilon_0}\left(\frac{Q}{r_B} - \frac{Q}{r_A}\right) = +\frac{U}{q} = +\frac{w}{q}$$

- The SI unit of potential difference is JC^{-1}, the other name for which is volt (V). Chemical cell, such as dry cell is a source of potential difference and voltmeter is a device which is used for measuring potential difference between two points.
- Charge is basically inherent in matter which is composed of atoms. Atoms, which themselves are neutral, are infact composed of a positively charged massive nucleus. and negatively charged electrons around it to fulfill the conditions of neutrality and stability.
- Electrically, materials are of two types: conductors which can conduct charges through them due to presence of large number of free electrons and insulators which do not conduct charge due to lack of sufficient number of free electrons.
- When a cell in connected across a conductor the free electrons move from lower to higher potential in external circuit. The flow of electrons from lower to higher potential in the conductor constitutes what is called electric current. Electric current is defined as the rate of flow of charge i.e., $I = \frac{Q}{t} = \frac{n|e|}{t}$.

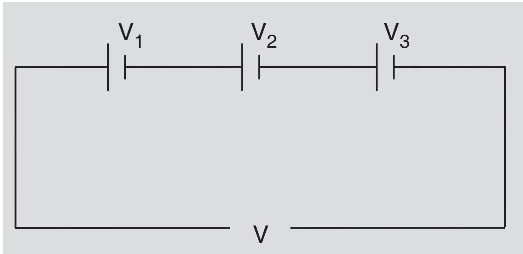
  Conventionally the direction of current is taken as the direction of flow of positive charge, that is, opposite to the direction of flow of electrons. Thus conventional current flows from positive to negative terminal of the cell in external circuit.
- Current is measured in amperes (A) with the help of a device called ammeter.
- When potential difference across a conductor is increased, the current through the conductor also increases such that the ratio $\frac{V}{I}$ remains constant. The relation $\frac{V}{I} = R$ is called Ohm's

law and the constant R is called resistance of the conductor. SI unit of resistance is ohm (Ω) and it is measured with the help of a device called Ohm-meter.

- Resistance of a given conductor is constant at a constant temperature and is given by $R = \rho \dfrac{l}{A}$, where ρ is called resistivity of its material, l = length and A = area of cross section.
- Resistance may be combined in two different ways: in series and in parallel. In series combination resistors are connected end to end in such a way that same current flows through all the resistors. In parallel combination one end of all the resistors is connected to the positive terminal of the battery and the other end to its negative terminal.



- The resistance of series combination is given by $R = r_1 + r_2 + r_3$. The resistance of parallel combination is given by $\dfrac{1}{R} = \dfrac{1}{r_1} + \dfrac{1}{r_2} + \dfrac{1}{r_3} + \ldots$
- A combination of cells is called battery. Normally we use series batteries, where in the total potential difference of the combination is given by the sum of the potential differences of individual cells. i.e., $v = v_1 + v_2 + v_3$



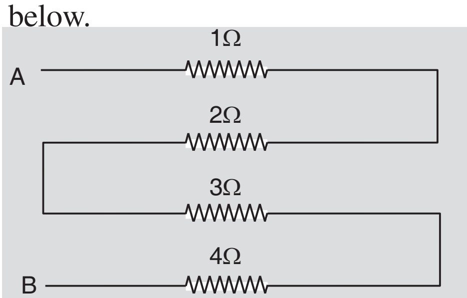
- There are three effects of electric current: heating effect, magnetic effect and chemical effect.
- When current is passed through a conductor, work is done in over coming the resistance, which manifests itself in the form of heat. This effect is called heating effect of electric current and is the basic principle behind electrical appliances like electric stove, electric iron, electric geyser, room heater, soldering iron and electric bulb etc.
- $Q = W = qV = VIt = \dfrac{V^2}{R}t = I^2Rt = Pt.$

  These relations help us to calculate heat produced in different situations.
- The electric energy is measured in kilowatt hour (kWh), 1 kWh = 3.6×10^6 J.

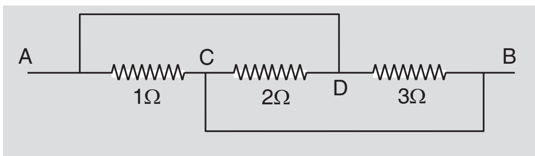
Build Your Understanding

1. Find the equivalent resistance between points A and B of the resistance combinations given below.

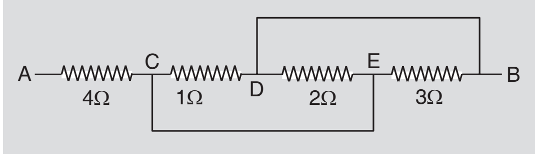
(i)



(ii)



(iii)

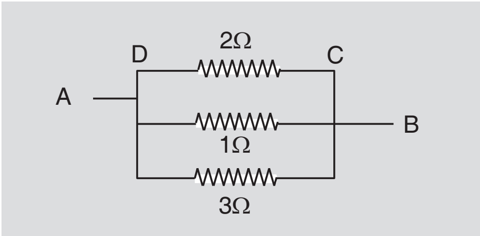


Sol:

(i) The resistances are connected in series:

$$R_{eq} = 1 + 2 + 3 + 4 = 10\ \Omega$$

(ii) As shown in the equivalent circuit the 3 resistors are connected in parallel

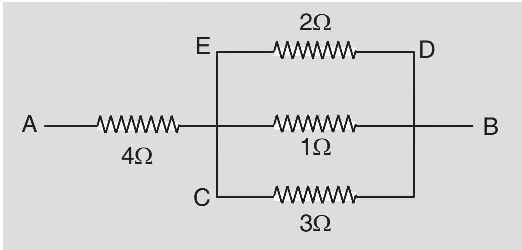


$$\therefore \quad \frac{1}{R_{eq}} = \frac{1}{2} + \frac{1}{1} + \frac{1}{3} = \frac{3+6+2}{6} = \frac{11}{6}$$

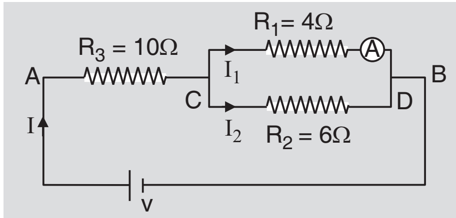
$$\Rightarrow R_{eq} = \frac{6}{11}\Omega$$

(iii) As shown in the equivalent circuit the four resistors are connected in mixed combination: A parallel combination of 1, 2, 3, Ω in series with 4Ω resistor. Therefore the equivalent resistance is

$$R_{eq} = 4 + \frac{6}{11} = \frac{50}{11}\Omega$$



2. In the adjoining circuit if ammeter reads 3A find the voltage of the cell.



Sol: $V_{CD} = I_1 R_1 = 3 \times 4 = 12\ \text{V}$

$$I_2 = \frac{V_{CD}}{R_2} = \frac{12}{6} = 2\,\text{A}$$

$$I = I_1 + I_2 = 3 + 2 = 5\,\text{A}$$

Total resistance $R = R_3 + \dfrac{R_1 R_2}{R_1 + R_2}$

$$= 10 + \frac{4 \times 6}{4+6} = 10 + 2.4 = 12.4\ \text{V}$$

$$\therefore \quad V = IR = 5 \times 12.4 = 62\ \text{V}$$

✔ Maximise Your Marks

- kwh is the commercial unit of electrical energy. It is the unit in which your electric meter reads your electric energy consumption.
- Commercial unit of electric power is horse power (H.P.)

  1 H.P. = 746 W
- Because, energy E = P. t, take *t* in *s* if E is in J and take *t* in *h* if E is in kilowatt hour.
- You should know the electric consumption by various household appliances. Switch on the high power devices like geyser, electric iron, heater etc. for the time they are needed. Your geyser may consume 2 units in one hour.

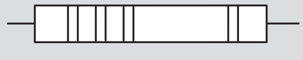
★ Stretch Yourself

1. The power rating of a microwave oven is 1 kw. Calculate

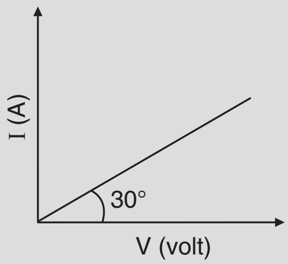
   (i) current it draws from a 200 V mains.

   (ii) Cost of energy it consumes in 30 minutes at the rate of Rs 4/unit.

2. A carbon resistor has strips of different colours on its body as shown. What is the purpose of these colour strips.



3. Draw a circuit diagram for the experimental set up to verify Ohm's Law. I-V graph for a conductor is shown in fig. calculate its resistance.



Test Yourself

1. A wire of resistance R is stretched to double its length. How will its resistance change? (Assume no change in temperature). Will there be any change in its resistivity?
2. 3 cells of 2 V each are connected in series. What will be the voltage of the combination?
3. A 100 watt lamp is lighted 5 h a day for thirty days. Calculate the cost of energy consumed at the rate of Rs 4 per unit.