16

ELECTRIC CURRENT

16.1 INTRODUCTION

In our daily life we read books with the light of electric bulb and tube light, listen music on a tape recorder or radio receiver, see different programes on television, enjoy cool breeze from electric fan or cooler. Do you know, what makes these appliances work. It is electric current Electricity is a unique gift of science to mankind. Our every day life is governed directly or indirectly by many applications of electricity. We cannot imagine to live without electricity in the modern world. At home you observe that by merely switching on an electric bulb starts glowing. Why does it so happen? What is the function of a switch?

In the previous lessons you have studied about static electric charge and their effects. Electric charge is stored in capacitors. In the present lesson you will study the electric charges in motion. You will also learn, in this lesson, that the rate of flow of charge through a conductor depends upon the nature of material and potential difference (Ohms law). You will study the distribution of current in circuits, laws necessary to understand various electrical circuits and how to calculate current in circuit networks (Kirchhoffs laws).

16.2 OBJECTIVES

After studying this lesson, you should will be able to;

- *explain drift velocity of electrons, charge transport and electric current;*
- *state and prove ohm's law and distinguish between Ohmic and non-ohmic resistances;*
- *define and explain resistivity and discuss the factors on which resistivity depends;*
- *deduce equivalent resistance for a series and parallel combination of resistors;*
- *calculate resistance on the basis of colour codes;*
- *state and apply Kirchhoff's laws to closed electric circuits;*
- *deduce Wheatstone Bridge equation under balanced condition and use the equation to find unknown resistance; and*
- *explain the principle of potentiometer and apply it to calculate the e.m.f. and internal resistance of a cell.*

16.1 ELECTRIC CURRENT

In the previous lessons you have studied that when a potential difference is applied across a conductor an electric field sets in the conductor and electrons drift in the direction opposite to the field. Due to electron drift charge flows through the conductor and we say that electric current is flowing through it. The direction of current is taken opposite to the direction of flow of electrons (negative charge) and in the direction of flow of positive charge. Let a charge ΔQ be passing across a conducting wire in short time interval Δt. Then, we define electric current as

$$I = \frac{\Delta Q}{\Delta t} \quad .....(16.1)$$

The electric current through any conductor is the rate of transfer of charge from one side of any cross section of conductor to the other side. The SI unit of current is ***ampere*** (symbol A). If one coulomb of charge passes through a cross-section of the conductor per second then the current is one ampere.

$$\text{Ampere (A)} = \frac{\text{coulomb (C)}}{\text{second (s)}}$$

Commonly used sources of current are electric cells, electric generators etc.

16.3.1 Ohm's Law

In 1826 German Scientist George Simon Ohm studied the relation between current flowing in a conductor and potential difference applied across it. He expressed this relation in the form of a law known as Ohm's law. According to this law: ***the electric current through a conductor is directly proportional to the potential difference across it provided the physical conditions such as temperature are unchanged.***

Let V be the potential difference applied across the conductor and I be the current flowing through it. According to Ohm's law,

$$V \propto I$$

$$\text{or} \quad V = RI \quad \text{or} \quad \frac{V}{I} = R \quad ....(16.2)$$

where constant R is the electrical resistance applied by the conductor in flowing the electric current. Resistance is the property of the material of the conductor which opposes the flow of current throught it. The V-I graph for a metallic conductor is a straight line (Fig 16.1).

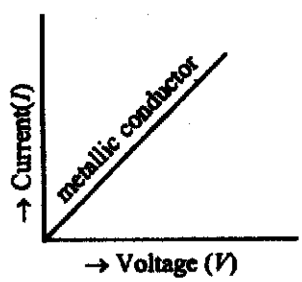


Fig.16.1: V-I graph for a metallic conductor

Unit of resistance is Ohm. It is expressed by symbol Ω (Omega)

1 Ohm =1 volt/1ampere

Now, let us study the factors which effect the resistance of a conductor. For this, you may perform two simple experiments :

(1) Take different lengths of a conducting wire of same materiel and same area. Apply same voltage across those alternately and read the value of current for each conducting wire. You will observe that current changes inversely proportion to the length of the conductor. ***It shows that the resistance of the conductor is directly proportional to the length (ℓ) of the conductor i.e.***

$$R \propto \ell$$

(2) Take *conducting wires of same material and of same length but of different cross - sectional area. Apply same potential difference and read the value of current for each of them. You will observe that the value of current is in proportion to the area of cross – section. This shows that the resistance of the conductor is inversely proportional to the area of cross section (A) i.e.*

$$R \propto \ell / A$$

thus on combining above two relations, $R \propto \dfrac{\ell}{A}$

or $$R = \rho - \frac{\ell}{A} \qquad \text{....(16.3)}$$

where ρ is constant for the material at constant temperature and is called ***specific resistance or resistivity.***

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

If ℓ=1m, A=1m^2, then ρ=(R Ohm) (1m^2)/1m = R Ohm × m

Thus, ***the value of resistivity of a material is equal to resistance of a wire of the material of 1m length and 1m^2 area of cross –section and is expressed in Ω-m.***

Inverse of resistivity is called ***conductivity*** or ***specific conductance*** and is represented by σ.

$$\sigma = \frac{1}{\rho} \qquad \text{...(16.4)}$$

Unit of conductivity is Ohm^{-1} metre^{-1} ($\Omega^{-1}m^{-1}$)or mho meter^{-1}.

Resistivity *depends on the nature of the material but it is independent of its dimensions*, whereas the resistance of a couductor depends on its dimensions as well as on the material of which it is made up of.

In terms of free electron concentration (n) and relaxation time (τ) the expression for resistivity is,

$$\rho = \frac{2m}{ne^2\tau} \qquad \text{....(16.5)}$$

where e and m are respectively charge and mass of an electron. The resistivity at a temperature is inversely proportional to free electron concentration. Thus, for a conductor having large number of free electrons resistivity and hence resistance is small. Silver is the best conductor, copper and aluminium are also good conductors. Due to very low resistance copper and aluminium wires are used as connecting wires for joining various components is electrical circuits and house hold fittings.

Several resistance wires of high resistivity are made of materials obtained by alloying some metals. Some of the important alloys are magnanin (84%Cu, 4% Ni and 12% Mn), constanton (60% Cu, 40% Zn) and nichrom (80% Ni, 20%Cr). Resistance wires for electric heater, electric iron etc. are made of these alloys.

Due to extremely high resistivity ebonite, mica, china clay, fused quartz etc are used as ***insulators***. In household wiring, copper and aluminium conductors are covered with a layer of some insulating materials like P.V.C. (polyvinyl chloride), rubber, cotton etc.

We have materials like germanium (Zn) and silicon (Si) which have resistivity much smaller than that of insulators but much greater than that of metals. They are called ***semi-conductors*** semiconductors are used to make electronic devices such as diode, transistor etc. In book-5 you will study semi-conductors in details.

16.3.2 Temperature Dependence of Resistance

You have read in previous section, the following relation for resistivity and relaxation time.

$$\rho = \frac{2m}{ne^2\tau}$$

according to which the resistivity is inversely proportional to relaxation time τ. The resistance of a wire of length ℓ and area of cross – section A is given by,

$$R = \rho \frac{\ell}{A} = \frac{2m\ell}{ne^2\tau A}$$

For a given wire ℓ, A and n are constants, therefore resistance

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

Relaxation time is the average time between successive collisions of electrons with the lattice ions (positive ions of metal). If mean free path (the average distance between two successive collisions) of electrons is λ and root mean square speed is v_{rms}, then

$$\tau = \frac{\lambda}{v_{rms}} \qquad \text{....(16.6)}$$

$$R \propto \frac{1}{\tau} \propto \frac{v_{rms}}{\lambda} \qquad \text{....(16.7)}$$

With increase of temperature, root mean square speed increases ($v_{rms} \propto T$) and mean free path decreases (because amplitude of vibration of lattice increases) so that collisions of electrons with the lattice take place more frequently. As a result *resistivity and hence,*

resistance of the wire increases with increase of temperature. In other words conductivity of conductor decreases with increase of temperature.

If R_o and R_t are the values of resistance of a wire at 0°C and t°C respectively then R_t may be obtained by relation

$$R_t = R_o (1 + \alpha t) \qquad ....(16.8)$$

Where α is a constant, called ***temperature coefficient of resistance*** (or resistivity). Then,

$$\alpha = \frac{R_t - R_o}{R_\alpha} \text{ (per 1°C)}$$

If R_o=1Ω and t = 1°C, then ;$\alpha = R_t - R_o$, the increase in resistance. Thus, ***temperature coefficient of resistance is equal to changes in resistance of a wire of resistance one Ohm at 0°C when temperature changes by 1°C.***

If the resistance of a wire at temperature t_1° C is R_1 and at t_2°C, is R_2, then

$R_1 = R_o (1+\alpha t_1)$ and $R_2 = R_o (1+\alpha t_2)$

on dividing $\dfrac{R_1}{R_2} = \dfrac{1+\alpha t_1}{1+\alpha t_2}$

So that

$$\alpha = \frac{R_2 - R_1}{R_1 t_2 - R_2 t_1} \text{ (per°C)} \qquad ....(16.9)$$

The resistivity of alloys also increases with increase of temperature but increase is very small in comparison to that for metals. For alloys such as meganin, constnanton and nichrome temperature coefficient of resistivity is negligibly small and resistivity is high, hence these are used to make resistance wires or *standard resistances*.

Here, you note that the resistivity of some materials like carbon, silicon, germanium etc. decreases with increase of temperature that is temperature coefficient of resistivity for these materials is negative.

16.3.3 Drift Velocity of Electrons

You see that by switching on electricity of a power station, all the electrical appliances connected to the power station at once start working if local switches are on, even though power station is far away. Have you ever throught what is happening here ? On switching, charge transport takes place in the form of electron drift in the supply line.

As we have learnt that a solid conductor consists of ions placed in a regular arrangement and free electrons are not bound to any particular atom. The free electrons can move about in the entire volume of the material. The ions which are much heavier than the electrons can only vibrate about their fixed positions. The mean positions of the ions form a regular periodic pattern which is called a lattice.

Free electons collide or interact with the ions at the lattice positions. The speed and direction changes randomly at each such event. As a result the electrons move in zigzag path (Fig. 16.2). In a metal, a large number of free electrons move in random directions. The number of electrons crossing an area ΔA from one side very nearly equals the number crossing from other side in any given time interval. Therefore, no net transport of charge across any cross section takes place.

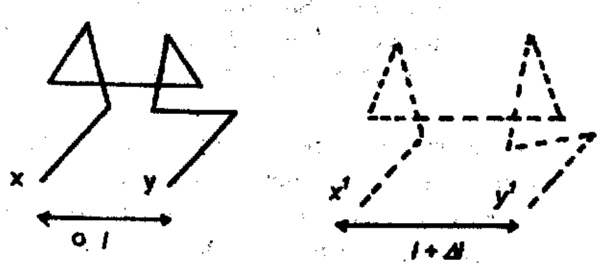


Fig. 16.2: Zig-zag motion of the electrons

When electric field is applied accross the conductor, a force acts on each electron in the direction opposite to the field. The electrons get drifted slowly in the direction of force. The drift is much lesser than the actual velocity of the electron. At each collision electron starts a fresh in random direction with a random speed but gains a velocity component v' due to electric field. This component v' increases with time till next collision occurs. Again it starts afresh with a random velocity and in the process the velocity component in the direction of field is lost. If the electron drifts a distance ℓ in long time t, then drift velocity,

$$v_d = \frac{\ell}{t} \qquad .....(16.10)$$

You may define the ***drift velocity*** as ***an average velocity component with which electrons drift opposite to the direction of electric field.***

Let τ be the average time called as mean free time between successive collisions and a be the acceleration due to electric field E. Then

$$a = \frac{\text{force acting on an electron}}{\text{mass of the electron}} = \frac{eE}{m} \qquad ...(16.11)$$

Where e and m are charge and mass of electrons. Therefore, the displacement of electron in the direction of force,

$$\Delta l = \frac{1}{2} a \tau^2 = \frac{1}{2}\left(\frac{eE}{m}\right)\tau^2$$

The drift velocity is,

$$v_d = \frac{\Delta l}{\tau} = \frac{1}{2}\left(\frac{eE}{m}\right)\tau = \frac{1}{2}\frac{eE}{m}\tau \qquad ....(16.12)$$

It shows that drift velocity of electrons is directly proportional to electric field.

16.3.4 Atomic Explanation of Ohm's Law

Let us consider a cylindrical conductor of cross-sectional area A, in which an electric field E exists. In time Δt charge drifts a distance $v_d \Delta t$, where v_d is the drift velocity. Consider a length $v_d \Delta t$ of the conductor (Fig 16.3).

The volume of this portion is $A\ v_d\ \Delta t$. Let there be n free electrons per unit volume of conductor. The number of electrons in this portion is $nAv_d \Delta t$. All these electrons cross the area A in time Δt. Therefore, charge crossing this area in time Δt is,

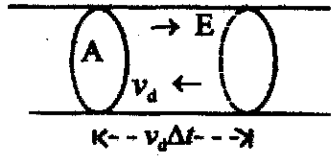


Fig. 16.3: Cross-section of a conductor.

$$\Delta Q = nAv_d \Delta t.\ e$$

$$\text{or Current } I = \frac{\Delta Q}{\Delta t} = Ane\ v_d = \frac{Ane^2 \tau E}{2m} = \frac{Ane^2 \tau V}{2m\ell} \qquad ...(16.13)$$

Thus, $I \propto V$

This is Ohm's law.

It is clear from this expression that the currant is directly proportional to the drift velocity of free electrons in a conductor.

Example16.1 : *A total of 6.0×10^{16} electrons pass through any cross - section of a conducting wire per second. Find the current.*

Solution : The total charge crossing the cross section in one second is,

$$\Delta Q = ne = 6.0 \times 10^{16} \times 1.6 \times 10^{-19} \text{C}$$
$$= 9.6 \times 10^{-3} \text{C}$$

The value of current

$$I = \frac{\Delta Q}{\Delta t} = \frac{9.6 \times 10^{-3}\ \text{C}}{1\ \text{s}} = 9.6 \times 10^{-3} \text{A}$$

Example 16.2 : *Calculate the drift speed of electrons when 1 A of current flows in a copper wire of cross - section $2mm^2$. The number of free electrons in $1\ cm^3$ of copper is 8.5×10^{22}*

Solution : From the current and drift velocity relation

$$I = A\,n\,e\,v_d$$

So that,

$$v_d = \frac{I}{Ane} = \frac{1}{2 \times 10^{-6} \times 8.5 \times 10^{28} \times 1.6 \times 10^{-19}}$$

$$= 3.6 \times 10^{-3}\ \text{m/s}$$

Super Conductors: We see that for some materials below a certain temperature resistivity suddenly becomes zero. This temperature is called ***critical temperature*** for this transition. The material in this state is called ***superconductor*** and the phenomenon is called superconductivity. It was observed for mercury in 1911 by Kamerleigh Onnes. Critical temperature for mercury is 4.2K.

If an electric current is set up in a superconductor, it can persist for long time even for months and years after removing the applied potential difference.Superconductivity exists at very low temperatures which are difficult to obtain. Scientists are trying to prepare compounds and alloys which would be superconducting at room temperatures (300K). Superconductivity at around 125K has already been achieved and efforts are on to improve upon this. Superconductors are used to construct very strong magnets. Possible applications of superconductors are ultra fast computer switches and transmission of electric power through superconducting power lines.

Example 16.3: *Two wires A and B of same mass and material are taken. Diameter of wire A is half than that of wire B. If resistance of wire A is 24Ω find the resistance of wire B.*

Solution : Let r_A and r_B be radii and ℓ_A, ℓ_B be lengths of wire A and B respectively. As mass and density of the wires is the same, we have

$$\pi r_A^2 \ell_A d = \pi r_B^2 \ell_B d$$

$$\therefore \quad \frac{\ell_A}{\ell_B} = \frac{r_B^2}{r_A^2}$$

Resistances of wires A and B are

$$R_A = \frac{\rho \ell_A}{\pi r_A^2} \text{ and } R_B = \frac{\rho \ell_B}{\pi r_B^2}$$

$$\therefore \quad \frac{R_A}{R_B} = \frac{\ell_A}{\ell_B} \times \frac{r_B^2}{r_A^2} = \frac{r_B^2}{r_A^2} \times \frac{r_B^2}{r_A^2} = \left(\frac{r_B}{r_A}\right)^4$$

$$\therefore \quad r_A = \frac{r_B}{2} \quad \therefore \quad \frac{R_A}{R_B} = (2)^4$$

$$= 16$$

$$\therefore \quad R_B = \frac{R_A}{16} = \frac{24}{16} = 1.5 \text{ ohm}$$

16.3.5 Ohmic and Non-Ohmic Resistances

You may easily see by drawing graph between voltage and current across conductors that many conductors obey Ohm's law. Their resistance is called Ohmic resistance or linear resistance. But Ohm's law does not always hold good. If we replace the resistance wire by a torch bulb in an electrical circuit and note down values of current (I) for different voltages (V) then we see that the entire V–I graph drawn is not straight line (Fig 16.4-a). For low values of V, it remains straight line and then becomes curved. For high voltage current through the filament of the bulb becomes large so that the temperature of the filament of bulb becomes more and more as current increases in the filament. Ratio V/I for low value of I gives resistance of the filament. Ohm's low holds in metallic wires for low values of current only.

Other examples of non-ohmic resistances are vacuum diode, semiconductor diode, transistor, liquid electrolytes etc. In vacuum diode ohm's law does not hold even for low values of current. Its V-I curve is shown in Fig 16.4-b.

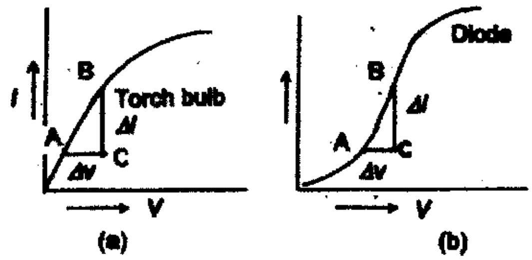


Fig. 16.4: V–I graph for non-ohmic conductor

16.3.6. Resistors

For different electrical and electronic circuits we require resistors of different values. Resistors may be divided into two groups; wire wound resistors and carbon resistors

In a ***wire wound resistor a resistance wire (of maganin, constanton or nichrome) of definite langth according to value of resistance is wound two fold over insulating cylinder to make it non inductive.***

To make ***carbon resistor***, *carbon with a suitable binding agent is molded into a cylinder. Wire leads are attached to this cylinder for connecting it to an electrical circuit.* The value of resistance is indicated by four coloured bands marked on the surface of the cylinder (Fig 16.5) and meaning of different colours are given in table 16.1 the colours and their orders may be remembered by the statement given on the next page.

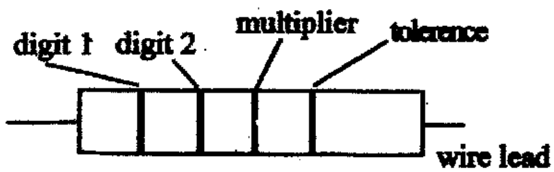


Fig. 16.5: Colour bonds on a resistor

Table 16..1 : *Resistance codes (resistance given in ohm)*

Colour	*Digit*	*Multiplier*	*Tolerance*	*Colour*	*Digit*	*Multiplier*	*Tolerance*
Black	0	1		Blue	6	10^6	
Brown	1	10		Violet	7	10^7	
Red	2	10^2		Gray	8	10^8	
Orange	3	10^3		White	9	10^9	
Yellow	4	10^4		Gold		0.1	5%
Green	5	10^5		Silver		0.01	10%

B	B	R	O	Y	Great	Britain	Very	Good	Wife
Black	Brown	Red	Orange	Yellow	Green	Blue	Violet	Gray	White

For example suppose the colours on the resistor shown in Fig. 16.5 are brown, yellow, green and gold as read from left to right. Using the table the resistance is

Brown	Yellow	Green	Gold
1	4	$\times 10^5$	$\pm 5\%$

$$= 14 \times 10^5 \pm 14 \times 10^5 \times \frac{5\ \Omega}{100}$$

$$= (1.4 \pm 0.07)\ 10^6\ \Omega \quad = (1.4 \pm 0.07)\ \text{M}\Omega$$

Some times tolerance is missing from the code and there are only three bands. Then the tolerance is 20%.

INTEXT QUESTIONS 16. 1

1. *Electrons move continuously inside a conductor even then no current flows through it unless a potential differences is applied across it. Explain*

....

2. *When a current is established in a wire. the free electrons drift in the direction opposite to the current. Does the number of free electrons in the wire continuously decrease ?*

....

3. *In a TV tube the electrons are accelerated from the rear to the front. What is the direction of current ?*

....

4. *A potential difference V is applied across a copper wire of length l and diameter d. What will be the effect on drift velocity of electrons if*
   (i) V becomes twice
   (ii) l becomes twice.
   (iii) d becomes twice

....

5. *Why are resistance wires made of magamin, constanton and nichrome? Give two reasons.*

....

6. *What will be the ratio of currents flowing through two wires of same material if they have:*
   a. Same area of cross section but length in the ratio 2:1
   b. Same length but area of cross-sections in the ratio 2:1

....

16.4 COMBINATIONS OF RESISTORS

When we want to increase or decrease the current of a circuit we have to reduce or increase the resistance of the circuit. For this resistors are combined. Two types of combinations are frequently used. Here, we define ***equivalent resistance of the combination*** as a single resistance which draws same current as the given combination when same potential difference is applied across it.

16.4.1 Series Combination

You may connect more resistors in series by joining them end to end such that ***same current passes through all the resistors.*** In fig 16.6 three resistors of resistances R_1, R_2 and R_3 are shown connected in series. The combination can be connected to a battery or other circuit at ends *A* and *D*. Let a current *I* flows through the series combination when it is connected to a battery of voltage *V*. Potential differences V_1, V_2 and V_3 be developed across R_1, R_2 and R_3 respectively due to this current *I*. Then $V_1 = IR_1$, $V_2 = IR_2$ and $V_3 = IR_3$. But sum of V_1, V_2 and V_3 is equal to *V* i.e.

$$V = V_1 + V_2 + V_3$$

$$V = IR_1 + IR_2 + IR_3$$

If equivalent resistance of this series combination is *R*, then

$$V = IR = I(R_1 + R_2 + R_3)$$

or $R = R_1 + R_2 + R_3$

This arrangement may be extended for any number of resistors

$$\boxed{R = R_1 + R_2 + R_3 + R_4 + \ ....} \quad ...(16.14)$$

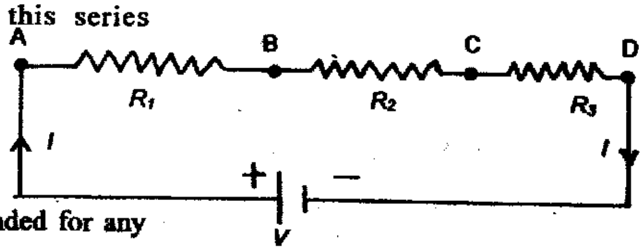


Fig. 16.6 : Series combination of resistance

Thus, ***equivalent resistance of a series combination of resistors is equal to sum of resistances of all resistors.*** If we require to apply a voltage across a resistor (say electric bulb) less than the constant voltage supply source, we should connect another resistor in series of it.

16.4.2 Parallel Combination

You may connect the resistors in parallel by joining their one end at one point and other ends at another point. In parallel Combination ***same potential difference exists across all resistors.***

Fig 16.7 shows the parallel combination of three resistors of resistances R_1, R_2 and R_3. Let the combination be connected to a battery of voltage *V* and draws a current *I* from the source.

The main current divides into three parts. Let I_1, I_2, I_3, be the currents flowing through resistors R_1, R_2, R_3 respectively, then $I_1 = V/R_1$, $I_2 = V/R_2$ and $I_3 = V/R_3$

The main current is the sum of I_1, I_2 and I_3

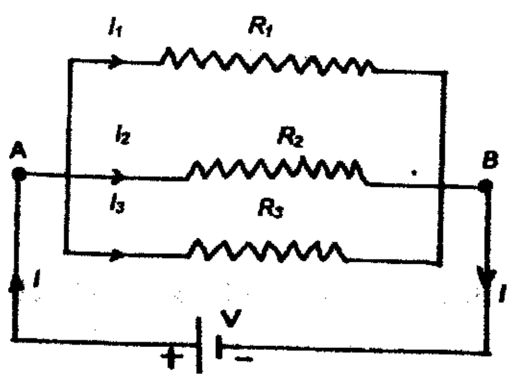


Fig.16.7: Parallel combination of resistances

i.e. $I = I_1 + I_2 + I_3$

or $I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$

If the equivalent resistance of combination is R, then

$V = IR$ or $I = V/R$

$$\therefore I = \frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\text{or } \frac{V}{R} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

The process may be extended for any number of resistors so that,

$$\boxed{\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4} + \ldots} \quad \text{...(16.15)}$$

From this we infer that ***inverse of equivalent resistance of parallel combination is equal to sum of inverses of indevidual resistances.***

For two resistors in parallel

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \text{ or } R = \frac{R_1 R_2}{R_1 + R_2} \quad \text{...(16.16)}$$

Note that the ***equivalent resistance of parallel combination is smaller than the smallest individual resistance.*** You may easily see this fact by a simple electrical circuit having a resistor of 2 Ω resistance connected across a battery of voltage 2 volt. It will draw a current of 1 ampere. When another resistor of 2 ohm resistance is connected in parallel, then it will also draw a current of 1 ampere. That is total current drawn from battery is 2 ampere, hence resistance of the circuit is halved. ***If we go on increasing the number of resistors in parallel the resistance of circuit goes on decreasing and the current drawn from battery goes on increasing.***

In our homes all the electrical appliances bulbs, fans, heaters etc are connected in parallel and each has separate switch (Fig. 16.8). Potential difference across each remains same so that current flowing in any of them does not depend upon the other. As we go on switching bulbs, and fans, the resistance of the electrical circuit of the house goes on decreasing and current drawing from mains goes on increasing.

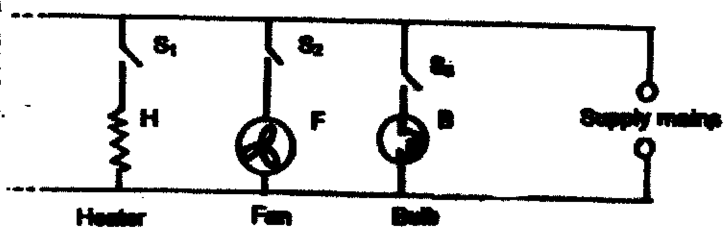


Fig. 16.8: Electrical circuit at our homes

16.4.3 Division of Current in Resistors Connected in Parallel

Let the two resistors of resistances R_1 and R_2 be connected in parallel between points A and B (Fig. 16.9). The main current I be divided into two parts I_1 and I_2 flowing through R_1 and R_2 respectively. The main current I is sum of I_1 and I_2 i.e.

$$I_1 + I_2 = I \qquad \text{...(16.17)}$$

According to Ohm's law

$$V_A - V_B = I_1 R_1$$

and also

$$V_A - V_B = I_2 R_2$$

$$\therefore \quad I_1 R_1 = I_2 R_2$$

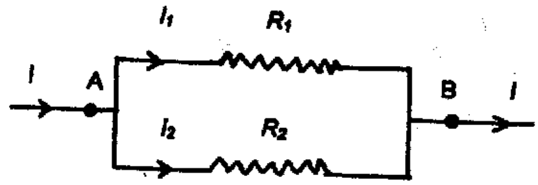


Fig. 16.9 : Division of current in resistors

From eq (16.17) $I_1 R_1 = (I - I_1) R_2$

$$I_1 (R_1 + R_2) = I R_2$$

or $$I_1 = \frac{R_2}{R_1 + R_2} I \qquad \text{...(16.18)}$$

Similarly,

$$I_2 = \frac{R_1}{R_1 + R_2} I \qquad \text{...(16.19)}$$

Example 16.4: *For a circuit shown in Fig 16.10, find the value of resistance R_2 and current I_2 flowing through R_2.*

Solution: If equivalent resistance of parallel combination of R_1 and R_2 is R, then

$$R = \frac{R_1 R_2}{R_1 + R_2} = \frac{10 R_2}{10 + R_2}$$

According to Ohm's law,

$$R = \frac{50}{10} = 5\,\Omega$$

$$\therefore \quad \frac{10 R_2}{10 + R_2} = 5$$

$$R_2 = 10\,\Omega$$

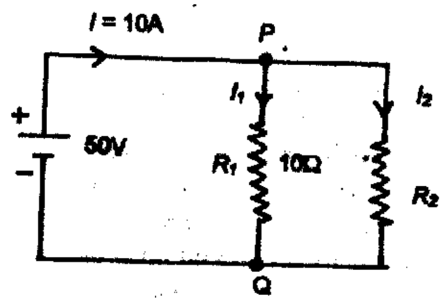


Fig. 16.10 : An Electrical Circuit

The current is equally divided into R_1 and R_2, hence $I_2 = 5$A.

Example 16.5: *Find equivalent resistance of the network shown in fig 16.11 between points (i) A and B and (ii) A and C.*

Solution:

(i) The 10 Ω and 30 Ω resistors are connected in parallel between points A and B. The equivalent resistance between A and B is

$$R_1 = \frac{10 \times 30}{10+30} \text{ ohm} = 7.5\ \Omega$$

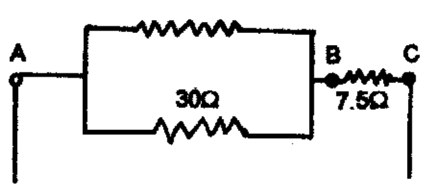


Fig. 16.11

(ii) The resistance R_1 is connected in series with resistor of 7.5 Ω, hence the equivalent resistance between points *A* and *C* is,

$R_2 = (R_1 + 7.5)$ ohm = (7.5+7.5) ohm=15 Ω

Example 16.6: *Find potential difference between points A and B of the network shown in Fig 16.12 and distribution of given main current through different resistors.*

Solution : Between points A and B resistors of 4Ω, 6Ω and 8Ω resistances are in series and these are in parallel to 9Ω resistor.

Equivalent resistance of series combination is

$R_1 = (4 + 6 + 8)$ ohm = 18Ω

If equivalent resistance between *A* and *B* is

$R = 9\times18 / (9+18)$ ohm = 6Ω

Potential difference between *A* and *B* is

$V = IR = 2.7 \times 6\ V$

$= 16.2\ V$

Current through 9 Ω resistor = 16.2/9=1.8A

Current through 4Ω, 6Ω and 8Ω resistors

= 2.7–1.8 = 0.9A

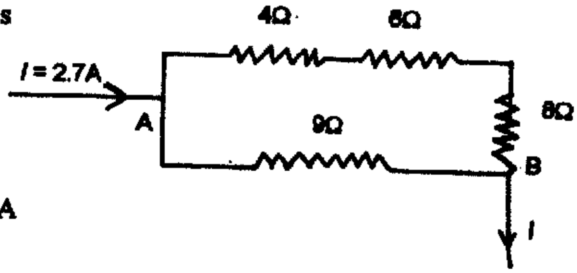


Fig. 16.12

INTEXT QUESTIONS 16.2

1. *Which of the following is same for each of the resistors connected in series*
   (a) potential difference (b) current (c) power (d) heat generated

   ....

2. *Which of the followings is same for each resistors connected in parallel*
   (a) potential difference (b) current (c) power (d) heat generated

   ....

3. *Three resistors having resistances 1Ω, 100Ω and 10 000Ω are connected in parallel. What will be the order of equivalent resistance.*

   ....

4. *A uniform wire of resistance 50Ω is cut into 5 equal parts. These parts are now connected in parallel. The equivalent resistance of the combination is*
   (a) 2 Ω (b) 10Ω (c) 250Ω (d) 625Ω

   ....

16.5 KIRCHHOFF'S LAW

Ohm's law gives current - voltage relation in simple electrical circuits. But when the circuit is complicated, you will face difficulty in finding current distribution by Ohm's law. Kirchhoff in 1842 formulated the following two laws which enable us to find the distribution of current in complicated electrical circuits or electrical networks.

(i) **Kirchhoff's First Law (Junction Law):** It states that ***the sum of all the currents directed towards a junction (point) in an electrical network is equal to the sum of all the currents directed away from the junction.***

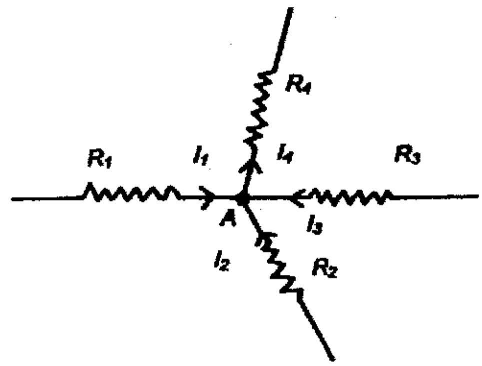


Fig. 16.13: Distribution of current at a junction in the circuit

Thus, in Fig 16.13,

$$I_1 + I_2 = I_3 + I_4$$

$$\text{or } I_1 + I_2 - I_3 - I_4 = 0$$

If we take currents approaching point A in Fig 16.13 as positive and that leaving the point as negative, then the above relation may be written as

$$I_1 + I_2 + (-I_3) + (-I_4) = 0 \qquad ....(16.20)$$

Hence the first law may also be stated in other words that ***the algebraic sum of currents at a junction is zero.***

Kirchhoff's first law tells us that there is no accumulation of charge at any point if steady current flows in it. The net charge coming towards the point should be equal to that going away from it in the same time.

(ii) **Kirchhoff's Second Law (Loop Law):** *This law is generalization of Ohm's law. It tells that **the algebraic sum of the products of the currents and resistances in any closed loop (or mesh) in an electrical network is equal to the algebraic sum of electromotive forces acting in the loop.***

While using this law we start from a point on the loop and go along the loop either clock-wise or anti clock – wise to reach the same point again. The product of current and resistance is taken as positive when we traverse in the direction of current and e.m.f. is taken positive when we traverse from negative to positive electrode through the cell. Mathematically you can write the law as

$$\Sigma IR = \Sigma E \qquad ...(16.21)$$

Let us take an electrical network shown in Fig 16.14. For closed mesh ADCBA

$$I_1R_1 - I_2R_2 = E_1 - E_2$$

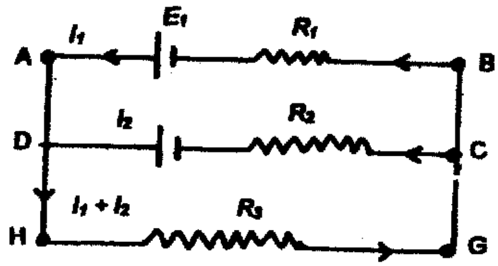


Fig. 16.14: An electrical network

For mesh DHGCD

$$I_2R_2 + (I_1 + I_2)R_3 = E_2$$

and for mesh AHGBA

$$I_1R_1 + (I_1 + I_2)R_3 = E_1$$

In more general form Kirchhoff's second law is stated as: ***The algebraic sum of all the potential differences along a closed loop in a circuit is zero.***

Example 16.7: *Consider the network as shown in Fig.16.15. Current is supplied to the network by two batteries as shown. Find the values of currents I_1, I_2, I_3. The directions of the currents are as indicated by the arrows.*

Solution : Applying Kirchhoff's Ist law to junction C, we get

$$I_1 + I_2 - I_3 = 0 \quad .....(1)$$

Applying Kirchhoff's IInd law to the closed meshes ACDA and BCDB, we get

$$5I_1 + 2I_3 = 12A \quad ....(2)$$
$$3I_2 + 2I_3 = 6A \quad ....(3)$$

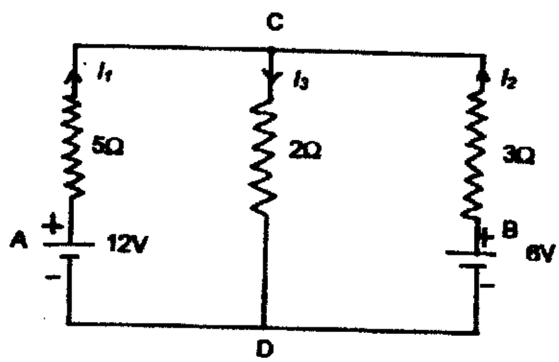


Fig. 16.15

subtracting eq (3) from eq (2) we get

$$5I_1 - 3I_2 = 6A \quad ...(4)$$

Multiplying eq.(1) by 2 and adding with eqn.(2) we get

$$7I_1 + 2I_2 = 12A \quad ....(5)$$

Multiplying eq.(1) by 2 and eq.(5) by 3 and adding them we get

$$31I_1 = 48A$$

$$I_1 = 1.548A$$

Putting value of I_1 in eq.(5) we get

$$I_2 = 0.58A$$

and from eq.1 we get $I_3 = I_1 + I_2 = 2.128A$

INTEXT QUESTIONS 16.3

1. *For a circuit shown in Fig. 16.16 find the value of current flowing in the circuit and potential difference between points A and B.*

   ....

2. *Apply Kirchhoff's law to find the value of current I_3 flowing through R_3 in the circuit of Fig 16.17*

   ....

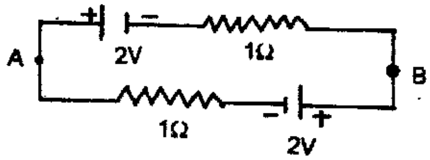


Fig. 16.16

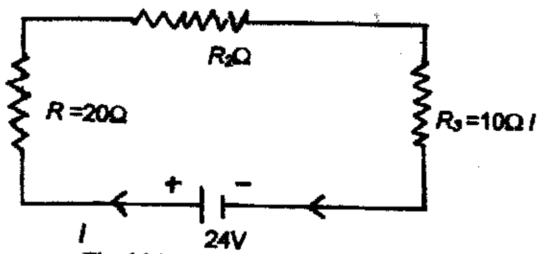


Fig. 16.17

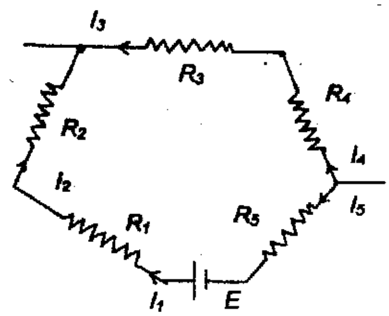


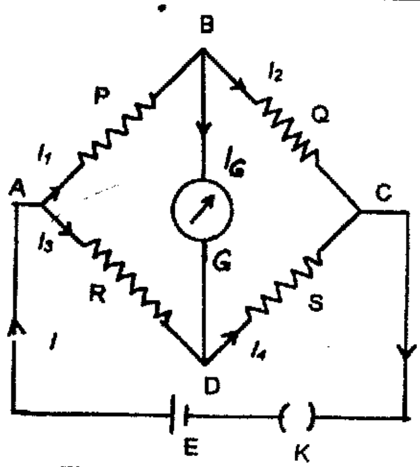
Fig. 16.18

3. *For the circuit shown in Fig 16.18, evaluate the current flowing through resistance R_2.*

   ....

16.5 WHEAT STONE BRIDGE

As you have learnt that a resistance can be measured by Ohm's law using a voltmeter and an ammeter in an electrical circuit. But this measurement is not accurate. To measure it more accurately Kristie devised and Wheat Stone popularized a special network design called Wheat Stone Bridge. It is an arrangement of four resistances which can be used to measure one of them in terms of the rest.



Consider the circuit as shown in Fig 16.19 where:

Fig. 16.19: Wheat Stone Bridge network

(i) *S* is a unknown resistance to be measured. Arm CD of the bridge is called unknown arm.

(ii) *P* and *Q* are two adjustable resistances connected in two ratio arms AB and BC of the bridge.

(iii) *R* is adjustable known resistance. Arm AD is called known arm.

(iv) A sensitive galvanometer G is connected in one of the cross arm BD of the bridge.

(v) A battery E along with a key K is connected in other cross arm AC. Arm AC and BD are called conjugate arms.

On closing the key, in general there will be some current I flowing through the galvanometer and you will get some deflection in the galvanometer It indicates that there is some potential difference between points B & D.

We shall now consider the following three cases:

(i) **Point B is at higher potential than point D:** Current will flow from B towards D and galvanometer will show deflection in one direction.

(ii) **Point B is at lower potential than point D:** Current will flow from point D towards B and galvanometer will show deflection in opposite direction:

(iii) **Both points B and D are at same potential:** In this case no current flows through the galvanometer which will show no deflection i.e. the galvanometer is in condition. In this condition the Wheat stones bridge is said to be in the ***state of balance.***

The points B and D will be at the same potential only when the potential drop across P is equal to that across R. Thus at the null State

$$I_1P = I_3R \qquad \text{...(16.22)}$$

Applying Kirchhoff's first law at junction B and D we get

and $I_1 - I_2 - I_G = 0$

$$I_3 + I_G - I_4 = 0$$

At the null state $I_G = 0$

$$\therefore \; I_1 = I_2 \qquad \text{....(16.23)}$$

and $I_3 = I_4$ ....(16.24)

Also potential drop across Q will be equal to that across S. So that

$$I_2Q = I_4S \qquad \text{....(16.25)}$$

Dividing eqn.(16.22) by eqn.(16.25)

$$\frac{I_1P}{I_2Q} = \frac{I_3R}{I_4S}$$

Using eqns (16.23) and (16.24) we get

$$\boxed{\frac{P}{Q} = \frac{R}{S}} \qquad \text{.....(16.26)}$$

This is the condition for which a Wheat stone Bridge is balanced

From eq.(16.26) unknown resistance S is

$$\boxed{S = \frac{QR}{P}} \qquad \text{....(16.27)}$$

You can easily see that the measurement of resistance by Wheat Stone's Bridge method has the following merits.

(i) *The balance condition given by eq (16.26) at null position is independent of the applied voltage E. In other words if you change the e.m.f. of the cell, the balance will not change.*

(ii) *The measurement of resistance does not depend on the accuracy of calibration of the galvanometer. Galvanometer is used only as a null indicator.*

The main factor affecting the accuracy of measurement by Wheat Stone Bridge is its sensitivity with which the changes in the null condition can be detected. It has been found that the bridge has the greatest sensitivity when the resistances are as nearly equal as possible.

Example 16.8 : *Find the value of R in Fig 16.20 so that there is no current in the 50 Ω resistor.*

Solution: This is the Wheat Stone bridge with the galvanometer replaced by 50Ω resistor. The bridge is balanced because there is no current in 50Ω resistor, hence,

20/10=40/R

$$\therefore \quad R = \frac{40 \times 10\Omega}{20 = 20} = 20\,\Omega$$

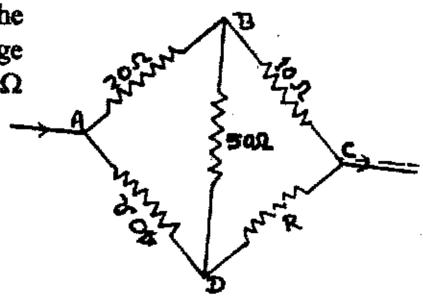


Fig. 16.20

INTEXT QUESTIONS 16.4

1. *Consider the circuit shown in Fig. 16.21 when the bridge is balanced the resistances are given: P=20Ω, Q=50Ω and R = 10Ω. What will be the value of the unknown resistance?*

   ....

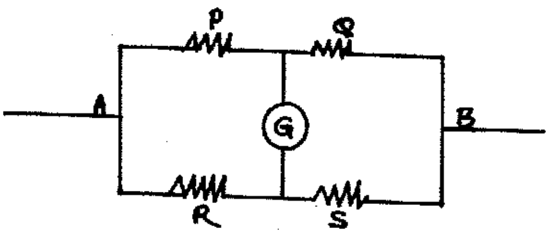


Fig. 16.21

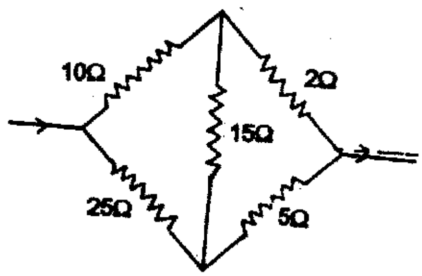


Fig. 16.22

2 *In a circuit given in Fig 16.22, find current through 2Ω resistor*

....

3 *In a Wheat Stone Bridge circuit P and Q, the ratio arms being approximately equal, the bridge is balanced when R=500Ω. On interchanging P and Q the value of R for the balance is 510Ω, find the value of the unknown resistance S.*

....

16.6 ELECTROMOTIVE FORCE (E.M.F.) AND POTENTIAL DIFFERENCE

EMF is the short name of electromotive force. EMF *of a cell or battery equals the potential difference between its terminals when the terminals are not connected externally.* You may easily understand the difference between e.m.f. and potential difference of a cell. For this connect a cell in a circuit having a resistor *R* and key K. A voltmeter of very high resistance is connected in parallel to the cell as shown in Fig 16.23. When key is closed voltmeter reading will decrease. Do you explain the reason for this decrease in voltmeter reading ? Actually when key K is opened no significant current flows through the loop having cell and voltmeter due to very high resistance of voltmeter. Hence, voltmeter reading is equal to e.m.f. E of the cell which is the potential difference between terminals of the cell when no current is drawn from it. When key K is closed current flows outside and inside the cell. The cell introduces a resistance r, called ***internal resistance*** to the circuit. Let current I be flowing in the circuit. Potential drop Ir across internal resistance r due to current flow acts opposite to the e.m.f. of the cell. Hence, voltmeter reading will be $E-Ir$ and is equal to V. But $V = IR$

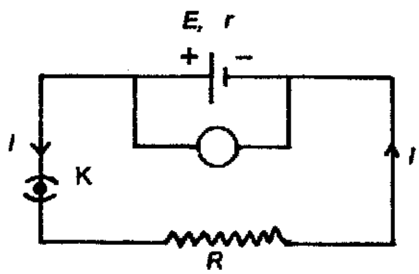


Fig. 16.23: Circuit diagram connected with voltmeter

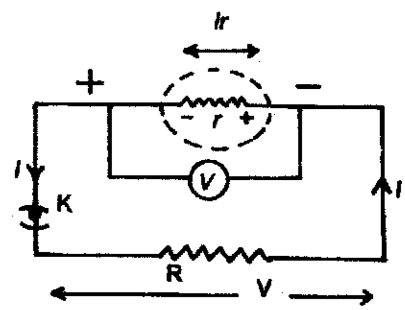


Fig. 16.24 : Circuit diagram showing internal resistance

$\therefore \quad E - Ir = IR = V$

or $\boxed{E = V + Ir}$ ...(16.28)

Thus, e.m.f of a cell is always greater than the potential difference across external resistance unless internal resistance is zero.

E.m.f of a cell depends on: (i) the liquid used in the cell (ii) the material of the plates, and (iii) temperature of the liquid.

Note that the e.m.f. of a cell does not depend at all on the size of the cell i.e. on the area of plates and distance between then. This means that if you have two cells of different size one big and one small, can the e.m.f.s be the same? Yes the e.m.f. will be the same if the cells are made up of same material and liquid. Then what is the difference ? If the cell is of large size it will be of less resistance to the passage of current through it.

Example 16.9 : ***When a current drawn from a battery is 0.5A, its terminal potential difference is 20V. And when current drawn from it is 2.0A, the terminal voltage reduces to 16 V. Find out e.m.f. and internal resistance of battery.***

Solution : Let E and r be the e.m.f. and internal resistance of battery. When a current I ampere is drawn from it, then potential drop across internal resistance or inside the cell is $= Ir$, then

$$V = E - Ir$$

For $I = 0.5$A, V=20 Volt, we have

$$20 = E - 0.5r \qquad \text{..... (i)}$$

For $I = 2.0$A, V=16 volt we have

$$16 = E - 2r \qquad \text{.....(ii)}$$

From eqs (i) and (ii)

$$2E - r = 40$$
$$E - 2r = 16$$

solving we get

$$E = 21.3\ V, r = 2.67\ \Omega$$

16.7 POTENTIOMETER

You have already studied how to measure e.m.f. of a source or potential difference across a circuit element using voltmeter. An ideal voltmeter should have infinite resistance so that it does not draw any current when connected across a source of e.m.f. Practically it is not possible to make a voltmeter which will not draw any current. To overcome this difficulty a circuit devised by Poggendorf and known as potentiometer is used for measuring the e.m.f. of a source or the potential difference across a circuit element without drawing any current from it. It employs a null method. The potentiometer can also be used for the measurement of the internal resistance of a cell, the current flowing in a circuit and comparison of resistances.

16.7.1 Description of the Potentiometer

The potentiometer consists of a wooden board on which a number of resistance wires (usually ten) of uniform cross - sectional area are stretched parallel to each other. The wire is of maganin or nichrome. These wires are joined in series by thick copper strips. In this way these wires together act as a single wire of length equal to the sum of the length of all the wires. The end terminals of the wires are provided with connecting screws.

A meter scale is fixed on the wooden board parallel towires. A jockey (a sliding contact maker) is provided with the arrangement. It makes a knife edge contact at any desired point on the wire. Jockey has a pointer which moves over the scale. It determines the position of the knife edge contact. In Fig. 16.25 a ten wire potentiometer is shown. A and B are ends of the wire. K is a jockey and S is a scale. Jockey slides over a rod CD.

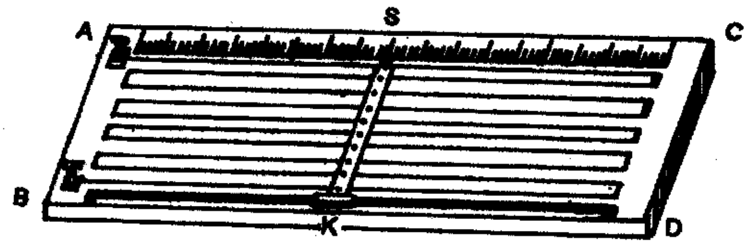


Fig. 16.25 : Potentiometer

16.7.2 Theory of Measurement by Potentiometer

Let us consider that a steady source of e.m.f. E (say an accumulator) be connected across the uniform resistance wire AB of length ℓ. Positive terminal of accumulator is connected at end A (Fig 16.26). A steady current I flows through the wire. Potential difference across AB is given by

$$V_{AB} = RI \qquad ...(16.29)$$

If r is the resistance per unit length of the wire, and k is the potential fall across unit length of the wire,

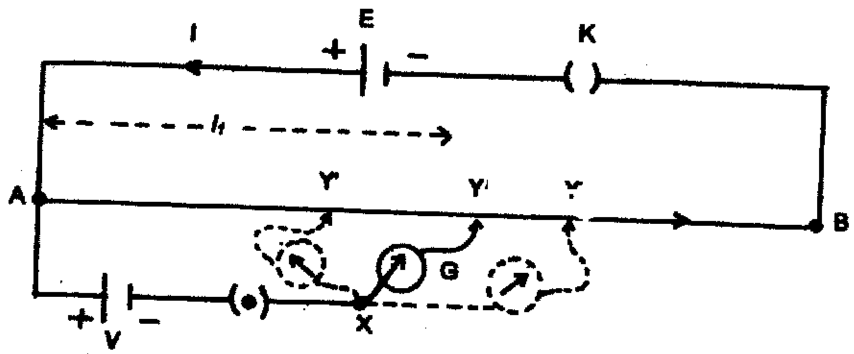


Fig. 16.26: Circuit diagram of potentiometer

Then, $R = r\,\ell$ and $k = r\,\ell$

$$\therefore \quad V_{AB} = k\,\ell = E \qquad ...(16.30)$$

$$\text{or} \quad k = \frac{E}{\ell}$$

For a length ℓ_1 of the wire, potential fall

$$V_1 = k\ell_1 = \frac{E}{\ell}\ell_1 \qquad .....(16.31)$$

Thus, potential falls linearly with the distance along the wire from A to B.

Let us measure an unknown voltage V say a cell of e.m.f.E. The positive terminal of the cell is connected to end A of the wire and negative terminal through a galvanometer to jockey having variable contact Y. Note that V must be less than E.

Let you start jockey moving from A towards B. Suppose at position Y potential fall across the length AY' of the wire be less than voltage V. Than current in the loop AY' XA due to voltage V exceeds the current due to potential difference across AY". Hence galvanometer shows some deflection in one direction. Then jockey is moved away say at Y' such that potential fall across AY' is greater than the voltage V, then galvanometer shows deflection in other direction. Now in between Y' and Y" the jockey is moved slowly. The stage is reached say point Y such that potential fall across AY is equal to voltage V. Then point X and Y will be at same voltage and hence the galvanometer will not show any deflection i.e. null point is achieved. If ℓ_1 is the length between A and Y, then

$$V = k\ell_1 = \frac{E\ell_1}{\ell}$$

Thus, the unknown voltage V is measured when no current is drawn from it.

The potentiometer has certain advantage. They are as follows :

(i) When the potentiometer is balanced, no current is drawn from the circuit on which the measurement is being made.

(ii) It produces no change in condition in any circuit to which it is connected.

(iii) It makes use of null method for the measurement, the galvanometer used need not be calibrated.

16.7.3 Comparison of the E.M.Fs of two Cells by Potentiometer

You have already studied how to measure the e.m.f. of a cell using a potentiometer. We shall now extend the same technique for comparison of e.m.fs of two cells. Let us take, for example, a Daniel cell and a Leclanche cell and let E_1 and E_2 be their e.m.f s.

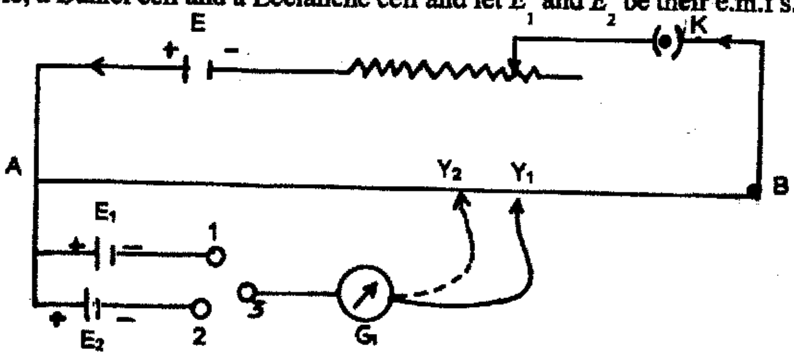


Fig. 16.27: Comparison of emfs of two cell

Potentiometer connections are made as shown in Fig 16.27. One cell say of e.m.f E_1 is connected in the circuit by connecting terminals of 1 and 3 of key K_1. The balance point is obtained by moving the jockey on the potentiometer wire as explained earlier. Let the balance point on potentiometer be at point Y_1 and let the length $AY_1 = \ell_1$. Then other cell of e.m.f. E_2 is connected in the circuit by connecting terminals 2 and 3 of the key K_2. Again balance is obtained at point Y_2 and let length $AY_2 = \ell_2$.

Applying potentiometer principle,

$$E_1 = k\ell_1 \text{ and } E_2 = k\ell_2$$

Where k is the potential gradient along the wire AB

$$\frac{E_1}{E_2} = \frac{\ell_2}{\ell_2}$$

If e.m.f. of one cell is known, say E_2, the e.m.f. of other cell can be determined

$$E_1 = \frac{\ell_1}{\ell_2} E_2 \qquad \text{....(16.32)}$$

16.7.4 Determination of Internal Resistance of the Cell

You have learnt that cells always offer resistance to the flow of current through them, which is often very small. This resistance is called the *internal resistance* of the cell and depends on the size of the cell i.e. the area of the plates immersed in the liquid, the distance of the plates and the strength of the electrolyte used in the cell.

Let us now learn how to measure the internal resistance of the cell using a potentiometer. Connections are made as shown in Fig 16.28. There is a cell of emf E_1 and internal resistance r. A resistance box R with a key K_1 is connected in parallel with the cell. Rest of the circuit

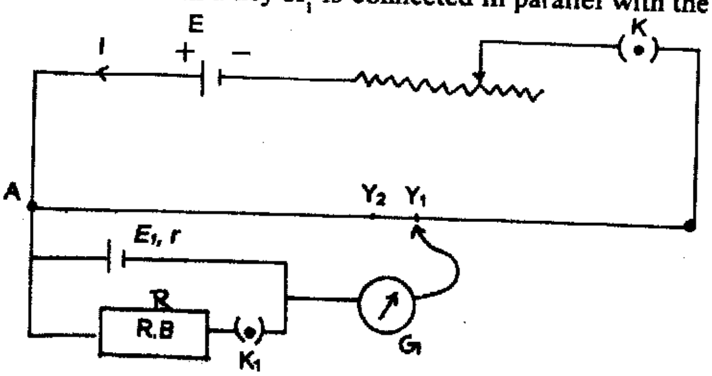


Fig. 16.28: Determination of internal resistance of cell

is similar to that in previous section. First of all key K is closed and a current I flows through wire AB. The key K_1 is kept open and on moving jockey balance is obtained with the cell at point say Y_1. Let $AY_1 = \ell_1$ then

$$E_1 = k\ell_1 \qquad \text{...(16.33)}$$

Now key K_1 is closed .This introduces a resistance across the cell. A current say I_1 will flow in loop $E_1RK_1E_1$ due to cell E_1. This current I_1 is given by Ohm's law as,

$$I_1 = \frac{E_1}{R + r} \qquad \text{....(16.34)}$$

Where r is the internal resistance of the cell. Now, terminal potential difference V_1 of the cell will be less than E_1 by an amount $I_1 r$.

The value of V_1 is

$$V_1 = I_1 R = \frac{E_1}{R+r} R \quad \text{....(16.35)}$$

Then, potential difference V_1 is balanced on the potentiometer wire without change in current I. Let the balance point be at point Y_1 such that $AY_1 = \ell_2$ then

$$V_1 = k\ell_2 \quad \text{.....(16.36)}$$

From eqs (16.33) and (16.36)

$$\frac{E_1}{V_1} = \frac{\ell_1}{\ell_2}$$

From eq (16.35)

$$\frac{E_1}{V_1} = \frac{R+r}{R}$$

$$\frac{R+r}{R} = \frac{\ell_1}{\ell_2}$$

$$\text{or } r = R\left(\frac{\ell_1}{\ell_2} - 1\right) \quad \text{.....(16.37)}$$

Thus, by knowing R, ℓ_1, and ℓ_2 the value of r is calculated.

Example 16.10 : *Length of a potentiometer wire is 5 m. It is connected with a battery of fixed e.m.f. Null point is obtained for the Daniel cell at 100 cm on it. If the length of the wire is kept 7 m, then what will be the position of null point ?*

Solution : Let the e.m.f. of battery be E volt, the potential gradient for 5 m length is

$$k_1 = \frac{E}{5} \text{ V/m}$$

When the length of potentiometer wire is 7 m potential gradient is

$$k_2 = \frac{E}{7} \text{ V/m}$$

Now, if null point is obtained at length ℓ_2, then

$$E_1 = k_2\ell_2 = \frac{E}{7}\ell_2 \text{ V}$$

Here same cell is balanced in two arrangements, hence

$$\frac{E}{5} = \frac{E}{7}\ell_2$$

$\ell_2 = 7/5 = 1.4$ m

INTEXT QUESTIONS 16.5

1. *When current drawn from a cell increases, potential difference between plates decreases. Why ?*

   ....

2. *Is it possible that potential difference between, plates of a cell becomes zero ?*

   ....

3. *In the 16.29 shown, if r is the resistance per unit length of the wire AB. The value of potential difference between A and B due to cell of e.m.f.E is given by*

   (a) $r\ell/I$ (b) $r\ell I$ (c) rI/ℓ (d) $I/r.\ell$

   ....

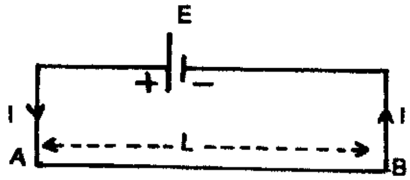


Fig. 16.29

4. *Potentiometer circuit is used to compare e.m.fs of two cells E_1 and E_2. The balance point on potentiometer wire is obtained at a distance ℓ meters and $\ell/2$ meters for E_1 and E_2 respectively. If E_1 = 2 volts, find the value of E_2*

   ....

16.8 WHAT YOU HAVE LEARNT

- Drift velocity is the average velocity component with which electrons move opposite to the field when an electric field exists in a conductor.
- Electric current through any cross-sectional area is the rate of transfer of charge from one side to other side of the area. Unit of current is ampere denoted by A.
- Ohm's law states that the current flowing through a conductor is proportional to the potential difference when physical conditions, temperature etc remain unchanged.
- Resistivity (or specific resistance) of a material equals the resistance of a wire of the material of 1m length and 1m^2 area of cross section. Unit of resistivity is ohm meter.
- Ratio *V/I* is called resistance and is denoted by *R*. Unit of resistance is ohm (denoted by Ω)
- Resistance of a conductor for which *V/I* ratio is not constant but depends on the value of voltage applied, is called non-ohmic resistance.
- For a series combination of resistors the equivalent resistance is sum of resistances of all resistors.
- For parallel combination of resistors inverse of equivalent resistance is sum of inverse of all the resistances.
- Kirchhoff's laws to study systematically the complicated electrical circuits are:

  Law I: The sum of all the currents directed towards a point in an electrical network is equal to the sum of all currents directed away from the point.

  Law II : The algebraic sum of all potential differences along a closed loop in an electrical network is zero.
- The Wheat Stone Bridge circuit is used to measure accurately an unknown resistance (*S*) by comparing it with known resistances (*P*, *Q* and *R*). In the balanced condition *P/Q = R/S*
- The e.m.f of a cell is equal to potential difference at its terminals when a circuit is not connected to it i.e. it is open.
- A potentiometer measures voltages without drawing current. Therefore, it can be used to measure e.m.f. of source that has appreciable internal resistance.

16. 9 TERMINAL QUESTIONS

1. What is drift velocity of free electrons in a metallic conductor ? For a current carrying conductor establish relation between current, drift velocity v_d, concentration of conduction electrons n and electronic charge e.
2. Define electric current and discuss Ohm's law.
3. Define resistivity of a conductor. How does the resistance of a wire depend upon the resistivity of its material, its length and area of cross-section?
4. Define electrical conductivity. Write its unit. How does electrical conductivity depend upon free electron concentration of the conductor ?
5. Explain the difference between ohmic and non-ohmic resistances. Give some examples of non-ohmic resistances.
6. What is the effect of temperature on the resistivity of the material ? Why does the electrical conductivity of a conductor decrease with increase in temperature ?
7. The colours on the resistor shown in Fig. 16.30 are red orange, green and gold as read from left to right. What is resistance of it according to colour code ?

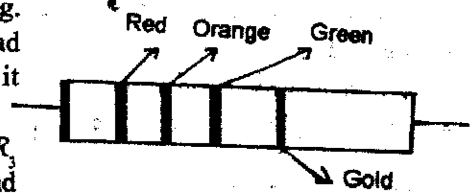


Fig. 16.30

8. Three resistors of resistances R_1, R_2, and R_3 are connected (i) in series (ii) in parallel. Find out equivalent resistance of combination in each case.
9. What is the difference in e.m.f. and potential difference between electrode of a cell Derive relation between the two.
10. What are Kirchhoff's laws governing the currents and electromotive forces in an electrical network?
11. Give theory of Wheat Stone's Bridge method for measuring resistances.
12. Discuss the theory of the potentiometer.
13. How will you measure unknown potential difference with the help of a potentiometer ?
14. Describe potentiometer method of comparing the e.m.f of two cells.
15. How will you find the internal resistance of a cell with the help of a potentiometer ? What are the factors responsible for the internal resistance of the cell?
16. A wire of length 1m and radius 0.1 mm has a resistance of 100 Ω. Find the resistivity of the material.
17. Consider a wire of length 4m and cross-sectional area 1 mm^2 carrying a current of 2A. If each cubic meter of the material contains 10^{29} free electrons find the average time taken by an electron to cross the length of the wire.
18. Suppose you have three resistors each of value 30Ω. List all the different resistances you can obtain.
19. The potential difference between the terminals of a battery of e.m.f 6.0V and internal resistance 1 Ω drops to 5.8V when connected across an external resistor. Find the resistance of the external resistor.
20. For the circuit shown in fig 16.31 calculate the value of current I and resistance R.

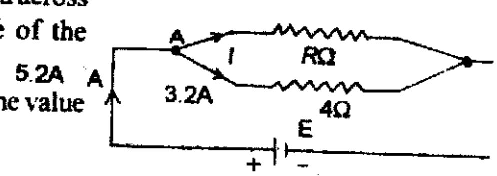


Fig. 16.31

21. Four resistors P, Q, R and X whose values area 2, 2, 2 and 3 ohms respectively are joined to form a Wheat Stone Bridge. Calculate the value of resistance with which the resistance X must be shunted in order that the bridge may be balanced.
22. The potentiometer set-up has been used for measuring the e.m.f of a cell X. When a standard cell of e.m.f 1.02 volt is connected to the circuit, the null point is obtained at a distance of 1.02m on the potentiometer wire. When the unknown cell X is connected, the null is obtained at a distance of 0.6m. Calculate the e.m.f of the cell X.
23. Potentiometer circuit is used for comparing e.m.f of two cells E_1 and E_2. Cell E_1 gives null when the jockey is placed on the second wire opposite to 0.5m mark and cell E_2 gives null when the jockey is at 0.2 m mark on the third wire. Compare the e.m.fs of cells E_1 and E_2.
24. A cell gives no deflection in a galvanometer connected with potentiometer circuit when jockey is at 1.20m. On connecting 10Ω resistance across the cell, the null point is at 1m. Calculate the internal resistance of the cell.

CHECK YOUR ANSWERS

Intext questions 16.1

1. Due to high resistivity and low temperature coefficient of resistance
5. (a) 1:2 (b) 2:1

Intext Questions 16.2

1. (b) 2.(a) 3. 1Ω. 4. (b)

Intext Questions 16.3

1. 2A, $V_B = V_A$ 2. 0.4A 3. 0.4A

Intext Questions 16.4

1. 25Ω
2. Using $I_1 = \frac{R_2 I}{R_1 + R_2}$

$$= \frac{30}{42} \times 1.4 = 1A$$

3. ~ 505Ω

Intext Questions 16.5

1. $V = E - Ir$. With increase of current, Ir increase resulting decrease of V.
2. Yes, when cell is short circuited
3. (b).
4. 1 ;

Terminal Questions

7. $(2.4 + 0.115)$ MΩ. 16. $\pi \times 10^{-4}$ Ω m 17. 8.9 hours
18. 10Ω, 20Ω, 45Ω, 90Ω, 19. 29Ω, 20. 2A, 6.4Ω
21. 6Ω. 22. 0.6, 23. $E_1 : E_2 = 5:2$