2. Current Electricity

The branch of Physics which deals with the study of motion of electric charges is called current electricity. In an uncharged metallic conductor at rest, some (not all) electrons are continually moving randomly through the conductor because they are very loosely attached to the nuclei. The thermodynamic internal energy of the material is sufficient to liberate the outer electrons from individual atoms, enabling the electrons to travel through the material. But the net flow of charge at any point is zero. Hence, there is zero current. These are termed as free electrons. The external energy necessary to drive the free electrons in a definite direction is called electromotive force (emf). The emf is not a force, but it is the work done in moving a unit charge from one end to the other. The flow of free electrons in a conductor constitutes electric current.

2.1 Electric current

The current is defined as the rate of flow of charges across any cross sectional area of a conductor. If a net charge q passes through any cross section of a conductor in time t, then the current $I = q / t$, where q is in coulomb and t is in second. The current I is expressed in ampere. If the rate of flow of charge is not uniform, the current varies with time and the instantaneous value of current i is given by,

$$i = \frac{dq}{dt}$$

Current is a scalar quantity. The direction of conventional current is taken as the direction of flow of positive charges or opposite to the direction of flow of electrons.

2.1.1 Drift velocity and mobility

Consider a conductor XY connected to a battery (Fig 2.1). A steady electric field E is established in the conductor in the direction X to Y. In the absence of an electric field, the free electrons in the conductor move randomly in all possible directions.

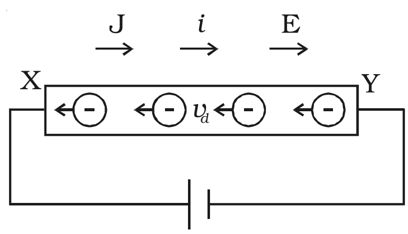

Fig 2.1 Current carrying conductor

They do not produce current. But, as soon as an electric field is applied, the free electrons at the end Y experience a force F = eE in a direction opposite to the electric field. The electrons are accelerated and in the process they collide with each other and with the positive ions in the conductor.

Thus due to collisions, a backward force acts on the electrons and they are slowly drifted with a constant average drift velocity v_d in a direction opposite to electric field.

Drift velocity is defined as the velocity with which free electrons get drifted towards the positive terminal, when an electric field is applied.

If τ is the average time between two successive collisions and the acceleration experienced by the electron be a, then the drift velocity is given by,

$$v_d = a\tau$$

The force experienced by the electron of mass m is

$$F = ma$$

Hence $a = \frac{eE}{m}$

$$\therefore v_d = \frac{eE}{m}\tau = \mu E$$

where $\mu = \frac{e\tau}{m}$ is the mobility and is defined as the drift velocity acquired per unit electric field. It takes the unit $m^2V^{-1}s^{-1}$. The drift velocity of electrons is proportional to the electric field intensity. It is very small and is of the order of 0.1 cm s^{-1}.

2.1.2 Current density

Current density at a point is defined as the quantity of charge passing per unit time through unit area, taken perpendicular to the direction of flow of charge at that point.

The current density **J** for a current I flowing across a conductor having an area of cross section A is

$$\mathbf{J} = \frac{(q/t)}{A} = \frac{I}{A}$$

Current density is a vector quantity. It is expressed in A m^{-2}

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* In this text book, the infinitesimally small current and instantaneous currents are represented by the notation i and all other currents are represented by the notation I.

2.1.3 Relation between current and drift velocity

Consider a conductor XY of length L and area of cross section A (Fig 2.1). An electric field E is applied between its ends. Let n be the number of free electrons per unit volume. The free electrons move towards the left with a constant drift velocity v_d.

The number of conduction electrons in the conductor = nAL

The charge of an electron = e

The total charge passing through the conductor $q = (nAL)\, e$

The time in which the charges pass through the conductor, $t = \frac{L}{v_d}$

The current flowing through the conductor, $I = \frac{q}{t} = \frac{(nAL)e}{(L/v_d)}$

$$I = nAev_d \qquad ...(1)$$

The current flowing through a conductor is directly proportional to the drift velocity.

From equation (1), $\frac{I}{A} = nev_d$

$$\boldsymbol{J} = nev_d \qquad \left[\because \boldsymbol{J} = \frac{I}{A}, \textit{current density}\right]$$

2.1.4 Ohm's law

George Simon Ohm established the relationship between potential difference and current, which is known as Ohm's law. The current flowing through a conductor is,

$$I = nAev_d$$

But $v_d = \frac{eE}{m} \cdot \tau$

$$\therefore \quad I = nAe\,\frac{eE}{m}\tau$$

$$I = \frac{nAe^2}{mL}\tau V \qquad \left[\because E = \frac{V}{L}\right]$$

where V is the potential difference. The quantity $\frac{mL}{nAe^2\tau}$ is a constant for a given conductor, called electrical resistance (R).

$$\therefore \quad I \;\alpha\; V$$

The law states that, at a constant temperature, the steady current flowing through a conductor is directly proportional to the potential difference between the two ends of the conductor.

(i.e) $I \propto V$ or $I = \frac{1}{R}V$

$\therefore$ $V = IR$ or $R = \frac{V}{I}$

Resistance of a conductor is defined as the ratio of potential difference across the conductor to the current flowing through it. The unit of resistance is ohm (Ω)

The reciprocal of resistance is conductance. Its unit is mho (Ω^{-1}).

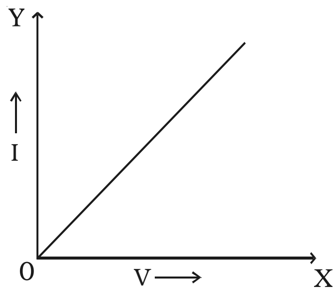


Fig 2.2 V–I graph of an ohmic conductor.

Since, potential difference V is proportional to the current I, the graph (Fig 2.2) between V and I is a straight line for a conductor. Ohm's law holds good only when a steady current flows through a conductor.

2.1.5 Electrical Resistivity and Conductivity

The resistance of a conductor R is directly proportional to the length of the conductor l and is inversely proportional to its area of cross section A.

$$R \propto \frac{l}{A} \quad \text{or} \quad R = \frac{\rho l}{A}$$

ρ is called specific resistance or electrical resistivity of the material of the conductor.

If l = 1 m, A = 1 m^2, then ρ = R

The electrical resistivity of a material is defined as the resistance offered to current flow by a conductor of unit length having unit area of cross section. The unit of ρ is ohm–m (Ω m). It is a constant for a particular material.

The reciprocal of electrical resistivity, is called electrical conductivity, $\sigma = \frac{1}{\rho}$

The unit of conductivity is mho m^{-1} (Ω^{-1} m^{-1})

2.1.6 Classification of materials in terms of resistivity

The resistivity of a material is the characteristic of that particular material. The materials can be broadly classified into conductors and insulators. The metals and alloys which have low resistivity of the order of 10^{-6} – 10^{-8} Ω m are good conductors of electricity. They carry current without appreciable loss of energy. Example : silver, aluminium, copper, iron, tungsten, nichrome, manganin, constantan. The resistivity of metals increase with increase in temperature. Insulators are substances which have very high resistivity of the order of 10^{8} – 10^{14} Ω m. They offer very high resistance to the flow of current and are termed non–conductors. Example : glass, mica, amber, quartz, wood, teflon, bakelite. In between these two classes of materials lie the semiconductors (Table 2.1). They are partially conducting. The resistivity of semiconductor is 10^{-2} – 10^{4} Ω m. Example : germanium, silicon.

Table 2.1 Electrical resistivities at room temperature (NOT FOR EXAMINATION)

Classification	**Material**	**ρ (Ω m)**
conductors	silver	1.6×10^{-8}
	copper	1.7×10^{-8}
	aluminium	2.7×10^{-8}
	iron	10×10^{-8}
Semiconductors	germanium	0.46
	silicon	2300
Insulators	glass	10^{10} – 10^{14}
	wood	10^{8} – 10^{11}
	quartz	10^{13}
	rubber	10^{13} – 10^{16}

2.2 Superconductivity

Ordinary conductors of electricity become better conductors at lower temperatures. The ability of certain metals, their compounds and alloys to conduct electricity with zero resistance at very low temperatures is called superconductivity. The materials which exhibit this property are called superconductors.

The phenomenon of superconductivity was first observed by Kammerlingh Onnes in 1911. He found that mercury suddenly showed zero resistance at 4.2 K (Fig 2.3). The first theoretical explanation of superconductivity was given by Bardeen, Cooper and Schrieffer in 1957 and it is called the BCS theory.

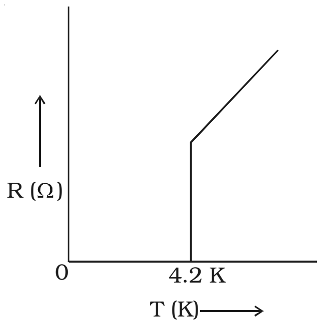


Fig 2.3 Superconductivity of mercury

The temperature at which electrical resistivity of the material suddenly drops to zero and the material changes from normal conductor to a superconductor is called the transition temperature or critical temperature T_C. At the transition temperature the following changes are observed :

(i) The electrical resistivity drops to zero.

(ii) The conductivity becomes infinity

(iii) The magnetic flux lines are excluded from the material.

Applications of superconductors

(i) Superconductors form the basis of energy saving power systems, namely the superconducting generators, which are smaller in size and weight, in comparison with conventional generators.

(ii) Superconducting magnets have been used to levitate trains above its rails. They can be driven at high speed with minimal expenditure of energy.

(iii) Superconducting magnetic propulsion systems may be used to launch satellites into orbits directly from the earth without the use of rockets.

(iv) High efficiency ore–separating machines may be built using superconducting magnets which can be used to separate tumor cells from healthy cells by high gradient magnetic separation method.

(v) Since the current in a superconducting wire can flow without any change in magnitude, it can be used for transmission lines.

(vi) Superconductors can be used as memory or storage elements in computers.

2.3 Carbon resistors

The wire wound resistors are expensive and huge in size. Hence, carbon resistors are used. Carbon resistor consists of a ceramic core, on which a thin layer of crystalline carbon is deposited. These resistors are cheaper, stable and small in size. The resistance of a carbon resistor is indicated by the colour code drawn on it (Table 2.2). A three colour code carbon resistor is discussed here. The silver or gold ring at one end corresponds to the tolerance. It is a tolerable range (±) of the resistance. The tolerance of silver, gold, red and brown rings is 10%, 5%, 2% and 1% respectively. If there is no coloured ring at this end, the tolerance is 20%. The first two rings at the other end of tolerance ring are significant figures of resistance in ohm. The third ring indicates the powers of 10 to be multiplied or number of zeroes following the significant figure.

Table 2.2 Colour code for carbon resistors

Colour	Number
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Grey	8
White	9

Example :

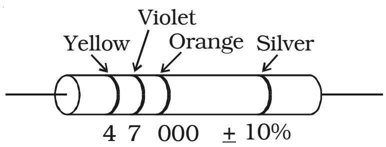


Fig 2.4 Carbon resistor colour code.

The first yellow ring in Fig 2.4 corresponds to 4. The next violet ring corresponds to 7. The third orange ring corresponds to 10^3. The silver ring represents 10% tolerance. The total resistance is $47 \times 10^3 \pm 10\%$ i.e. 47 k Ω, 10%. Fig 2.5 shows 1 k Ω, 5% carbon resistor.

Presently four colour code carbon resistors are also used. For certain critical applications 1% and 2% tolerance resistors are used.

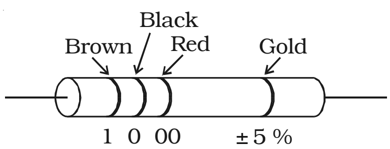


Fig 2.5 Carbon resistor

2.4 Combination of resistors

In simple circuits with resistors, Ohm's law can be applied to find the effective resistance. The resistors can be connected in series and parallel.

2.4.1 Resistors in series

Let us consider the resistors of resistances R_1, R_2, R_3 and R_4 connected in series as shown in Fig 2.6.

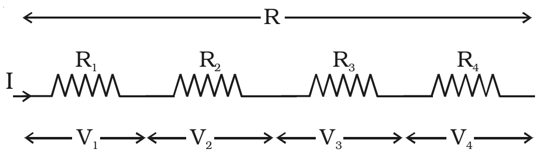


Fig 2.6 Resistors in series

When resistors are connected in series, the current flowing through each resistor is the same. If the potential difference applied between the ends of the combination of resistors is V, then the potential difference across each resistor R_1, R_2, R_3 and R_4 is V_1, V_2, V_3 and V_4 respectively.

The net potential difference $V = V_1 + V_2 + V_3 + V_4$

By Ohm's law

$V_1 = IR_1$, $V_2 = IR_2$, $V_3 = IR_3$, $V_4 = IR_4$ and $V = IR_s$

where R_S is the equivalent or effective resistance of the series combination.

Hence, $IR_S = IR_1 + IR_2 + IR_3 + IR_4$ or $R_S = R_1 + R_2 + R_3 + R_4$

Thus, the equivalent resistance of a number of resistors in series connection is equal to the sum of the resistance of individual resistors.

2.4.2 Resistors in parallel

Consider four resistors of resistances R_1, R_2, R_3 and R_4 are connected in parallel as shown in Fig 2.7. A source of emf V is connected to the parallel combination. When resistors are in parallel, the potential difference (V) across each resistor is the same.

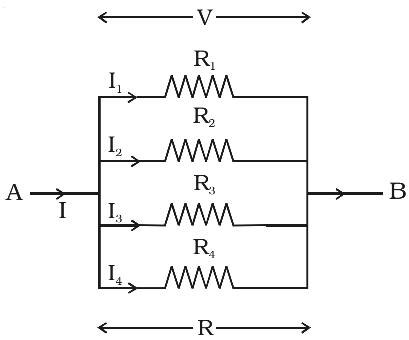


Fig 2.7 Resistors in parallel

A current I entering the combination gets divided into I_1, I_2, I_3 and I_4 through R_1, R_2, R_3 and R_4 respectively,

such that $I = I_1 + I_2 + I_3 + I_4$.

By Ohm's law

$$I_1 = \frac{V}{R_1},\quad I_2 = \frac{V}{R_2},\quad I_3 = \frac{V}{R_3},\quad I_4 = \frac{V}{R_4}\ \text{and}\ I = \frac{V}{R_P}$$

where R_P is the equivalent or effective resistance of the parallel combination.

$$\therefore \frac{V}{R_P} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} + \frac{V}{R_4}$$

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \frac{1}{R_4}$$

Thus, when a number of resistors are connected in parallel, the sum of the reciprocal of the resistance of the individual resistors is equal to the reciprocal of the effective resistance of the combination.

2.5 Temperature dependence of resistance

The resistivity of substances varies with temperature. For conductors the resistance increases with increase in temperature. If R_o is the resistance of a conductor at 0^o C and R_t is the resistance of same conductor at t^o C, then

$$R_t = R_o (1 + \alpha t)$$

where α is called the temperature coefficient of resistance.

$$\alpha = \frac{R_t - R_o}{R_o t}$$

The temperature coefficient of resistance is defined as the ratio of increase in resistance per degree rise in temperature to its resistance at 0^o C. Its unit is per ^{o}C.

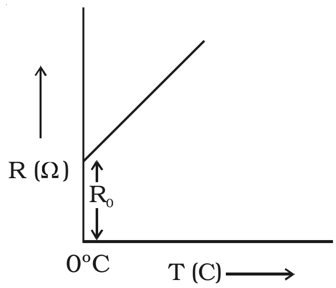


Fig 2.8 Variation of resistance with temperature

The variation of resistance with temperature is shown in Fig 2.8.

Metals have positive temperature coefficient of resistance, i.e., their resistance increases with increase in temperature. Insulators and semiconductors have negative temperature coefficient of resistance, i.e., their resistance decreases with increase in temperature. A material with a negative temperature coefficient is called a thermistor. The temperature coefficient is low for alloys.

2.6 Internal resistance of a cell

The electric current in an external circuit flows from the positive terminal to the negative terminal of the cell, through different circuit elements. In order to maintain continuity, the current has to flow through the electrolyte of the cell, from its negative terminal to positive terminal. During this process of flow of current inside the cell, a resistance is offered to current flow by the electrolyte of the cell. This is termed as the internal resistance of the cell.

A freshly prepared cell has low internal resistance and this increases with ageing.

Determination of internal resistance of a cell using voltmeter

The circuit connections are made as shown in Fig 2.9. With key K open, the emf of cell E is found by connecting a high resistance voltmeter across it. Since the high resistance voltmeter draws only a very feeble current for deflection, the circuit may be considered as an open circuit. Hence the voltmeter reading gives the emf of the cell. A small value of resistance R is included in the external circuit and key K is closed. The potential difference across R is equal to the potential difference across cell (V).

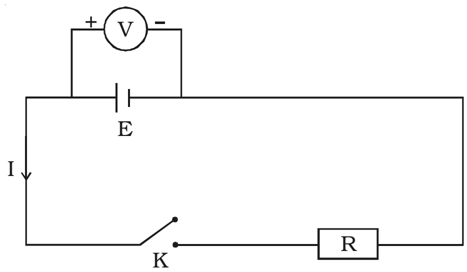


Fig 2.9 Internal resistance of a cell using voltmeter.

The potential drop across R, V = IR ...(1)

Due to internal resistance r of the cell, the voltmeter reads a value V, less than the emf of cell.

Then V = E − Ir or Ir = E–V ...(2)

Dividing equation (2) by equation (1)

$$\frac{Ir}{IR} = \frac{E-V}{V} \quad \text{or} \quad r = \left(\frac{E-V}{V}\right)R$$

Since E, V and R are known, the internal resistance *r* of the cell can be determined.

2.7 Kirchoff's law

Ohm's law is applicable only for simple circuits. For complicated circuits, Kirchoff's laws can be used to find current or voltage. There are two generalised laws : (i) Kirchoff's current law (ii) Kirchoff's voltage law

Kirchoff's first law (current law)

Kirchoff's current law states that the algebraic sum of the currents meeting at any junction in a circuit is zero.

The convention is that, the current flowing towards a junction is positive and the current flowing away from the junction is negative. Let 1,2,3,4 and 5 be the conductors meeting at a junction O in an electrical circuit (Fig 2.10). Let I_1, I_2, I_3, I_4 and I_5 be the currents passing through the conductors respectively. According to Kirchoff's first law.

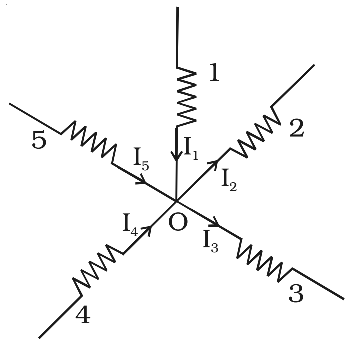


Fig 2.10 Kirchoff's current law

$$I_1 + (-I_2) + (-I_3) + I_4 + I_5 = 0 \quad \text{or} \quad I_1 + I_4 + I_5 = I_2 + I_3.$$

The sum of the currents entering the junction is equal to the sum of the currents leaving the junction. This law is a consequence of conservation of charges.

Kirchoff's second law (voltage law)

Kirchoff's voltage law states that the algebraic sum of the products of resistance and current in each part of any closed circuit is equal to the algebraic sum of the emf's in that closed circuit. This law is a consequence of conservation of energy.

In applying Kirchoff's laws to electrical networks, the direction of current flow may be assumed either clockwise or anticlockwise. If the assumed direction of current is not the actual direction, then on solving the problems, the current will be found to have negative sign. If the result is positive, then the assumed direction is the same as actual direction.

It should be noted that, once the particular direction has been assumed, the same should be used throughout the problem. However, in the application of Kirchoff's second law, we follow that the current in clockwise direction is taken as positive and the current in anticlockwise direction is taken as negative.

Let us consider the electric circuit given in Fig 2.11a.

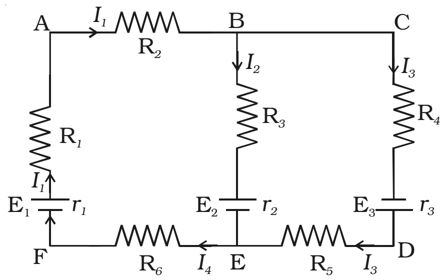


Fig 2.11a Kirchoff's laws

Considering the closed loop ABCDEFA,

$I_1R_2 + I_3R_4 + I_3r_3 + I_3R_5 + I_4R_6 + I_1r_1 + I_1R_1 = E_1 + E_3$

Both cells E_1 and E_3 send currents in clockwise direction.

For the closed loop ABEFA

$I_1R_2 + I_2R_3 + I_2r_2 + I_4R_6 + I_1r_1 + I_1R_1 = E_1 - E_2$

Negative sIgn in E_2 indicates that it sends current in the anticlockwise direction.

As an illustration of application of Kirchoff's second law, let us calculate the current in the following networks.

Illustration I

Applying first law to the Junction B, (FIg.2.11b)

$I_1 - I_2 - I_3 = 0$

$\therefore$ $I_3 = I_1 - I_2$ ...(1)

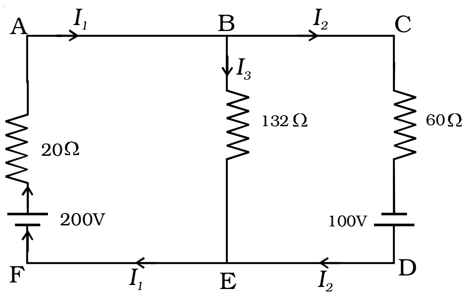


Fig 2.11b Kirchoff's laws

For the closed loop ABEFA,

$132\ I_3 + 20I_1 = 200$ ...(2)

Substituting equation (1) in equation (2)

$132\ (I_1 - I_2) + 20I_1 = 200$

$152I_1 - 132I_2 = 200$ ...(3)

For the closed loop BCDEB,

$60I_2 - 132I_3 = 100$

substituting for I_3,

$\therefore$ $60I_2 - 132\ (I_1 - I_2) = 100$

$-\ 132I_1 + 192I_2 = 100$ ...(4)

Solving equations (3) and (4), we obtain

$I_1 = 4.39$ A and $I_2 = 3.54$ A

Illustration 2

Taking the current in the clockwise direction along ABCDA as positive (FIg 2.11c)

$$10\,I + 0.5\,I + 5\,I + 0.5\,I + 8\,I + 0.5\,I + 5\,I + 0.5\,I + 10\,I = 50 - 70 - 30 + 40$$

$$I\,(10 + 0.5 + 5 + 0.5 + 8 + 0.5 + 5 + 0.5 + 10) = -10$$

$$40\,I = -10$$

$$\therefore \quad I = \frac{-10}{40} = -0.25\ A$$

The negative sign indicates that the current flows in the anticlockwise direction.

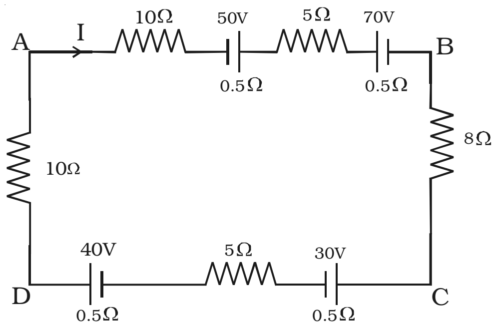


Fig 2.11c Kirchoff's laws

2.7.1 Wheatstone's bridge

An important application of Kirchoff's law is the Wheatstone's bridge (FIg 2.12). Wheatstone's network consists of resistances P, Q, R and S connected to form a closed path. A cell of emf E is connected between points A and C. The current I from the cell is divided into I_1, I_2, I_3 and I_4 across the four branches. The current through the galvanometer is I_g. The resistance of galvanometer is G.

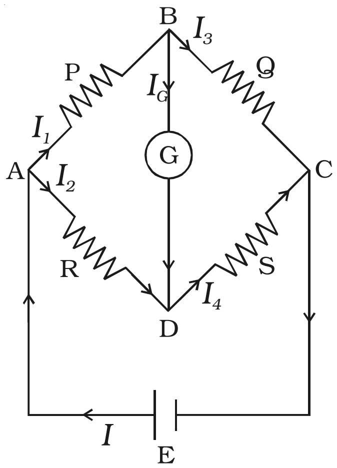


Fig 2.12
Wheatstone's bridge

Applying Kirchoff's current law to junction B,

$$I_1 - I_g - I_3 = 0 \qquad \ldots(1)$$

Applying Kirchoff's current law to junction D

$$I_2 + I_g - I_4 = 0 \qquad \ldots(2)$$

Applying Kirchoff's voltage law to closed path ABDA

$$I_1 P + I_g G - I_2 R = 0 \qquad \ldots(3)$$

Applying Kirchoff's voltage law to closed path ABCDA

$$I_1 P + I_3 Q - I_4 S - I_2 R = 0 \qquad \ldots(4)$$

When the galvanometer shows zero deflection, the points B and D are at same potential and $I_g = 0$. Substituting $I_g = 0$ in equation (1), (2) and (3)

$$I_1 = I_3 \quad ...(5)$$

$$I_2 = I_4 \quad ...(6)$$

$$I_1P = I_2R \quad ...(7)$$

Substituting the values of (5) and (6) in equation (4)

$$I_1P + I_1Q - I_2S - I_2R = 0$$

$$I_1 (P + Q) = I_2 (R+S) \quad ...(8)$$

Dividing (8) by (7)

$$\frac{I_1(P+Q)}{I_1P} = \frac{I_2(R+S)}{I_2R}$$

$$\therefore \frac{P+Q}{P} = \frac{R+S}{R}$$

$$1+\frac{Q}{P} = 1+\frac{S}{R}$$

$$\therefore \frac{Q}{P} = \frac{S}{R} \quad \text{or} \quad \frac{P}{Q} = \frac{R}{S}$$

This is the condition for bridge balance. If P, Q and R are known, the resistance S can be calculated.

2.7.2 Metre bridge

Metre bridge is one form of Wheatstone's bridge. It consists of thick strips of copper, of negligible resistance, fixed to a wooden board. There are two gaps G_1 and G_2 between these strips. A uniform manganin wire AC of length one metre whose temperature coefficient is low, is stretched along a metre scale and its ends are soldered to two copper strips. An unknown resistance P is connected in the gap G_1 and a standard resistance Q is connected in

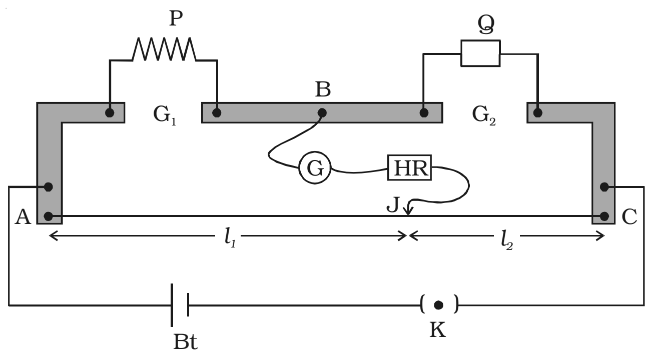


Fig 2.13 Metre bridge

the gap G_2 (Fig 2.13). A metal jockey J is connected to B through a galvanometer (G) and a high resistance (HR) and it can make contact at any point on the wire AC. Across the two ends of the wire, a Leclanche cell and a key are connected.

Adjust the position of metal jockey on metre bridge wire so that the galvanometer shows zero deflection. Let the point be J. The portions AJ and JC of the wire now replace the resistances R and S of Wheatstone's bridge. Then

$$\frac{P}{Q} = \frac{R}{S} = \frac{r.AJ}{r.JC}$$

where r is the resistance per unit length of the wire.

$$\therefore \quad \frac{P}{Q} = \frac{AJ}{JC} = \frac{l_1}{l_2}$$

where AJ = l_1 and JC = l_2

$$\therefore \quad P = Q\frac{l_1}{l_2}$$

Though the connections between the resistances are made by thick copper strips of negligible resistance, and the wire AC is also soldered to such strips a small error will occur in the value of $\frac{l_1}{l_2}$ due to the end resistance. This error can be eliminated, if another set of readings are taken with P and Q interchanged and the average value of P is found, provided the balance point J is near the mid point of the wire AC.

2.7.3 Determination of specific resistance

The specific resistance of the material of a wire is determined by knowing the resistance (P), radius (r) and length (L) of the wire using the expression $\rho = \frac{P\pi r^2}{L}$

2.7.4 Determination of temperature coefficient of resistance

If R_1 and R_2 are the resistances of a given coil of wire at the temperatures t_1 and t_2, then the temperature coefficient of resistance of the material of the coil is determined using the relation,

$$\alpha = \frac{R_2 - R_1}{R_1 t_2 - R_2 t_1}$$

2.8 Potentiometer

The Potentiometer is an instrument used for the measurement of potential difference (Fig 2.14). It consists of a ten metre long uniform wire of manganin or constantan stretched in ten segments, each of one metre length. The segments are stretched parallel to each other on a horizontal wooden board. The ends of the wire are fixed to copper strips with binding screws. A metre scale is fixed on the board, parallel to the wire. Electrical contact with wires is established by pressing the jockey J.

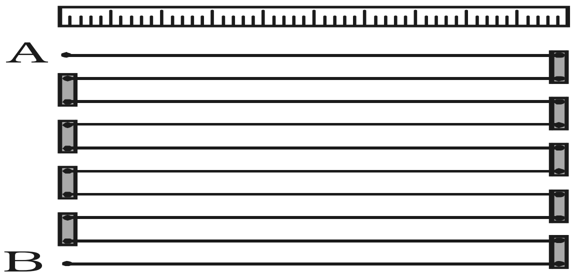


Fig 2.14 Potentiometer

2.8.1 Principle of potentiometer

A battery Bt is connected between the ends A and B of a potentiometer wire through a key K. A steady current I flows through the potentiometer wire (Fig 2.15). This forms the primary circuit. A primary cell is connected in series with the positive terminal A of the potentiometer, a galvanometer, high resistance and jockey. This forms the secondary circuit.

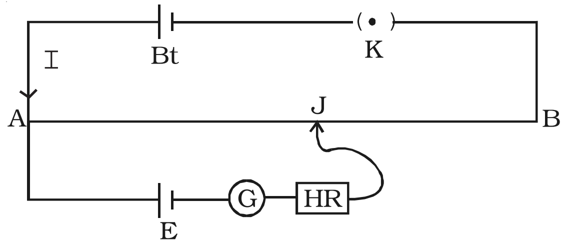


Fig 2.15 Principle of potentiometer

If the potential difference between A and J is equal to the emf of the cell, no current flows through the galvanometer. It shows zero deflection. AJ is called the balancing length. If the balancing length is l, the potential difference across AJ = Irl where r is the resistance per unit length of the potentiometer wire and I the current in the primary circuit.

$\therefore\ E = Irl,$

since I and r are constants, $E \propto l$

Hence emf of the cell is directly proportional to its balancing length. This is the principle of a potentiometer.

2.8.2 Comparison of emfs of two given cells using potentiometer

The potentiometer wire AB is connected in series with a battery (Bt), Key (K), rheostat (Rh) as shown in Fig 2.16. This forms the primary circuit. The end A of potentiometer is connected to the terminal C of a DPDT switch (six way key–double pole double throw). The terminal D is connected to the jockey (J) through a galvanometer (G) and high resistance (HR). The cell of emf E_1 is connected between terminals C_1 and D_1 and the cell of emf E_2 is connected between C_2 and D_2 of the DPDT switch.

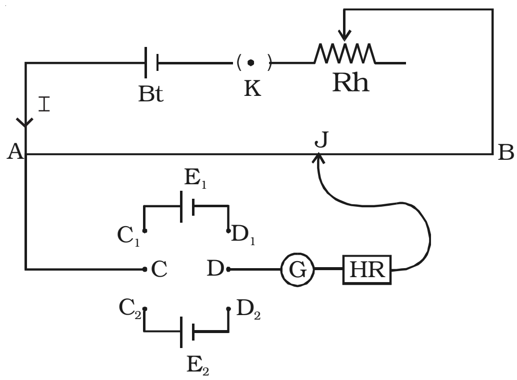


Fig 2.16 comparison of emf of two cells

Let I be the current flowing through the primary circuit and *r* be the resistance of the potentiometer wire per metre length.

The DPDT switch is pressed towards C_1, D_1 so that cell E_1 is included in the secondary circuit. The jockey is moved on the wire and adjusted for zero deflection in galvanometer. The balancing length is l_1. The potential difference across the balancing length l_1 = Irl_1. Then, by the principle of potentiometer,

$$E_1 = Irl_1 \quad ...(1)$$

The DPDT switch is pressed towards E_2. The balancing length l_2 for zero deflection in galvanometer is determined. The potential difference across the balancing length is l_2 = Irl_2, then

$$E_2 = Irl_2 \quad ...(2)$$

Dividing (1) and (2) we get

$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

If emf of one cell (E_1) is known, the emf of the other cell (E_2) can be calculated using the relation.

$$E_2 = E_1 \frac{l_2}{l_1}$$

2.8.3 Comparison of emf and potential difference

1. The difference of potentials between the two terminals of a cell in an open circuit is called the electromotive force (emf) of a cell. The difference in potentials between any two points in a closed circuit is called potential difference.

2. The emf is independent of external resistance of the circuit, whereas potential difference is proportional to the resistance between any two points.

2.9 Electric energy and electric power.

If I is the current flowing through a conductor of resistance R in time t, then the quantity of charge flowing is, $q = It$. If the charge q, flows between two points having a potential difference V, then the work done in moving the charge is = $V.\ q = V\ It$.

Then, electric power is defined as the rate of doing electric work.

$$\therefore \quad \text{Power} = \frac{Work\ done}{time} = \frac{VIt}{t} = VI$$

Electric power is the product of potential difference and current strength.

Since V = IR, Power = I^2R

Electric energy is defined as the capacity to do work. Its unit is joule. In practice, the electrical energy is measured by watt hour (Wh) or kilowatt hour (kWh). 1 kWh is known as one unit of electric energy.

(1 kWh = 1000 Wh = 1000 × 3600 J = 36×10^5 J)

2.9.1 Wattmeter

A wattmeter is an instrument used to measure electrical power consumed i.e energy absorbed in unit time by a circuit. The wattmeter consists of a movable coil arranged between a pair of fixed coils in the form of a solenoid. A pointer is attached to the movable coil. The free end of the pointer moves over a circular scale. When current flows through the coils, the deflection of the pointer is directly proportional to the power.

2.10 Chemical effect of current

The passage of an electric current through a liquid causes chemical changes and this process is called electrolysis. The conduction is possible, only in liquids wherein charged ions can be dissociated in opposite directions (Fig 2.17). Such liquids are called electrolytes. The plates through which current enters and leaves an electrolyte are known as electrodes. The electrode towards which positive ions travel is called the cathode and the other, towards which negative ions travel is called anode. The positive ions are called cations and are mostly formed from metals or hydrogen. The negative ions are called anions.

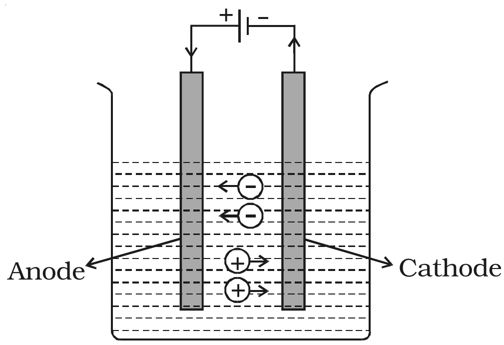


Fig 2.17 Conduction in liquids

2.10.1 Faraday's laws of electrolysis

The factors affecting the quantities of matter liberated during the process of electrolysis were investigated by Faraday.

First Law : The mass of a substance liberated at an electrode is directly proportional to the charge passing through the electrolyte.

If an electric current *I* is passed through an electrolyte for a time *t*, the amount of charge (q) passed is *I t*. According to the law, mass of substance liberated (*m*) is

$$m \,\alpha\, q \quad \text{or} \quad m = zIt$$

where Z is a constant for the substance being liberated called as electrochemical equivalent. Its unit is kg C^{-1}.

The electrochemical equivalent of a substance is defined as the mass of substance liberated in electrolysis when one coulomb charge is passed through the electrolyte.

Second Law : The mass of a substance liberated at an electrode by a given amount of charge is proportional to the *chemical equivalent of the substance.

If E is the chemical equivalent of a substance, from the second law

$$m \,\alpha\, E$$

---

*Chemical equivalent = $\dfrac{\text{Relative atomic mass}}{\text{Valency}} = \dfrac{\text{mass of the atom}}{1/12 \text{ of the mass } C^{12} \text{ atom x valency}}$

2.10.2 Verification of Faraday's laws of electrolysis

First Law : A battery, a rheostat, a key and an ammeter are connected in series to an electrolytic cell (Fig 2.18). The cathode is cleaned, dried, weighed and then inserted in the cell. A current I_1 is passed for a time *t*. The current is measured by the ammeter. The cathode is taken out, washed, dried and weighed again. Hence the mass m_1 of the substance deposited is obtained.

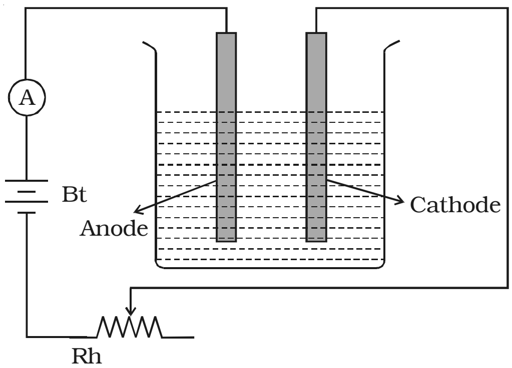


Fig 2.18 Verification of Faraday's first law

The cathode is reinserted in the cell and a different current I_2 is passed for the same time *t*. The mass m_2 of the deposit is obtained. It is found that

$$\frac{m_1}{m_2} = \frac{I_1}{I_2}$$

$$\therefore \quad m \propto I \qquad ...(1)$$

The experiment is repeated for same current *I* but for different times t_1 and t_2. If the masses of the deposits are m_3 and m_4 respectively, it is found that

$$\frac{m_3}{m_4} = \frac{t_1}{t_2}$$

$$\therefore \quad m \propto t \qquad ...(2)$$

From relations (1) and (2)

$m \propto It$ or $m \propto q$ Thus, the first law is verified.

Second Law : Two electrolytic cells containing different electrolytes, $CuSO_4$ solution and $AgNO_3$ solution are connected in series with a battery, a rheostat and an ammeter (Fig 2.19). Copper electrodes are inserted in $CuSO_4$ and silver electrodes are inserted in $AgNO_3$.

The cathodes are cleaned, dried, weighed and then inserted in the respective cells. The current is passed for some time. Then the cathodes are taken out, washed, dried and weighed. Hence the masses of copper and silver deposited are found as m_1 and m_2.

It is found that $\frac{m_1}{m_2} = \frac{E_1}{E_2}$, where E_1 and E_2 are the chemical equivalents of copper and silver respectively.

$m \propto E$

Thus, the second law is verified.

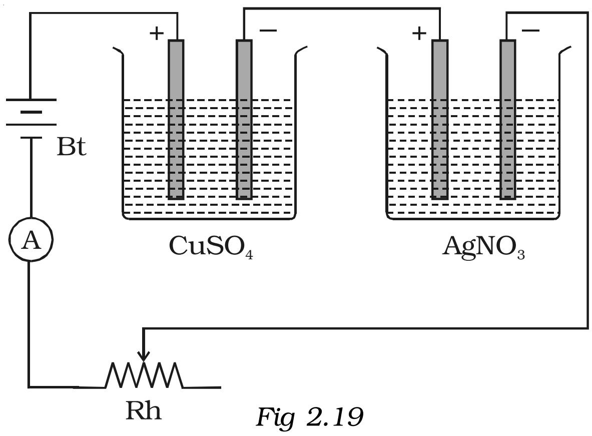


Fig 2.19
Verification of Faraday's second law

2.11 Electric cells

The starting point to the development of electric cells is the classic experiment by Luige Galvani and his wife Lucia on a dissected frog hung from iron railings with brass hooks. It was observed that, whenever the leg of the frog touched the iron railings, it jumped and this led to the introduction of animal electricity. Later, Italian scientist and genius professor Alessandro Volta came up with an electrochemical battery. The battery Volta named after him consisted of a pile of copper and zinc discs placed alternately separated by paper and introduced in salt solution. When the end plates were connected to an electric bell, it continued to ring, opening a new world of electrochemical cells. His experiment established that, a cell could be made by using two dissimilar metals and a salt solution which reacts with atleast one of the metals as electrolyte.

2.11.1 Voltaic cell

The simple cell or voltaic cell consists of two electrodes, one of copper and the other of zinc dipped in a solution of dilute sulphuric acid in a glass vessel (Fig 2.20). On connecting the two electrodes externally, with a piece of wire, current flows

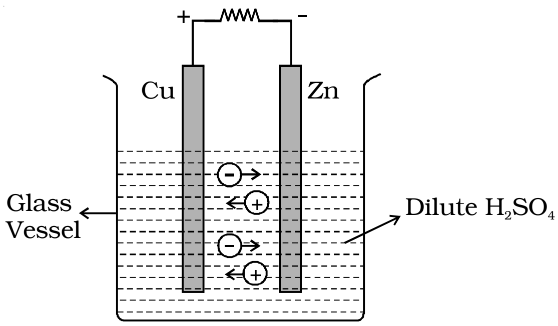


Fig 2.20 Voltaic cell

from copper to zinc outside the cell and from zinc to copper inside it. The copper electrode is the positive pole or copper rod of the cell and zinc is the negative pole or zinc rod of the cell. The electrolyte is dilute sulphuric acid.

The action of the cell is explained in terms of the motion of the charged ions. At the zinc rod, the zinc atoms get ionized and pass into solution as Zn^{++} ions. This leaves the zinc rod with two electrons more, making it negative. At the same time, two hydrogen ions ($2H^+$) are discharged at the copper rod, by taking these two electrons. This makes the copper rod positive. As long as excess electrons are available on the zinc electrode, this process goes on and a current flows continuously in external circuit. This simple cell is thus seen as a device which converts chemical energy into electrical energy. Due to opposite charges on the two plates, a potential difference is set up between copper and zinc, copper being at a higher potential than zinc. The difference of potential between the two electrodes is 1.08V.

2.11.2 Primary Cell

The cells from which the electric energy is derived by irreversible chemical actions are called primary cells. The primary cell is capable of giving an emf, when its constituents, two electrodes and a suitable electrolyte, are assembled together. The three main primary cells, namely Daniel Cell and Leclanche cell are discussed here. These cells cannot be recharged electrically.

2.11.3 Daniel cell

Daniel cell is a primary cell which cannot supply steady current for a long time. It consists of a copper vessel containing a strong solution of copper sulphate (Fig 2.21). A zinc rod is dipped in dilute sulphuric acid contained in a porous pot. The porous pot is placed inside the copper sulphate solution.

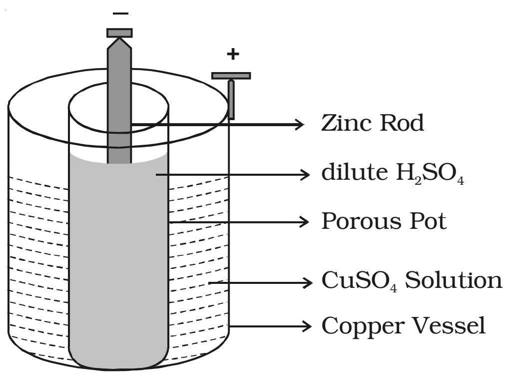


Fig 2.21 Daniel cell

The zinc rod reacting with dilute sulphuric acid produces Zn^{++} ions and 2 electrons.

Zn^{++} ions pass through the pores of the porous pot and reacts with copper sulphate solution, producing Cu^{++} ions. The Cu^{++} ions deposit on the copper vessel. When Daniel cell is connected in a circuit, the two electrons on the zinc rod pass through the external circuit and reach the copper vessel thus neutralizing the copper ions. This constitutes an electric current from copper to zinc. Daniel cell produces an emf of 1.08 volt.

2.11.4 Leclanche cell

A Leclanche cell consists of a carbon electrode packed in a porous pot containing manganese dioxide and charcoal powder (Fig 2.22). The porous pot is immersed in a saturated solution of ammonium chloride (electrolyte) contained in an outer glass vessel. A zinc rod is immersed in electrolytic solution.

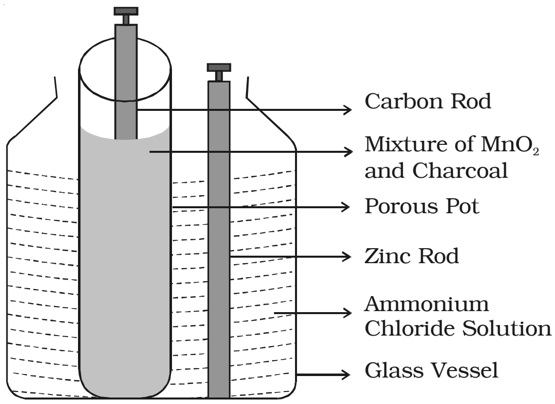


Fig 2.22 Leclanche cell

At the zinc rod, due to oxidation reaction Zn atom is converted into Zn^{++} ions and 2 electrons. Zn^{++} ions reacting with ammonium chloride produces zinc chloride and ammonia gas.

i.e $$Zn^{++} + 2\ NH_4Cl \rightarrow 2NH_3 + ZnCl_2 + 2\ H^+ + 2e^-$$

The ammonia gas escapes. The hydrogen ions diffuse through the pores of the porous pot and react with manganese dioxide. In this process the positive charge of hydrogen ion is transferred to carbon rod. When zinc rod and carbon rod are connected externally, the two electrons from the zinc rod move towards carbon and neutralizes the positive charge. Thus current flows from carbon to zinc.

Leclanche cell is useful for supplying intermittent current. The emf of the cell is about 1.5 V, and it can supply a current of 0.25 A.

2.11.5 Secondary Cells

The advantage of secondary cells is that they are rechargeable. The chemical reactions that take place in secondary cells are reversible. The active materials that are used up when the cell delivers current can be reproduced by passing current through the cell in opposite direction. The chemical process of obtaining current from a secondary cell is called discharge. The process of reproducing active materials is called charging. The most common secondary cells are lead acid accumulator and alkali accumulator.

2.11.6 Lead – Acid accumulator

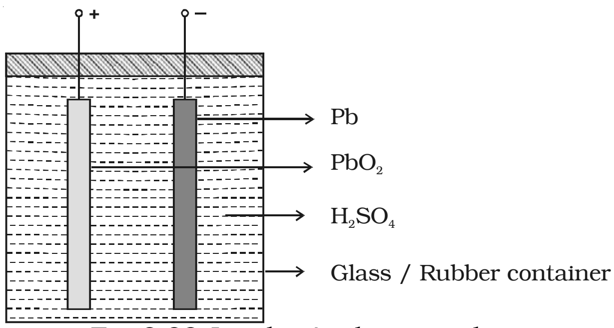


Fig 2.23 Lead - Acid accumulator

The lead acid accumulator consists of a container made up of hard rubber or glass or celluloid. The container contains dilute sulphuric acid which acts as the electrolyte. Spongy lead (Pb) acts as the negative electrode and lead oxide (PbO_2) acts as the positive electrode (Fig 2.23). The electrodes are separated by suitable insulating materials and assembled in a way to give low internal resistance.

When the cell is connected in a circuit, due to the oxidation reaction that takes place at the negative electrode, spongy lead reacting with dilute sulphuric acid produces lead sulphate and two electrons. The electrons flow in the external circuit from negative electrode to positive electrode where the reduction action takes place. At the positive electrode, lead oxide on reaction with sulphuric acid produces lead sulphate and the two electrons are neutralized in this process. This makes the conventional current to flow from positive electrode to negative electrode in the external circuit.

The emf of a freshly charged cell is 2.2 Volt and the specific gravity of the electrolyte is 1.28. The cell has low internal resistance and hence can deliver high current. As the cell is discharged by drawing current from it, the emf falls to about 2 volts. In the process of charging, the chemical reactions are reversed.

2.11.7 Applications of secondary cells

The secondary cells are rechargeable. They have very low internal resistance. Hence they can deliver a high current if required. They can be recharged a very large number of times without any deterioration in properties. These cells are huge in size. They are used in all automobiles like cars, two wheelers, trucks etc. The state of charging these cells is, simply monitoring the specific gravity of the electrolyte. It should lie between 1.28 to 1.12 during charging and discharging respectively.

Solved problems

2.1 If 6.25×10^{18} electrons flow through a given cross section in unit time, find the current. (Given : Charge of an electron is 1.6×10^{-19} C)

Data : $n = 6.25 \times 10^{18}$; $e = 1.6 \times 10^{-19}$ C ; t = 1 s ; I = ?

Solution : $I = \frac{q}{t} = \frac{ne}{t} = \frac{6.25 \times 10^{18} \times 1.6 \times 10^{-19}}{1} = 1$ A

2.2 A copper wire of 10^{-6} m^2 area of cross section, carries a current of 2 A. If the number of electrons per cubic metre is 8×10^{28}, calculate the current density and average drift velocity.

(Given $e = 1.6 \times 10^{-19}$C)

Data : $A = 10^{-6}$ m^2 ; Current flowing I = 2 A ; $n = 8 \times 10^{28}$

$e = 1.6 \times 10^{-19}$ C ; J = ? ; v_d =?

Solution : Current density, $J = \frac{I}{A} = \frac{2}{10^{-6}} = 2 \times 10^6 A/m^2$

$J = n\, e\, v_d$

or $v_d = \frac{J}{ne} = \frac{2 \times 10^6}{8 \times 10^{28} \times 1.6 \times 10^{-19}} = 15.6 \times 10^{-5}$ m s^{-1}

2.3 An incandescent lamp is operated at 240 V and the current is 0.5 A. What is the resistance of the lamp ?

Data : V = 240 V ; I = 0.5 A ; R = ?

Solution : From Ohm's law

$$V = IR \quad \text{or} \quad R = \frac{V}{I} = \frac{240}{0.5} = 480\ \Omega$$

2.4 The resistance of a copper wire of length 5m is 0.5 Ω. If the diameter of the wire is 0.05 cm, determine its specific resistance.

Data : l = 5m ; R = 0.5 Ω ; d = 0.05 cm = 5×10^{-4} m ;

$r = 2.5 \times 10^{-4}$m ; ρ = ?

Solution : $R = \frac{\rho l}{A}$ or $\rho = \frac{RA}{l}$

$A = \pi r^2 = 3.14 \times (2.5 \times 10^{-4})^2 = 1.9625 \times 10^{-7}\ m^2$

$$\rho = \frac{0.5 \times 1.9625 \times 10^{-7}}{5}$$

$\rho = 1.9625 \times 10^{-8}\ \Omega\, m$

2.5 The resistance of a nichrome wire at 0°C is 10 Ω. If its temperature coefficient of resistance is 0.004/°C, find its resistance at boiling point of water. Comment on the result.

Data : At 0°C, R_o = 10 Ω ; α = 0.004/°C ; t = 100°C ;

At t°C, R_t = ?

Solution : $R_t = R_o (1 + \alpha t)$

$= 10 (1 + (0.004 \times 100))$

$R_t = 14\ \Omega$

As temperature increases the resistance of wire also increases.

2.6 Two wires of same material and length have resistances 5 Ω and 10 Ω respectively. Find the ratio of radii of the two wires.

Data : Resistance of first wire R_1 = 5 Ω ;

Radius of first wire = r_1

Resistance of second wire R_2 = 10 Ω

Radius of second wire = r_2

Length of the wires = l

Specific resistance of the material of the wires = ρ

Solution : $R = \frac{\rho l}{A}; A = \pi r^2$

$\therefore\ R_1 = \frac{\rho l}{\pi r_1^2}$; $R_2 = \frac{\rho l}{\pi r_2^2}$

$\frac{R_2}{R_1} = \frac{r_1^2}{r_2^2}$ or $\frac{r_1}{r_2} = \sqrt{\frac{R_2}{R_1}} = \sqrt{\frac{10}{5}} = \frac{\sqrt{2}}{1}$

$r_1 : r_2 = \sqrt{2} : 1$

2.7 If a copper wire is stretched to make it 0.1% longer, what is the percentage change in resistance?

Data : Initial length of copper wire $l_1 = l$

Final length of copper wire after stretching

$l_2 = l + 0.1\%$ of l

$= l + \frac{0.1}{100} l$

$= l\,(1 + 0.001)$

$l_2 = 1.001\ l$

During stretching, if length increases, area of cross section decreases.

Initial volume $= A_1 l_1 = A_1 l$

Final volume $= A_2 l_2 = 1.001\ A_2 l$

Resistance of wire before stretching $= R_1$.

Resistance after stretching $= R_2$

Solution : Equating the volumes

$A_1 l = 1.001\ A_2 l$

(or) $A_1 = 1.001 A_2$

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

$R_1 = \frac{\rho l_1}{A_1}$ and $R_2 = \frac{\rho l_2}{A_2}$

$$R_1 = \frac{\rho l}{1.001 A_2} \text{ and } R_2 = \frac{\rho 1.001 l}{A_2}$$

$$\frac{R_2}{R_1} = (1.001)^2 = 1.002$$

Change in resistance = (1.002 – 1) = 0.002

Change in resistance in percentage = 0.002 × 100 = 0.2%

2.8 The resistance of a field coil measures 50 Ω at 20°C and 65 Ω at 70°C. Find the temperature coefficient of resistance.

Data : At R_{20} = 50 Ω ; 70°C, R_{70} = 65 Ω ; α = ?

Solution : $R_t = R_o (1 + \alpha t)$

$R_{20} = R_o (1 + \alpha\ 20)$

$50 = R_o (1 + \alpha\ 20)$ ...(1)

$R_{70} = R_o (1 + \alpha\ 70)$

$65 = R_o [1 + \alpha\ 70]$ ...(2)

Dividing (2) by (1)

$$\frac{65}{50} = \frac{1 + 70\alpha}{1 + 20\alpha}$$

$65 + 1300\ \alpha = 50 + 3500\ \alpha$

$2200\ \alpha = 15$

$\alpha = 0.0068\ /\ ^{o}C$

2.9 An iron box of 400 W power is used daily for 30 minutes. If the cost per unit is 75 paise, find the weekly expense on using the iron box.

Data :

Power of an iron box P	= 400 W
rate / unit	= 75 p
consumption time t	= 30 minutes / day
cost / week	= ?

Solution :

Energy consumed in 30 minutes = Power × time in hours

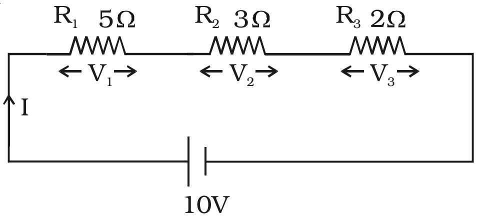
= 400 × ½ = 200 W h

Energy consumed in one week = 200 × 7 = 1400 Wh = 1.4 unit

Cost / week = Total units consumed × rate/ unit

= 1.4 × 0.75 = Rs.1.05

2.10 Three resistors are connected in series with 10 V supply as shown in the figure. Find the voltage drop across each resistor.



Data : $R_1 = 5\Omega$, $R_2 = 3\Omega$, $R_3 = 2\Omega$; V = 10 volt

Effective resistance of series combination,

$R_s = R_1 + R_2 + R_3 = 10\Omega$

Solution : Current in circuit $I = \frac{V}{R_s} = \frac{10}{10} = 1A$

Voltage drop across R_1, $V_1 = IR_1 = 1 \times 5 = 5V$

Voltage drop across R_2, $V_2 = IR_2 = 1 \times 3 = 3V$

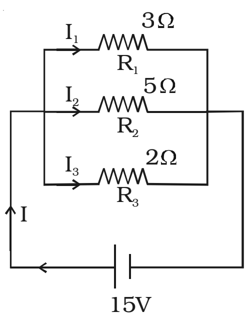
Voltage drop across R_3, $V_3 = IR_3 = 1 \times 2 = 2V$

2.11 Find the current flowing across three resistors 3Ω, 5Ω and 2Ω connected in parallel to a 15 V supply. Also find the effective resistance and total current drawn from the supply.

Data : $R_1 = 3\Omega$, $R_2 = 5\Omega$, $R_3 = 2\Omega$; Supply voltage V = 15 volt

Solution :

Effective resistance of parallel combination



$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{3} + \frac{1}{5} + \frac{1}{2}$$

$R_p = 0.9677\ \Omega$

Current through R_1, $I_1 = \frac{V}{R_1} = \frac{15}{3} = 5A$

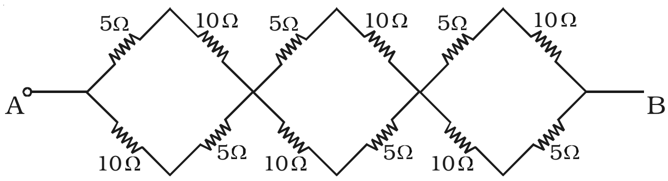
Current through R_2, $I_2 = \frac{V}{R_2} = \frac{15}{5} = 3A$

Current through R_3, $I_3 = \frac{V}{R_3} = \frac{15}{2} = 7.5A$

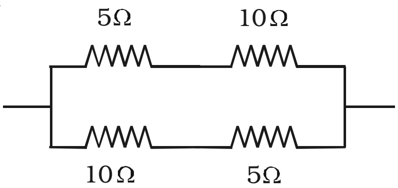
Total current $I = \frac{V}{R_P} = \frac{15}{0.9677} = 15.5$ A

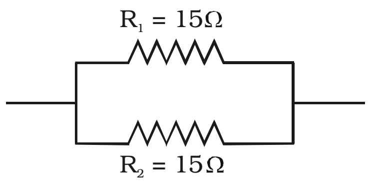
2.12 In the given network, calculate the effective resistance between points A and B

(i)



Solution : The network has three identical units. The simplified form of one unit is given below :

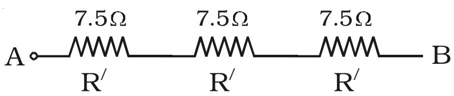




The equivalent resistance of one unit is

$$\frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{15} + \frac{1}{15} \text{ or } R_P = 7.5\ \Omega$$

Each unit has a resistance of 7.5 Ω. The total network reduces to



The combined resistance between points A and B is

$R = R' + R' + R'$ $(\because R_s = R_1 + R_2 + R_3)$

$R = 7.5 + 7.5 + 7.5 = 22.5\ \Omega$

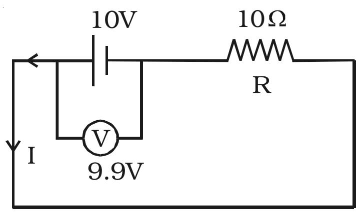
2.13 A 10 Ω resistance is connected in series with a cell of emf 10V. A voltmeter is connected in parallel to a cell, and it reads. 9.9 V. Find internal resistance of the cell.

Data : R = 10 Ω ; E = 10 V ; V = 9.9 V ; r = ?

Solution : $r = \left(\frac{E-V}{V}\right)R$

$= \left(\frac{10-9.9}{9.9}\right)\times 10$

$= 0.101\ \Omega$



Self evaluation

(The questions and problems given in this self evaluation are only samples. In the same way any question and problem could be framed from the text matter. Students must be prepared to answer any question and problem from the text matter, not only from the self evaluation.)

2.1 A charge of 60 C passes through an electric lamp in 2 minutes. Then the current in the lamp is

(a) 30 A (b) 1 A (c) 0.5 A (d) 5 A

2.2 The material through which electric charge can flow easily is

(a) quartz (b) mica (c) germanium (d) copper

2.3 The current flowing in a conductor is proportional to

(a) drift velocity

(b) 1/ area of cross section

(c) 1/no of electrons

(d) square of area of cross section.

2.4 A toaster operating at 240V has a resistance of 120Ω. The power is

(a) 400 W (b) 2 W (c) 480 W (d) 240 W

2.5 If the length of a copper wire has a certain resistance R, then on doubling the length its specific resistance

(a) will be doubled (b) will become $1/4^{th}$

(c) will become 4 times (d) will remain the same.

2.6 When two 2Ω resistances are in parallel, the effective resistance is

(a) 2 Ω (b) 4 Ω (c) 1 Ω (d) 0.5 Ω

2.7 In the case of insulators, as the temperature decreases, resistivity

(a) decreases (b) increases

(c) remains constant *(d) becomes zero*

2.8 *If the resistance of a coil is 2 Ω at 0^oc and α = 0.004 /^{o}C, then its resistance at 100^o C is*

(a) 1.4 Ω *(b) 0 Ω* *(c) 4 Ω* *(d) 2.8 Ω*

2.9 *According to Faraday's law of electrolysis, when a current is passed, the mass of ions deposited at the cathode is independent of*

(a) current *(b) charge* *(c) time* *(d) resistance*

2.10 *When n resistors of equal resistances (R) are connected in series, the effective resistance is*

(a) n/R *(b) R/n* *(c) 1/nR* *(d) nR*

2.11 *Why is copper wire not suitable for a potentiometer?*

2.12 *Explain the flow of charges in a metallic conductor.*

2.13 *Distinguish between drift velocity and mobility. Establish a relation between drift velocity and current.*

2.14 *State Ohm's law.*

2.15 *Define resistivity of a material. How are materials classified based on resistivity?*

2.16 *Write a short note on superconductivity. List some applications of superconductors.*

2.17 *The colours of a carbon resistor is orange, orange, orange. What is the value of resistor?*

2.18 *Explain the effective resistance of a series network and parallel network.*

2.19 *Discuss the variation of resistance with temperature with an expression and a graph.*

2.20 *Explain the determination of the internal resistance of a cell using voltmeter.*

2.21 *State and explain Kirchoff's laws for electrical networks.*

2.22 *Describe an experiment to find unknown resistance and temperature coefficient of resistance using metre bridge?*

2.23 *Define the term specific resistance. How will you find this using a metre bridge?*

2.24 *Explain the principle of a potentiometer. How can emf of two cells be compared using potentiometer?*

2.25 *Distinguish between electric power and electric energy*

2.26 *State and Explain Faraday's laws of electrolysis. How are the laws verified experimentally?*

2.27 *Explain the reactions at the electrodes of (i) Daniel cell (ii) Leclanche cell*

2.28 *Explain the action of the following secondary cell.*

(i) lead acid accumulator

2.29 *Why automobile batteries have low internal resistance?*

Problems

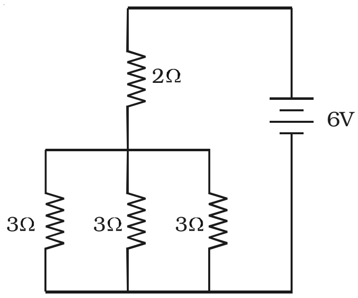
2.30 *What is the drift velocity of an electron in a copper conductor having area $10 \times 10^{-6} m^2$, carrying a current of 2 A. Assume that there are 10×10^{28} electrons / m^3.*

2.31 *How much time 10^{20} electrons will take to flow through a point, so that the current is 200 mA? ($e = 1.6 \times 10^{-19}$ C)*

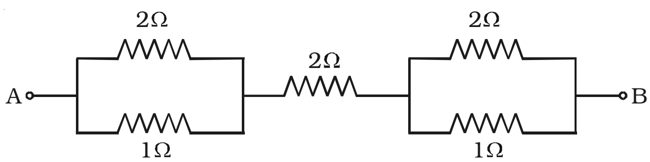
2.32 *A manganin wire of length 2m has a diameter of 0.4 mm with a resistance of 70 Ω. Find the resistivity of the material.*

2.33 *The effective resistances are 10Ω, 2.4Ω when two resistors are connected in series and parallel. What are the resistances of individual resistors?*

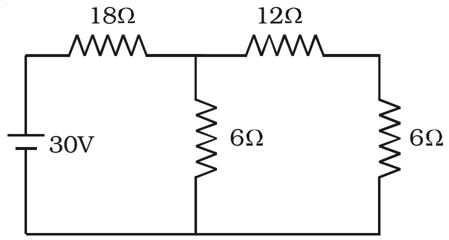
2.34 *In the given circuit, what is the total resistance and current supplied by the battery.*



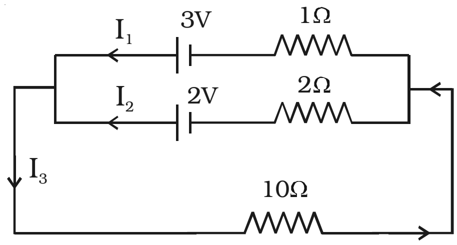
2.35 *Find the effective resistance between A and B in the given circuit*



2.36 Find the voltage drop across 18 Ω resistor in the given circuit



2.37 Calculate the current I_1, I_2 and I_3 in the given electric circuit.



2.38 The resistance of a platinum wire at 0^0 C is 4 Ω. What will be the resistance of the wire at 100°C if the temperature coefficient of resistance of platinum is 0.0038 /^{0} C.

2.39 A cell has a potential difference of 6 V in an open circuit, but it falls to 4 V when a current of 2 A is drawn from it. Find the internal resistance of the cell.

2.40 In a Wheatstone's bridge, if the galvanometer shows zero deflection, find the unknown resistance. Given P = 1000Ω Q = 10000 Ω and R = 20 Ω

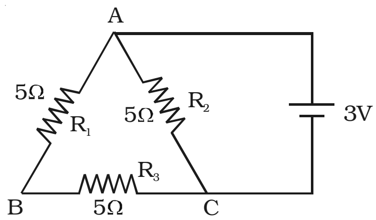
2.41 An electric iron of resistance 80 Ω is operated at 200 V for two hours. Find the electrical energy consumed.

2.42 In a house, electric kettle of 1500 W is used everyday for 45 minutes, to boil water. Find the amount payable per month (30 days) for usage of this, if cost per unit is Rs. 3.25

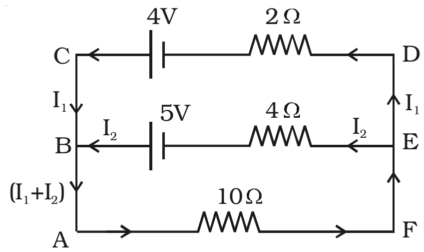
2.43 A 1.5 V carbon – zinc dry cell is connected across a load of 1000 Ω. Calculate the current and power supplied to it.

2.44 In a metre bridge, the balancing length for a 10 Ω resistance in left gap is 51.8 cm. Find the unknown resistance and specific resistance of a wire of length 108 cm and radius 0.2 mm.

2.45 Find the electric current flowing through the given circuit connected to a supply of 3 V.



2.46 In the given circuit, find the current through each branch of the circuit and the potential drop across the 10 Ω resistor.



Answers

2.1	*(c)*	**2.2**	*(d)*	**2.3**	*(a)*	**2.4**	*(c)*
2.5	*(d)*	**2.6**	*(c)*	**2.7**	*(b)*	**2.8**	*(d)*
2.9	*(d)*	**2.10**	*(d)*				

2.17	33 kΩ	**2.30**	1.25×10^{-5} m s^{-1}
2.31	80s	**2.32**	4.396 μΩ m
2.33	6 Ω and 4Ω	**2.34**	3 Ω and 2A
2.35	3.33 Ω	**2.36**	24 V
2.37	0.5 A, –0.25 A, 0.25 A	**2.38**	5.52 Ω
2.39	1 Ω	**2.40**	200 Ω
2.41	1 kWh	**2.42**	Rs. 110
2.43	1.5 mA; 2.25 mW	**2.44**	1.082×10^{-6} Ω m
2.45	0.9 A	**2.46**	0.088A, 0.294A, 3.82 V