Chapter - 2

Current Electricity, Thermal & Chemical Effects of Current

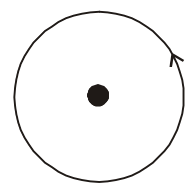
1. Rate of flow of charges is called current.

$$\therefore \quad I = \frac{dQ}{dt} \quad \Rightarrow \quad I = \frac{\text{total charge that crosses any cross-section}}{\text{time taken}} = \frac{Q}{t}$$

$$\Rightarrow \quad I = \frac{ne}{t}$$, where n = number of electrons crossing any cross-section in time t

2. Electron-current due to an electron moving in an orbit around the nucleus of an atom is given by the relation :

$I = \nu e$, where ν = frequency of rotation of electron



$I = \dfrac{ve}{2\pi r}$ where v = orbital velocity of electron

r = radius of orbit

Ex.1: Calculate electron current in first orbit of hydrogen atom of radius 0.53 Å, if speed of electron in this orbit is 2.18×10^6 ms^{-1}.

Sol.: $I = \dfrac{ve}{2\pi r} = \dfrac{2.18 \times 10^6 \times 1.6 \times 10^{-19}}{2 \times 3.14 \times 0.53 \times 10^{-10}}$

$= \dfrac{2.18 \times 1.6}{2 \times 3.14 \times 0.53} \times 10^{-3} = 1.05 \times 10^{-3}$ A = 1.05 mA

Drift Velocity

1. (a) When we apply a potential difference across a wire, an electric field, E, is set up in the wire :

$$E = \frac{V}{l} = \frac{\text{Applied potential difference}}{\text{Length of the wire}}$$

(b) Under the influence of this electrical field, E, charge carriers (electrons) of mass m flow in the wire with a drift velocity, v_d, given by the relation :

$v_d = -\dfrac{eE}{m}\tau$, where τ = average relaxation time

= average time interval between two collisions (the collision is between electrons and the static atoms of the wire)

(c) If J is current density (current per unit surface area) when applied electric field is E and σ is electrical conductivity, then

$$J = \sigma E \quad \Rightarrow \sigma = \frac{J}{E}$$

2. Current in terms of drift velocity is given by the relation :

$I = -v_d Ane$, where A = area of cross-section of wire

n = number of charge carriers (electrons) per unit volume in the wire

3. $\therefore\ I = -\left(-\frac{eE\tau}{m}\right) Ane = EA\frac{\tau ne^2}{m} = \frac{V}{l}\ A\ \frac{\tau ne^2}{m}$

$$\Rightarrow \frac{\tau ne^2}{m} = \frac{I}{V}.\frac{l}{A} = \frac{1}{R}.\frac{l}{A} = \frac{1}{\rho} = \sigma \text{ (conductivity)}$$

Ex.2: The number density of conduction electrons in a copper conductor is estimated to be 8.5×10^{28} m^{-3}. How long does an electron take to drift from one end of a wire, of length 3.0 m, to its other end? Area of cross-section of the wire is 2.0×10^{-6} m^2 and the current through the wire is 3.0 A.

Sol.: $n = 8.5 \times 10^{28}$ m^{-3} $\quad A = 2 \times 10^{-6}$ m^2 $\quad I = 3.0$ A $\quad l = 3.0$ m

$I = eAn\, v_d$

$$v_d = \frac{I}{eAn} = \frac{3}{1.6\times10^{-19}\times(2\times10^{-6})\times(8.5\times10^{28})} = \frac{3}{1.6\times2\times8.5}\times10^{-3}\ \text{m s}^{-1} \approx 0.11\times10^{-3}\ \text{ms}^{-1}$$

$$\therefore \quad t = \text{time taken} = \frac{\text{distance between two ends of the wire}}{\text{drift velocity of electron}} = \frac{3}{0.11\times10^{-3}}\ \text{s}$$

$$= 27.3 \times 10^3 \text{ sec} = 7.58 \text{ hrs.}$$

Ohm's Law and its Applications

1. $I \propto V$, provided physical conditions, like temperature, pressure, etc. remain constant.

   $\Rightarrow V = IR$, where R = resistance of the wire = $\rho\frac{l}{A} = \rho\ \frac{l}{\pi r^2}$

   where ρ = resistivity or specific resistance of material of wire

2. Unit of ρ is Ω m (ohm-metre) and its dimensions are $ML^3\ T^{-3}\ A^{-2}$

3. If length of the wire is stretched uniformly such that its length becomes n times the original length, then its resistance will increase to n^2 times its original resistance.

4. If a wire is uniformly stretched such that its radius become $\frac{1}{n}$ of its original radius, then the resistance of the wire will increase to n^4 times its original resistance.

5. For resistances in series : $R = R_1 + R_2 + R_3 + ...$

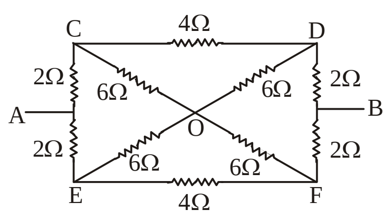
6. For resistances in parallel : $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + ...$

7. For two resistances in parallel : $R = \frac{R_1 R_2}{R_1 + R_2}$

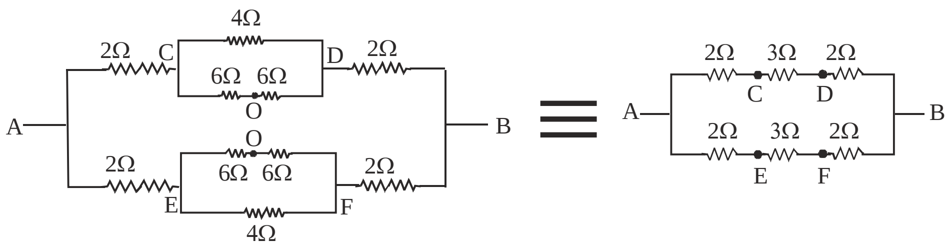
8. For two resistances in parallel : $I_1 R_1 = I_2 R_2$

   $\Rightarrow \frac{I_1}{I_2} = \frac{R_2}{R_1}$ i.e., the currents in the wires are in the inverse ratio of their resistances.

Ex.3: Find the resistance between points A and B in the following network of resistances.

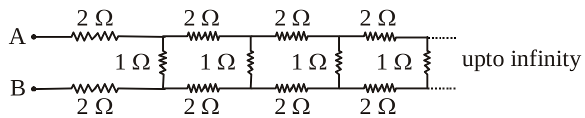


Sol.: Due to symmetry, current from *C* towards *O* equals current from *O* towards *D*, and current from *E* towards *O* equals current from *O* towards *F*. Thus, the current through *COD* is not affected by the current through *EOF*. So, the paths *COD* and *EOF* can be considered to be separate. Therefore, the equivalent diagram becomes



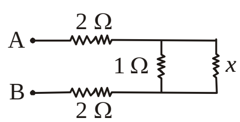
∴ The resultant resistance between *A* and *B* $[R_{AB}] = 3.5\ \Omega$.

Ex.4: In the following network of resistances, find the resultant resistance between *A* and *B*.



Sol.: Let the resistance of the network be *x* ohms.

The network is made-up infinite number of groups of resistances. If one such first group is removed, even then the remaining number of groups is infinite and the resistance of the remaining infinite group will also be *x* ohms. Then, the first group of resistances will be in parallel with the remaining infinite number of groups of resistances, as shown under :



So, 1 Ω and *x* Ω are in parallel and this group is in series with the other 2 Ω resistances. But the resistance of the combination is *x* Ω.

$$\therefore \quad 2 + 2 + \frac{1 \times x}{1 + x} = x \qquad\qquad 4 + \frac{x}{1+x} = x$$

$$\Rightarrow \quad 4 + 4x + x = x + x^2 \qquad \Rightarrow \quad x^2 - 4x - 4 = 0$$

$$x = \frac{4 \pm \sqrt{16+16}}{2} = (2 + 2\sqrt{2})\ \Omega$$ .....**Ans.**

Conversion of Galvanometer into (i) Ammeter and (ii) Voltmeter

1. Every galvanometer has a resistance (R_g) and gives a maximum deflection when a fixed maximum current (I_g) is passed through it or when a fixed maximum potential difference (V_g) is applied across it, such that

   $V_g = R_g . I_g$ where I_g = maximum current which galvanometer can measure

   V_g = maximum P.D. which galvanometer can measure

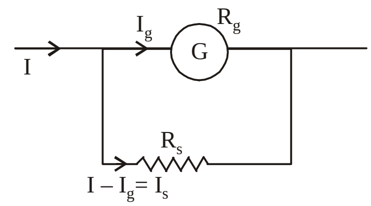
2. (a) For measuring larger current I than I_g (which the galvanometer can measure), an alternative parallel wire (called shunt) is added.

   (b) Then, extra current $I - I_g = I_s$ flows through this shunt wire.

   (c) $I_s R_s = I_g . R_g$ $\Rightarrow (I - I_g)R_s = I_g . R_g$ .....(i)

(d) $I_g = I \times \frac{R_s}{R_s + R_g}$ $\Rightarrow$ $I = I_g \times \frac{R_s + R_g}{R_s}$ .....(ii)

(e) $I_s = I \times \frac{R_g}{R_s + R_g}$ $\Rightarrow$ $I = I_s \times \frac{R_s + R_g}{R_g}$ .....(iii)



Ex.5: A galvanometer of resistance G can measure a maximum current I. How can it be used to measure a maximum current nI ?

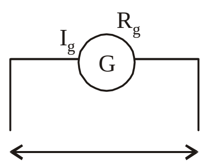
Sol.: For the purpose we use a resistance R_s in parallel with it.

Now, $I_g = I$ $\quad I_s = nI - I = I(n-1)$

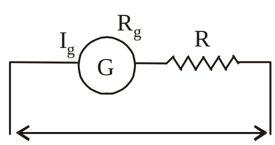
$\therefore$ $R_s.I_s = R_g.I_g$ becomes $R_s.I(n-1) = GI$

$\therefore$ $R_s = \frac{G}{n-1}$ to be added in parallel with galvanometer. .....**Ans.**

3. An ammeter is always added in series in a circuit for measuring current.
4. An ammeter measures slightly less current than what flows through the circuit, before inserting the ammeter in the circuit. So, there is always some small error in the measurement of current by the ammeter.
5. (a) Smaller the resistance of the ammeter, smaller is the error in the measurement of current.
   (b) An ideal ammeter (with no error in the measurement of current) has zero resistance.
6. In order to measure larger potential difference V than what a galvanometer can measure (V_g), a high resistance R is added in series with it.



$V_g = I_g \,.\, R_g$ .... (i)



$V = I_g(R_g + R)$ .....(ii)

Also $\frac{V}{V_g} = \frac{R_g + R}{R_g} = 1 + \frac{R}{R_g}$ $\Rightarrow$ $R = \left(\frac{V}{V_g} - 1\right) R_g$ .....(iii)

Ex.6: A galvanometer of resistance G can measure a maximum p.d. of V volt. How can it be used to measure a p.d. of nV volt ?

Sol.: For this purpose, we add a high resistance R. Because I_g is the maximum current that can pass through it, so now the p.d. across it will be $I_g(R + G) = nV$

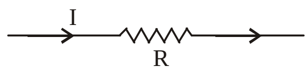
$\Rightarrow$ $R + G = n\frac{V}{I_g} = nG$ $\Rightarrow$ $R = (n-1)G$

OR using equation (iii), $R = \left(\frac{V}{V_g} - 1\right) R_g = (n-1)G$ $\quad (\because R_g = G)$ .....**Ans.**

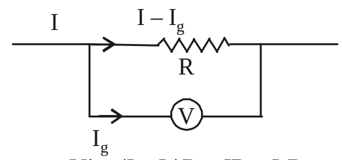
7. For measuring p.d. across any part of the circuit, voltmeter is used across or in parallel with that part of the circuit.
8. But when we add a voltmeter across a part of the circuit, then some current I_g flows through it. So, current through that part of the circuit will become less by I_g.

If R is the resistance of that part of the circuit, then p.d. across the circuit will become less by $I_g.R$

$V' = (I - I_g)\, R = IR - I_g R$



V = IR



$V' = (I - I_g)R = IR - I_gR$

9. So, a voltmeter measures slightly less p.d. across the part of a circuit than what actually exists when voltmeter is not applied.
10. Larger the resistance of galvanometer, smaller will be the current I_g through it and, hence, less will be the error in the measurement of p.d.
11. An ideal voltmeter (showing no error in the measurement of p.d.) should have infinite resistance.

Ex.7: A galvanometer has 250 markings on its scale with a least count of 1 mA and its resistance is 35 ohms. How can it be converted into

(i) an ammeter reading upto 2.0 A, and

(ii) a voltmeter reading upto 50 V

Sol.: (i) *For conversion into an ammeter*

$I_g = 250 \times 1 \text{ mA} = 0.25 \text{ A}$ $\quad I = 2.0 \text{ A}$

$\therefore$ $I_s = 2.0 - 0.25 = 1.75 \text{ A}$ $\quad R_g = 35\ \Omega$ $\quad R_s = ?$

$I_s \times R_s = I_g \times R_g$

$\Rightarrow \quad R_s = \dfrac{I_g \times R_g}{I_s} = \dfrac{0.25}{1.75} \times 35 = 5.0\ \Omega$ to be added in parallel .....**Ans.**

(ii) *For conversion into a voltmeter*

$I_g = 0.25 \text{ A}$ $\quad R_g = 35\ \Omega$ $\quad V = 50 \text{ V}$ $\quad R = ?$

$V = I_g (R + R_g)$ $\quad \Rightarrow\ 50 = 0.25\, [R + 35]$

$\therefore$ $R = 200 - 35 = 165\ \Omega$ to be added in series. .....**Ans.**

Effect of Temperature on Resistance

1. (a) The resistance of a semi-conductor (germanium or silicon) decreases with rise in temperature.
   (b) At 0 K, resistance of a semi-conductor is infinite.
2. The resistance of a resistor (made of material other than semi-conductor) increases with rise in temperature, given by the relation :

   $R_t = R_0 (1 + \alpha\, t)$

   where R_0 = resistance at 0ºC

   R_t = resistance at any temperature t ºC

   α = temperature coefficient of resistance and its unit is $ºC^{-1}$
3. Standard resistances are made of manganin or constantan (alloys), because their temperature-coefficient of resistance is very small. So, the resistance remains almost same over a large range of temperature.
4. Heating elements are made of nichrome (alloy) or tungsten, because their temperature-coefficients of resistance are large and also their melting points are high.

Ex.8: A silver wire has a resistance of 2.0 ohm at 25ºC and a resistance of 2.55 ohm at 100ºC. Find the temperature coefficient of resistance of silver.

Sol.: $R_t = R_0 (1 + \alpha\, t)$

$\therefore$ $2.00 = R_0 (1 + \alpha \times 25)$ .....(i)

$2.55 = R_0 (1 + \alpha \times 100)$ .....(ii)

$$\Rightarrow \quad \frac{2.55}{2} = \frac{1+100\,\alpha}{1+25\alpha} \qquad \Rightarrow \; 2.55 + 63.75\,\alpha = 2 + 200\,\alpha$$

$$\Rightarrow \quad 136.25\,\alpha = 0.55 \qquad \Rightarrow \; \alpha = \frac{0.55}{136.25} = 0.004\ ^{\circ}C^{-1}$$ .....**Ans.**

Colour-Coded Resistances

1. Resistances or resistors available in the market have small rings of various colours. The resistance of such a resistor can be known by the colours of these rings.
2. Generally, a colour-coded resistor has four rings of different colours. Each digit (from 0 to 9) has been assigned a fixed colour.
3. First three rings have any of the following ten colours; each colour representing a digit from 0 to 9, given as under :

Colour :	**B**lack	**B**rown	**R**ed	**O**range	**Y**ellow	**G**reen	**B**lue	**V**iolet	**G**rey	**W**hite
Numerical value :	0	1	2	3	4	5	6	7	8	9

4. (a) Colour of the first ring gives the first digit of the resistance.
   (b) Colour of the second ring gives the second digit of the resistance.
   (c) Colour of the third ring gives the number of zeros, after the first two digits, corresponding to the digit of the colour.
   (d) Colour of the fourth ring gives the tolerance of the resistance (variation in the resistance which the resistor can offer, over its resistance given by the colours of the first three rings), given as under:
      (i) if colour of the fourth ring is golden, tolerance is 5%
      (ii) if colour of the fourth ring is silvered, tolerance is 10%
      (iii) if there is no fourth ring, then tolerance is 20%

Ex.9: (a) A colour coded resistor has brown, grey, yellow and silver-coloured rings. What is the resistance of this resistor ?

(b) What are colours of the rings of a resistor having a resistance of 4.7 ± 20% kΩ

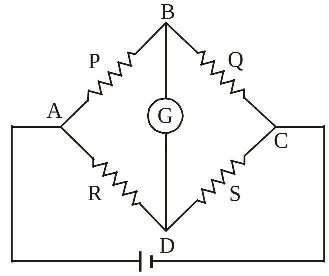
Sol.: (a) The resistance of the resistor is 180000 ± 10% Ω = (180 ± 18) kΩ .....**Ans.**

(b) The resistance is 4700 ± 20% Ω. Therefore the colours of the rings are : yellow, violet and red. There is no fourth ring, as the tolerance is 20%. .....**Ans.**

Kirchhoff's Law for Electrical Circuits and Wheatstone Bridge

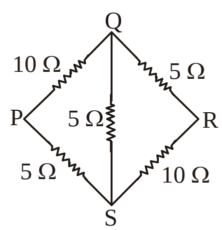
1. (a) *Junction Rule* : The sum of currents entering a junction is equal to the sum of currents leaving the same junction. Net charge at any point, in an electrical circuit, is zero. This law is based on the law of conservation of charges.
   (b) *Closed-mesh Rule* : In a closed mesh, the sum of the products of 'current and resistance' in each part of the closed circuit, *taken in a particular order*, is equal to the sum of e.m.f.s of the sources in this closed circuit, *taken in the same order*. This law is based on the law of conservation of energy.
2. *Wheatstone bridge* is the application of Kirchhoff's law of electrical circuits i.e. we use Kirchhoff's law to prove Wheatstone bridge principle.
3. Four resistances *P*, *Q*, *R* and *S* are joined between points *A*, *B*, *C* and *D*, as shown in the circuit, such that across *A* and *C* there is a cell and across *B* and *D* there is a galvanometer. Now, if these four

resistances are so adjusted that there is no current through the path of galvanometer, then the ratio of the corresponding resistances is same i.e. $\frac{P}{Q} = \frac{R}{S}$ or $\frac{P}{R} = \frac{Q}{S}$. This is also called balanced Wheatstone bridge (*bridge means electrical circuit*).

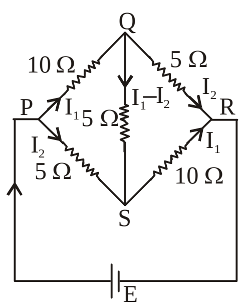


4. In the balanced Wheatstone bridge, points connecting the galvanometer (when no current passes through it) are at same potential.
5. (i) *Metre-bridge* is based on Wheatstone bridge principle.
   (ii) In a metre-bridge, null point should lie in the centre; this is to avoid resistances of solderings and strips on both the sides of the gaps.
   (iii) If the resistances of the solderings and strips on both the sides of the gaps are given, then we can have null point anywhere on the wire of the metre-bridge.

Ex.10: Find the resistance between P and R in the network of resistances shown between P, Q, R and S as given in figure (i)



(i)



(ii)

Sol.: Let I_1 be the current entering 10 Ω resistance between P and Q and I_2 entering 5 Ω resistance between P and S. Then, due to symmetry current leaving 10 Ω resistance between S and R will be I_1 and leaving 5 Ω resistance between Q and R will be I_2. The distribution of currents is shown in figure (ii) above

$\therefore$ For closed mesh *PSREP* $\quad 5\,I_2 + 10\,I_1 = E$ .....(i)

For closed mesh *PSQREP* $\quad 5\,I_2 - 5(I_1 - I_2) + 5\,I_2 = E$

$\Rightarrow \quad 15\,I_2 - 5\,I_1 = E$ .....(ii)

2 × (ii) + (i) gives $35\,I_2 = 3\,E \quad \Rightarrow \quad I_2 = \frac{3}{35}E$ .....(iii)

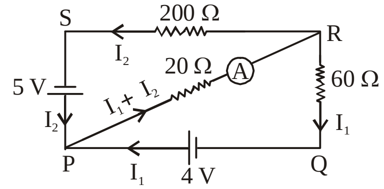
$\therefore \quad 10\,I_1 = E - 5 \times \frac{3}{35}E = \frac{20}{35}E \quad \Rightarrow \quad I_1 = \frac{2}{35}E$ .....(iv)

$\therefore$ Current through circuit $I_1 + I_2 = \frac{3}{35}E + \frac{2}{35}E = \frac{5}{35}E = \frac{E}{7}$

If R is the resistance of the circuit between P and R, then

$R \times \frac{E}{7} = E \quad \Rightarrow \quad R = 7\ \Omega$ .....**Ans.**

Ex.11: Network *PQRS* is made as under. *PQ* has a battery of 4.0 V and negligible resistance with positive potential connected to *P*. *QR* has a resistance of 60 Ω. *PS* has a battery of 5.0 V and negligible resistance with positive terminal connected to *P*. *RS* has a resistance of 200 Ω. If a milliammeter of 20 Ω resistance is connected between *P* and *R*, then calculate the reading of the milliommeter.



Sol.: Let I_1 be the current from cell of emf 4.0 V and I_2 from cell of emf 5.0 V. Then, the distribution of currents is shown in the circuit, in accordance with Kirchhoff's junction rule.

For closed circuit *PQRP*, $20(I_1 + I_2) + 60 I_1 = 4$

$\Rightarrow \quad 20 I_1 + 5 I_2 = 1$ .....(i)

For closed circuit *PRSP* $20(I_1 + I_2) + 200 I_2 = 5$

$\Rightarrow \quad 4 I_1 + 44 I_2 = 1$ .....(ii)

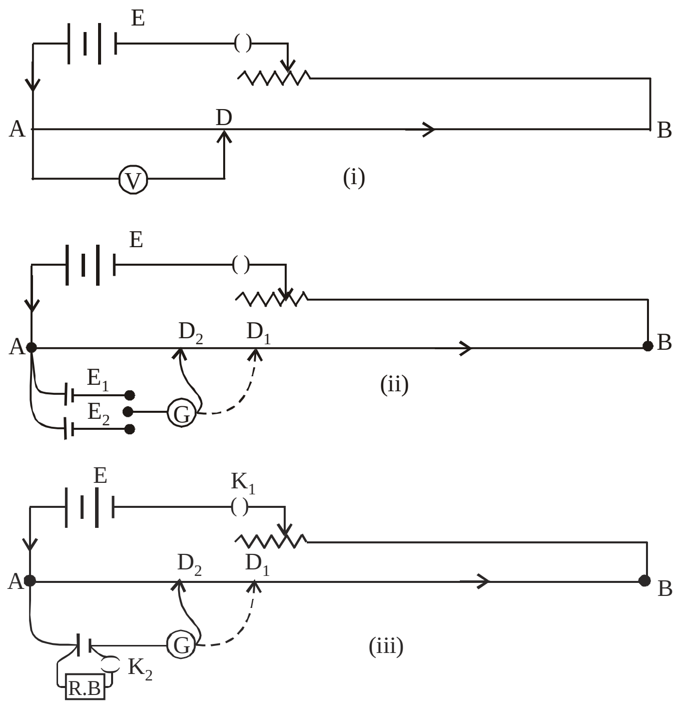
(5 × ii) – (i) gives $215 I_2 = 4 \Rightarrow I_2 = \frac{4}{215}$ A .....(iii)

$\therefore$ From (i), $20 I_1 = 1 - 5 \times \frac{4}{215} = \frac{39}{43} \Rightarrow I_1 = \frac{39}{860}$ A ....(iv)

$\therefore$ Current through ammeter $= I_1 + I_2 = \frac{39}{860} + \frac{4}{215} = \frac{39+16}{860} = \frac{55}{860} = \frac{11}{172}$ A .....**Ans.**

Potentiometer

1. Potentiometer consists of a uniform wire of large length of 4 m, 6 m, 8 m, etc.
2. The potential drop across the potentiometer wire is directly proportional to its length (this is because the wire is of uniform area of cross-section).



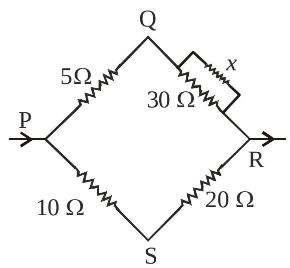
3. Through the path of galvanometer, current from the battery of *e.m.f.* E can be varied i.e. if point D is closer to point A, less current flows through the path of galvanometer; and if point D is farther from point A, then more current flows through the path of galvanometer.
4. *For comparing e.m.f.s of two cells*, the positive terminals of both the cells and the positive terminal of the battery (of e.m.f. E) are connected to the same end A of the potentiometer wire. Now, we locate point D on the potentiometer wire so that no current flows through the path of galvanometer. Then [see figure (ii)]

   E.M.F. of cell = P.D. across A and D on potentiometer wire .....(*i*)

   For two cells, $\frac{E_1}{E_2} = \frac{AD_1}{AD_2} = \frac{l_1}{l_2}$ .....(*ii*)
5. *For finding internal resistance* (r) *of a cell* :
   (i) We connect a cell [see figure (iii)] and locate a point D_1 on potentiometer wire so that no current flows through the path of galvanometer, when key K_2 is not used.
   (ii) Now, we take out some resistance R from the resistance-box (R.B.) and use key K_2 also, and locate a point D_2 on the potentiometer wire so that no current flows through the path of galvanometer.

   Then, $r = R\left[\frac{l_1}{l_2} - 1\right]$ where l_1 = length AD_1 of potentiometer wire
   l_2 = length AD_2 of potentiometer wire

Ex.12: Find the unknown resistance x, so that a galvanometer put across Q and S shows no deflection, for any current entering P and leaving R.



Sol.: For no current through galvanometer across Q and S,

$$\frac{5}{10} = \frac{R_{QR}}{20} \quad \Rightarrow \quad R_{QR} = \frac{5 \times 20}{10} = 10\ \Omega$$

$$\therefore \quad \frac{1}{30} + \frac{1}{x} = \frac{1}{10} \quad \Rightarrow \quad \frac{1}{x} = \frac{1}{10} - \frac{1}{30} = \frac{3-1}{30} = \frac{2}{30} = \frac{1}{15}$$

$$\Rightarrow \quad x = 15\ \Omega$$ .....**Ans.**

A Single Cell and Number of Cells

1. Potential difference (V) across the terminals of a cell is the work done in taking a unit charge across the two terminals, through an external resistance R. Mathematically,

   $V = IR$ .....(*i*)
2. E.M.F. (electromotive force) E of a cell is the work done in carrying a unit charge from one terminal to the other through the external resistance,; and then back from the second terminal to the first through the electrolyte (internal resistance) of the cell. Mathematically,

   $E = IR + Ir = I(R + r)$ .....(*ii*)

   $\therefore \quad E = V + Ir$ .....(*iii*)

   Also $\frac{E}{V} = \frac{R+r}{R} = 1 + \frac{r}{R}$ .....(*iv*)

3. E.M.F. of the cell is also defined as the potential difference across the two terminals of a cell, when no current is being drawn from the cell, or when the cell is in open circuit.
4. E.M.F. of the cell can be found only by a potentiometer, while potential difference across a cell can be found by using a voltmeter.
5. For a single cell, $I = \frac{E}{R+r} = \frac{\text{Total e.m.f.}}{\text{Total resistance of the circuit}}$
6. A cell gives maximum power to the external source if $r = R$; then

$$I = \frac{E}{2r} \text{ or } I = \frac{E}{2R} \quad \text{and} \quad P = \frac{E^2}{4R} \text{ or } P = \frac{E^2}{4r}$$

7. For n cells in series, $I = \frac{nE}{nr+R}$ .....(*i*)

   Current drawn is maximum if $R >> r$
8. For m cells in parallel $I = \frac{mE}{r+mR}$ .....(*ii*)

   Current drawn is maximum if $r >> R$
9. For N cells such that there are m rows having n cells each :

   $N = n\,m$ and $I = \frac{n\,mE}{nr+mR} = \frac{NE}{nr+mR}$ .....(*iii*)

   Current drawn is maximum if $nr = mR \Rightarrow R = \frac{nr}{m}$ i.e. the cells are so arranged that external resistance of the circuit is equal to total internal resistance of all the cells in mixed grouping.
10. The above results can be tabulated as under :

Mode of connection	*Current*	*Condition for maximum current*
Mixed grouping $N = nm$	$I = \frac{n\,mE}{n\,r+mR}$	$nr = mR \Rightarrow R = \frac{nr}{m}$
All cells in series (m = 1)	$I = \frac{nE}{n\,r+R}$	$R >> r$
All cells in parallel (n = 1)	$I = \frac{mE}{r+mR}$	$r >> R$

Ex.13: Through an external resistance of 4.5 Ω, maximum current is required to be sent from 36 identical cells, each of internal resistance 0.5 Ω and emf 1.5 V. Find the arrangement of the cells. Also find the current through the external resistance and current drawn from each cell.

Sol.: ∵ External and internal resistances cannot be ignored as compared to each other, so the cells should be used in mixed grouping,

Let n be the number of cells in each row and let m be the number of such parallel rows.

$\therefore\ nm = 36$ .....(i)

Also, for max. current $\frac{n}{m}=\frac{R}{r}=\frac{4.5}{0.5}=9$ .....(ii)

Multiplying (i) and (ii) $n^2 = 36 \times 9 \Rightarrow n = 18$

$\therefore m = 2$

So, the cells should be used in 2 parallel rows of 18 cells each. .....**Ans.**

I = current in external resistance $= \frac{NE}{nr+mR}$

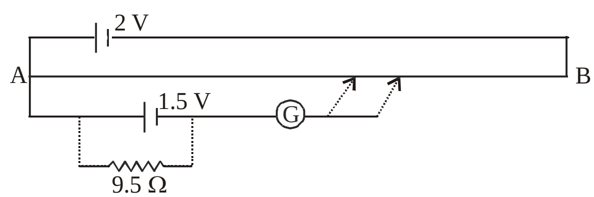
$$= \frac{36\times1.5}{(18\times0.5)+2\times4.5}=\frac{36\times1.5}{18}=3.0 \text{ A}$$ .....**Ans.**

$\because$ Two identical rows of cells are contributing current of 3.0 A

$\therefore$ Current through each row of cells will be 1.5 A

Hence, current from each cell = 1.5 A .....**Ans.**

Ex.14: A cell of steady emf. 2.0 V is put across a potentiometer wire. For finding internal resistance of a cell of emf 1.5 V, it is connected as shown under. The balance point for this cell in open circuit is 76.3 cm. When a resistance of 9.5 Ω is put across this cell, the balance point shifts to 64.8 cm. Find the internal resistance of the cell.



Sol.: $R = 9.5\ \Omega$ $l_1 = 76.3\ \Omega$ $l_2 = 64.8\ \Omega$ $r = ?$

$$r = R\left[\frac{l_1}{l_2}-1\right] = 9.5 \times \left[\frac{76.3}{64.8}-1\right]$$

$= 9.5 \times [1.1775 - 1] = 9.5 \times 0.1775 = 1.686\ \Omega$ .....**Ans.**

Ex.15: Two wires of equal lengths, one of aluminium and the other of copper have same resistance. Which of the two wires is lighter, if specific resistances of copper and aluminium are, respectively, $1.72 \times 10^{-8}\ \Omega$ m and $2.63 \times 10^{-8}\ \Omega$ m and the respective relative densities are 8.9 and 2.7. Hence, explain why aluminium wires are preferred for over-head power cables.

Sol.: $$R = \rho.\frac{l}{A} = \rho.\frac{l}{\text{volume}/l} = \rho.\frac{l^2}{\text{volume}} = \rho.\frac{l^2}{\text{mass}/\text{density}} = \frac{\rho\, l^2 \times \text{density}}{\text{mass}}$$

$\because$ Resistances R and lengths l are equal

$$\therefore \frac{\rho_{Cu}\times d_{Cu}}{m_{Cu}} = \frac{\rho_{Al}\times d_{Al}}{m_{Al}}$$

$$\frac{m_{Cu}}{m_{Al}}=\frac{\rho_{Cu}}{\rho_{Al}}\times\frac{d_{Cu}}{d_{Al}}=\frac{1.72\times10^{-8}}{2.63\times10^{-8}}\times\frac{8.9}{2.7}=\frac{1.72\times8.9}{2.63\times2.7}=2.16 \qquad \text{.....\textbf{Ans.}}$$

Clearly, for same length and same resistance, mass of copper wire is more than two times the mass of aluminium wire. For this reason, aluminium wires are preferred or over-head power cables.

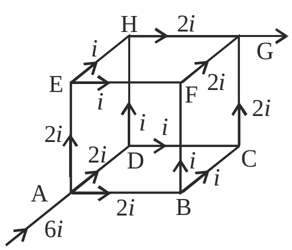
Some Other Informations and Problems

1. J = current density = current per unit area = $\frac{I}{\text{Area}}$ (Am^{-2})

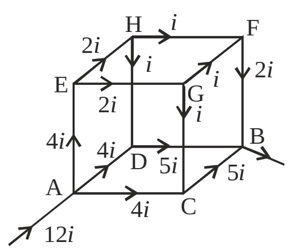
2. (i) Thermistor is heat-sensitive resistor and is generally made of semiconductors.
   (ii) In thermistor with negative temperature-coefficient of resistance, the resistance decreases with increase in temperature. Such a thermistor is used in resistance thermometer to measure low temperature with a great accuracy.

3. (i) Super-conductor is that substance which loses all its resistance at a temperature, called critical temperature.
   (ii) In a ring made of super-conductor current will flow for ever.
   (iii) Lead, tin and indium become super-conductors at temperatures 7.2 K, 3.7 K and 3.4 K, respectively.
   (iv) In 1988, an alloy $Ti_2Ba_2Ca_2Cu_3O_{10}$ was found to be super-conductor at a comparitively workable higher temperature of 125 K.

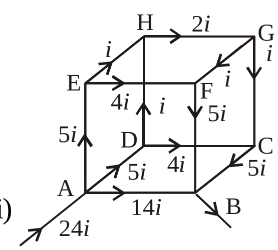
4. Twelve wires of resistance R each are joined to form a skeleton cubes as shown under : Then

(i) 

Resistance across diagonal of cube

(ii) 

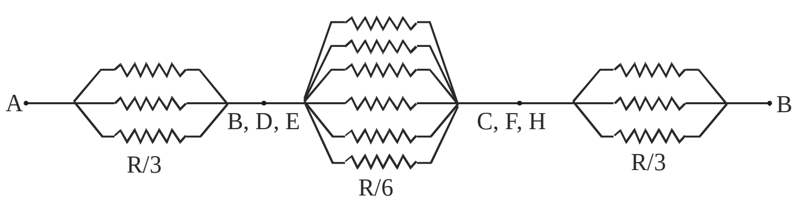
Resistance across diagonal of any face of the cube

(iii) 

Resistance across any two nearest corners of the cube

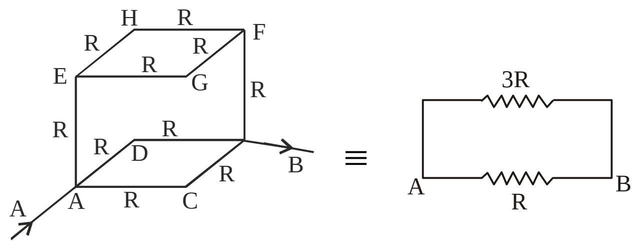
$R_{AB}=\frac{10}{12}R=\frac{5}{6}R$ $\qquad$ $R_{AB}=\frac{9}{12}R=\frac{3}{4}R$ $\qquad$ $R_{AB}=\frac{7}{12}R$

(i) [B, D & E] and [C, F & H] are at same potentials. So the equivalent diagram is



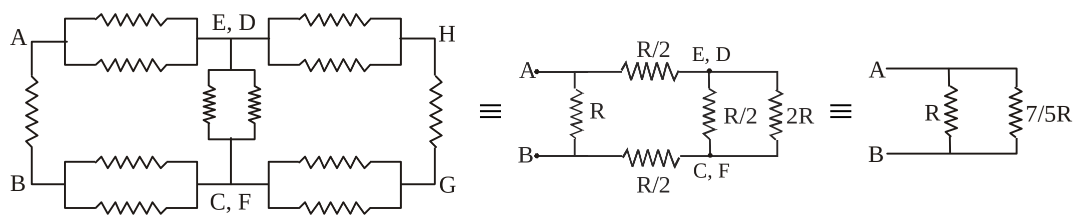
$$\Rightarrow R_{AB}=\frac{R}{3}+\frac{R}{6}+\frac{R}{3}=\frac{5R}{6}$$

(ii) $(D \& H)$ and $(C \& G)$ are at same potential and therefore connection between D & H and also between C & G can be ignored. Then, the circuit can also be shown as under :



$$\therefore \quad R_{AB} = \frac{3R \times R}{3R + R} = \frac{3}{4}R$$

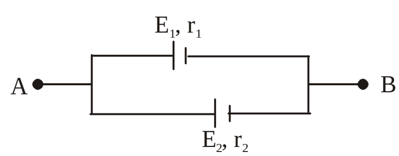
(iii) D & E and C & F are at same potentials. So the equivalent diagram can be shown as under :



$$\therefore \qquad R_{\text{AB}} = \frac{1 \times 1.4}{1 + 1.4} = \frac{1.4}{2.4} = \frac{7}{12}R$$

5. If two cells of e.m.f.'s E_1 and E_2 and of internal resistances r_1 and r_2, respectively, joined in parallel between two points A and B, then their equivalent e.m.f. (representing a single cell) is given by the relation :

$$E = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$$



6. Resistance of human body (dry) ≈ 10 kΩ (10^4 Ω).

Ex.16: Two cells A and B have emf's 2.5 V and 1.5 V, respectively, and their internal resistances are 0.2 Ω and 0.1 Ω, respectively. Find their resultant emf

(i) if their similar polarities are joined to the same common points

(ii) if their opposite polarities are joined to the same common points

Sol.: $E_1 = 2.5$ V $\quad r_1 = 0.2\ \Omega \quad E_2 = 1.5$ V $\quad r_2 = 0.1\ \Omega$

(i) *When same polarities are joined*

$$E = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2} = \frac{2.5 \times 0.1 + 1.5 \times 0.2}{0.2 + 0.1} = \frac{0.55}{0.3} = 1.83 \text{ V}$$ .....**Ans.**

(ii) *When opposite polarities are joined*

Here, one polarity is negative and the other is positive

$$\therefore \quad E = \frac{-E_1 r_2 + E_2 r_1}{r_1 + r_2} = \frac{-2.5 \times 0.1 + 1.5 \times 0.2}{0.2 + 0.1} = \frac{0.05}{0.3} = 0.167 \text{ V}$$ .....**Ans.**

THERMAL EFFECT OF CURRENT

1. Heat produced in time t in a wire of resistance R, through which a current I flows, or across which a potential difference V is applied, is :

$$H = I^2 Rt = VIt = \frac{V^2}{R}\,t \qquad .....(i)$$

$H = QV$, where Q is charge taken across a p.d. of V .....(*ii*)

$H = Pt$, where P is the electrical power consumed and t is time .....(*iii*)

2. Electrical power = electrical energy consumed per second

$$\Rightarrow \quad P = \frac{\text{Electrical energy}}{\text{time}} = I^2 R = VI = \frac{V^2}{R} \qquad .....(iv)$$

3. Unit of electrical energy = 1 kWh = 3.6×10^6 J
4. kWh = units of energy consumed by an electrical appliance

$$= \frac{\text{Power in Watt}}{1000} \times \text{time in hours} \qquad .....(v)$$

Ex.1: A night bulb is marked 15 W, 230 V. Calculate the cost of its operation for 8 hours per night for a month of 30 days, if electric energy is supplied at the rate of Rs. 2.50 a unit.

Sol.: $P = 15$ W $\qquad$ t (in hours) = 8 × 30 hours

Units of electricity (kWh) consumed

$$= \frac{\text{Power in watt}}{1000} \times \text{time in hr} = \frac{15}{1000} \times (8 \times 30) = 3.6 \text{ kWh}$$

∴ Cost = units × rate = 3.6 × 2.50 = Rs. 9.00. .....**Ans.**

Ex.2: An immersion rod is rated 1 kW and 250 V. Find the time taken by this immersion rod to raise the temperature of 10 litres of water from 16ºC to 40ºC, assuming that 20% of energy goes out as radiations. Take J = 4.18 joule/calorie.

Sol.: Let t be the time required for the purpose.

∴ Electrical energy used for heating water

= 80% of $P \times t = 0.8 \times 1000 \times t$ J = $800\,t$ J .....(i)

Heat energy required to heat the water (sp. heat of water = 4180 J kg^{-1} $^{o}C^{-1}$)

= $m\,s\,\theta = 10 \times 4180 \times [40 - 16]$ J = $10 \times 4180 \times 24$ J .....(ii)

Applying principle of conservation of energy

$800\,t = 10 \times 4180 \times 24$

$$t = \frac{41800 \times 24}{800} = 1254 \text{ s} = 20 \text{ min, } 54 \text{ sec.}$$ .....**Ans.**

5. When two bulbs or resistors are joined in series, then current through both is same

$$\therefore \quad \frac{H_1}{H_2} = \frac{I^2 R_1 t}{I^2 R_2 t} = \frac{R_1}{R_2}$$ i.e., heat produced is directly proportional to resistance.

6. When two bulbs or resistors are joined in parallel with each other, or both are connected to same source of e.m.f., then p.d. across each is same.

$$\therefore \quad \frac{H_1}{H_2} = \frac{(V^2/R_1)t}{(V^2/R_2)t} = \frac{R_2}{R_1}$$ i.e., heat produced is inversely proportional to resistance.

7. Let one heater boil a certain amount of water in time t_1 and another heater boil the same amount of water in time t_2. Now, if both the heaters are joined in series, then

t = time taken now to boil same amount of water = $t_1 + t_2$

8. Let one heater boil a certain amount of water in time t_1 and another heater boil the same amount of water in time t_2. Now, if both the heaters are joined in parallel, then

t = time taken now to boil same amount of water = $\frac{t_1 t_2}{t_1 + t_2}$

9. When electrical devices, consuming powers P_1, P_2, P_3,....., are connected in series across the same source, then the electric power P consumed by the combination is given by the relation :

$$\frac{1}{P} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3} + ...$$

10. When electrical devices, consuming powers P_1, P_2, P_3,....., are connected in parallel across the source, then the electric power P consumed by the combination is given by the relation :

$P = P_{1+} P_{2+} P_{3+}.....$

11. (i) *Fuse* : It is an electric device, used in series before an electrical appliance to save it against damage due to fluctuation of voltage.

(ii) It is an alloy of lead and tin (63% tin + 37% lead); and has large resistance but low melting point.

(iii) Safe current through a fuse wire is independent of its length.

(iv) Safe current through a fuse wire $\propto$ (radius of fuse wire)$^{3/2}$.

Ex.3: A fuse with a circular cross-sectional radius of 0.15 mm blows at 2.0 A. What should be the radius of the cross-section of the fuse, of the same material, which will blow at 16.0 A?

Sol.: Other factors remaining same, safe current through a fuse $\propto$ (cross-sectional radius)$^{3/2}$

$$\frac{I_1}{I_2} = \left(\frac{r_1}{r_2}\right)^{3/2} \quad \Rightarrow \quad \frac{r_1}{r_2} = \left(\frac{I_1}{I_2}\right)^{2/3}$$

$$\Rightarrow \quad \frac{0.15\text{ mm}}{r_2} = \left(\frac{2}{16}\right)^{2/3} = \left(\frac{1}{8}\right)^{2/3} = \left(\frac{1}{2}\right)^{2} = \frac{1}{4}$$

$\therefore$ $r_2 = 0.15 \times 4 = 0.60$ mm .....**Ans.**

12. (i) Electric power delivered by a cell to an external source of resistance R is maximum when, R = internal resistance of cell.

(ii) Efficiency of a cell, when it is delivering maximum power to an external source, is 50%.

Ex.4: A cell produces same rate of heat in external resistance R_1 as well as in external resistance R_2. Find its internal resistance.

Sol.: Let internal resistance of the cell be r and let its emf be E.

When used with external resistance R_1

Current through $R_1 = \frac{E}{R_1 + r}$

$\therefore$ Power developed in $R_1 = \left(\frac{E}{R_1 + r}\right)^2 \times R_1$ .....(i)

When used with external resistance R_2

Current through $R_2 = \frac{E}{R_2 + r}$

$\therefore$ Power consumed in $R_2 = \left(\dfrac{E}{R_2 + r}\right)^2 \times R_2$ .....(ii)

As per problem, $\left[\dfrac{E}{R_1 + r}\right]^2 \times R_1 = \left[\dfrac{E}{R_2 + r}\right]^2 \times R_2$

$\Rightarrow$ $(R_2 + r)^2 \times R_1 = (R_1 + r)^2 \times R_2$

$\Rightarrow$ $(R_2^2 + 2r\ R_2 + r^2) \times R_1 = (R_1^2 + 2r\,R_1 + r^2)R_2$

$\Rightarrow$ $R_1R_2^2 + 2r\,R_1\,R_2 + r^2\ R_1 = R_1^2R_2 + 2rR_1R_2 + r^2R_2$

$\Rightarrow$ $r^2R_1 - r^2R_2 = R_1^2R_2 - R_1R_2^2$

$\Rightarrow$ $r^2\ (R_1 - R_2) = R_1R_2\ (R_1 - R_2)$

$\Rightarrow$ $r^2 = R_1R_2$ $\Rightarrow$ $r = \sqrt{R_1R_2}$ .....**Ans.**

Ex.5: An electric bulb is marked 100 W, 250 V. If the voltage drops to 200 V, find the units of energy consumed by the bulb in 1day.

Sol.: $P = \dfrac{V^2}{R}$ $\Rightarrow$ $\dfrac{P_1}{P_2} = \dfrac{V_1^2}{V_2^2}$ $\Rightarrow$ $\dfrac{100}{P_2} = \dfrac{(250)^2}{(200)^2}$

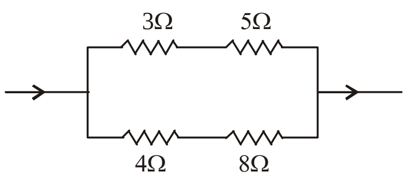
$\therefore$ $P_2 = 100 \times \dfrac{200 \times 200}{250 \times 250} = 64\ \text{W}$

$\therefore$ Energy consumed = $P_2 \times t = 64 \times 24 \times 60 \times 60$ J $= 5.5296 \times 10^6$ J

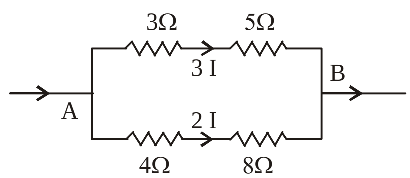
$= \dfrac{5.5286 \times 10^6}{3.6 \times 10^6}\ \text{kWh} = 1.536\ \text{kWh}$ .....**Ans.**

Ex.6: In the circuit shown, if heat energy produced in 3 Ω resistance is 5.4 cal/min, then what will be the heat produced in cal/min in 4 Ω resistance ?

Sol. Resistance of (3 Ω + 5 Ω) and (4 Ω + 8 Ω) are joined to same common points *A* and *B*. So, currents through these paths are in the inverse ratio of the resistances i.e. 3*I* : 2*I*, as shown in figure (*ii*)



(*i*)



(ii)

Now,

$(3\ I)^2 \times 3 = 5.4$ $\Rightarrow$ $27\ I^2 = 5.4$ $\Rightarrow I^2 = \dfrac{5.4}{27} = \dfrac{54}{270} = \dfrac{1}{5}$

$\therefore$ Heat energy produced in 4 Ω resistance

$= (2\ I)^2 \times 4 = 16\ I^2 = 16 \times \dfrac{1}{5} = 3.2$ cal/min. .....**Ans.**

CHEMICAL EFFECTS OF CURRENT

1. The process by which free elements are liberated from an electrolytic solution, by the passage of an electric current through it, is called electrolysis.
2. The vessel in which electrolysis is carried out is called voltameter or electrolytic cell.

3. Mass of an atom = Atomic mass of atom × 1.66×10^{-27} kg
For example : Mass of a single $_8O^{16}$ atom = $16 \times 1.66 \times 10^{-27}$ kg

4. Mass of one molecule = Molecular mass × 1.66×10^{-27} kg
For example : Mass of one molecule of water (H_2O) = $18 \times 1.66 \times 10^{-27}$ kg

5. (i) Chemical equivalent of substance = $\dfrac{\text{Atomic mass or molecular mass of substance}}{\text{Valency of the substance}}$

(ii) Chemical equivalent of a substance, expressed in gram, is called gram equivalent of that substance.

Faraday's Laws of Electrolysis

1 The mass (m) of the ions deposited or liberated at cathode in electrolysis is directly proportional to the charge that passes through the electrolyte.

$i.e.\ m \propto Q \quad \Rightarrow \quad m = ZQ = ZIt$ .....(i)

where Z = a constant, called electrochemical equivalent (e.c.e.) (Its units are g coul^{-1}, and its value is different for different elements)

2. If the same electric current is passed through two or more electrolytes for the same time, then the ratio of masses deposited or liberated at the respective cathodes is equal to the ratio of their chemical equivalents (or equivalent masses).

$$i.e.\quad \frac{m_1}{m_2} = \frac{E_1}{E_2} = \frac{(M_1/p_1)}{(M_2/p_2)} \qquad .....(ii)$$

$$\because \text{ Equivalent mass } = \frac{\text{Molecular mass}}{\text{Valency}} = \frac{M}{p} \qquad .....(iii)$$

3. Using first law of electrolysis for two masses (for same charge)

$$\frac{m_1}{m_2} = \frac{Z_1}{Z_2} \qquad .....(i)$$

3. Using second law of electrolysis for two masses (for same charge)

$$\frac{m_1}{m_2} = \frac{E_1}{E_2} \qquad .....(ii)$$

$\therefore$ Combining (i) and (ii), we get $\dfrac{E_1}{E_2} = \dfrac{Z_1}{Z_2} \quad \Rightarrow \quad \dfrac{E_1}{Z_1} = \dfrac{E_2}{Z_2}$

$$\Rightarrow \frac{E}{Z} = \text{constant} = F \text{ (Faraday)} \qquad .....(iii)$$

$$F = \frac{E}{m/Q} \quad \Rightarrow \quad \frac{F}{Q} = \frac{E}{m} \qquad (\because\ m = ZQ) \qquad .....(iv)$$

4. $\therefore$ If $m = E$, then $F = Q$
i.e. Faraday is that charge which deposits a mass of one equivalent mass of a substance.
Hence, units and value of F = 96500 C/gm. equivalent
i.e., A charge of 96500 C deposits 1 gram equivalent of a substance. .....(v)

5. *Back e.m.f. in voltameter* :

(i) In electrolysis or in a voltameter, H^+ ions (or electropositive ions) go to cathode and may cover it, while electronegative ions go to anode and may cover it. This deposition of ions on the electrodes sets up an e.m.f., opposite to the applied e.m.f., and is called back e.m.f.

(ii) Back e.m.f. is also produced in electric motor, when armature of motor rotates (see back e.m.f. in chapter E.M.I. also).

(iii) $\therefore I \text{ (current)} = \dfrac{E-e}{R} = \dfrac{\text{Applied e.m.f.} - \text{back e.m.f.}}{\text{Resistance of circuit}}$

(iv) If the electrodes are of same nature as of the products of the reaction, then back e.m.f. is zero, as in case of copper voltameter, product of the reaction, Cu, forms a coherent film of copper cathode.

(v) If the electrodes are of different nature than the product of the reaction, then a back e.m.f. is set up. *For example*, a back e.m.f. of 1.67 *V* is set up in water voltameter, a back e.m.f. of 1.34 *V* is set up in voltameter with platinum electrodes in $CuCl_2$ solution.

Ex.7: In a silver plating system, an electrolysis current of 5.0 A is used for certain time and 0.5 mole of silver is deposited. How much mass of copper and iron will be deposited in their respective plating systems, if an electrolysis current of 10.0 A is passed for twice the time used for silver plating. (Relative atomic mass of silver = 107.3, of copper 63.54 and of iron = 55.86). Also, express the results in mole.

Sol.: Mass of silver deposited for 5 A and for certain time = 0.5 mole

∴ Mass of silver deposited for 10 A and for double the time = $0.5\times\frac{10}{5}\times 2$ = 2 mole

= 2 × 107.3 g .....(i)

Equivalent mass = $\frac{\text{Atomic mass}}{\text{Valency}}$ ∴ $E_{\text{silver}} = \frac{107.3}{1} = 107.3$

$E_{\text{copper}} = \frac{63.54}{2} = 31.77$ $E_{\text{iron}} = \frac{55.86}{3} = 18.62$

Using Faraday's second law of electrolysis for same current passed for same time through different electrolytes

$$\frac{m_{\text{copper}}}{m_{\text{silver}}} = \frac{E_{\text{copper}}}{E_{\text{silver}}}$$

∴ $m_{\text{copper}} = m_{\text{silver}}\times\frac{E_{\text{copper}}}{E_{\text{silver}}} = (2\times 107.3)\times\frac{31.77}{107.3} = 63.54$ .....(ii)**Ans.**

Number of moles of copper deposited = $\frac{\text{mass}}{\text{atomic mass}} = \frac{63.54}{63.54} = 1$ mole .....(iii)**Ans.**

Similarly, $\frac{m_{\text{iron}}}{m_{\text{silver}}} = \frac{E_{\text{iron}}}{E_{\text{silver}}}$

$m_{\text{iron}} = (2\times 107.3)\times\frac{18.62}{107.3} = 37.24$ g .....(iv) **Ans.**

Number of moles of iron deposited = $\frac{\text{mass}}{\text{atomic mass}} = \frac{37.24}{55.86} = \frac{2}{3}$ .....(v) **Ans.**

Ex.8: A steady current of 10.0 A is passed through a water voltameter for 300 s. Estimate the volume of H_2 evolved at standard temperature and pressure. Relative molecular mass of H_2 is 2.016. Use standard value of Faraday.

Sol.: Charge passed through water voltameter = $I\,t$ = 10 × 300 = 3000 C

For charge of 36500 C, mass of H-atoms deposited = 1.008 g

[∵ Equivalent mass of hydrogen atom = $\frac{2.016}{2} = 1.008$]

∴ For charge of 3000 C, mass of H-atoms deposited = $1.008\times\frac{3000}{96500}$ g .....(i)

This will also be mass of H_2 gas.

Now, volume of 2.016 g of H_2 = 22.4 litre

$\therefore$ Volume of $\frac{1.008 \times 3000}{96500}$ g of H_2

$$= \frac{22.4}{2.016} \times \frac{1.008 \times 3000}{96500}$$

$$= 0.348 \text{ litres} = 348 \text{ cm}^3$$ ....**Ans.**

Various Cells

Cell	***Anode***	***Cathode***	***Electrolyte***	***E.M.F.***	***Polariser***
Voltaic	Cu	Zn	dil. H_2SO_4	1.08 V	……….
Daniell	Cu	Zn	dil. H_2SO_4	1.08 V	$CuSO_4$
Leclanche } Dry cell	Carbon	Zn	NH_4Cl soln.	1.45 V	MnO_2
Lead storage cell or Acid Accumulator	PbO_2	Pb	dil. H_2SO_4	2.05 V	……….
Alkali Accumulator or Adison Accumulator	$Ni(OH)_4$	Fe	KOH soln.	1.36 V	……….

Reactions in Various Cells

1. *Voltaic Cell* :

In electrolyte	:	H_2SO_4	$\rightarrow$	$2\,H^+ + SO_4^{2-}$
At cathode	:	Zn	$\rightarrow$	$Zn^{2+} + 2e^-$
		$Zn^{2+} + SO_4^{2-}$	$\rightarrow$	$ZnSO_4$
At anode	:	$2\,H^+$	$\rightarrow$	$H_2 - 2e^-$
Total reaction	:	$H_2SO_4 + Zn$	$\rightarrow$	$ZnSO_4 + H_2$

2. *Daniell cell* :

In electrolyte	:	H_2SO_4	$\rightarrow$	$2\,H^+ + SO_4^{2-}$
At cathode	:	Zn	$\rightarrow$	$Zn^{2+} + 2e^-$
		$Zn^{2+} + SO_4^{2-}$	$\rightarrow$	$ZnSO_4$
At anode	:	$2\,H^+$	$\rightarrow$	$H_2 - 2e^-$
		$H_2 + CuSO_4$	$\rightarrow$	$H_2SO_4 + Cu$
Total reaction	:	$Zn + CuSO_4$	$\rightarrow$	$ZnSO_4 + Cu$

3. *Leclanche Cell* : or *Dry cell*

In electrolyte	:	$2\,NH_4Cl$	$\rightarrow$	$2\,NH_3\uparrow + 2\,H^+ + 2\,Cl^-$
At cathode	:	Zn	$\rightarrow$	$Zn^{2+} + 2e^-$
		$Zn^{2+} + 2\,Cl^-$	$\rightarrow$	$ZnCl_2$
At anode	:	$2\,H^+$	$\rightarrow$	$H_2 - 2e^-$
		$2\,MnO_2 + H_2$	$\rightarrow$	$Mn_2O_3 + H_2O$

Total reaction : $2\,NH_4Cl + Zn + 2\,MnO_2 \rightarrow 2\,NH_3 + ZnCl_2 + Mn_2O_3 + H_2O$

4. *Lead Storage Cell*

or *Acid Accumulator*

(a) *During Discharging* (or when it is being used)

In electrolyte	:	H_2SO_4	$\rightarrow$	$2\ H^+ + SO_4^{2-}$	
At cathode	:	$Pb + SO_4^{2-}$	$\rightarrow$	$PbSO_4 + 2e^-$	
At anode	:	$2\ H^+$	$\rightarrow$	$H_2\ - 2e^-$	
		$PbO_2 + H_2 + H_2SO_4$	$\rightarrow$	$PbSO_4 + 2\ H_2O$	
Total reaction	:	$Pb + PbO_2 + 2\ H_2SO_4$	$\rightarrow$	$2\ PbSO_4 + 2\ H_2O$	I

(b) *During Charging*

In electrolyte	:	H_2SO_4	$\rightarrow$	$2H^+ + SO_4^{2-}$	
At cathode	:	$2\ H^+$	$\rightarrow$	$H_2\ - 2e^-$	
		$PbSO_4 + H_2$	$\rightarrow$	$Pb + H_2SO_4$	
At anode	:	$2\ H^+$	$\rightarrow$	$H_2\ - 2e^-$	
At anode	:	$PbSO_4 + 2\ H_2O + SO_4^{2-}$	$\rightarrow$	$PbO_2 + 2\ H_2SO_4 + 2e^-$	
Total reaction	:	$2\ PbSO_4 + 2\ H_2O$	$\rightarrow$	$Pb + PbO_2 + 2\ H_2SO_4$	II

Hence, from total reactions during charging and discharging, we see that ideally no reactant is consumed during complete cycle of charging and discharging of acid accumulator. Only, it should be charged at appropriate time and periodically H_2O should be added, which may be lost due to evaporation.

5. *Edison Accumulator* :

or *Alkali Accumulator*

(a) *During Discharging* (or when it is being used)

In electrolyte	:	$2\ KOH$	$\rightarrow$	$2\ K^+ + 2\ OH^-$	
At cathode	:	$Fe + 2\ OH^-$	$\rightarrow$	$Fe(OH)_2 + 2e^-$	
At anode	:	$Ni(OH)_4 + 2\ K^+$	$\rightarrow$	$2\ KOH + Ni(OH)_2 - 2e^-$	
Total reaction	:	$Fe + Ni(OH)_4$	$\rightarrow$	$Fe(OH)_2 + Ni(OH)_2$	I

(b) *During Charging*

In electrolyte	:	$2\ KOH$	$\rightarrow$	$2\ K^+ + 2\ OH^-$	
At cathode	:	$Fe(OH)_2 + 2\ K^+$	$\rightarrow$	$Fe + 2\ KOH - 2e^-$	
At anode	:	$Ni(OH)_2 + 2\ OH^-$	$\rightarrow$	$Ni(OH)_4 + 2e^-$	
Total reaction	:	$Fe(OH)_2 + Ni(OH)_2$	$\rightarrow$	$Fe + Ni(OH)_4$	II

Hence, from total reactions during charging and discharging, we see that ideally no reactant is consumed during complete cycle of charging and discharging of the alkali accumulator. It has certain advantage over lead accumulator : it is strong, durable and lighter; though it is costlier and has less e.m.f.

6. (i) While charging a reversible cell or an accumulator, positive of the source (for charging) is connected to the positive of the cell.

(ii) During charging, terminal voltage across the cell is greater than the e.m.f. of the cell.

(iii) E.M.F. of the charging source should be greater than the E.M.F. of the cell to be charged.

(iv) Then, current through cell = $\dfrac{\text{E.M.F. of Source} - \text{E.M.F. of cell(s)}}{\text{Resistance of the circuit}}$

Ex.9: A series of 6 lead accumulators, each of e.m.f. 2.0 V and internal resistance 0.5 Ω, are charged by a 100 V *dc* supply. (a) What series resistance should be used in the charging circuit in order to limit the current to 8.0 A ? (b) Using the required resistor, find

(i) the total power supplied by the *dc* source,

(ii) the power supplied by the *dc* source, dissipated as heat, and

(iii) energy stored in battery in 15 minutes.

Sol.: (a) Resistance of the circuit = $\dfrac{\text{E.M.F. of source} - \text{Total e.m.f. of cells}}{\text{Current in the circuit}}$

Let R be the resistance, added in series in the circuit, to limit the currrent.

$$R + (6 \times 0.5) = \frac{100 - 6\times 2}{8} = \frac{100-12}{8} = \frac{88}{8} = 11\ \Omega$$

$\therefore$ R, external resistance required = 11 – 3 = 8 Ω .....(*i*)**Ans.**

(b) (i) Power supplied by *dc* source = EI = 100 × 8 = 800 W .....(*ii*)**Ans.**

(ii) Power supplied by *dc* source, dissipated as heat

= Power consumed in resistance of cct.

= $I^2 (R + n\,r) = 8^2 (8 + 6 \times 0.5)$

= 64 (8 + 3) = 64 × 11 = 704 W .....(*iii*)**Ans.**

(iii) Power stored in accumulator = Power supplied to accumulator

= n(e.m.f. of each cell) × I

= 6 × 2 × 8 = 96 W

(Also, Power supplied by *dc* source

= Power dissipated as heat in resistance + Power stored in cells)

$\therefore$ Energy stored in cells in 15 minutes = $P \times t$ = 96 × 15 × 60

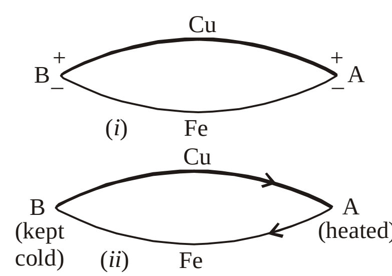
= 86400 J = 86.4 kJ .....(*iv*)**Ans.**

THERMO-ELECTRICTY

Seebeck Effect (*Thermo-electric effect*)

1. Whenever two elements of different electronic configurations are brought in contact, one element loses electrons and the other gains electrons. This produces a potential difference between the twoelements and this potential difference is called contact potential.

2. When two wires, one of copper and the other of iron are brought incontact, as shown in figure (*i*), then at junctions *A* and *B*, copper becomes positive and iron becomes negative. This produces a contact potential difference at junctions *A* and *B*. But, under same conditions of temperature, the two contact potential differences are equal in magnitude but in opposite directions. Hence, no current flows across two junctions.



3. Now, if A is heated and B is kept cold [see figure (ii)], then contact potential difference at A becomes larger than that at B. Hence, current starts flowing from copper to iron at end A, or from iron to copper at end B.
4. The current that flows across the two junctions of two wires of different materials, when one junction is heated and the other is kept cold at some fixed temperature, is called thermo-electric current. This phenomenon is called thermo-electric effect or Seebeck effect and the combination of such two wires is called thermo-couple.
5. After experimental verification, Seebeck arranged following metals in the form of a series, called thermoelectric series :

   Te, Sb, Fe, Cd, Zn, Ag, Au, Mo, Cr, Sn, Pb, Hg, Mn, Cu, Pt, Pd, Co, Ni, Bi.

   (i) At the cold junction, current will flow from the metal occurring earlier to the metal occurring later in the thermoelectric series.

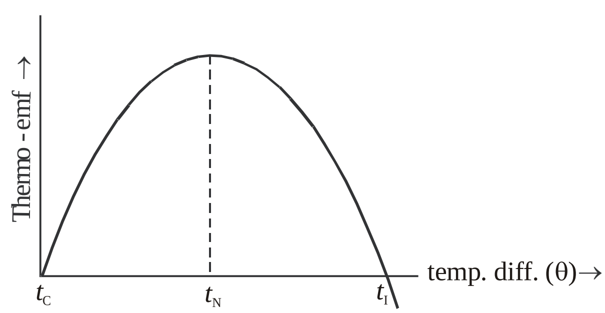
   (ii) Greater the separation of the metals in the thermoelectric series, greater is the thermo-e.m.f. between two junctions, for same temperature difference across the two junctions.

   (iii) *For example*, at cold junction, current flows from Fe to Cu; or at hot junction current flows from Cu to Fe, in a copper-iron couple.

   Also, at cold junction current flows from antimony to bismuth in Sb-Bi thermocouple.
6. The thermo-emf, V, between two junctions and the temperature difference, θ, between them are related by the relation :

$$V = \alpha\,\theta + \frac{1}{2}\beta\,\theta^2, \text{ where } \alpha \text{ and } \beta \text{ are constants for a thermo-couple} \quad .....(i)$$

7. (i) The graph between thermo-emf along y-axis and temperature difference between two junctions along x-axis, is a parabola.



   (ii) The temperature of hot junction at which thermo-emf is maximum, or when the slope of the curve is zero, is called neutral temperature (t_N) and is given by the relation :

$$\frac{dV}{d\theta} = 0 \Rightarrow \frac{d}{d\theta}\left[\alpha\,\theta + ½\,\beta\theta^2\right] = 0 \quad \Rightarrow \quad \alpha + \beta\theta_N = 0$$

$$\Rightarrow \theta_N = -\frac{\alpha}{\beta} \qquad \text{where, } \theta_N = t_N - t_C \qquad .....(ii)$$

(iii) Temperature of inversion (t_I) is the temperature of hot junction at which thermo-emf again becomes zero and if the temperature is further increased, the direction of the current is inverted or changed.

i.e. $\alpha\theta + \frac{1}{2}\beta\theta^2 = 0 \quad \Rightarrow \quad [\alpha + \frac{1}{2}\beta\theta_I] = 0$

$$\Rightarrow \quad \theta_I = -\frac{2\alpha}{\beta} = 2\theta_N \text{ [using (ii)]} \qquad .....(iii)$$

(iv) Now, $\theta_N = t_N - t_C$ and $\theta_I = t_I - t_C$.
Using these relations in (iii) we get :

$$t_I - t_C = 2[t_N - t_C] \quad \Rightarrow \quad t_N = \frac{t_I + t_C}{2} \qquad .....(iv)$$

(v) t_N of a thermocouple is fixed, whereas t_C and t_I are variables. *For example*, if t_I increases, then t_C decreases but t_N remains unaffected.

8. Seebeck effect is a reversible process

9. (i) Rate of change of thermo-emf with the change in the temperature difference of the temperatures of the two junctions is called Seebeck coefficient (S).

$$\therefore \quad S = \frac{dV}{d\theta} = \frac{d}{d\theta}[\alpha\theta + \frac{1}{2}\beta\theta^2] = \alpha + \beta\theta \qquad .....(i)$$

And if β is negligible, then $S = \alpha$ .....(*ii*)

(ii) Seebeck coefficient is also called thermo-electric power.

10. (i) Units of Seebeck coefficient (S) are VK^{-1} or $JC^{-1}K^{-1}$ or $JA^{-1}s^{-1}K^{-1}$

(ii) Dimensions of Seebeck coefficient are $ML^2T^{-3}A^{-1}K^{-1}$

Ex.10: The thermo-electric emf, E, of a copper-constantan thermo-couple and the temperature, t, of the hot junction (with cold junction at 0ºC) are found to satisfy approximately the relation : $E = at + \frac{1}{2}bt^2$, where t is in ºC. If $a = 40\ \mu V\ ºC^{-1}$ and $b = 0.04\ mV\ ºC^{-2}$, what is the temperature of the hot junction when thermo-electric emf is measured to be 8.0 mV ?

Sol.: $E = \frac{8}{1000}$ V $\qquad a = \frac{40}{10^6}$ V ºC^{-1} $\qquad b = \frac{0.04}{10^6}$ V ºC^{-1}

Putting these values, the given equation becomes

$$\frac{8}{1000} = \frac{40}{10^6}t + \frac{1}{2}\times\frac{0.04}{10^6}t^2$$

$$\Rightarrow \quad 8 = \frac{40}{1000}t + \frac{2}{100000}t^2$$

$$\Rightarrow \quad t^2 + 2000\,t - 400000 = 0$$

$$\Rightarrow \quad t = \frac{-2000 \pm \sqrt{(2000)^2 + 4\times 400000}}{2}$$

$$= \frac{-2000 \pm 2366.4}{2} = 183.2\,°C \qquad .....\textbf{Ans.}$$

(Neglecting negative value)

Peltier Effect

1. Peltier effect is reverse of Seebeck effect
2. When electric current is passed through a thermocouple, then heat is evolved at one junction and absorbed at another junction. *For example*, in a copper-iron thermocouple, if current flows from copper to iron, then this junction will become cold (as heat is required to be supplied at this junction, for the current to flow from copper to iron, as per Seebeck effect).
3. Quantity of heat absorbed or evolved = $\pi I t$, where π = Peltier coefficient, and t = time
4. The value of Peltier coefficient is different at the two junctions of a thermocouple, as it depends upon the temperature of the junction.
5. Let π_2 be the Peltier coefficient at a junction where energy is absorbed and π_1 be that at the other junction where energy is emitted, then

   Net energy absorbed = $\pi_2 It - \pi_1 It = (\pi_2 - \pi_1)It$ .....(*i*)

   If emf E is set up due to the energy absorbed, then also

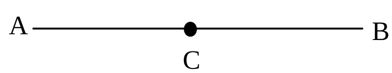
   Energy absorbed = $E I t$ .....(*ii*)

   $\therefore$ Comparing (i) and (ii), we get $E = \pi_2 - \pi_1$ and is called Peltier e.m.f. .....(*iii*)
6. Peltier effect is also a reversible process.
7. (i) Units of Peltier coefficient, π, are J A^{-1} s^{-1}

   (ii) Dimensions of Peltier coefficient are $ML^2T^{-3}A^{-1}$

Thomson Effect

1. When a current is passed through a thermo-couple, heat is evolved or absorbed not only at the junction but throughout the wire. This is due to the fact that different parts of the same wire are at different temperatures.
2. Thomson effect is a reversible process.
3. Let the wire AB be heated at its mid-point C.



   (i) When the current is passed in the direction of increasing temperature, then heat is absorbed along its length (AC); and when the current is passed in the direction of decreasing temperature, then heat is evolved along its length (CB). This type of effect is called *positive Thomson Effect*. Metals like copper, silver, zinc, antimony, cadmium show positive Thomson effect.

   (ii) When the current is passed in the direction of increasing temperature, then heat is evolved along its length; and when the current is passed in the direction of decreasing temperature, then heat is absorbed along its length. This type of effect is called *negative Thomson Effect*. Metals like iron, bismuth, cobalt, platinum, nickel show negative Thomson effect.

   (iii) Thomson effect for lead is practically zero i.e., heat will neither be evolved nor absorbed, when the current is flowing either in the direction of increasing temperature or decreasing temperature along the wire of Pb.

(iv) $Q = \sigma I t$, where σ = Thomson coefficient

Q = Heat produced per degree temperature difference along the wire

(v) Units of Thomson coefficient are $JA^{-1}\ s^{-1}\ K^{-1}$

(vi) Dimensions of Thomson coefficient are $ML^2T^{-3}A^{-1}K^{-1}$)

4. *Relation between Seebeck, Peltier and Thomson coefficients* :

(i) If V is thermo-e.m.f., then $S = \dfrac{dV}{dT}$ (S = Seebeck coefficient) .....(*i*)

(ii) $\pi = T.\dfrac{dV}{dT} = T.S$ (π = Peltier coefficient) .....(*ii*)

(iii) $\sigma = -T\dfrac{d^2V}{dT^2} = -T\left(\dfrac{dS}{dT}\right)$ (σ = Thomson coefficient) .....(*iii*)

Ex.11: The emf in a thermocouple, one junction of which is kept at 0ºC, is given by the relation : $V = \alpha t + ½ \beta t^2$. Find (i) Seebeck coefficient, (ii) Peltier co-efficient, (iii) Thomson coefficient, and (iv) neutral temperature.

Sol.: In absolute temperature, $V = \alpha (T - 273) + ½ \beta(T - 273)^2$

(i) $S = \dfrac{dV}{dT} = \alpha + \beta (T - 273) = \alpha + \beta t$ .....(*i*)**Ans.**

(ii) $\pi = T\dfrac{dV}{dT} = T[\alpha + \beta t]$ .....(*ii*)**Ans.**

(iii) $\sigma = -T\dfrac{d^2V}{dT^2} = -T\left(\dfrac{dS}{dT}\right)$

$= -T\dfrac{d}{dT}[\alpha + \beta (T - 273)]$

$= -T\left[\dfrac{d}{dT}(\alpha) + \beta\dfrac{d}{dT}(T - 273)\right]$

$= -T[0 + \beta] = -T\beta \qquad = -(t + 273)\beta$ .....(*iii*)**Ans.**

(iv) At neutral temperature, $\dfrac{dV}{dT} = 0 \quad \Rightarrow \quad S = 0$

Ex.12: An electric motor operating at 50 V *dc* supply draws a current of 12.0 A. If the efficiency of the motor is 30%, estimate the resistance of the motor-winding.

Sol.: Input power given to the motor $= V\,I = 50 \times 12 \text{ W} = 600 \text{ W}$

$\therefore$ Output power of the motor $= \text{Input} \times \text{efficiency} = 600 \times \dfrac{30}{100} = 180 \text{ W}$

Loss in power in the motor = output – input = 600 – 180 = 420 W

Clearly this loss appears as heat in the resistance R of the wire of winding

$\Rightarrow \quad I^2 R = 420 \qquad \Rightarrow \quad (12)^2 R = 420$

$$\therefore \quad R = \frac{420}{12 \times 12} = 2.92\ \Omega$$ .....**Ans.**