CURRENT ELECTRICITY

(Electric Current, Thermal and Chemical Effectof Current)

ELECTRIC CURRENT

Consider the ends of the conductor be connected to a battery, i.e., an electric field is maintained within the conductor. Now the field acts on the electrons and gives them a resultant motion in the direction of $-\vec{E}$ because a free charge in electric field experiences a force. The flow of electrons constitutes an electric current.

The time rate of flow of charge through any cross section is called current. If a charge Δq passes through an area in time Δt, then the average electric current through the area in this time is defined as

$$i_{av} = \frac{\Delta q}{\Delta t} \quad ...(1)$$

Now, the instantaneous current is given by

$$i = \lim_{\Delta t \to 0} \frac{\Delta q}{\Delta t} = \frac{dq}{dt} \quad ...(2)$$

The SI unit of current is ampere. If one coulomb of charge crosses an area in one second, the current is one ampere. For transient currnet $i = \frac{dq}{dt}$ while for steady current $i = \frac{q}{t}$

The conventional current is in opposite direction to the direction of movment of electrons.

CURRENT DENSITY

The current density j at a point is defined as a vector having magnitude equal to current-per unit area surrounding that point and normal to the direction of charge flow, i.e., direction in which current passes through that point.

If $\overrightarrow{\Delta S}$ be the area vector corresponding to area ΔS, then $\Delta i = \vec{j}.\overrightarrow{\Delta S}$

The total current through finite surface area S is

$i = \int_s \vec{j}.\overrightarrow{\Delta S}$, If current i is uniformally distributed over an areas and perpendicular to it then $i = \int \vec{j}.\overrightarrow{\Delta S}$

DRIFT VELOCITY

we know that a conductor contains a large number of free electrons or conduction electrons. When electrons leave their atoms and become free, the atoms of the conductor become positively charged and are called positive ions. So, the remaining material is a collection of relatively positive ions known as lattice.

In the absence of any external electric field, the electric current through this area is zero, otherwise the conductor will not remain equipotential.

When an electric field is established between the two ends of the conductor, the free electrons experience an electric force opposite to the field. Due to this force, the motion of electrons is accelerated.

The field does not give an accelerated motion to the electrons but it simply gives them a small constant velocity along the conductor which is superimposed on the random motion of the electrons. So, the electrons drift slowly opposite to the applied field. The net transfer of electrons across a cross section results in current. If the electron drifts a distance l in a long time t. we define drift velocity as

$$v_d = \frac{l}{d} \quad ...(1)$$

The drift velocity is the average uniform velocity by free electrons inside a conductor by the application of an electric field.

where e is charge of electron with mass m.

[$\because$ force on electron due to electric field, F = e E and acceleration , a = F/m = (e E/m)]

$$\therefore \quad v_d = \frac{eE}{m}.\tau \quad \tau \text{ in time between two successive collision.} \quad ...(3)$$

RELATIONSHIP BETWEEN CURRENT DENSITY AND DRIFT

An electric field is maintained between the two ends of a conductor towards the left. The electrons move towards the right. Let the drift velocity of the electrons be v_d. Suppose there are n charge carriers per unit volume and each charge carrier has a charge e. In time dt, the electron advance a distance l which is given by

$$l = v_d\, dt$$

Now calculate the number of electrons crossing the length l of the conductor in time dt. This will be equal to the number of electrons contained in a volume Al, i.e. Av_d dt.

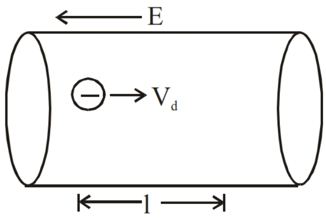
$\therefore$ number of electrons = volume × number of electrons per unit volume

$= A\, v_d\, dt \times n$

Hence charge crossing in time dt

= number of electrons × charge on the electron

$= Av_d\, dt\, n\, e$



Further, current $\quad i = \frac{\text{charge crossing in time dt}}{\text{time dt}}$

$$i = \frac{Av_d dt\, n\, e}{dt} = Av_d ne$$

So $\quad \boxed{i = neAv_d} \quad ...(1)$

The current density is given by

$$j = \frac{i}{A} = \frac{neAv_d}{A}$$

or $\quad \boxed{j = nev_d} \quad ...(2)$

Mobility of free electron is defined in a conductor is drift velocity acquired per unit electric field strength.

applied across the conductor, $\mu = \frac{Vd}{E} \Rightarrow Vd = \mu E$

or $\quad i = \mu(neA)E$

OHM'S LAW

The current flowing through a conductor is always directly proportional to the potential difference across its two ends.

$$V \propto i \quad \text{or} \quad V = Ri$$

where R is a constant of proportionality and is called as resistance of the conductor. So, the reistance of a conductor is defined as the ratio of the potential difference applied across the conductor to the current flowing through it, i.e. $R = V/i$. The value of resistance depends upon the nature of conductor, its dimensions and physical conditions.

We know that drift velocity v_d is given by

$$v_d = \left(\frac{eE}{m}\right)\tau$$

$$= \left(\frac{eV}{ml}\right)\tau \qquad \left(\because E = \frac{V}{l}\right) \qquad ...(1)$$

We also know that relation betwen current i and drift velocity v_d is given by

$$i = neAv_d \qquad ...(2)$$

Substituting the value of v_d in eq. (2) from eq. (1), we have

$$i = neA\left(\frac{eV}{ml}\right)\tau = \left(\frac{ne^2A\tau}{ml}\right)V$$

or $$\frac{V}{i} = \frac{ml}{ne^2A\tau} = R \qquad \text{a constant}$$

R is constant for a given conductor, known as resistance of the conductor. Therefore,

$$V = R\,i$$

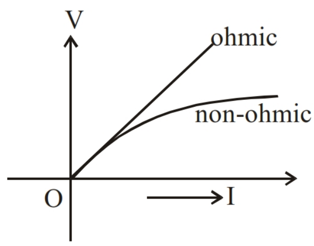
We know that

$$j = n\,e\,v_d$$

Further, $$v_d = \left(\frac{eE}{m}\right)\tau$$

$\therefore$ $$j = ne\left[\left(\frac{eE}{m}\right)\tau\right] = \frac{ne^2\tau}{m}E$$

or $$j = \sigma E \qquad \text{where } \sigma = \frac{ne^2\tau}{m}$$



The constant σ is called as electrical conductivity and is temperature dependent. So we have

$$\boxed{j = \sigma E}$$

This equation is known as Ohm's law.

V-I line is not a straight line.

RESISTIVITY AND CONDUCTIVITY

The reistance of a conductor is directly proportional to its length l and inversely proportional to the area of cross section A, i.e.

$$R \propto l \qquad \text{and} \qquad R \propto \frac{1}{A}$$

$$R \propto \frac{l}{A} \qquad \text{or} \qquad R = \rho\left(\frac{l}{A}\right)$$

If $l = 1$ and $A = 1$, then $R = \rho$

Therefore, specific resistance of the material of a conductor is equal to the resistance offered by the wire of unit length and unit area of corss section of the material of wire. Its unit is ohm-metre. This is constant for a material.

The reciprocal of resistivity of the material of a conductor is called as conductivity

$$\sigma = \frac{1}{\rho} = \frac{j}{E}$$

The unit of conductivity is ohm^{-1} metre^{-1} $(\Omega m)^{-1}$. Good conductors of electricity have large conductivity than insulators.

FACTORS AFFECTING ELECTRICAL RESISTIVITY

The drift velocity v_d in magnitude of electrons is given by

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

The current flowing through the conductor due to drift of electrons is given by

$$i = nAev_d$$

$$= nAe\left(\frac{eE}{m}\right)\tau = \frac{nAe^2E}{m}\tau \qquad ...(2)$$

If V be the potential difference applied across the two ends of the conductor, then

$$E = \frac{V}{l} \qquad ...(3)$$

From eqs. (2) and (3) we get,

$$i = \frac{nAe^2V}{ml}\tau$$

$$\text{or} \quad R = \frac{V}{i} = \frac{m}{ne^2\tau}\left(\frac{l}{A}\right) \text{ or } R = \rho\left(\frac{l}{A}\right) \qquad ...(4)$$

where $\rho = \text{resistivity} = \dfrac{m}{ne^2\tau}$

The resistivity ρ of the material of a conductor depends upon the following factors:

(i) It is inversely proportional to the number of free electrons per unit volume n of the conductor, i.e., depends on the nature of material.

(ii) It is inversely proportional to the average relaxation time τ of free electrons in the conductor. As τ is a function of temperature and hence the resistivity of a conductor depends on its temperature. The resistivity increases with the increase in temperature of conductor.

TEMPERATURE DEPENDENCE OF RESISTIVITY

Small temperature variations, the variation of resistivity can be expressed as

$$\rho(T) = \rho(T_0)[1 + \alpha(T - T_0)]$$

where $\rho(T)$ and $\rho(T_0)$ are the resistivities at temperature T and T_0 respectively and α is temperature coefficient of resistivity.

The resistance of a conductor is given by

$$R = \rho\left(\frac{l}{A}\right)$$ $\rho(T) =$ Resistivity at temperature T

$\rho(T_0) =$ Resistivity at temperature of T_0.

The resistance depends on the length and area of cross section besides resistivity. When the temperature increases, the length and area of cross section also increases are quite small and the factor (l/A) may be treated as constant. Therefore,

$R \propto \rho$ $R(T) =$ Restance at temperature T.

Now, $R(T) = T(T_0)\left[1 + \alpha(T - T_0)\right]$ $R(T)$ = Resistance at temperature T_0.

where α is known as temperature coefficient of resistance.

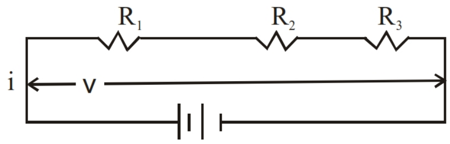
Grouping of Resistance

(A) Resistances in Series

In the shown figure. shows the series combination of three resistors having resistanceR_1 and R_3 and. A battery of e.m.f. E is connected across this combination. In this combination, the same current i is flowing through each resistor.

Let V_1 , V_2 and V_3 be the potential differences across R_1 , R_2 and R_3 respectively. Now according to Ohn's

$V_1 = i\,R_1$, $V_2 = i\,R_2$ and $V_3 = i\,R_3$



Further $V = V_1+V_2+V_3$

$= iR_1 + iR_2 + iR_3$

$= i(R_1 + R_2 + R_3)$ ...(1)

If R_2 be the equivalent resistance of series combination, then the potential difference V across the combination will be

$V = i\,R_S$ ...(2)

Compairing eqs. (1) and 2), we get

$R_S = R_1 + R_2 + R_3$ ...(3)

In series combination, the following points should be remembered

(i) The current is same in every part of the circuit

(ii) The total reistance of the circuit is equqal to the sum of indivd resistances connected in the circuit.

(iii) The total resistance of series combination is more than the greatest resistance of the circuit.

(iv) The potential difference across any resistor is proportional to its resistance, i.e. $v_1 : v_2 : v_3 = R_1 : R_2 : R_3$

(B) Resistance in Parallel

Fig. shows a parallel combination of three resistors having resistance R_1, R_2 and R_3 battery of e.m.f. E is connected points A and B. Let i be the current from the battery and i_1, i_2 and i_3 be the currents through resistance R_1 , R_2 and R_3 respectively. Then

$i = i_1 + i_2 + i_3$ ...(5)

As shown in the figure, the potential difference across each resistance is V. Applying Ohm's law, we have

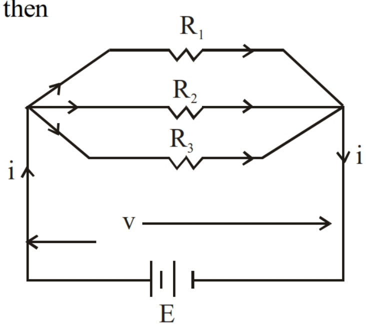
$V = i_1R_1 = i_2\,R_2 = i_3\,R_3$

or $i_1 = \frac{V}{R_1}$, $i_2 = \frac{V}{R_2}$ and $i_3 = \frac{V}{R_3}$

Substituting these values in eq. (5), we get

$$i = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3} \qquad \text{...(6)}$$

Let R_p be the equivalent resistance of the parallel combination, then



$$V = i R_p \quad \text{or} \quad i = \frac{V}{R_p} \qquad \text{...(7)}$$

Comparing eqs. (6) and (7), we get

$$\frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

or
$$\boxed{\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}} \qquad \text{...(8)}$$

The reciprocal of equivalent resistance of parallel combination is equal to the sum of the reciprocals of the individual resistances.

The following points should be remembered in case of parallel combination:

(i) The potential difference across each resistance is the same

(ii) The current is different in different resistances. The sum of the currents in different resistances is equal to the main currents in the circuit, i.e.,

$$i = i_1 + i_2 + i_3 \qquad \text{...(9)}$$

(iii) The current through any registor is inversely proportional to its resistance.

(iv) The total resistance in parallel combination is less than the least resistance used in the circuit.

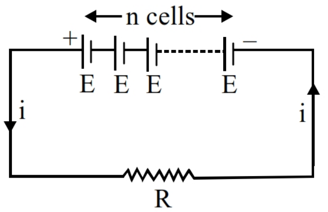
BATTERY AND ELECTROMOTIVE FORCE (E.M.F.)

A battery is a device which maintains a constant potential difference between its two terminals.

The potential difference between the two terminals. The potential difference between two terminals provides an electrostatic field Ee between tw terminals the emf is defined as the work done while by cell a unit positive charge flows from –ve plate to +ve plate.

GROUPING OF CELLS

(1) Sereis grouping : Fig shows a series combination of n cells each of e.m.f. E and internal resistance r.



$\therefore$ current through the circuit $= \dfrac{\text{total emf}}{\text{total resistance}}$

or
$$i = \frac{nE}{(R + nr)} \qquad \text{...(1)}$$

(i) If R>>r, r i.e., the effective internal resistance is as far far less than external resistance r can be neglected in comparison of R, then

$$i = \frac{nE}{R} = \text{n times the current drawn from single cell.} \qquad \text{...(2)}$$

(ii) If r >> R, i.e., the effective internal resistance is far far greater than external resistance, then R can be neglected in comparison to hr, then

$$i = \frac{nE}{nR} = \frac{E}{r} \qquad ...(3)$$

The current in the circuit is the same as due to a single cell, so n of useful

(iii) If in series grouping of n cells, s cells are reversed, then

$$E_{eq} = (n-s)E - sE = (n-2s)E$$

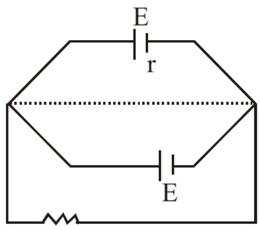
Total resistance of the circuit = (R+n r)

$$\therefore \qquad i = \frac{(n-2s)E}{(R+nr)} \qquad ...(4)$$

(2) Parallel grouping

$\therefore$ Total Resistance of the circuit $= [R + (r/n)]$ [$\because$ R and (r/n) are in series]

Now, current in the cirut, $i = \dfrac{E}{R + \left(\dfrac{r}{n}\right)}$ ...(5)



(i) If R>> (r/n), i.e. (r/n) can be neglected in comparison to R, then

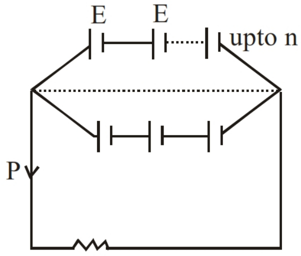
$$i = \frac{E}{R} \qquad ...(6)$$

Therefore, the current in the circuit is equal to the circuit current due to a single cell.

(ii) If (r/n) >> R, i.e., R can be neglected in comarison to (r/n), then

$$i = \frac{nE}{r} \qquad ...(7)$$

Therefore, if the effective internal resistance is greater than the external resistance, the current in the circuit is equal to n time the circuit current due to a single cell.



(3) Mixed Grouping

Total resistance of circuit $= R + \left(\dfrac{nr}{m}\right)$

The current i in the circuit is given by

$$i = \frac{nE}{R + (nr/m)} = \frac{nmE}{mR + nr} = \frac{NE}{mR + nr}$$

The current i in the circuit will be maximum when the factor (m R+ n r) in the denominator is minimum. The denominator is minimum when mR = n r

$$\therefore \qquad R = \left(\frac{nr}{m}\right)$$

Hence current will be maximum when external resistance is equal to the total internal resistance of all the cells.

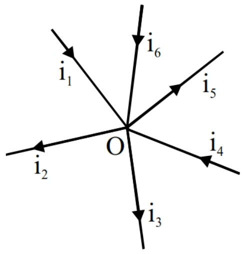
KIRCHHOFF'S LAW

Ohmm;s law is unable to give current in complicated cirucit. Kirchhoff's in1842, gave two general laws which are extremely useful in electrical circuits. There are.

(i) The algebraic sum of the currents at any junction in a circuit is zero, i.e.

$$\sum i = 0$$

This means that there is no accumulation of electric charge at any point in the circuit.



(ii) In any closed circuit,the algebraic sum of the products of the current and resistance of each part of the circuit is equal to the total emf in the circuit i.e.,

$$\sum iR = \sum E$$

The product of current and resistance is taken as positive when we traverse in the direction of current. The emf is taken positive when we traverese from negative to positive electrode through electrolyte.

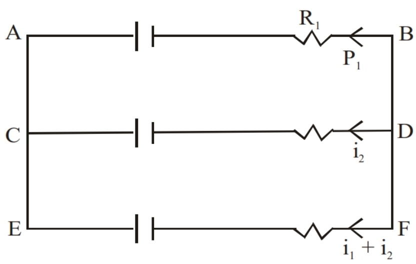
Let us apply Kirchhoff's second law to figure shown

For the mesh ACDBA,

$$i_1R_1 - i_2R_2 = E_1 - E_2 \qquad ...(i)$$

For the mesh EFDCE

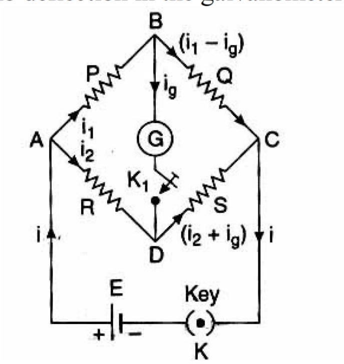
$$i_2R_2 + (i_1 + i_2) R_3 = E_2 \qquad ...(ii)$$



From FFBAE, $i_1 R_1 + (i_1 + i_2) R_3 = E_1$ ...(iii)

CONDITION OF BALANCE IN WHEATSTONE'S BRIDGE

When there is no deflection in the galvanometer, the bridge is known as balanced. The condition of balance is given by

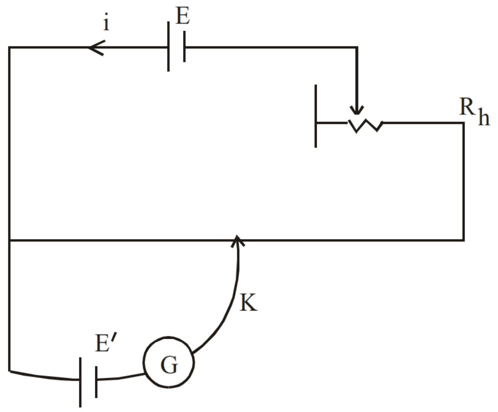


$$\frac{P}{Q}=\frac{R}{S} \quad \text{or} \quad \frac{P}{R}=\frac{Q}{S}$$

When galvanometer and battery are exchanged then still the galvanometer shows no reflection.

POTENTIOMETER

Potentiometer is a device which is used to meosure the potential difference more accurately then an ideal voltmeter. The potentiometer does not any current from source. Hence it is equivalent to an draw ideal voltmeter.



Let v be potential difference across certain portion of wire. Let i be current through portion of stretched wire

$v = iR$ --- (i) $R = \rho.\frac{l}{A}$

$v = i\rho\left(\frac{l}{A}\right)$ For i = constant through wire of uniform cross-section

If L = total length of potentiometer wire

$\varepsilon =$ emf of driving cell or standard cell.

$$K = \frac{\varepsilon}{L}$$

$$V = K.l \Rightarrow v = \frac{\varepsilon}{L}.l$$

Comparision of emfs of two cells can found by potentiometer $\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}$ where l_1 and l_2 are balancing lengths while cells of ε_1 and ε_2 are attached respectively.

The internal resistance r of a cell is given by $r = \left(\frac{i_1}{i_2} - 1\right)R$; where l_1 and l_2 are balancing lengths and R is external resistance

HEATING EFFECT OF CURRENT

The phenomenon in which heat energy is produced in a conductor due to flow of electric current (flow of electrons) is known as heating effect of current.

Consider a resistor of resistance R. Let a potential difference V is maintained at its ends and a current i is flowing through it for a time t. If the charge q flows through it in time t, then

$q = i\,t$ [charge = current × time]

Now, the workdone by electric field on free electrons in time t is given by

$= V(i\,t)$ joule

$= (i\,R)(i\,t) = i^2\,R\,t$ joule

The workdone by electric field is converted in thermal energy of resistor through the collisions with ions or atoms. The thermal energy is generally referred to as heat produced in resistor. So, the amount of heat produced (H) is given by $\boxed{H = W = i^2Rt \text{ joule}}$

In calorie, the heat produced is given by

$$H = \frac{i^2Rt}{4.18} \text{ calorie}$$ This is expression for joule's law of heating...(4)

JOULE'S LAWS OF HEATING

Joule's laws :

(a) The heat produced in a given resistor in a given time is proportional to the square of current flowing in it, i.e.,

$$H \propto i^2 \qquad ...(1)$$

(b) The heat produced in a given resistor in a given time by a given current is directly proportional to the resistance, i.e.,

$$H \propto R \qquad ...(2)$$

(c) The heat produced in a given resistor by a given current is proportional to time t for which the current is passed, i.e.,

$$H \propto t \qquad ...(3)$$

ELECTRIC POWER

The electric power is defined as the rate at which work is done by the source of e.m.f. in maintaining the current in an electric circuit.

If an amount of work W is done in maintaining electric current in a circuit for a time t, then electric power is given by

$$P = \frac{W}{t} \qquad ...(1)$$

Let a current i ampere flows through a conductor for a time t second under a potential difference V volt. The workdone for maintaining the current is given by

$$W = Vit \text{ joule} \quad ...(2)$$

So, the power of an electric circuit is one watt when one ampere current flows through it under a potential difference of one watt.

1 watt = 1 joule/sec.

The bigger units of electric power are

$1 \text{ kW} = 10^3 \text{ W}$ and $1 \text{ MW} = 10^6 \text{ W}$

Commercial unit of power is horse power (HP).

1 HP = 746 watt.

Other expression for power are :

$$P = i^2R \text{ and } P = \frac{V^2}{R}$$

$$\boxed{P = Vi = i^2R = \frac{V^2}{R}} \quad ...(3)$$

(i) When resistances are connected in series.

In this case, the current in each resistance will be the same. Hence from eq. (3), we have

$$P \propto V \text{ and } p \propto R$$

This shows that in series connections, the potential difference and power consumed will be more in larger resistance.

(ii) When resistances are connected in parallel.

In this case, the potential difference V across each resistance is same. Hence from eq. (3), we have

$$P \propto \left(\frac{1}{R}\right) \text{ and } i \propto \left(\frac{1}{R}\right)$$

This shows that in parallel connections, the current and power consumed will be more in smaller resistance.

APPLICATIONS OF HEATING EFFECT OF CURRENT

(1) Series combination of bulbs :

Consider a series combination of three bulbs of powers P_1, P_2 and P_3 which are manufactured for working on a supply of V volt. The resistances of these bulbs are respectively.

$$R_1 = \frac{V^2}{P_1}, R_2 = \frac{V^2}{P_2} \text{ and } R_3 = \frac{V^2}{P_3} \quad ...(1)$$

$\therefore$ total resistance, $R = R_1 + R_2 + R_3$ ...(2)

Effective power $\frac{V^2}{P} = \frac{V^2}{P_1} + \frac{V^2}{P_2} + \frac{V^2}{P_3}$

or $$\frac{1}{P} = \frac{1}{P_1} + \frac{1}{P_2} + \frac{1}{P_3} \quad ...(3)$$

Current through each bulb

$$i = \frac{V}{R_1 + R_2 + R_3} \quad ...(4)$$

The brightness of these bulbs are

$$H_1 = i^2 R_1,\ H_2 = i^2 R_2 \text{ and } H_3 = i^2 R_3 \ ...(5)$$

This shows that the bulb with highest resistance will glow with maximum brightness. Further $R \propto \frac{1}{P}$, therefore, the bulb of lowest power or wattage will have highest resistance and will glow with maximum brightness.

(2) Parallel combination of bulbs :

Consider a parallel combination of three bulbs of powers P_1, P_2 and P_3 respectively which are manufactured for working on a supply voltage V volt. In this case, we have

$$R_1 = \frac{V^2}{P_1}, R_2 = \frac{V^2}{P^2} \text{ and } R_3 = \frac{V^2}{P_3} \ ...(6)$$

Now $\frac{1}{R}=\frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_3}$ ...(7) (where R is effective resistance of the circuit)

From eqs. (6) and (7), we get

$$P = P_1 + P_2 + P_3 \quad ...(8)$$

The brightness of three bulbs will be respectively

$$H_1 = \frac{V^2}{R_1},\ H_2 = \frac{V^2}{R_2} \text{ and } H_3 = \frac{V^2}{R_3}$$

The resistance of highest wattage (power) bulb is minimum and hence the bulb of maximum wattage will glow with maximum brightness.

SEEBECK EFFECT

Seeback discovered that if two dissimilar metals (say bars or wires of copper and iron) are joined in series to form a closed circuit, and their two junctions are maintained at different temperatures, an e.m.f. is developed.

The current produced in this way without the use of a cell or a battery is known as thermoelectric current and the e.m.f. responsible for thermoelectric current is known as thermo e.m.f. This effect is known as Seebeck effect. The arrangement of wires is known as thermocouple.

Seebeck observed that the magnitude and direction of thermo e.m.f. depends on

(i) the nature of metals forming the thermocouple.

(ii) differnece in temperatures of two junctions.

Seebeck also observed that if the hot and cold junctions are interchanged then the direction of thermoelectric current is also reversed. This shows that seebeck effect is reversible effect.

Thermoelectric Series

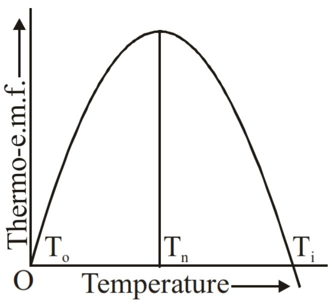
Seebeck arranged a large number of metals in a series such that when any two of these metals form a thermocouple, the current at the cold junction is from the metal occurring earlier in the series to the metal occurring later in the series. The series is known as themoelectric series. The series is as follows :

Antimony, nichrome, iron, zinc, copper, gold, silver, lead, aluminium, mercury, platinum, nickel constantan, bismuth.

Variation of thermo e.m.f. with temperature

(Neutral temperature and temperature of inversion) :

If a graph is plotted between the temperature of the hot junction and the thermo e.m.f. e, the cold junction being kept at 0°C, a parabolic curve is obtained as shown in fig. The thermo e.m.f.



increases with the temperature of hot junction and becomes maximum at a particular temperature. The temiperature of the hot junction at which thermo e.m.f., in a thermocouple is maximum is known as neutral temperature T_n for that couple.

Thus the temperature at which the thermo e.m.f. is zero is known as inversion temperature or temperature of inversion.

Beyond this temperature the e.m.f. again increases but in the reverse direction.

The temperature of inversion depends upon

(i) the nature of materials forming the thermocouple

(ii) the temperature of cold junction.

The thermo e.m.f., e varies with temperature according to the following equation.

$$e = aT + bT^2 \qquad ...(1)$$

$$\frac{de}{dT} = a + 2bT$$

at $T = T_n$, e is maximum, i.e., $\frac{de}{dT} = 0$. Thus

$$0 = a + 2bT_n$$

or $$T_n = -\frac{a}{2b} \qquad ...(2)$$

Further at $T = T_i, e = 0$. Thus from equation (1)

$$0 = aT_i + bT_i^2$$

$$T_i = -\frac{a}{b} \qquad ...(3)$$

From equations (2) and (3)

$$T_i = 2T_n$$

Thus the inversion temperature T_i is as much above the neutral temperature as the temperature of the cold junction (0°C) is below it. T_i is therefore not a constant for the given thermocouple but depends upon the temperature of the cold junction.

If T_0 be the temperature of cold junction, then

$$T_i - T_n = T_n - T_0 \quad \text{or} \quad T_i = 2T_n - T_0$$

$$\therefore \quad \boxed{T_n = \frac{T_i + T_0}{2}}$$

Peltier's Effect :

Peltier discovered an effect which is the converse of Seebeck effect. When a current is passed across the junction of two dissimilar metals, heat is evolved at one junction and absorbed at the other, i.e., one junction is heated and the other is cooled. This effect is known as Peltier effect.

Peltier Coefficient :

The amount of heat (in joules) absorbed or evolved at a junction of two different metals when one coulomb of charge flows at the junction is called the Peltier coefficient. It is denoted by

$$\pi = \frac{\Delta H}{\Delta Q} = \frac{\text{Peltier heat}}{\text{charge flowing}}$$

This coefficient is not constant but varies as the absolute temperature of the junction. It also depends on the metal used.

If a charge q coulomb passes across a junction having a peltier coefficient π volt, then the energy absorbed or evolved at the junction = πq joule.

If V be the junctional P.D. in volt, then

energy absorbed or evolved = Vq joule

$$\therefore \quad \pi q = Vq$$

$$\pi = V$$

Hence the Peltier coefficient expressed in joule per coulomb is numerically equal to the junctional P.D. in volt.

Thomson effect :

Thomson observed that when two parts of a single conductor are maintained at different temperatures and a current is passed through it, heat may be absorbed or evolved in different sections of may be absorbed or evolved in different sections of the conductor. This effect is called Thomson effect.

According to Thomson effect, heat is absorbed or evolved in excess of Joule heat when a current is passed through an unequally heated conductor.

Thomson coefficient :

Thomson coefficient is defined as the amount of heat evolved or absorbed when a unit positive charge is passed through a part of the wire whose ends are maintained at a unit temperature difference. This is denoted by σ.

Let a charge ΔQ is passed through a small part of the wire having a temperature difference ΔT between the ends. Thomson heat is

$$\Delta H = \sigma(\Delta Q)(\Delta T)$$

or

$$\sigma = \frac{\Delta H}{(\Delta Q)(\Delta T)}$$

CHEMICAL EFFECT OF ELECTRIC CURRENT

It has been observed that some liquids allow the passage of current through them while some do not show such behaviour. On the basis of their electrical behaviour liquids can be divided into the following three categories :

(i) The liquids which do not allow the current to pass through them. For example distilled water, vegetable oil etc.

(ii) The liquids which allow the current to pass through them but do not dissociate into ions. For example, mercury.

(iii) The liquids which allow current to pass through them and also dissociate into ions. For example salt solutions, acid and bases. Such liquids are called electrolytes.

Thus when a current is passed through an electrolyte, it dissociates into ions. This is known as chemical effect of current.

FARADAY'S LAWS OF ELECTROLYSIS

The relation between quantity of electric charge passed and the amount of ion deposited at the electrode is given by Faraday's laws of electrolysis. There are two laws :

Faraday's first law :

According to Faraday's first law, the mass of the substance deposited or liberated in electrolysis is directly proportional to the charge passed through the electrolyte.

Let m be the mass of a substance deposited or liberated at an electrode when a charge q is passed through the electrolyte. Thus

$$m \propto q \quad \text{or} \quad m = Zq \qquad ...(1)$$

where Z is constant of proportionality and is known as electrochemical equivalent (E.C.E.) of the substance.

If i be the current passed through the electrolyte for a time t, then

$$q = i\,t \qquad ...(2)$$

From eqs. (1) and (2)

$$m = Z\,i\,t \qquad ...(3)$$

If q = 1 coulomb, then Z = m

Thus the electrochemical equivalent (E.C.E.) of a substance may be defined as the mass of the substance liberated or deposited on an electrode during electrolysis when one coulomb of charge is passed through the electrolyte.

The S.I. unit of E.C.E. is kg/coulomb. But generally this is expressed in gram/coulomb (gC^{-1}). The value of E.C.E. of copper and silver are $3294 \times 10^{-7}\ gC^{-1}$ and $11180 \times 10^{-7}\ gC^{-1}$ respectively.

Faraday's second law :

According to Faraday's second law, when the same amount of charge is passed through different electrodes, the masses of different substances deposited or libarated at the electrodes are proportional to their chemical equivalents.

If m_1 and m_2 be the masses of the substances deposited or liberated and E_1 and E_2 be their respective chemical equivalent, then

$$\frac{m_1}{m_2} = \frac{E_1}{E_2} \quad \text{or} \quad \frac{Z_1 it}{Z_2 it} = \frac{E_1}{E_2} \quad \text{or} \quad \frac{Z_1}{Z_2} = \frac{E_1}{E_2}$$

The chemical equivalent of the substance is defined as the ratio of atomic weight to the valency. Thus

$$E = \frac{\text{atomic weight}}{\text{valency}}$$

The atomic weight of silver is 108 and its valency is 1. Therefore, its chemical equivalent is 108. Similarly, the chemical equivalent of copper is 31.75.

FARADAY CONSTANT

From Faraday's second law

$$\frac{Z_1}{Z_2} = \frac{E_1}{E_2} \quad \text{or} \quad \frac{E_1}{Z_1} = \frac{E_2}{Z_2}$$

$$\therefore \quad \frac{E}{Z} = \text{a constant} = F \text{ (Faraday constant)}$$

Thus the ratio of $\left(\frac{E}{Z}\right)$ is same for all substances and is called as Faraday constant.

Now, $$F = \frac{E}{Z} = \frac{E}{\left(\frac{m}{q}\right)} = \frac{Eq}{m}$$

So, the Faraday constant is equal to the charge required to liberate one gram equivalent of substance at an electrode during electrolysis. Its value is 96500 C/gram equivalent.

In case of copper, E.C.E. = $0.0003294\ gC^{-1}$ and E = 31.75 g

$\therefore$ Faraday constant = $\dfrac{31.75}{0.0003294}$

= 96500 C/gram equivalent.

The charge of 1 mole of electrons is called one faraday. So

one faraday = $N_A \times e$

= $(6.023 \times 10^{23}) \times (1.602 \times 10^{-19}$ C)

= 96500 C.

Therefore, faraday is unit of charge (1 faraday = 96500 C) while the quantity charge per mole of electrons is called Faraday constant (F = 96500 C/mole or 1 faraday).