## NCERT-XII / Unit- 03 – Current Electricity

### CURRENT ELECTRICITY

**OHM'S LAW:-** Let us consider a conductor through which a current I is flowing and V be the potential difference between its ends ,then Ohm's law states that

$V \propto I$

or, $V = R I$ ……..(1)

where R is the resistance of the conductor.

Its SI units of resistance is ohm, and is denoted by Ω.

The resistance R not only depends on the material of the conductor but also on its dimensions .

**Resistivity:-**The resistance R of a conductor of length $l$ and cross-sectional area A is found to be ,

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

Combining, we have

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

where ρ is called resistivity or specific resistance and

ρ depends on the material of the conductor but not on its dimensions.

**Current density** :-

Using Ohm's law

$$V = I \times R = \frac{I\rho l}{A}$$

The current density is defined as the current through unit area normal to the current,

$I/A =$ **j** , is called current density .

The SI units of the current density is $A/m^2$

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**Ohm's law in classical form:-**

If E is the magnitude of uniform electric field in the conductor whose length is $l$, then the potential difference V across its ends is $E\ l$.

Using these, the last equation reads

$E\,l = j\,\rho\,l$

or $E = j\,\rho$ ........................(1)

In vector form $\mathbf{E} = \mathbf{j}\,\rho$ ........................(2)

The current density is defined as the current through unit area normal to the current. It is directed along E .

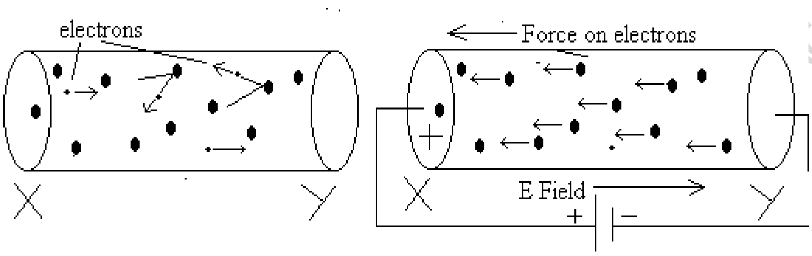
Equation (1)can be written as $\mathbf{j} = \sigma\,\mathbf{E}$ ……………..(2)

where $\sigma = 1/\rho$ is called the conductivity.

**This is Ohm's law in classical form**.

**Q- What is drift velocity ? Final an expression for it**

The uniform velocity with which free electrons present in a conductor are being drifted in an direction opposite is the applied electric field when connected to a source is known as drift velocity.




Let us consider a conductor (XY) having n no. of free electrons which are moving randomly with all kind of velocity, resulting zero net motion i.e.

$$\vec{u}_1 + \vec{u}_2 + \ldots\ldots + \vec{u}_n = 0 --- (1)$$

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Let the X end of the conductor be connected to + ve terminal and Y end be connected to – ve terminal of a source , creating an electric field $\vec{E}$ in direction from end X to Y. The acceleration acting on the electrons

$$\vec{a} = -\frac{e\vec{E}}{m} \quad ....\{2\}$$

Now all the free electrons are bound to move in a direction from end Y to X and at this stage the average velocity of the free electrons is known as drift velocity ($\vec{v_d}$) , which is given as

$$\therefore \vec{v_d} = \frac{\vec{v_1} + \vec{v_2} + .......\vec{v_n}}{n}$$

$$= \frac{(v_1 + at_1) + (v_2 + at_2) + ........(u_n + at_n)}{n}$$

$$- = \frac{(\vec{v_1} + \vec{v_2} + .....\vec{v_n}) + a(t_1 + t_2 + .... + t_n)}{n}$$

$$= \frac{O + \vec{a}(t_1 + t_2 + .......t_n)}{n} \Rightarrow \vec{v_d} = \vec{a}\,.\,\tau_{av} .................(3)$$

where, $\tau_{av} = \dfrac{(t_1 + t_2 + .......t_n)}{n}$

is the mean relaxation time Putting (2) in (3) $\vec{v_d} = -\dfrac{e\vec{E}}{m}\tau_{av}$ ............ (4)

**here negative sign indicates that direction of drift velocity is opposite to the applied electric field**.

The drift velocity is independent of time as $\tau_{av}$ is constant . The electrons move with an average velocity which is independent of time, although electrons are accelerated . This is the **phenomenon of drift** & the velocity is called drift velocity.

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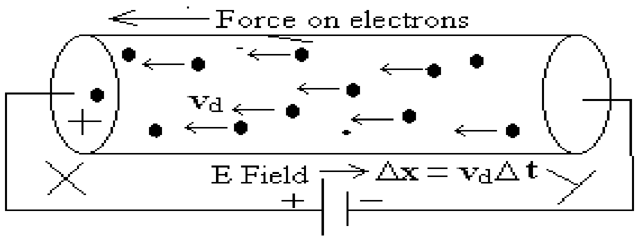
**Expression for current in terms of drift velocity**




Let a portion of the conductor be connected to the source so that I amount of current is flowing through the conductor creating an electric field along its length and the direction of drift velocity is opposite to that of drift velocity .

Due to the drift of all the free electrons in a small time interval $\Delta t$ crosses a length $\Delta x = v_d \Delta t$ , through its cross section A .

If n be the number of free electrons per unit volume of the conductor , then total electrons crossing A in time $\Delta t$ is

$N = n A \Delta x = n A v_d \Delta t$

Total charge crossing A in time $\Delta t$ = Ne ( e = charge of electron)

$\Rightarrow I \Delta t = n A v_d \Delta t\, e$

$\Rightarrow$ $\mathbf{I = n e A v_d}$ **.............(1)**

As e is constant $\mathbf{I \propto n}$ ; $\mathbf{I \propto A}$ ; $\mathbf{I \propto v_d}$

Putting the value of $v_d$ in {1}we have ,

$$I = neA\left(\frac{eE\tau_{av}}{m}\right) = \frac{ne^2AE\tau_{av}}{m} \quad \text{.......................\{2\}}$$

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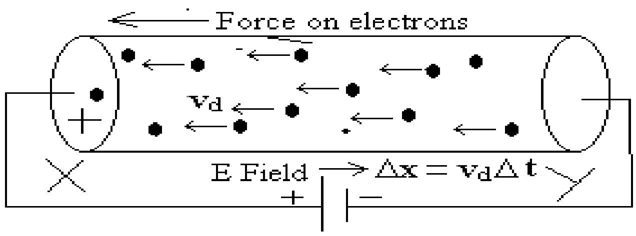
**Proof of Ohm's law and expression for resistance , resistivity , current density and conductivity**




Let a portion of the conductor be connected to the source so that ***I*** amount of current is flowing through the conductor creating an electric field along its length and the direction of drift velocity is opposite to that of drift velocity .

Due to the drift of all the free electrons in a small time interval Δt crosses a length $\Delta x = v_d \Delta t$ ,through its cross section A .

If n be the number of free electrons per unit volume of the conductor , then total electrons crossing A in time Δt is

$$\mathbf{N = n\,A\,\Delta x = n\,A\,v_d\,\Delta t}$$

Total charge crossing A in time Δt = Ne ( e = charge of electron)

=> $I\,\Delta t = n\,A\,v_d\,\Delta t\,e$

=> $\mathbf{I = n\,e\,A\,v_d}$ ………….{1}

Putting the value of $v_d$ in {1}we have

$$\Rightarrow I = neA\left(\frac{eE\tau_{av}}{m}\right) = \frac{ne^2AE\tau_{av}}{m}$$

$$\Rightarrow \frac{I}{A} = \frac{ne^2E\tau_{av}}{m}$$

$$\Rightarrow J = \frac{ne^2E\tau_{av}}{m} \quad \text{……………..\{2\}}$$

This is the expression for current density .

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Comparison equation (2) with J = σ E shows that Eq. (2) is exactly the Ohm's law .

The conductivity σ as $\sigma = \frac{ne^2\tau_{av}}{m}$ ……………..{3}

So resistivity can be given as $\rho = \frac{1}{\sigma} = \frac{m}{ne^2\tau_{av}}$ …{4}

It is seen that resistivity of the material of the conductor is independent of the dimension of the conductor .

The resistance of the conductor is $R = \rho\frac{l}{A} = \frac{ml}{nAe^2\tau_{av}}$ ……..{5}

**Mobility** The mobility( μ) defined as the magnitude of the drift velocity per unit electric field:

$\mu = \frac{|\mathbf{v}_d|}{E}$ …………………………..(1)

The SI unit of mobility is $m^2/Vs$ and is $10^4$ of the mobility in practical units ($cm^2/Vs$).

**Mobility is a + ve quantity .**

Putting the expression for drift velocity in(1)we have

$\mu = \frac{v_d}{E} = \frac{e\tau}{m}$ ..........................(2)

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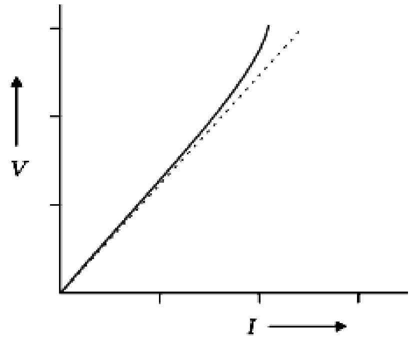
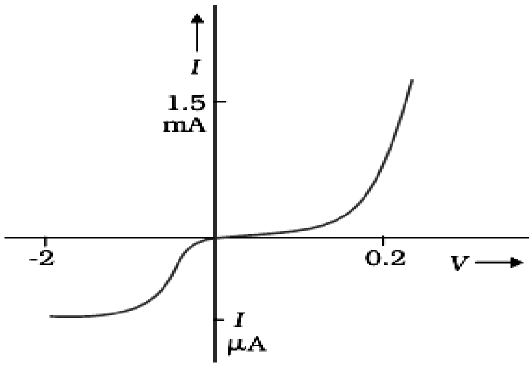
## LIMITATIONS OF OHM'S LAW

The limitation of Ohm's law of following types:

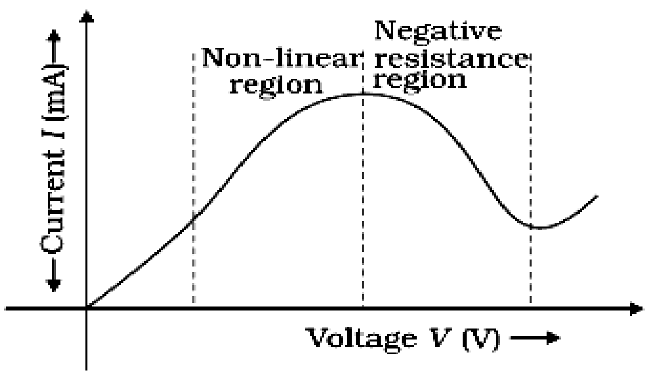
(a) V ceases to be proportional to I .




(b)The relation between V and I depends on the sign of V. In other words, if I is the current for a certain V, then reversing the direction of V keeping its magnitude fixed, does not produce a current of the same magnitude as I in the opposite direction . This happens in a diode




(c)The relation between V and I is not unique, i.e., there is more than one value of V for same current I . A material exhibiting such behaviour is GaAs.



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RESISTIVITY :-

Metals have low resistivities in the range of $10^{-8}$ Ωm to $10^{-6}$ Ωm.

Insulators like ceramic, rubber and plastics are having resistivities in the range $10^{5}$Ωm to $10^{16}$Ωm.

**The resistivity of semiconductor depends on**

1. temperature – decreasing with rise of temperature

2.presence of small amount of impurities.

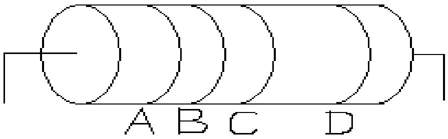
**Commercial Resistors** :

It is of two types: wire bound resistors and carbon resistors.

**Wire bound resistors:** They are made by winding the wires of an alloy, viz., manganin, constantan, nichrome or similar ones. The choice of these materials is dictated mostly by the fact that their resistivities are relatively insensitive to temperature. These resistances are typically in the range of a fraction of an ohm to a few hundred ohms.

**Carbon resistors**: Resistors in the higher range are made mostly from carbon. They are compact, inexpensive and thus find extensive use in electronic circuits. Carbon resistors are small in size and hence their values are given using a colour code.

COLOUR-CODE OF RESISTANCE




The resistance of a conductor is given as **R = (AB X C) Ω ± D**

**B B ROY** living in **G**reat **B**ritain having **V**ery **G**ood **W**ife

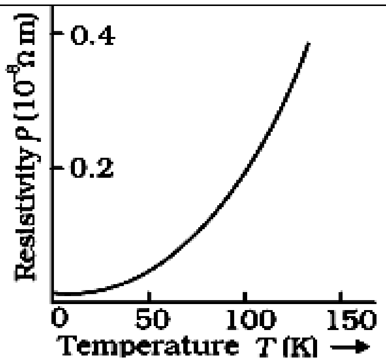
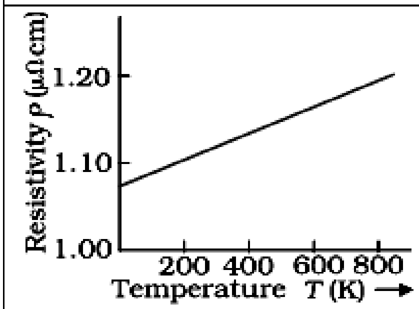
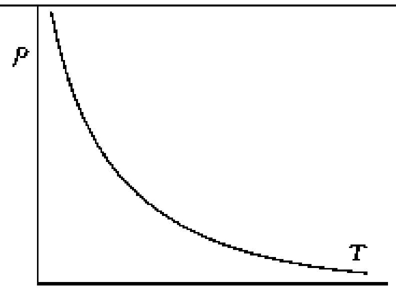
[***Every capital letter signifies a particular colours***]

| Code | Colour | A and B | C | D |
|---|---|---|---|---|
| B | Black | 0 | $10^0$ | x |
| B | Brown | 1 | $10^1$ | x |
| R | Red | 2 | $10^2$ | x |
| O | Orange | 3 | $10^3$ | x |
| Y | Yellow | 4 | $10^4$ | x |
| G | Green | 5 | $10^5$ | x |
| B | Blue | 6 | $10^6$ | x |
| V | Violet | 7 | $10^7$ | x |
| G | Green | 8 | $10^8$ | x |
| W | White | 9 | $10^9$ | x |
| | Gold | x | $10^{-1}$ | 5% |
| | Silver | x | $10^{-2}$ | 10% |
| | No colour | x | x | 20% |

**Tempature dependence of resistivity :-**

The resistivity of a material is dependent on temperature and is approximately given by, $\boldsymbol{\rho_T = \rho_0 [1 + \alpha (T - T_0)]}$ ……………………..1

where $\rho_T$ is the resistivity at a temperature T and $\rho_0$ is the same at a reference temperature $T_0$. α is called the temperature co-efficient of resistivity, and the dimension of α is $(\text{Temperature})^{-1}$ For metals, α is positive

| | |
|---|---|
|  | 1) From eq (1) $\boldsymbol{\rho_T}$ **-T** graph for **copper** must be a straight line. At temperatures much lower than 0°C, the graph, deviates considerably from a straight line |
|  | 2)The graph shows the very weak dependence of resistivity of Nichrome (which is an alloy of nickel, iron & chromium) with temperature |
|  | Graph is showing that the resistivities of semiconductors decrease with increasing temperatures. |

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Nichrome , Manganin and constantan have very weak dependence of resistivity with temperature. These materials are thus widely used in wire bound standard resistors since their resistance values would change very little with temperatures.

Temperature dependence of resistivity:

The resistivity of a material is given by $\rho = \frac{1}{\sigma} = \frac{m}{n e^2 \tau}$

ρ thus depends inversely both on the number( n) of free electrons per unit volume and on the average time τ between collisions. As we increase temperature, average speed of the electrons, which act as the carriers of current, increases resulting in more frequent collisions. The average time of collisions τ, thus decreases with temperature.

In a metal, n is not dependent on temperature to any appreciable extent and thus the decrease in the value of τ with rise in temperature causes ρ to increase as we have observed.

For insulators and semiconductors, however, n increases with temperature. This increase more than compensates any decrease in τ in above equation so that for such materials, ρ decreases with temperature.

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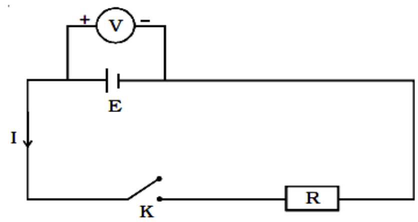
### Cells (Electrochemical cells)

**Internal resistance of a cell :- The resistance offered by the electrolyte of a cell to the flow of current through it, is called internal resistance of the cell .**

**Emf (electro motive force)** : - The potential different between the two terminals of a cell when, no current is drawn from it, i.e. in a open circuit is known as EMF of the cell.

**Terminal potential different** :- The potential different between the two terminals of a cell when current is drawn from it, i.e. in a closed circuit is known as terminal potential different.

### Find out an expression for internal resistance of a cell




Solution : - Let us consider a cell of EMF, E and r as internal resistance which is connected to an external resistance of R and a key K. A voltmeter is connected to record the potential different between the two terminals of the cell .

When the circuit is open the actual potential different across the two terminals of the battery which is known as EMF (E), is seen in the voltmeter.

When the key is closed , let I amount of current be flowing in the circuit producing a potential different of IR across the external resistance Ir across the internal resistance.

So **E = IR + Ir ………………….1**

The potential difference across R is equal to the potential difference across cell (V) as both are connected to the same points.

**V = IR** ----------------------------------2

(1) => **E = V + Ir**  => Ir = E – V

so $r = \frac{E-V}{I}$ or $r = \left(\frac{E-V}{V}\right)R$ …..3

This the equation for internal resistance.

**Q. Why emf is always greater than terminal potential different of the cell ?**

Ans : - (EMF) is the actual potential different between two terminals of a cell as shown by the voltmeter. While terminal potential different (V) is the potential different across the external resistance (R) when (I) amount of current is flowing through it. As the two ends of the external resistance are connected to a voltmeter, so at this stage reading of the voltmeter (V = IR), which is the terminal potential different.

But there will be a small potential different (Ir) across the internal resistance (r) then total potential drop in the circuit,

IR + Ir = E (actual potential different of the cell)

V + Ir = E > V

Hence emf of a cell is greater than terminal potential different by an amount (Ir), potential drop across the internal resistance

**For numerical**,

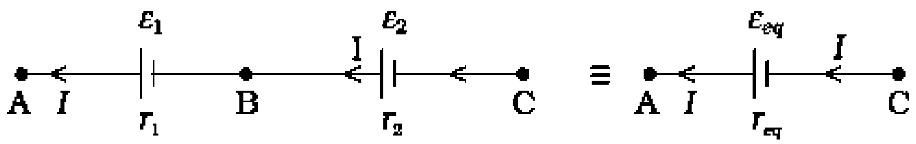
1) During charging of a cell EMF is less than its terminal potential difference , then **E = V – Ir ,**

**It is because, during charging current is given to the cell**

2) During charging of a cell EMF is greater than its terminal potential difference , then **E = V + Ir**

**It is because, during discharging current is given by the cell**

**RESULTANT TERMINAL POTENTIAL DIFF OF TWO CELLS IN SERIES**




Let $\varepsilon_1$, $\varepsilon_2$ are the emf's of the two cells with $r_1$, $r_2$ as their internal resistances are connected in series .

Let V(A), V(B), V(C) be the potentials at A, B and C

Then V(A) – V(B) is the potential difference between the positive & negative terminals of the first cell.

$$V_{AB} \equiv V(A) - V(B) = \varepsilon_1 - I r_1$$

Similarly, $V_{BC} \equiv V(B) - V(C) = \varepsilon_2 - I r_2$

Hence, the potential difference between the terminals A and C of the combination is

$$V_{AC} \equiv V(A) - V(C) = [V(A) - V(B)] + [V(B) - V(C)]$$

$$= (\varepsilon_1 + \varepsilon_2) - I(r_1 + r_2)$$

If we wish to replace the combination by a single cell between A and C of emf $\boldsymbol{\varepsilon_{eq}}$ and internal resistance req, we would have

$\mathbf{V_{AC} = \varepsilon_{eq} - I\, r_{eq}}$

Comparing the last two equations, we get

$\mathbf{\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2}$ **and** $\mathbf{r_{eq} = r_1 + r_2}$

In Fig.ii, we had connected the negative electrode of the first to the positive electrode of the second. then we will get

$\mathbf{\varepsilon_{eq} = \varepsilon_1 - \varepsilon_2}$ **and** $\mathbf{r_{eq} = r_1 + r_2}$

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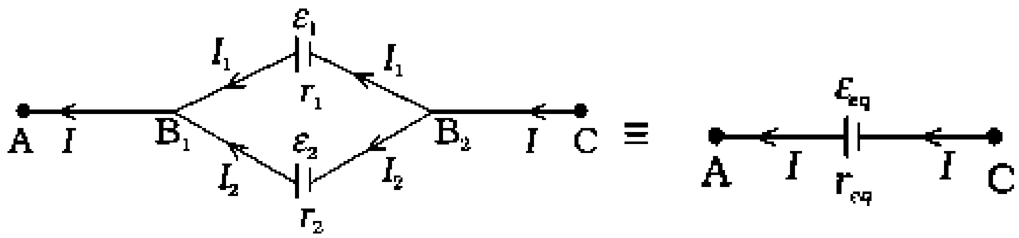
**RESULTANT TERMIBLA POTENTIAL DIFF OF TWO CELLS IN PARALLEL**




Considering a parallel combination of the cells giving currents $I_1$ and $I_2$. At the point $B_1$, $I_1$ and $I_2$ meet to make I .

So we have $\mathbf{I = I_1 + I_2}$

Let V ($B_1$) and V ($B_2$) be the potentials at $B_1$ and $B_2$,

$$V \equiv V(B_1) - V(B_2) = \varepsilon_1 - I_1 r_1 = \varepsilon_2 - I_2 r_2$$

Combining the last three equations

$$I = I_1 + I_2 = \frac{\varepsilon_1 - V}{r_1} + \frac{\varepsilon_2 - V}{r_2} = \left(\frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2}\right) - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

so, $V$ is given by, $V = \dfrac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2} - I\dfrac{r_1 r_2}{r_1 + r_2}$

If we want to replace the combination by a single cell, between $B_1$ and $B_2$, of emf $\varepsilon_{eq}$ and internal resistance req, we would have

$$\mathbf{V = \varepsilon_{eq} - I\, r_{eq}}$$

The last two equations should be the same ;

$$\varepsilon_{eq} = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2} \qquad r_{eq} = \frac{r_1 r_2}{r_1 + r_2}$$

We can put these equations in simpler way

$$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} \qquad \frac{\varepsilon_{eq}}{r_{eq}} = \frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2}$$

If the negative terminal of the second is connected to positive terminal of the first, then in above equations $\varepsilon_2 \rightarrow -\varepsilon_2$

## NCERT-XII / Unit- 03 – Current Electricity

**Electric energy and electric power**.

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

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

**Power = Workdone /time = Vit / t = VI**

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

Since **V = IR, Power = $I^2R$**

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

1 kWh is known as one unit of electric energy.

**1 kWh = 1000 Wh = 1000 × 3600 J = 36 × $10^5$ J**

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01. **State Kirchoff's laws**.

Ans : -There are two Kirchoff's laws. According to first laws --

**i) The sum of current meeting a point in an electrical circuit is zero.**

**ii) The sum of the product of current and resistance in a closed circuit is equal to the sum of e.m.f. present in that closed circuit.**

Mathematically -

**$1^{ST}$ law $\sum I = 0$ and**

**$2^{ND}$ law $\sum IR = \sum E$**

**Sign convention of the first law** :

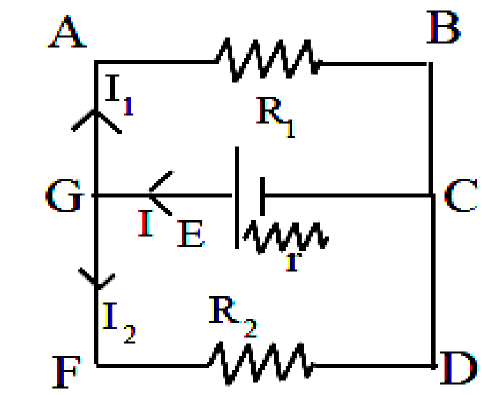
**The incoming current is taken as + ve, while the out going current is taken as – ve.**

**Sign convention of the second law**

**i) In a closed circuit current in anticlock wise, direction is tken as +ve while in clockwise direction, it is taken as – ve.**

**ii) The emf of the battery is +ve if we sends current in anticlock wise direction and consider as -ve, if it sends current in clockwise direction.**

**Explanation of the 2nd law –**




We have three closed mesh or loop in given circuit, and

Using the 2nd law to the mesh—

i)GABCG: $-I_1R_1 - Ir = - E$

ii)GFDCG: $I_2R_2 + Ir = E.$

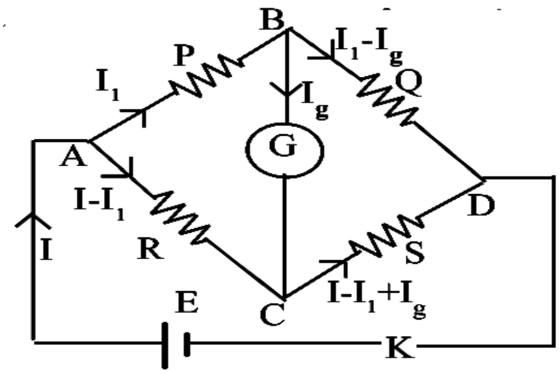
iii) ABDGA: $I_2R_2 - I_1R_1 = 0$

**02. State and prove Wheatstone bridge principle.**

Ans : -**WHEATSTONE BRIDGE PRINCIPLE**

Statement : **If four resistances (P, Q, R,S) are connected along the four arms of a square bridge with a galvanometer and a cell (E) in between diagonally opposite terminals, them no current flows through the galvanometer if P/Q = R/S which is known as wheatstone bridge principle.**

Proof : -




Let us considered four resistances (P,Q,R,S) be connected across the four arms of a square bridge ABCD along AB, DB, AC and CD respectively. Let the galvanometer (G) be connected between B and C and a cell with a key K connected in between A and D .

Let I be the total circuit flowing from the battery which will be distributed into

**(i) $I_1$ along AB,**

**(ii) $I - I_1$ along AC ,**

**(iii) $I_g$ along BC,**

**(iv $I_1 - I_g$ along BD,**

**(v) $I - I_1 + I_g$ along CD** , as shown in figure below .

Using 2nd kirchoff's 2nd law to the mesh ABCA,

$I_1P + (I - I_1) R + I_g G = 0$ ------- (i)

and to mesh BDCB,

$- ( I_1 - I_g) Q + I_g G + (I - I_1 + I_g) S = 0$ ------ (ii)

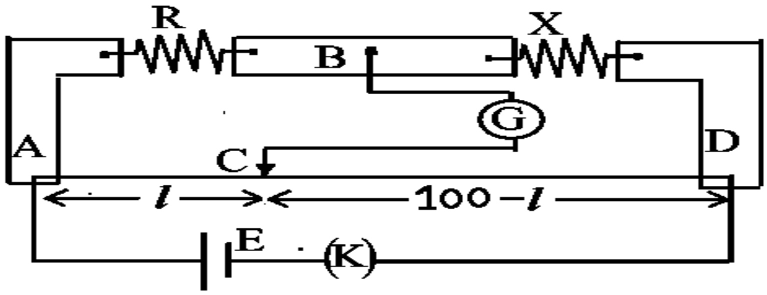
As no current flows through the galvanometer during its balanced condition i,e. $I_g$ = 0,putting it in (i) and (ii),

(i) ⇒ $- I_1 P + (I - I_1) R = 0 \Rightarrow I_1P = (I - I_1) R$ ---------- (iii)

ii)⇒ $- I1\ Q + (I - I_1) S = 0 \Rightarrow I_1Q = (I - I_1) S$ ---------- (iv)

(iii) ÷ (iv) ⇒ $P/Q = R/S$ , **which is known as Wheatstone Bridge balanced condition.**

**03. Explain the working of Meter bridge.**




A meter bridge is a resistance measuring instrument , which is based on the practical application of Wheatstone bridge principle .

It consist of1m long wire of uniform cross section made up of manganin or eureka, stretched between two copper string at A and B over a wooden box, with a meter scale below it. Let a known resistance R and an unknown resistance X be connected in between A and B in the left gap and in between B and C in right gap, of the meterbridge. From the terminal B, a galvanometer is connected to a jockey (J) which can be slided over the wire AD.In between AD a cell of emf E with a key is connected externally. Sliding a jokey, a balancing length AC = $l$ is obtained for which the galvanometer is showing zero deflection.

Using wheatstone bridge, we have

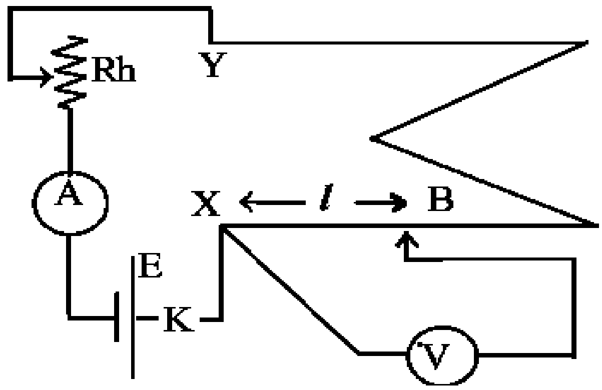
$$\frac{\text{Resistance in bet A and B}}{\text{Resistance in bet B and D}} = \frac{\text{Resistance in bet A and C}}{\text{Resistance in bet C and D}}$$

$$\Rightarrow \frac{R}{X} = \frac{l\rho}{(100 - l)\rho},$$ [*Where $\rho$ is resistance per unit length*]

Knowing R and measuring $l$, X can be calculated .

## NCERT-XII / Unit- 03 – Current Electricity

04. **Give the theory of potentiometer.**




A potentiometer is a device with the help of which we can measure potential difference in term of length. It consist of ten 1m long wires of uniform cross - section connected in series of over an wooden box. A rheostat is used in external circuit in order to made the current constant, which is observed bythe ammeter A. When current is passing through the wires, we get a definite value of potential difference for a definite length, which is measured by the volt meter.

Potentiometer is used to compare the emf of two cells or to measure the internal resistance of a cell. shown in the above diagram let l be the length of the potentiometer wire for which V be the potential difference as measure by the voltmeter.

By Ohm's law , V = IR ---------- (i)

Where, I is the current which is made constant by using the rheostat in the external circuit .

$R = \rho l/A$ ------- (ii)

Where ρ & A, are the resistivity and uniform cross sectional area of a potentiometer wire .

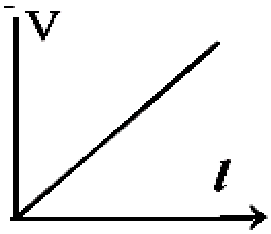
(i) ⇒ $V = I \rho l/A$

as I , ρ A are constant ,

$V \propto l$ ---- (iii)

i.e " the potential difference across a definite portion of the wire is directly proportional it length".

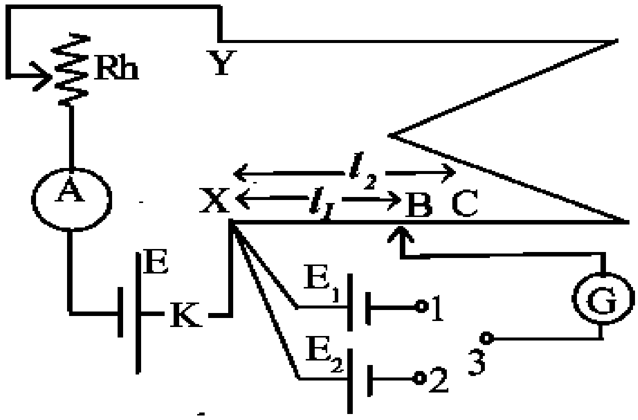
**The graph between potential difference V and length of a potentiometer wire is linear.**




Slope of the $V - l$ graph is known as potential gradient of the potentiometer , which is constant for a particular potentiometer .

**<u>05. How emf of two cells can be campared with the help of potentiometer ?</u>**

**<u>Ans-</u>**




The diagram below is showing the circuital arrangement for the comparison of emf $E_1$and $E_2$ of the two given cells, with the help of potentiometer.

The positive terminals of the two given cells are connected to the terminal X of the potentiometer while their -ve terminals are connected to the a jockey through a galvanometer and a 2 - way key.

Closing the terminals 1 and 3 of the key and sliding the jockey alng the potentiometer wire, balancing length AB = $l_1$ is obtained for the emf $E_1$ of the first cell.

$$E_1 = k\, l_1 \quad \text{.....................(i)} \quad ,$$

where k is potential difference for unit length of the wire.

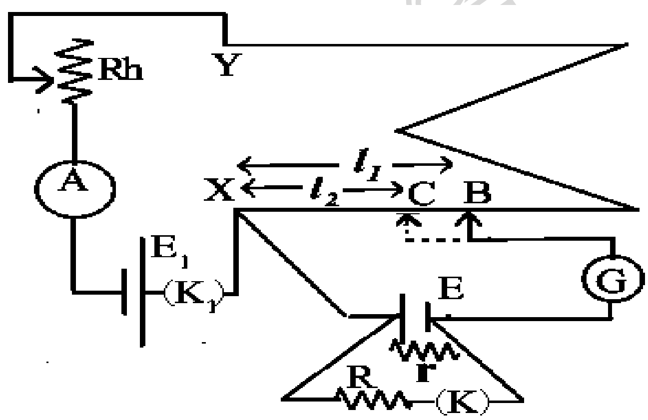
Simillarly closing terminals 2 and 3 of the 2-way key, balancing length AC = $l_2$ is obtained for the emf $E_2$ of the second cell.

$$E_2 = k\, l_2 \quad \text{....................(ii)}$$

Deviding (i) by (ii) $\Rightarrow \frac{E_1}{E_2} = \frac{l_1}{l_2}$ ................(3)

Thus emf can be compared by measuring length $l_1$ and $l_2$ ,

**06. How internal resistance of a cell can be measured with the help of potentiometer.**




Ans- The adjacent diagram is showing the circuital arrangement for the calculation of internal resistance 'r' of a cell of emf E. The positive terminal of the battery is connected to the terminal X of the potentiometer, while the - ve terminal is connected to a jockey through a galvanometer. Across the cell an external resistance R with a key 'K' is connected.

Keeping the key K opened, balancing length AB = $l_1$ is obtained from the potentiometer wire for the the emf E of the cell by sliding the jockey along the potentiometer wire.

E = k $l_1$ .................(i) ,

where k is potential difference per unit length.

Closing the key, balancing length AC = $l_2$ is obtained for the terminal potential difference V of the cell.

**V = k $l_2$ ..................(ii)**

Putting the (i) and (ii) in the expression for internal resistance of a cell we have ,

$$r = \left(\frac{E - V}{V}\right)R = \left(\frac{kl_1 - kl_2}{kl_2}\right)R \Rightarrow r = \left(\frac{l_1 - l_2}{l_2}\right)R$$

**Thus internal resistance of a cell can be calculated with the help of potentiometer.**