Chapter : 3

Current Electricity

Current Electricity

The branch of Physics which deals with the study of electric charges in motion is called current electricity.

Electric current

The flow of electric charges in a particular direction constitutes electric current.

The electric current is defined as *the rate of flow of charges across any cross sectional area of a conductor is known as electric current.*

$$I = \frac{q}{t}$$

Where, I = electric current

q= charge passed through any cross section of conductor

t= time

If the rate of flow of charge is *not uniform* then current varies with time and is given by-

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

Note

- Current is a scalar quantity.
- The direction of conventional current is taken as the direction of flow of positive charges or opposite to the direction of flow of electrons.
- Units of electric current: Ampere (in S.I. System)- *One ampere represents the passage of one coulomb of charge per second.*
- An electric current is due to the drift of -
  1. Electrons in a metallic conductor.
  2. Positive and negative charges in an electrolyte.
  3. Electrons and ions in gases in discharge tubes.
  4. Electrons and holes in a semiconductor.

How Electric Current Flow in the Conductor

When no potential difference is applied across a conductor, the electrons are in random motion. The average velocity of electrons is zero. Thus the motion of electrons does not constitute any transport of charge in any direction. The current in the conductor is zero.

When potential difference is maintained (*i.e. battery is connected)* across a conductor, the electrons gain some average velocity in the direction of positive potential (towards positive terminal of battery). And thus current is set up in the conductor.

Ohm's Law

It states that *physical conditions like temperature pressure etc. remaining constant, the current flowing through a conductor is always directly proportional to the potential difference across the conductor.*

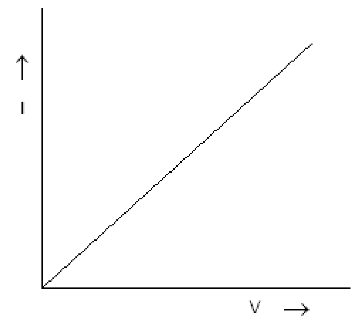
i.e. $I \propto V$

or $V \propto I$

or **V = IR** ←---------(1)

Where R is constant of proportionality, called resistance of conductor.

From (1) $\frac{V}{I} = R = \text{constant}$



So, if we plot a graph between V and I it will be a Straight line as shown in figure.

Resistance

It is the property of a body due to which it opposes the flow of current through the conductor. *It is equal to ratio of potential difference applied to the current flowing through the conductor.i.e.*

$$R = \frac{V}{I}$$

Unit of R*:* unit of resistance is *ohm (Ω) in S.I. system.*

One Ohm*: Resistance of a conductor is said to be one ohm if a potential difference of one volt produces one ampere current through it.*

Cause of Resistance: As we know that there are large numbers of free electrons in a conductor. When a potential difference is applied across the ends of conductor the free electrons moves with higher energy and collide among themselves and with the atoms of conductor and causes obstacle to flow of current. This obstacle produces the opposition to flow of electrons *i.e.* produces resistance.

Conductance (G)

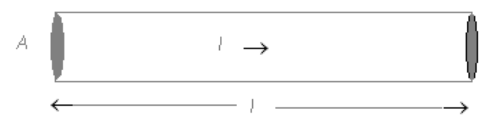
The reciprocal of resistance is known as conductance. *i.e.*

$$G = \frac{1}{R}$$

Unit of conductance is *Simen* or *mho.*

Resistivity (ρ)

As we know, resistance of a conductor (R) is



(i) Directly proportional to length(l) of conductor

i.e. $R \propto l$

(ii) Inversely proportional to the area of cross-section (A) of the conductor

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

Combining these two points, we have $R = \rho \frac{l}{A}$

Where, ρ is the constant of proportionality, called *resistivity* of the material.

If l = 1, A = 1 then ρ = R

So, ρ is defined as the resistance of a material having unit length and unit area of cross-section.

- ρ depends on the nature of material, but not on the dimensions of the material.
- Unit of ρ is **ohm-metre**

Conductivity (σ)

*The reciprocal of resistivity (*ρ) is called conductivity (σ) *i.e.*

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

Unit of conductivity is *Simen per metre*

Current density (J)

The electric current per unit area ,taken normal to the current, is known as Current Density.

$J = \frac{I}{A}$

- Unit of J is Ampere/metre^2
- The current density is a vector quantity directed along the flow of current.
- When the plane of small area A makes an angle θ with the direction of current, then

  $J = \frac{I}{A\cos\theta}$

  Or $I = JA\cos\theta$

  Or $I = \vec{J}.\vec{A}$
- 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 given by-

  $V = E\,l$ (as $E = \frac{V}{l}$)

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

  Or $E\,l = J\,\rho\,l$

  Or $E = J\,\rho$

  In vector form

  $\vec{E} = \rho\vec{J}$

  Or $\vec{J} = \sigma\vec{E}$

  Where σ is conductivity.

Drift Velocity

When no Electric field is applied across a conductor, the electrons are in random motion. The average velocity of electrons is zero. Thus the motion of electrons does not constitute any transport of charge in any direction. The current in the conductor is zero.

But when Electric field is applied, the free electrons at negative end experience a force $F = eE$ in a direction opposite to the electric field *i.e.* towards positive end.

Thus due to collision, there act backward force on electron. So, the electron drift slowly towards positive end with a constant average velocity called, drift velocity v_d

So, drift velocity is defined as the velocity with which free electrons get drifted towards the positive terminal, when electric field is applied is known as drift velocity

Expression for drift velocity:

If τ = average time between two successive collisions

a = acceleration produced

Then, $\vec{v}_d = \vec{a}\,\tau$

Also $\vec{a} = \frac{\vec{F}}{m}$ *(F= force on electron, m= mass of electron)*

But $\vec{F} = -e\vec{E}$ where negative sign shows that direction of force is opposite to that of electric field.

So, $a = -\frac{e\vec{E}}{m}$

Or $\vec{v}_d = -\frac{e\vec{E}}{m}\tau$ where negative sign shows that direction of drift velocity is opposite to that of electric field.

Which is expression for drift velocity.

Note $\vec{v}_d \propto \vec{E}$

Mobility:

Magnitude of drift velocity is given by $v_d = \frac{eE}{m}\tau$

$$v_d = \frac{e\tau}{m}E$$

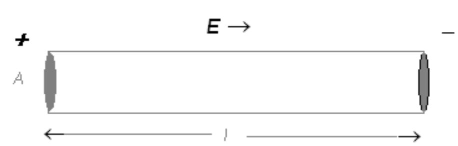
Or $$v_d = \mu E$$

where $\mu = \frac{e\tau}{m}$ is mobility, and is defined as the drift velocity acquired per unit electric field.

Unit of mobility= $m^2V^{-1}s^{-1}$

Relation between current and drift velocity

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



The number of conduction electrons in the conductor = *nAl*

The charge of an electron = *e*

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

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

Current flowing through the conductor, $I = \frac{q}{t} = \frac{(nAl)\,e}{l/v_d}$

So, $I = nAev_d$

Or $\frac{I}{A} = nev_d$

Or $\boldsymbol{J = nev_d}$

This is the relation between current and drift velocity.

Note:

$J = nev_d$

$\Rightarrow$ $J = \frac{ne^2 \tau E}{m}$

in vector form $\vec{J} = \frac{ne^2 \tau}{m} \vec{E}$

Also $\vec{J} = \sigma \vec{E}$

Comparing above two equations $\sigma = \frac{ne^2 \tau}{m}$

Deduction of Ohm's Law:

The current flowing through a conductor is given by, $I = nAev_d$

Also $v_d = \frac{eE}{m}\tau$

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

Or $I = nA\frac{e^2\tau}{ml}V$ as $E = \frac{V}{l}$

Where $\frac{ml}{nAe^2\tau}$ = *constant (= resistance)*

Therefore $\boldsymbol{I \propto V}$

Which is ohm's law.

Try example 3.1 and 3.2 from NCERT BOOK Download it from www.rsnotes.in or website of ncert

Limitations of Ohm's Law

1. For some good conductor graph between V and I is not exactly linear.
2. In diodes relation between V and I depends on sign of V.
3. For semiconductor graph between V and I is not linear.

Note: the conductors which do not obey ohm's law completely are called non-ohmic conductor e.g. semiconductors, and diodes.

Resistivity of Various Materials

Depending on resistivity, the materials can be classified as conductor, semiconductors and insulators.

The conductors (metals) have low resistivities in the range of 10^{-8} Ωm to 10^{-6} Ωm .

The insulators have very high resistivities in the range of 10^{8} Ωm to 10^{14} Ωm.

The semiconductors have resistivities between conductors and insulator *i.e.* in the range of 10^{-2} Ωm to 10^{4} Ωm.

Temperature Dependence of Resistance

As we know for metallic conductor

R = $\frac{ml}{nAe^2\tau}$

i.e. R $\propto \frac{1}{\tau}$

So, when temperature of a conductor is increased, the thermal energy of electron increases. Due to which the frequency of collision of free electrons with atoms or ions also increase and hence τ decreases. Hence, resistance increases.

If R_0 = resistance of conductor at 0^0C &

R_t = resistance of conductor at t^0C

And t = rise in temperatue.

Then $\mathbf{R_t = R_0\,(1 + \alpha t)}$ ←---(1)

Where α = temperature coefficient or resistance.

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

Or $\alpha = \frac{R_t - R_0}{R_0 t}$

i.e. Temperature coefficient of resistance = $\frac{\text{change in resistance}}{\text{Original resistance} \times \text{rise in temperature}}$

Hence α is defined as the change in resistance per unit original resistance per degree rise in temperature.

Unit of α = $^0C^{-1}$ or kelvin^{-1}

For metals: α is positive. So, from (1) $R_t > R_0$

Therefore resistance of metals increases with rise of temperature.(this implies that conductivity decreases with rise in temperature.)

For insulators and semiconductors: α is negative. So, from (1) $R_t < R_0$

Therefore resistance of insulators or semiconductors decrease with rise of temperature.(this implies that conductivity increases with rise in temperature.)

For Alloys: for alloys like Nichrome, Manganin etc *α is very-very small*. So, from (1) $R_t \approx R_0$

Therefore resistance of alloys almost remains same with rise in temperature. *That is why we use these alloys to make standard resistance coil.*

Similarly **resistivity** of a metallic conductor is given by $\boldsymbol{\rho_t = \rho_0 (1 + \alpha t)}$

Colour Code of Carbon Resistors

The value of resistors and their percentage accuracy are indicated on carbon resistor by colour code printed on them.

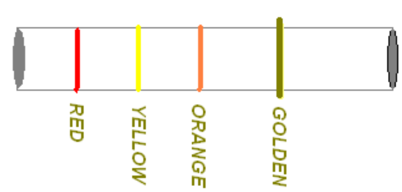
The colour code of carbon resistors is as given in the following table-

Colour	**black**	**brown**	**red**	**orange**	**yellow**	**green**	**blue**	**violet**	**grey**	**white**	**gold**	**silver**
No.	0	1	2	3	4	5	6	7	8	9		
Mult.	10^0	10^1	10^2	10^3	10^4	10^5	10^6	10^7	10^8	10^9	10^{-1}	10^{-2}

Colour	**green**	**silver**	**No Colour**
Tolerance	5%	10%	20%

Method1: when there is a set of rings of colours on the carbon resistors

1st ring colour gives the first significant figure



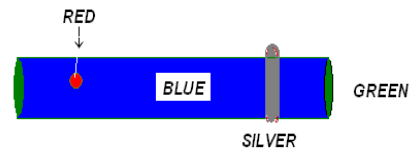
2st ring colour gives the second significant figure

3rd ring colour gives the multiplier

4th ring (if any) gives the tolerance

e.g. if 1st , 2nd,3rd and 4th colour are red, yellow, orange and golden respectively, then its value will be $24\times10^3 \pm 5\%$

Method2:



Colour of body gives the first significant figure

Colour of ends gives the second significant figure

Colour of dots gives the multiplier

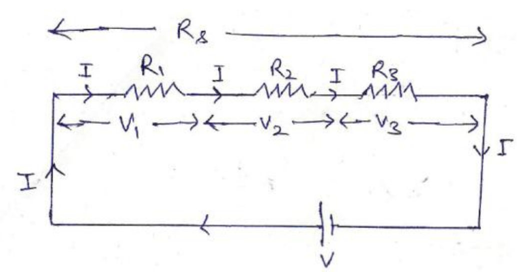
Ring (if any) gives the tolerance

e.g. if body colour be blue, end colour be green, dot be red and ring is silver, then its value will be $65\times10^2 \pm 10\%$

COMBINATION OF RESISTANCES

Resistances in Series

Resistance are said to be connected in series , if the same current is flowing through each resistor, when some potential difference is applied across the combination.



Let R_1,R_2 and R_3 are three resistances connected in series as shown in figure

If V_1,V_2 and V_3 is the potential drop across R_1,R_2 and R_3 respectively. Then,

$V = V_1 + V_2 + V_3$ ----------(1)

Also from Ohm's Law , $V = I R_s$ where R_s is the total resistance of series combination.

So, $V_1 = I R_1$, $V_2 = I R_2$ and $V_3 = I R_3$ ------------(2)

So, from (1) and (2), we have

$I R_s = I R_1 + I R_2 + I R_3$

Or $\mathbf{R_s = R_1 + R_2 + R_3}$

If there are *n* resistances connected in series then $\mathbf{R_s = R_1 + R_2 + \ldots\ldots\ldots + R_n}$

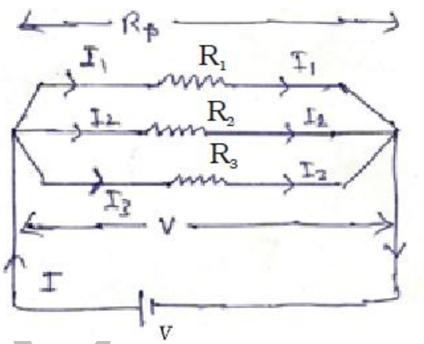
Hence if a number of resistances are connected in series then their resultant resistance is equal to sum of individual resistances.

Resistances in Parallel

A number of resistances are said to be connected in parallel if potential difference across each of them is the same and is equal to applied potential difference.

Let R_1, R_2 and R_3 are three resistances connected in parallel as shown in figure.

Let V = potential difference applied.



If I_1, I_2 and I_3 is the current flowing through R_1, R_2 and R_3 respectively. Then,

Then total current, $I = I_1 + I_2 + I_3$

Also $V = I_1R_1 = I_2R_2 = I_3R_3$

Or $I_1 = \frac{V}{R_1}, I_2 = \frac{V}{R_2}, \quad I_3 = \frac{V}{R_3}$

Or $\frac{V}{R_p} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$ where R_p is total resistance of parallel combination.

Or $\frac{\mathbf{1}}{\mathbf{R_p}} = \frac{\mathbf{1}}{\mathbf{R_1}} + \frac{\mathbf{1}}{\mathbf{R_2}} + \frac{\mathbf{1}}{\mathbf{R_3}}$

Similarly, if a number of resistances are connected in parallel, then the resultant resistance is given by-

$$\frac{\mathbf{1}}{\mathbf{R_p}} = \frac{\mathbf{1}}{\mathbf{R_1}} + \frac{\mathbf{1}}{\mathbf{R_2}} \text{ ………………. } + \frac{\mathbf{1}}{\mathbf{R_n}}$$

Hence , the reciprocal of resultant resistance in parallel is equal to sum of reciprocals of the individual resistances.

Terminal Potential Difference

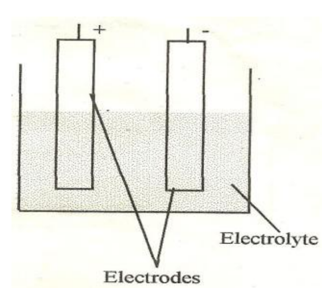
The potential difference between two electrodes of the cell in closed circuit *i.e.* when current is being drawn from it, is called terminal potential difference.

E.M.F.

Electromotive force is the maximum potential difference between two electrodes of the cell in poen circuit i.e. when no current is being drawn from it.

Internal Resistance of a Cell

The internal resistance of a cell is the resistance offered by electrolyte and electrodes of a cell when electric current flows through it.



Internal resistance depends on-

1. Distance between the electrodes
2. Nature of electrolyte
3. Nature of material of electrodes
4. Area of electrodes immersed in electrolyte.

Expression for Internal Resistance

Consider a circuit with a battery, key and a resistance R as shown in figure.

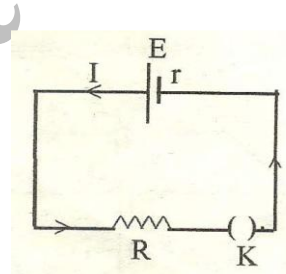
Let E = emf of the cell

r = internal resistance of the cell.

R = resistance connected &

I = current clowing through the circuit

Then, $I = \frac{\text{emf}}{\text{total resistance}} = \frac{E}{R+r}$



Or $E = IR + Ir$

Or $E = V + Ir$

Or $V = E - Ir$

Or $r = \frac{E-V}{I} = \frac{E-V}{V/R} = \frac{E-V}{V} R$

Or $\boldsymbol{r = \frac{E-V}{V} R}$ which is expression for internal resistance of a cell.

Difference between emf and potential difference

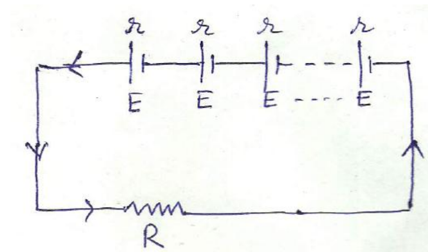
Emf	Potential Difference
Maximum value of potential difference between electrodes of a cell in open circuit is called emf	The potential difference between two electrodes of the cell in closed circuit *i.e.* when current is being drawn from it, is called terminal potential difference.
It is independent of resistance of circuit.	It depends upone the resistance of the circuit.
It is measured by potentiometer	It is measured by voltmeter.

GRUPING OF CELL

1. Cell in Series:

Let us consider *n* cells each of emf E and internal resistance *r* are connected in series, as shown in figure.

Then, total emf of circit = E + E + E+ ………..+ E = nE



And total internal resistance of circuit = r+ r + ……..+ r = nr

Total resistance of circuit = nr + R

I = $\frac{\text{emf}}{\text{total resistance}} = \frac{nE}{R+nr}$

If R>>nr , then I = $\frac{nE}{R}$ ⇒current in external circuit is n-times the current due to single cell. So, series combination is useful.

If R<<nr , then I = $\frac{nE}{nR} = \frac{E}{R}$ ⇒current in external circuit is same as due to single cell. So, series combination is not useful in this case.

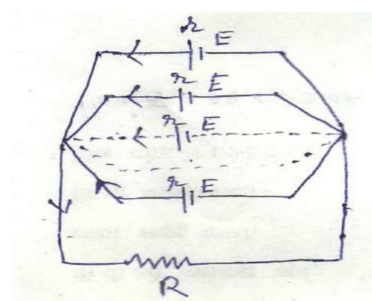
2. Cell in Parallel

Let us consider *m* cells each of emf E and internal resistance *r* are connected in parallel, as shown in figure

Then E = total emf or circuit

& R = external resistance

Then , total internal resistance r_i is given by



$\frac{1}{r_i} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r} + \ldots\ldots\ldots\ldots\ldots.\frac{1}{r} = \frac{m}{r}$

Or $r_i = \frac{m}{r}$

Total resistance of the circuit = R + r_i = R + $\frac{m}{r}$

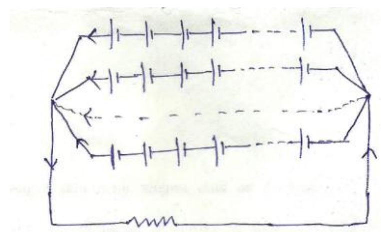
Or I = $\frac{E}{R+\frac{m}{r}} = \frac{E}{mR+r}$

If R<< r , then I = $\frac{mE}{R}$ ⇒current in external circuit is n-times the current due to single cell. So, parallel combination is useful.

If R>>r , then I = $\frac{mE}{mR} = \frac{E}{R}$ ⇒current in external circuit is same as due to single cell. So, parallel combination is not useful in this case.

Note in mixed grouping

n-cells are connected in each series and m such combination are connected in parallel, as shown in figure



Then, in the similar way,

Total emf = nE

Total resistance= R + $\frac{\mathrm{nr}}{\mathrm{m}}$

Then , I = $\frac{\mathrm{emf}}{\mathrm{total\ resistance}} = \frac{\mathrm{nE.m}}{\mathrm{mR+nr}}$

Combination is useful when internal resistance is equal to external resistance.

Note : Ohm 's law is unable to give current in complicated circuits.

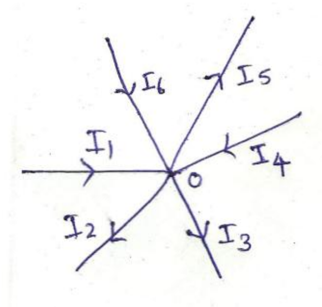
Kirchoff's Law:

Kirchoff's gave two laws which are very useful to give current in complicated circuits.

Kirchoff's 1st law or Junction Law: *It states that, the algebraic sum of the currents at any unction in a circuit is zero. i.e.*

$$\sum I = 0$$

So, according to this law there is no accumulation of electric current at any junction (the points where wires meets in an electric circuit).



By convention, the currents which flow towards a junction are taken as positive & the currents which flow away from the junction are taken as negative.

From figure, we have-

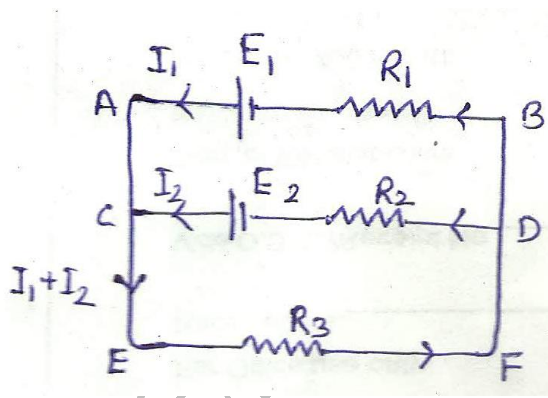
$$\mathrm{I_1 - I_2 - I_3 + I_4 - I_5 + I_6 = 0}$$

Kirchoff's 2nd Law or Loop Law: it states that , *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.*

$$\sum IR = \sum E$$

By convention, the product of current and resistance is taken as positive when we move in the direction of flow of current. The emf is taken positive when we move from negative to positive terminal through the cell and vice-versa.

Applying Kirchoff's to the circuit as shown in fig.



For the loop ACDBA,

$$I_1R_1 - I_2R_2 = E_1 - E_2$$

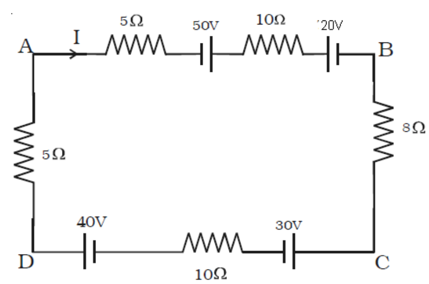
For the loop EFDBA

$$I_2R_2 + (I_1 + I_2)R_2 = E_2$$

For the loop EFBAE

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

ILLSTRATION: taking the current in the clockwise direction along ABCDA as positive

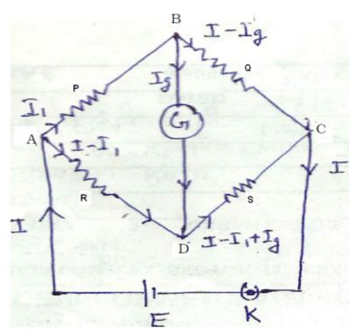


5I+ 10I + 8I + 10I + 5I = 50 - 20 - 30 +40

$\Rightarrow$ 38I = 40

$\Rightarrow$ I = $\frac{40}{38}$A

Wheatstone's Bride:



It is based on Kirchoff's Law. It is consist of four resistances P,Q,R and S to form a closed path. A galvanometer G, a cell of emf E, a key K is connected as shown in figure.

The current I is divided at various junctions according to Kirchoff's law as shown in figure.

Now applying Kirchoff's Voltage law to the closed path ABDA

$I_1P + I_gG - (I - I_1)R = 0$ ………….(1)

Now applying Kirchoff's Voltage law to the closed path BCDB

$(I - I_g)Q - (I - I_1 + I_g)S - I_gG = 0$ …………….(2)

If bridge is balanced, then galvanometer will show no deflection *i.e.* $I_g = 0$

Therefore, equation(1) becomes

$$I_1P + (I - I_1)R = 0 \qquad ....(3)$$

And, equation (2) becomes

$$I_1Q - (I - I_1)S = 0 \qquad ....(4)$$

Dividing (3) by (4) we have

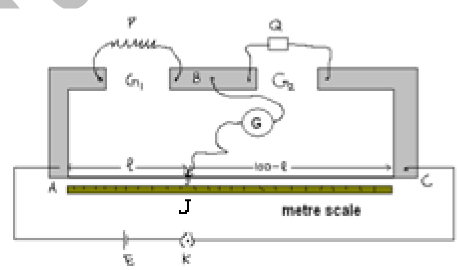
$$\frac{P}{Q} = \frac{R}{S}$$

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

Slide Wire Bridge or Meter Bridge

It is the practical application of wheatstone brdge. It is used to determine unknown resistance.

Construction: it is consist of 100cm long wire stretched and clamped between two metallic strips bent at right angle as shown in figure.(between two points A and C)



The metallic strip has two gaps G_1 and G_2 where resistance P and Q are connected. A cell E is connected between A and C through a key K. here J is jockey connected to B through galvanometer G. This jockey can be move over wire.

Working: A known resistance is taken out of the resistance box (Q) and jockey is moved till the deflection in the galvanometer is zero.

When galvanometer shows no deflection (say at point J) the bridge is said to be balanced and therefore

$$\frac{P}{Q} = \frac{R}{S} \qquad ....(1)$$

Here R = resistance of wire segment AJ

& S = resistance of wire segment JC

Let, *r* = resistance of the wire per unit length

If AJ = *l* and JC = *100-l*

Then , R = *r.l* *and S = r (100-l)*

Therefor, $\frac{R}{S} = \frac{r.l}{r(100-l)} = \frac{l}{(100-l)}$ *.................(2)*

From (1) and (2) we have $\frac{P}{Q} = \frac{l}{(100-l)}$

Or P = $\frac{l}{(100-l)} Q$

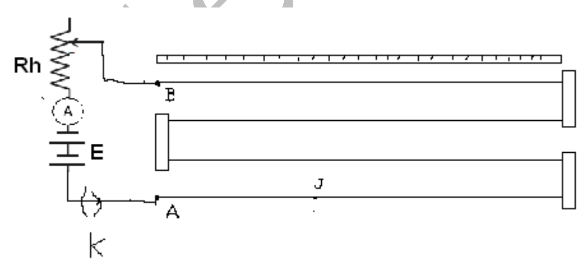
Hence by knowing Q and *l* we can calculate P

Note: If P is Known and Q is unknown then **Q =** $\frac{100-l}{l} P$

Potentiometer

It is an instrument used to compare the emfs of two cells and to determine the internal resistance of a cell.

Construction: It is consist of long uniform wire of constantan or manganin stretched in 4 to 10 segment, each of one metre length. Te segments are stretched parallel to each other on a wooden board. The ends of the wire are fixed to Cu strips. A metre scale is fixed parallel to the wire. To provide constant current through AB a source of emf E is connected across points A and B through an Ammeter a key K and a rheostat as shown in figure.

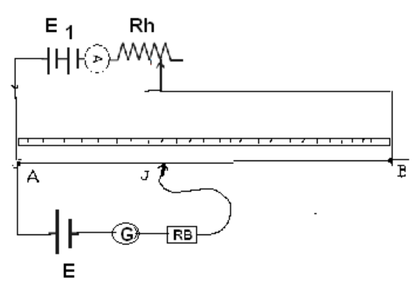


Principle of Potentiometer

An potential difference less than the total potential difference maintained across the potentiometer wire can be balanced against a convenient length of the potentiometer wire. The potential difference balanced is directly proportional to the length of the wire which balances the potential difference.

Proof:

Make the connections as shown in circuit diagram. Here $E_1 > E$. I is constnt current. G is galvanometer.



If the potential difference between A and J is equal to the emf of the cell, no current flows through the galvanometer. It shows zero deflection. AJ = *l* is called balancing length.

Then, potential difference across AJ = Ir*l*

Where, r= ressistance per unit length of potentiometer wire & I is current by E_1

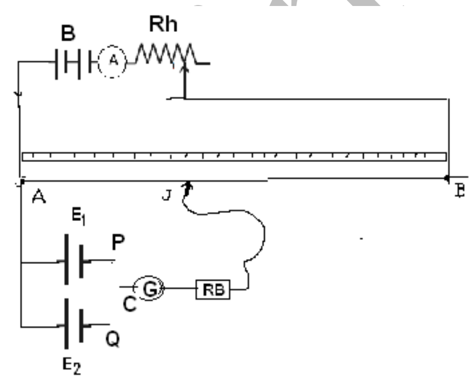
So, E = Ir*l*

Or $E \propto Irl$, *(As* I *and r are constant)*

Hence emf of the cell is directly proportional to its balancing length. i.e. The potential difference balanced is directly proportional to the length of the wire which balances the potential difference.Which is principle of a potentiometer.

To compare the emf's of two cells.

If we want to compare the emf's of two cells E_1 and E_2 , we make the connections as shown in the circuit diagram. Let *r* is the resistance per unit length of the potentiometer wire and I is the constant current flowing through it.



Here E_1 and E_2 is connected through a two way key.

Now we insert key between gap PC E_1 will be in circuit (and E_2 will be out of circuit.)

If balancing length in this case is l_1 then

$E_1 = l_1 r I$ --------------- (1)

Now we insert key between gap QC E_2 will be in circuit (and E_1 will be out of circuit.)

If balancing length in this case is l_2 then

$E_1 = l_2 r I$ --------------- (2)

Dividing (1) by (2), we have-

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

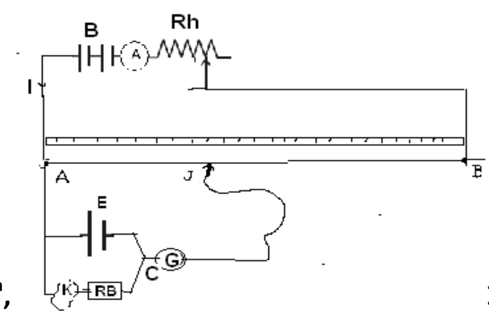
Or

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

Hence by knowing l_1 and l_2 we can compare emf's E_1 and E_2

To determine the internal resistance of a cell:

To determine the internal resistance of a cell E, we make the connections as shown in the circuit diagram. Here K is a key, if K is pressed E supply current which passes through resistance box RB.



Let r is the resistance per unit length of the potentiometer wire and I is the constant current flowing through it.

Now let **K is not pressed**, cell E will not supply any current.

If balancing length in this case is l_1 then, emf of the cell will be-

$$E = l_1 r I \quad \text{---------------} (1)$$

Now let **K is pressed**, cell E will not supply any current.

If balancing length in this case is l_2 then, terminal potential difference of the cell will be

$$V = l_2 r I \quad \text{---------------} (2)$$

Dividing (1) by (2), we have-

$$\frac{E}{V} = \frac{l_1 r I}{l_2 r I}$$

Or

$$\frac{E}{V} = \frac{l_1}{l_2}$$

As the internal resistance r_1 of the cell is given by

$$r_1 = \left(\frac{E}{V} - 1\right) R$$

Therefore, $$r_1 = \left(\frac{l_1}{l_2} - 1\right) R$$

Hence knowing l_1 and l_2 we can calculate the internal resistance of a cell.

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