CURRENT ELECTRICITY

Electric current

Current is the flow of charges. The strength of current passing through a given cross-sectional area of the conductor is the amount of charge flowing per unit time through that area.

Thus if a net charge Q flows in time t, the current, $I = Q/t$.

If the rate of flow of charge is constant and dose not varies with time, the current is said to be steady. If the rate of flow of charge varies with time, current is not steady. ie it. is variable.

If current is variable, then current at any instant is given by $I = \frac{\Delta Q}{\Delta t} = \frac{dQ}{dt}$

Current Density (J)

Current flowing per unit area is called current density J. Thus $J = \frac{I}{A}$; A = cross sectional area.

Direction of current

By convention, the direction of current is taken as that in which +ve charges flow. Considering external effects, +ve charges moving in one direction are equivalent to –ve charges moving in opposite direction. +ve charges move from the higher potential to the lower potential. ie conventional current flows from the +ve terminal of battery to the negative terminal.

Electric current is a scalar quantity.

The rate of flow of charge or the current through a conductor is the same for all cross sections even through the area of cross section may be different at different points.

NB **Resistance (R)**

Resistance of a conductor is the opposition offered by the conductor to the flow of current.

The resistance R of a conductor has been defined as the ratio of the pd V across the ends of the conductor to the current I flowing through it. ie, $R = \frac{V}{I}$

The SI unit of resistance is ohm (Ω)

When V = 1 volt and I = 1 ampere, $R = 1\Omega$

The resistance of a conductor is said to be 1 Ω if a current of 1 ampere flows through the conductor, when a pd of 1volt is applied between its ends.

Reciprocal of resistance is called conductance, denoted by C. $\therefore\ C = \frac{1}{R}$. unit: mho or seimen (S) or Ω^{-1}

NB **Ohm's law**

Ohm's law states that at constant temperature, the current flowing through a conductor is directly proportional to the potential difference between the ends of the conductor.

ie $I \propto V$ or $V \propto I$ Or $V = IR$; where R = resistance of conductor.

Metals and metallic alloys, which obey ohms law, are known as **ohmic conductors**. Conductors like electrolytes; gases etc do not obey ohms law and are known as **non – ohmic conductors.**

Note: The resistance of a conductor depends on (1) the material of the conductor (2) the dimensions [length and area of cross section] and (3) the temperature.

NB **Resistivity or Specific Resistance.**

At constant temperature, the resistance of a conductor is directly proportional to its length (λ) and inversely proportional to its area of cross section.

ie $R \propto \ell$

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

i.e $R \propto \frac{\ell}{A}$

OR $R = \frac{\rho \ell}{A}$; where ρ is called *resistivity or specific resistance* of the conductor.

Now resistivity, $\rho = \frac{RA}{\ell}$

If $A = 1m^2$, $\ell = 1m$, then $\rho = R$

Hence *resistivity of the material of a conductor is the resistance per unit length and unit area of cross section.*

Unit of resistivity = ohm metre [Ωm] The reciprocal of resistivity is called conductivity [σ]
Unit of conductivity = $ohm^{-1}m^{-1}$ or mho per metre.

Note: According to Ohm's law, $V = IR = \frac{I\rho l}{A}$. Now $\frac{I}{A} = J$; current density

$\therefore V = J\rho l$ i.e, $\frac{V}{l} = J\rho$ Therefore, Electric field, $E = J\rho$ or $j = \sigma E$; σ = conductivity.

Q1. An aluminium cylinder of length 20.0 cm has a cross sectional area of 4.00 x $10^{-4}m^2$. Calculate its resistance if the resistivity of aluminium is 2.82 x 10^{-8} Ωm. [1.41 x 10^{-5} Ω]

Q2. One metre length of a Nichrome wire has a resistance of 4.6 Ω. Calculate its resistivity if the diameter of the wire is 0.642 mm. $\frac{E_1}{E_2} = \frac{\ell_1}{\ell_2}$ [1.49 x 10^{-6} Ωm]

Q3. Find the resistivity and couductivity of a glass cylinder of length 20.0 cm and cross sectional area 4.00 x 10-4m2, if its resistance is 1.5 x 10^{13}ohm. [3.0 x 1010 Ωm, 3.33 x 10^{-11} $ohm^{-1}m^{-1}$]

Q4. A wire of resistance R is stretched till its length is increased 'n' times its original length. Calculate the new resistance. [n^2R]

Q5. A copper wire is stretched to make it 0.1% longer. What is the percentage change in its resistance.[0.2%]

Temperature dependence of resistivity.

The resistivity of a material is found to be dependent on the temperature. The resistivity of a metallic conductor is given by $\rho_T = \rho_0[1+\alpha(T-T_0)]$; where ρ_T is the resistivity at temperature T and ρ_0 is the resistivity at reference temperature T_0. α is called temperature coefficient of resistivity having unit $0C^{-1}$ or K^{-1}.

Now if R_T and R_0 are the resistances at T and T0 temperatures, then we can write,

$$R_T = R_0[1+\alpha(T-T_0)]$$

At 0^0C, $R_T = R_0[1+\alpha T]$

If R_1 and R_2 are the resistances of a conductor at temperatures t_1 and t_2, then from (1);

$$R_1 = R_0(1+\alpha t_1) \quad ....(a)$$
$$R_2 = R_0(1+\alpha t_2) \quad ....(b)$$

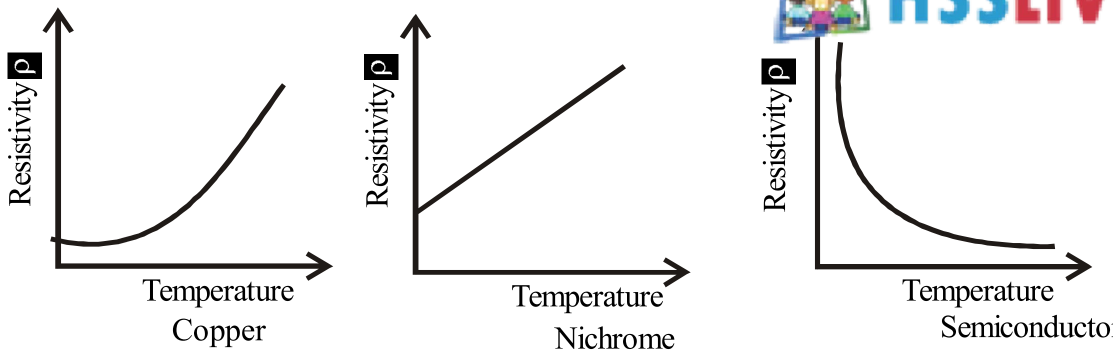
Dividing and rearranging, $\alpha = \frac{R_2 - R_1}{R_1 t_2 - R_2 t_1}$ Knowing R_1, R_2, t_1 and t_2, temp coe. of resistance can be calculated.

Note: (1) The resistance of metals generally increases with temperature. They are said to have positive temp coefficient of resistance. Eg: Al, Cu, Brass etc.

(2) The resistance of certain materials do not change with temperature. They have zero temp. coefficient. Eg: manganin, constantan, eureka etc. Hence they are used for making standard resistance coil in resistances boxes.

(3) The resistance of certain materials like semiconductors, decreases with rise in temp. These materials have negative temp. coefficient. Eg: Carbon, Germanium, Silicon etc.

Graphs showing variation of resistivity with temperature in case of a conductor (copper), resistor (Nichrome) and a semiconductor is as shown.



Q6. The resistance of a platinum wire is 50.0 ohm at 20°C. To what temperature, the wire must be raised so that its resistance is 76.8 ohm? ($\alpha = 0.00392\,^0C^{-1}$) [157°C]

Q7. At 160°C, the resistance of copper wire is 30 ohm. When the wire is placed in a liquid bath the resistance decreases to 20 ohm. Calculate the temperature of the bath if α for copper is $3.9 \times 10^{-3}\,^0C^{-1}$. [31.8°C]

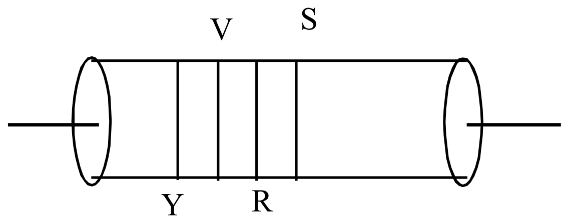
NB **Colour code of carbon resistors.

Resistances with wide range of values are extensively used in electrical and electronic circuits. Resistance of large values like 1kΩ , 4.7 kΩ, 1MΩ etc are needed in electronic circuits. They are often made of some semi conducting material like carbon. Usually, a colour code is used to indicate the value of resistance and its % reliability (tolerance). The carbon resistor is cylindrical in shape with two leads at its ends. The resistor has a set of concentric rings or bands of different colours.

The first two bands from the end indicate the first two significant figures (numerical value) of resistance in ohms. The third band indicates decimal multiplier. The last band stands for % tolerance.

Colour	Number	Multiplier	Tolerance.
Black	0	10^0	
Brown	1	10^1	
Red	2	10^2	
Orange	3	10^3	
Yellow	4	10^4	
Green	5	10^5	
Blue	6	10^6	
Violet	7	10^7	
Grey	8	10^8	
White	9	10^9	
Gold		10^{-1}	5
Silver		10^{-2}	10
No colour			20.

code: B.B. ROY Got Beautiful Very Good Wife.



If colour bands are yellow, violet, red and silver, resistance is $47 \times 10^2 \pm 10$ %. It means that the value of resistance may be higher or lower than 4.7 kΩ by 10%.

1. What do you mean by saying that resistivity of constantan is 49×10^{-8} ohm m.
2. A wire is stretched twice its length. What is its new resistance?

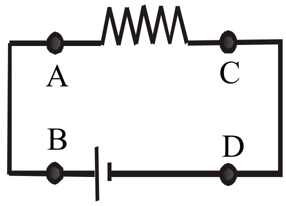
When wire is stretched, its volume remains constant. Therefore, $A_1 \ell_1 = A_2 \ell_2$.

$\ell_2 = 2\ell_1$ Therefore $A_2 = A_1/2$

$$\therefore R = \frac{\rho\, 2\ell_1}{A_1/2} = 4\frac{\rho \ell_1}{A_1}$$

So resistance becomes four times since ρ is constant.

Note: For a conductor the resistance is practically taken as zero. Hence there is no potential difference between any two points of a current carrying conductor (provided there is no resistance included between those points)



In fig A and B are at the same potential and C and D are at same potential.

NB **Drift Velocity.**

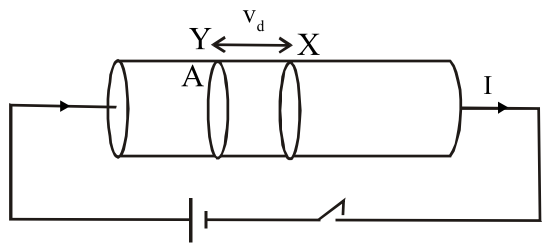
In a metallic conductor, there are a large number of free electrons. They wander freely through the conductor with very high velocity of the order of 10^6m/s since their mass is very small. These electrons collide with +ve metal ions and change their directions. The velocity of electrons are randomly distributed in all directions so that the net flow of electrons through the wire in one-way or the other is zero.

When the conductor is connected to a battery, an electric field is set up along the length of conductor from +ve to –ve terminal. Due to this field, the electron flows continuously from –ve to +ve terminal. During motion, they collide with metallic atoms. During a short time interval between collisions, each electron accelerates and gains an extra velocity towards +ve terminal. But this extra velocity is destroyed at each collision. The net result is that, the electrons in addition to their random motion, in all possible directions with very high speed, acquire a small speed called drift speed towards +ve terminal ie opposite to field direction.

Thus **drift velocity** *may be defined as the average velocity acquired by a free electron under an external electric field.*

Now, consider a metallic wire of cross-sectional area **A** in which a current **I** is flowing. Let the number of electrons/ unit volume (number density) be **n**. Consider a cylinder XY in the conductor. When pd is applied, all those electrons which are in the cylinder of length XY will pass through the section X in one second with a drift velocity v_d.

$\therefore XY = v_d$



Now, volume of cylinder $XY = Av_d$.

Number of electrons in this volume $= n A v_d$.

All these electrons pass through the section X.

Now as each electron carries a charge e, the total charge flowing per second through an area A is $neav_d$.

But rate of flow of charge is current.

Therefore, $I = neav_d$.

$$\text{Or drift velocity, } v_d = \frac{I}{neA}$$

Note: The force F acting on an electron moving in an electric field, E, $F = -eE$

i.e, $ma = -eE$. or $a = -\frac{eE}{m}$. m = mass of electron.

Now drift velocity, $v_d = a\tau$; where τ is the relaxation time i.e. the average time between two successive collissions.

Therefore, $v_d = \frac{e\tau}{m} E$ ....(1) i.e. $v_d = \frac{e\tau}{m}\left[\frac{V}{\ell}\right]$

Therefore $v_d \propto E$.

Here $\frac{e\tau}{m} = \mu$ is called **mobility of electrons.**

Therefore, $v_d = \mu E = \mu\left[\frac{V}{\ell}\right]$;where V is the pd between the ends of conductor of length ℓ .

Derivation of Ohm's law.

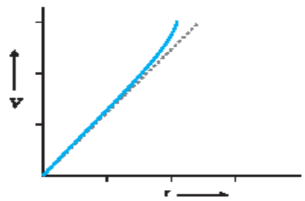
We know, Current, $I = neAv_d$ ....(1)

Also drift velocity, $v_d = \frac{e\tau}{m}\left[\frac{V}{\ell}\right]$ ....(2)

Substuting (2) in (1); $I = neA\frac{e\tau}{m}\left[\frac{V}{\ell}\right]$ i.e. $I = \frac{ne^2\tau}{m}\frac{A}{\ell}(V)$ Or $\underline{I \propto V}$; **which is Ohm's law.**

But $R = \frac{V}{I}$ $\therefore R = \frac{m}{ne^2\tau}\frac{\ell}{A} = \rho\frac{\ell}{A}$; where ρ = resistivity. $\therefore \rho = \frac{m}{ne^2\tau}$

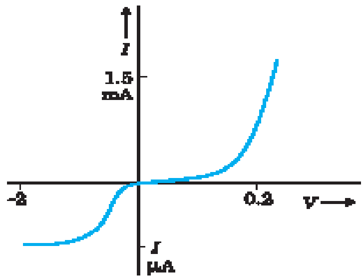
Conductivity, $\sigma = \frac{ne^2\tau}{m}$ So conductivity depends on number of charge carriers **n**.



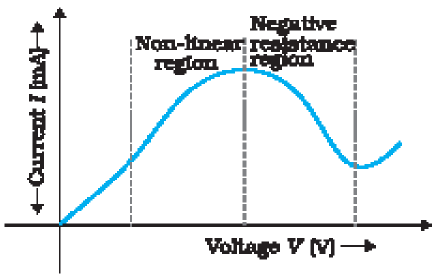
Limitations of Ohm's law

1. Certain materials do not obey Ohm's law. The deviations of Ohm's law are of the following types.

V stops to be proportional to I.



2.The relation between V and I depends on the sign of V. If I is the current for a certain V, the reversing the direction of V keeping its magnitude fixed, does not produce current of the same magnitude as I in the opposite direction.



3.The relation between V and I is not unique ie. there is more than one value of V for the same current I.

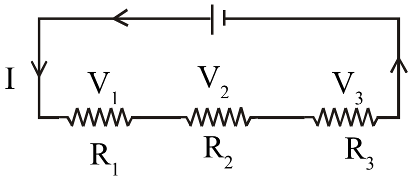
Resistances in Series and Parallel.

In electrical and electronic circuits, we need different values of resistances. But often we don't get exact value of resistances required. So we have to make suitable combination of resistance. The total resistance of the combination is called **equivalent resistance** or **effective resistance.**

Resistances can be connected in two ways namely – Series and Parallel.

** **Resistances in series.**

When resistances are connected in series, the current flowing through all the resistances will be the same.



Consider three resistors R_1, R_2 and R_3 connected in series.
Let a pd V be applied so that a current I flows through the combination.
Let V_1, V_2 and V_3 be the potential differences across R_1, R_2 and R_3 respectively.

Then $V_1 = I R_1$; $V_2 = IR_2$; $V_3 = IR_3$.

Now $V = V_1 + V_2 + V_3$.

ie $V = I R_1 + IR_2 + IR_3 = I (R_1 + R_2 + R_3)$.

Now if the three resistors are replaced by a single resistor of resistance R, then V = I R.

$\therefore\ IR = I (R_1 + R_2 + R_3)$.

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

Where R = effective or equivalent resistance. Thus when resistors are connected in series, the effective resistance is the sum of individual resistances.

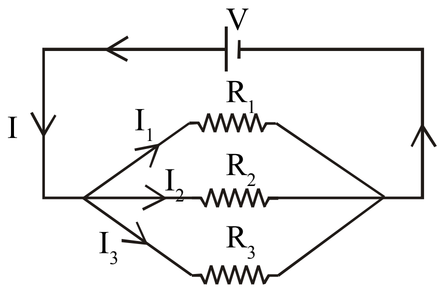
Note: (1) If n resistors each of resistance R are connected in series, then effective resistance, $R_S = n R$

(2) When resistances are connected in series, the effective resistance is greater than the greatest of the given resistors.

** Resistances in parallel.

When resistances are connected in parallel, the potential difference across the resistors is same and the total current is distributed among the resistors.

Consider three resistors R_1, R_2 and R_3 connected in parallel across a pd of V volt. Let I_1, I_2, I_3 be the currents through R_1, R_2 and R_3 respectively.



Then, $I_1 = \dfrac{V}{R_1}$; $I_2 = \dfrac{V}{R_2}$; $I_3 = \dfrac{V}{R_3}$

Now $I = I_1 + I_2 + I_3$.

$\therefore\ I = \dfrac{V}{R_1} + \dfrac{V}{R_2} + \dfrac{V}{R_3}$ $\qquad \therefore\ I = V\left[\dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}\right]$

Now if the three resistors are replaced by a single resistor of resistance R, then $I = \dfrac{V}{R}$

$$\therefore\ \frac{V}{R} = V\left[\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right]$$

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

Where R = effective or equivalent resistance.

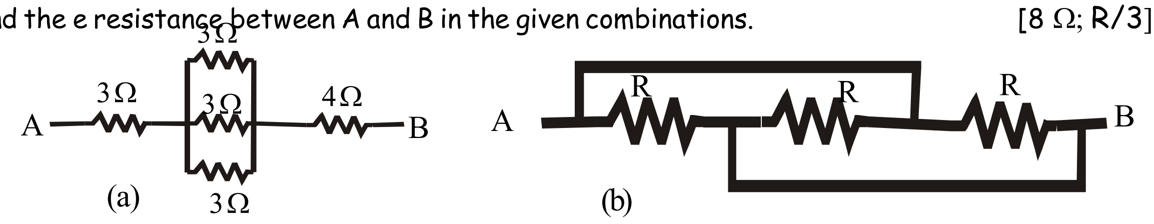
Note: 1) If two resistances R_1 and R_2 are connected in parallel; then effective resistance, $R_P = \dfrac{R_1 R_2}{R_1 + R_2}$

2) If n resistors of value r are connected in parallel, then effective resistance, $R_P = \dfrac{R}{n}$

3) When resistors are connected in parallel, the effective resistance is less then the least of the given resistors.

Q8. The effective resistance of a carbon wire and nichrome wire connected in series is 3 ohm. If the resistance of carbon wire is 1.25 ohm, what is the resistance of the nichrome wire? [1.75 ohm]
Q9. Three resistances 0.3 Ω, 10 Ω and 100 Ω are connected in parallel. Calculate the effective resistance. [0.098Ω]

Q10. Find the e resistance between A and B in the given combinations. [8 Ω; R/3]



Internal resistance of a cell.

When a cell is connected to an external circuit, a current will flow from the +ve terminal to the –ve terminal through the resistance. Since current flows in closed path, the same current will flow through the cell from –ve terminal to +ve terminal.

The medium of cell (electrolyte) offers a resistance to the flow of current through it. This is known as the internal resistance of the cell.

The internal resistance is in series with external resistance. The internal resistance depends on (1) the distance between electrodes of the cell (2) surface area of electrodes (3) the nature of electrolyte (4) the amount of current drawn from the cell.

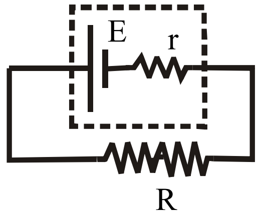
NB **e.m.f and Terminal Potential Difference of a cell.**

It is clear that the p.d between the terminals of a cell, when it is sending and not sending a current, are different.

The p.d between the terminals of a cell, when it is not sending a current, is called electromotive force (e.m.f). Here it is 'E'.

The p.d between the terminals of a cell, when it is sending a current, is called terminal p.d or voltage (V).

Let an external resistance R connected in series to a cell of emf E and internal resistance r. Now total resistance of the circuit = (R + r).



If I is the current drawn from the cell, then emf of cell, $E = I(R + r)$ ....(1)

From (1), $E = IR + Ir = V + Ir$; where V = IR is known as the **terminal pd** or **the external voltage.**

$\therefore V = E - Ir$ ....(2)

Also $I = \dfrac{E}{R + r}$ ....(3) Therefore terminal pd is always less than the emf by an amount equal to the potential drop across the internal resistance of the cell. This internal potential drop is **lost volt**.

Now current $= \dfrac{\text{emf}}{\text{total resistance}}$ $I = \dfrac{E - V}{r}$ If I = 0: E = V.

Thus e*mf of a cell is the terminal pd when no current is drawn from it.* OR *emf of a cell is equal to open circuit terminal pd of the cell.*

Note: For a cell, E = V + Ir. If internal resistance is zero, E = V. ie the external voltage is same and independent of resistance R. Now the cell is called a *constant voltage source.*

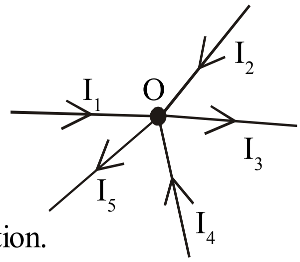
If the internal resistance is very large, ie r >>>R, then and the current drawn from the cell is constant and independent of external resistance R. A cell of very large internal resistance is called *constant current source.*

NB **Kirchoff's Laws:**

a) **First law: (Junction rule)**

"The algebraic sum of currents meeting at any junction in a closed circuit is zero. ie the total current entering the junction is equal to the total current leaving the junction".

Let currents I_1 and I_2 enter the junction O and currents I_3, I_4 and I_5 leave the junction as in figure. Taking the current flowing towards the junction as positive and flowing away from the junction as negative.



$I_1 + I_2 - I_3 - I_4 - I_5 = 0$ Or $I_1 + I_2 = I_3 + I_4 + I_5$

Thus total current reaching the junction is equal to total current leaving the junction.

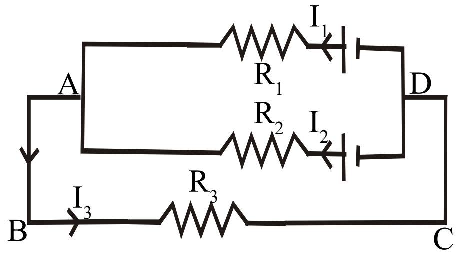
b) **Second law or loop rule.**

"In any closed circuit, the algebraic sum of the product of the current and resistance in each part of the circuit is equal to the net emf in the circuit. OR *Around any closed path in a circuit, the algebraic sum of all changes of potential is zero".*

Consider the given figure. Applying Kirchoff's second law to closed circuit ABCDE$_1$A, $I_1 R_1 + I_3 R_3 = E_1$

. For closed circuit ABCDE$_2$A; $I_2 R_2 + I_3 R_3 = E_2$

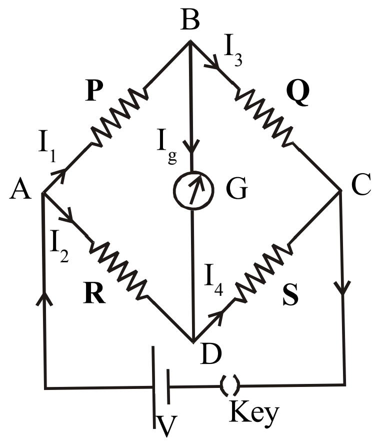
For closed circuit AE$_2$DE$_1$A; $I_1 R_1 - I_2 R_2 = E_1 - E_2$



Note: Kirchoff*'s laws prove the conservation of charge and energy.*

NB **The Wheatstone Bridge** — C. F. Wheatstone — 1833

Wheatstone bridge is an arrangement of four resistances P, Q, R, and S connected in the manner as shown in fig. A cell is connected between the points A and C and a galvanometer is connected between the points B and D through a key K. The currents through various branches are indicated in figure.



Let the current drawn from battery splits at A into I1and I_2. Now if one resistance (say R) is so adjusted that no current flows through the galvanometer G, then the currents and reach the point C where they recombine to form current .

When no current flows through the galvanometer, the bridge is said to be balanced. ie $I_g = 0$

Applying Kirchoff's loop rule in ABDA and BCDB;

$I_1 P + I_g G - I_2 R = 0$ i.e. $I_1 P + 0 - I_2 R = 0$

Or $I_1 P = I_2 R$ ....(1)

$I_1 Q - I_2 S - I_g G = 0$ Or $I_1 Q - I_2 S - 0 = 0$

i.e. $I_1 Q = I_2 S$ ....(2)

$$\frac{(1)}{(2)} \Rightarrow \frac{P}{Q} = \frac{R}{S}$$

This is the condition for balance for a Wheatstone bridge.

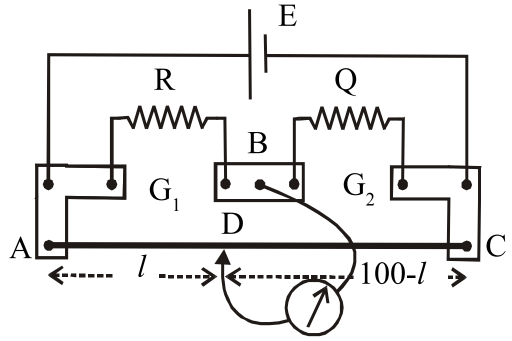
If we know any three resistances, we can find the fourth resistance from the above equation.

NB **Meter Bridge or Slide Wire Bridge.**

One common form of Wheatstone bridge is Meter Bridge used to measure an unknown resistance or to compare two unknown resistances.

Meter Bridge consists of a resistance wire AC one metre long and stretched between two fixed copper strips.

A resistance box R is connected in gap G_1, and unknown resistance Q is connected across gap G_2. A cell E is connected across AC and a galvanometer G is connected between B and D; where D is a movable point. At D there is a jockey, which slides along the wire so that contact may be made with the bridge wire at any point desired.



A suitable resistance R is introduced in the resistance box and the jockey is moved over the wire until the galvanometer shows zero deflection. Then the bridge is said to be balanced. The position of the jockey where galvanometer shows no deflection is called *null point.*

At balance, $\dfrac{R}{Q} = \dfrac{\text{Resistance of wire AD}}{\text{Resistance of wire DC}}$

Let AD = ℓ ; then DC = 100 – ℓ

$\therefore \dfrac{R}{Q} = \dfrac{\ell}{100-\ell}$ Knowing R and ℓ , the unknown resistance Q can be calculated.

#Note: 1) Determination of resistance using Wheatstone bridge is a null method. The internal resistance of the cell and the resistance of the galvanometer do not affect the measurement.

2) This method is not suitable for the measurement of very low or very high resistances.

NB **Potentiometer.**

A potentiometer is a device used to measure or compare potential difference. It consists of a uniform wire AB of length 10 metre stretched on a wooden board buy the side of a metre scale.

A steady current is passed through the wire with the help of a source of emf. Let the resistance per unit length of potentiometer wire be and the current passing be .

Let the null point be obtained at J.

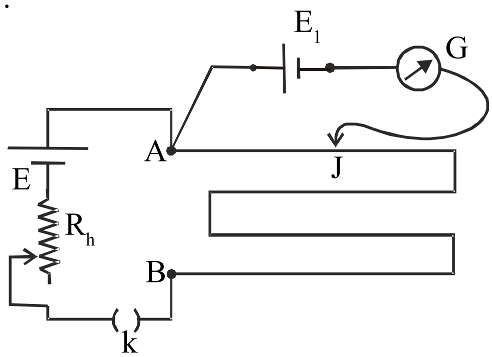
Then length of wire AB = L.

Length of wire AJ = ℓ

Pd across AJ = $\lambda\rho$ I

Pd across AB = Lρ I

$\therefore \dfrac{\text{pd across AJ}}{\text{pd across AB}} = \dfrac{\ell \rho I}{L\rho I} = \dfrac{\ell}{L}$

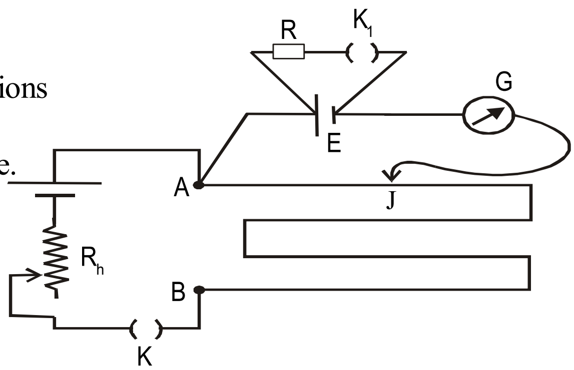


$\therefore$ Pd across AJ = $\dfrac{\lambda}{L}$ x Pd across AB

Thus *for a steady current passing through the potentiometer wire AB, the pd across any length of wire is proportional to length of wire.* ie E $\propto \lambda$ This is the **principle of potentiometer.**

Determination of internal resistance of cell.

To find the internal resistance of cell E, the connections are made as in figure.



First the emf of cell E is balanced on the potentiometer wire.

If balancing length is ℓ_1, then emf, $E = k\ \ell_1$ ....(1)

;where k =Pd across unit length of potentiometer wire.

Now by inserting key K_1, some current is drawn from the cell E and the pd across its two terminals, V is balanced.

If the balancing length is ℓ_2,

$$V = k\,\ell_2 \quad ....(2)$$

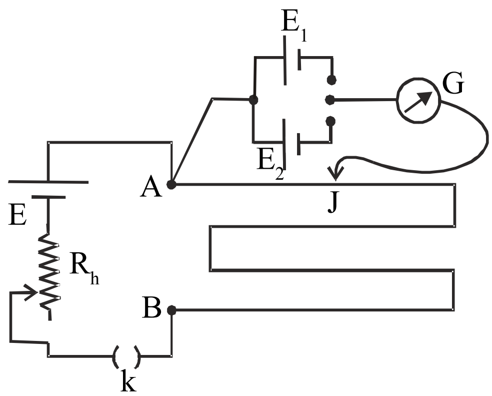
We know, internal resistance of cell, $r = \dfrac{E-V}{I} = \dfrac{E-V}{V}R$ ....(3)

From (1), (2) and (3); $r = R\left[\dfrac{\ell_1 - \ell_2}{\ell_2}\right]$

The experiment is repeated for different values of R and it is found that the internal resistance increases with external resistance.

Comparison of emf's of two cells.

The two cells of emf's E_1 and E_2 are connected as shown. Now the balancing lengths ℓ_1 and ℓ_2 for the two cells
are found out.



Then $E_1 \propto \ell_1$ and $E_2 \propto \ell_2$

$$\therefore \frac{E_1}{E_2} = \frac{\ell_1}{\ell_2}$$

With the help of rheostat different steady currents are passed through the potentiometer and the experiment is repeated. Mean value of is found out.

Sensitiveness of a potentiometer.

The sensitiveness of a potentiometer is its ability to measure even small potential differences accurately. Since potential is proportional to the balancing length, the sensitiveness depends on the **primary pd per unit length of the wire or the potential gradient**. Smaller the potential gradient, higher will be the sensitivity. The sensitivity of the galvanometer used in the circuit with affect the sensitiveness of the potentiometer.

As we use null method with no current drawn from the cell on obtaining the balancing length, the potentiometer method is preferred to other methods for determination of emf of a cell.

NB **Electric Power**

Electric power is the rate at which electric energy is converted into other forms of energy.

When a current I flows through a circuit of resistance R, the work done or energy produced in the circuit in a time t, $W = VIt = I^2Rt$.

Then power, $P = \dfrac{W}{t} = VI = I^2R$

Therefore, power = voltage x current.

The SI unit of power is volt — ampere or watt (W) or J/s.

Electrical energy

When a current flows through a conductor, the amount of energy converted into heat is $W = VIt = Pt$. Where P is the power and t the time.

Unit of energy is watt – second or joule.

For commercial purposes, we use the unit kilo watt hour (kWh)

One kilo watt hour is the energy consumed by a device in one hour at a rate of one kilowatt.

$1\,kWh = 1000\,Wh = 1000 \times 60 \times 60\,J$ ie $1\,kWh = 3.6 \times 10^6\,J$