CURRENT ELECTRICITY

Electric current

Flow of charge is called electric current and the rate of flow of charge in a circuit represents the magnitude of the electric current in that circuit.

It is generally represented by I. If dq amount charge flows in the circuit in time dt then the magnitude of electric current will be I

$= \frac{dq}{dt}$

The direction of electric current is taken to be opposite to be direction of the flow of electrons or the direction of flow of positive charge in a conductor is taken as the direction of the electric current.

Electric current is a scalar quantity. S.I. unit of electric current is coulomb/second or ampere.

OHM'S LAW

If the physical conditions of a conductor (such as temperature etc.,) remain same, then the potential difference across the ends of the conductor is directly proportional to the current flowing in it, that is

$$V \propto I \quad \text{or} \quad V = IR$$

Where, R is a constant, called resistance of the conductor.

RESISTANCE

The resistance of a conductor is directly *proportional* to its *length l* and *inversely proportional* to its cross–sectional area *A*. Thus,

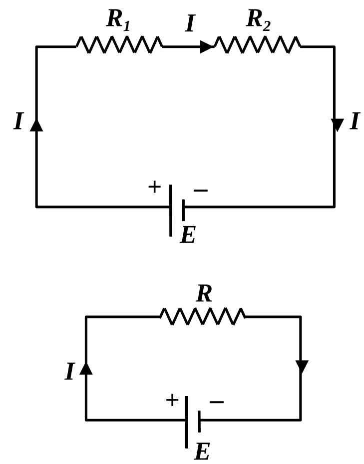
$$R = \frac{\rho l}{A}$$

The quantity ρ is called the ***resistivity*** of the material of which the conductor is made.

The SI unit of resistance is ohm (Ω)

CIRCUITS WITH RESISTORS

(i) Resistors in Series



Series combination of resistances R_1 and R_2.
Equivalent resistance $R = R_1 + R_2$

Two resistances are said to be in **series** if the same current passes through both resistors. *For example*, in the circuit shown, any current coming from the battery must pass through both resistors – *the current has no place else to go*.

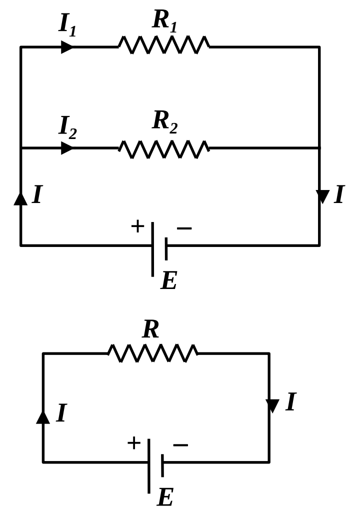
At every instant of time all circuit elements connected in a series combination carry the same current.

The equivalent resistance of N resistors connected in series is given by

$$R = R_1 + R_2 + \ldots + R_N = \sum_{i=1}^{N} R_i$$

The equivalent resistance of a series combination of resistances is always larger than any of the individual resistances.

(ii) Resistors in Parallel



Parallel combination of resistances R_1 and R_2
Equivalent resistance $R = \frac{R_1 R_2}{(R_1 + R_2)}$

Two resistors are said to be in parallel combination if the current I splits into two currents I_1 and I_2 such that

$I = I_1 + I_2$ but the voltage drop across each resistor is the same.

At every instant of time the potential difference across all circuit elements connected in parallel is the same.

For N resistors in a parallel combination, the equivalent resistance is

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + ... + \frac{1}{R_N} = \sum_{i=1}^{N} \frac{1}{R_i}$$

The total resistance of any parallel combination of *resistors must be less than any one of the individual resistors.*

RELAXATION TIME

The average time taken between two successive collisions is called relaxation time. It is represented by τ.

DRIFT VELOCITY OF FREE ELECTRONS

The drift velocity is the velocity acquired by the electron in a direction opposite to applied electric field due to the acceleration of electron during the relaxation time

drift velocity = acceleration x time

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

KIRCHHOFF'S LAWS

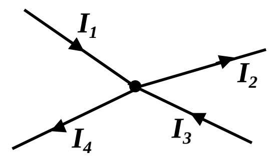
. ***Kirchhoff's laws are general and can be applied to any type of circuit***.

(i) Kirchhoff's Current Law (KCL)`

At any circuit junction the sum of the *currents entering the junction* must be equal to the sum of the *currents leaving the junction*.

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

or $$I_1 + I_3 = I_2 + I_4$$



Kirchoff's current law

It is based on conservation of charge.

(ii) Kirchhoff's Voltage Law (KVL)

The sum of *voltage changes across all the circuit elements* found when traversing one direction around *any closed circuit-loop must be zero*.

It is based on energy conservation.

ELECTROMOTIVE FORCE

When a cell produces a current I, the terminal potential difference is

$$V = E - Ir$$

Where, r is the internal resistance of the source and E is the *emf* of the source.

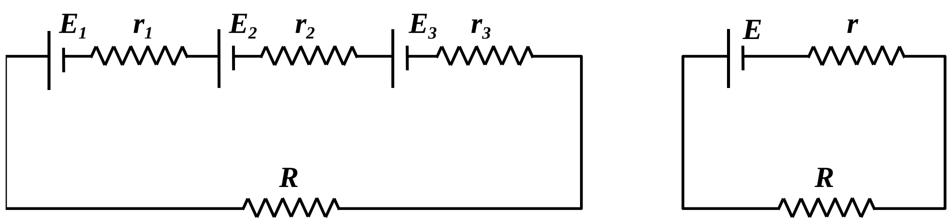
(i) Series Combination

If N sources of *emf* are connected in series, then the equivalent *emf* is given by

$$E = E_1 + E_2 + E_3 + \ldots\ldots\ldots + E_N \qquad \textbf{(7)}$$

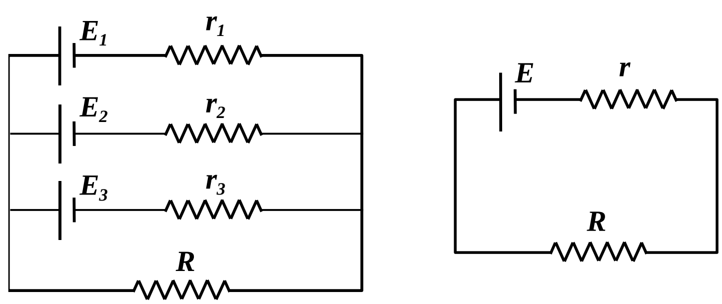
And, *total internal resistance* is given by

$$r = r_1 + r_2 + r_3 + \ldots\ldots\ldots\ldots\ldots + r_N$$



Series combination of batteries E_1, E_2 and E_3

(ii) Parallel Combination



Parallel combination of batteries E_1, E_2 and E_3

The *emf* and *internal resistance* of the equivalent battery are given by

$$E=\frac{\frac{E_1}{r_1}+\frac{E_2}{r_2}+\frac{E_3}{r_3}}{\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}} \quad \textbf{(8)}$$

and $\frac{1}{r}=\frac{1}{r_1}+\frac{1}{r_2}+\frac{1}{r_3}$

ELECTRICAL INSTRUMENTS

Galvanometer

Galvanometer detects the presence of current in the branch where it is connected. An instrument that measures current is called an ***ammeter,*** and one that *measures potential difference* is called a ***voltmeter***.

A galvanometer may be converted into an ammeter by connecting a low resistance (called ***shunt)*** in parallel to the galvanometer.

$$S=\frac{I_g G}{I-I_g}$$

Where, G = resistance of the galvanometer

I_g= full scale deflection current of the galvanometer

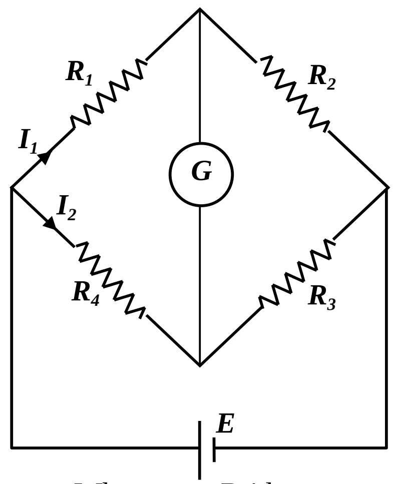
I = maximum current to be measured by the ammeter.

A *galvanometer* may be converted into a *voltmeter* by connecting a *high resistance in series* with the galvanometer.

$$R = \frac{V}{I_g} - G$$

Wheatstone bridge

It provides an accurate method of determining the resistance of an unknown resistor. Four resistors are connected as shown in figure one of them is an unknown whose resistance is to be measured. Let us assume that R_3 is unknown and R_2 can be varied as it is adjusted until no current flows in the galvanometer.



Wheatstone Bridge

In this condition

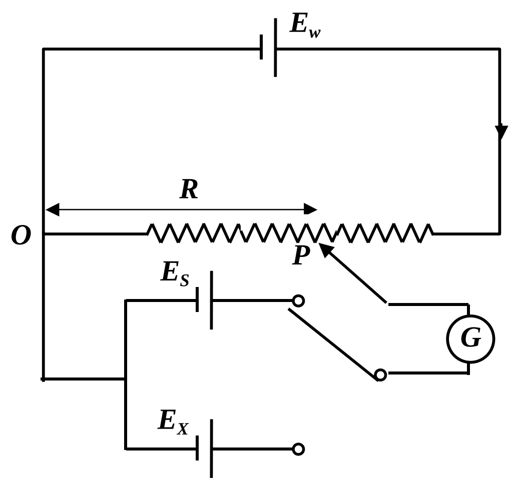
$$I_1R_1 = I_2R_4 \text{ and } I_1R_2 = I_2R_3$$

Thus $\frac{R_1}{R_2} = \frac{R_4}{R_3}$

or $R_1 R_3 = R_2 R_4$

Potentiometer

A quick method of measuring the *emf* of a battery is to connect a voltmeter directly across its terminals. However, since the *voltmeter has finite resistance*, one inevitably measures the *terminal potential difference rather than the true emf*. A potentiometer is an instrument that allows one to compare unknown *emf* with a *standard emf*. It is a null device, like the Wheatstone bridge.



Determination of an unknown emf using potentiometer