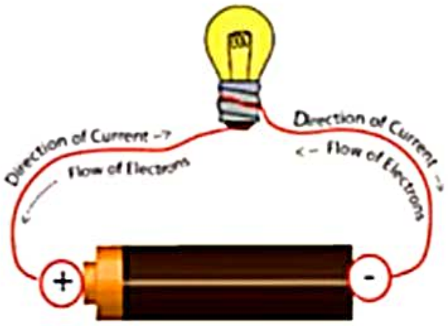
What is Electric current?

- ★ In metallic conductors electrons are free to move



- ★ When an electric field is applied across the conductor the random motion of the electrons become an ordered one.That is electric current is an ordered transfer of electric charge

Current I

Steady Current

- The measure of electric current is called Intensity of current I.
- It is defined as the charge that transferred across the surface in unit time.

If a net charge q passes through any cross section of the conductor in time t,then

Current I =q/t   Unit is Ampere(A)

Here the current is assumed to be constant ie equal amount of charge q passes through a given section in of the conductor in equal intervals of time.this current is called **Steady Current**

Current density

Current is a scalar

Current density J is a vector.

It is defined as the ratio of the current through a surface area perpendicular to the direction of motion of charge carriers .The direction of J is the direction of the velocity vector of the ordered motion of the positive charges.

$$J = \frac{I}{A_{\perp}}$$

Where $A_{\perp}$ is the area of cross section perpendicular to the current flow

If the current distribution is not uniform we have to consider the infinitesimal area ds across which current dI can be assumed as uniform

Then $$J = \frac{dI}{ds_{\perp}}$$

We can find the current passing through this surface as the flux of vector J

$$I = \int \vec{J} \cdot \vec{dS}$$

Current density(J) and conductivity(σ)

Current density J and Electric filed (E)at apoint on an isotropic medium are directly propotional

i.e $$\vec{J} \,\alpha\, \vec{E}$$

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

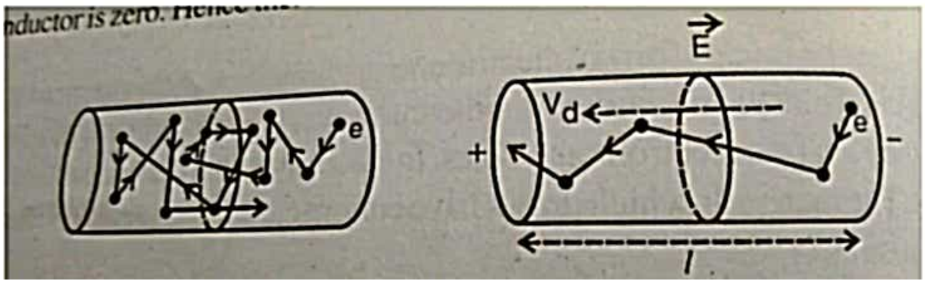
This equation is called differential form of Ohm's Law

σ is called conductivity which is scalar .Reciprocal is resistivity $\rho=1/\sigma$

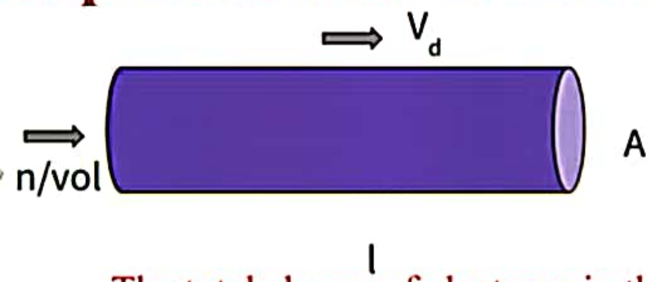
Drift Velocity

- Random motion of free electrons inside a conductor
- No net flow of electrons through the conductor
- When an electric field is applied electrons are accelerated to the positive terminal

When an electric field is applied across a conductor the electrons are drifted towards the positive terminal of the battery.This is called drift velocity of the electrons V_d. It is very small 0.1cm/s to 1cm/s.



Expression for drift velocity



The total charge of electrons in the conductor of volume V will be

$q = nAle$

V_d is the drift velocity of the electrons,the time taken by the electrons to cover a length l is given by

$t = l/V_d$

The current is given by

$$I = \frac{q}{t} = \frac{nAle}{t} = \frac{nAle}{\left(\frac{l}{V_d}\right)}$$

$I = nAeV_d$

$$I = nAeV_d \qquad \frac{I}{A} = neV_d \text{ ie } \quad J = neV_d$$

Drift Velocity(V_d) and Relaxation time(τ)

When an electric field E is applied to a conductor,the field applies a force eE on each electron

This force gives an acceleration *a* to the free electron in the opposite direction of E is given by

$$a = \frac{F}{m} = -\frac{eE}{m}$$

This accen will last for a very short time due to the collision of electrons with the positive ions in the metal

The kinetic energy gained will be completely lost during this collisions

Drift Velocity(V_d) and Relaxation time(τ)

The average time interval that elapses between two successive collisions of an electron is called relaxation time(τ)

The additional velocity acquired by the electron during time τ in the opposite direction of the field is

$$V_d = 0 + a\tau$$

$$V_d = -\frac{eE}{m}\tau$$

Mobility of free electron $\mu_e = \frac{V_d}{E}$

The average velocity acquired by the free electrons of a conductor in the opposite direction of the external applied electric field is called drift velocity.

Resistivity (ρ) and Relaxation time (τ)

We have

$$\rho = \frac{RA}{l}$$

Using Ohm's law $R = \frac{V}{I} = \frac{El}{I}$

But $I = neAV_d$

$$R = \frac{El}{nAeV_d}$$

We have

$$V_d = \frac{eE}{m}\tau \qquad R = \frac{\rho l}{A}$$

$$R = \frac{Elm}{nAeeE\tau} = \frac{ml}{nAe^2\tau} = \frac{\rho l}{A}$$

$$\rho = \frac{m}{ne^2\tau}$$

Resistivity and Temperature

Resistivity of the conductor increases with increase in temperature ,hence the value of resistance also increases with rise in temperature

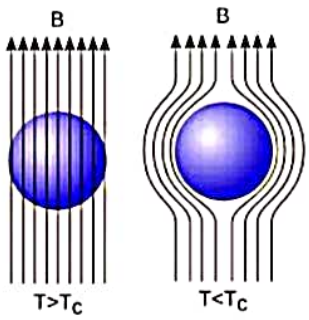
Let R -Resistance at temp T

R_0 is the resistance at 0^0C then the temperature coefficient of resistance of the material is given by

$$\propto = \frac{(R - R_0)}{R_0 T}$$

Superconductors

- Resistivity become zero below certain temperature,This temperature is called critical temperature
- For mercury resistance reduces to zero for temp below 4.2K
- At Superconducting state the material become Diamagnetic .Magnetic field is expelled out of the material at its superconducting state .This phenomenon is called Meissner Effect

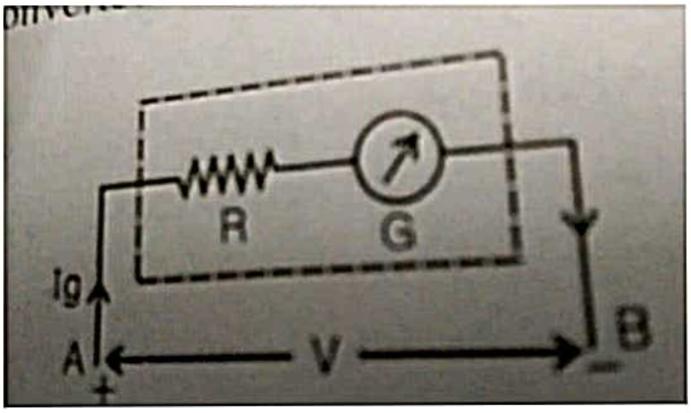


Conversion of a Galvanometer to Voltmeter

- Galvanometer is used to detect the presence of Current
- Principle of Galvanometer is that a current carrying loop or a coil placed in a magnetic field will experience a torque.
- In the galvanometer $I \propto \theta$ or $I=K\theta$, K is a constant called galvanometer constant.
- The max. safe current which can be passed through the galvanometer is $I_{g.}$
- That is the Galvanometer shows full deflection for the current I_g
- When we convert a Galvanometer to voltmeter or ammeter the current through the galvanometer should not be more than I_g

Conversion of a Galvanometer to Voltmeter

Galvanometer can be converted to voltmeter by connecting a large resistance in series to the galvanometer



Let G =the resistance of Galvanometer
Ig = the safe current through galvanometer
V be the p.d to be measured by the converted galvanometer across points A and B.

Where $\frac{V}{G} > I_g$

A high resistance is connected in series with the galvanometer such that

$$\frac{V}{(R+G)} = I_g$$

That is the Galvanometer shows full scale deflection for the p.d ' V'.

Thus the Galvanometer is converted to voltmeter which can measure a maximum p.d 'V'

If θ_g is the full scale deflection on galvanometer scale then p.d per deflection is $\frac{V}{\theta_g}$

Then if θ is the deflection for V' (where V'<V)

The potential difference V'=$\frac{V}{\theta_g}$ θ

Determining the value of R

The value of R can be calculated by

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

Or $$\frac{V}{I_g} = R+G$$

$$R = \left(\frac{V}{I_g} - G\right)$$

Now the total resistance of voltmeter is R'=R+G which is very high

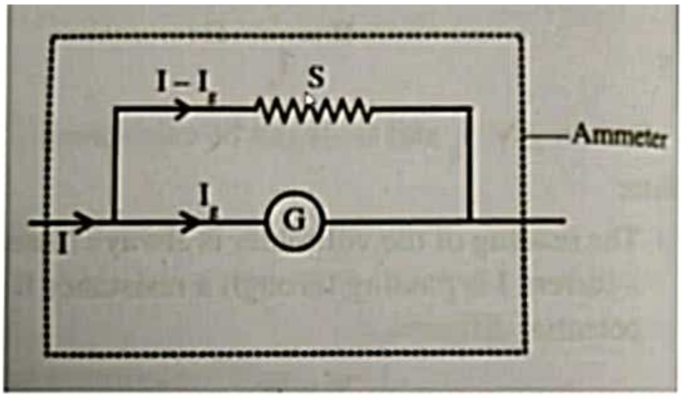
The ideal resistance of Voltmeter is infinity

Conversion of Galvanometer to Ammeter

A galvanometer is a device used to detect low current but an ammeter is a device used to measure current

A galvanometer can be converted into an ammeter by connecting a low resistance called shunt resistance parallel with the galvanometer .The resistance of the shunt depends upon the range of the Ammeter

Let Ig be the maximum current through the galvanometer producing full scale deflection and G be its resistance.To measure a current of I ampere a shunt of resistance S is connected in parallel with the Galvanometer



A part Ig passes through the galvanometer and remaining part (I-Ig) flows through the shunt

Since G and S are parallel

Potential difference across G = p.d across S

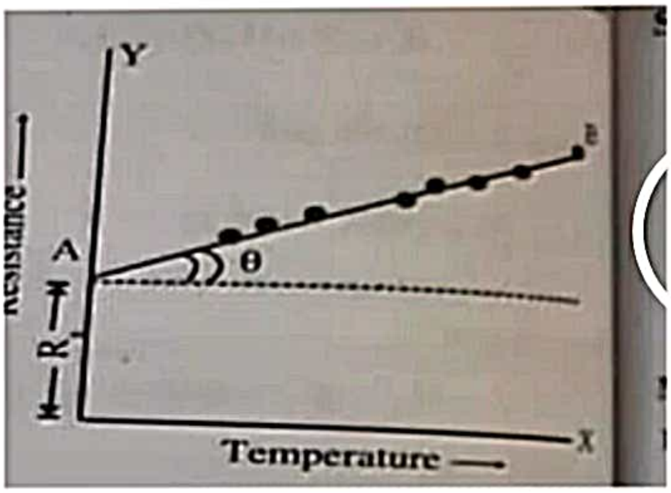
$I_g G = (I - I_g)S$ Or $S = I_g G/(I - I_g)$

Let R_0 and R_t resistance at 0 degrees and t degrees

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

$$\alpha = \frac{(R_t - R_0)}{R_0 t}$$

The increase of resistance per unit original resistance per degree rise of temperature is called temperature coefficient of resistance.

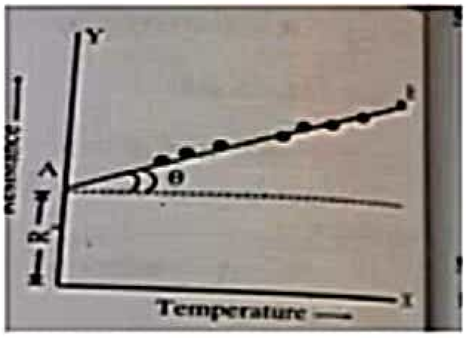


Slope of the line =tan θ=dR/dt

Y intercept $=R_0$

$$\alpha = \frac{1}{R_0}\frac{dR}{dt}$$

$$\alpha = \frac{(R_2-R_1)}{R_1t_2-R_2t_1}$$



Slope of the line =tan θ=dR/dt
Y intercept =R_0

$$\alpha = \frac{1}{R_0} \frac{dR}{dt}$$

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

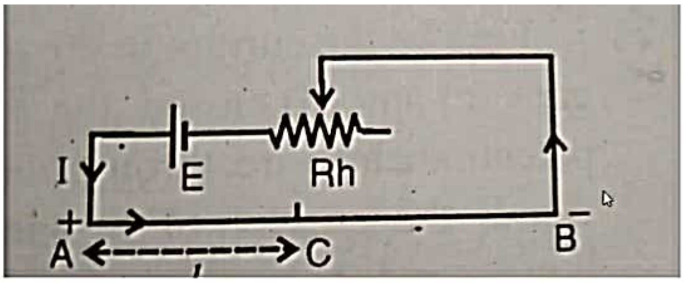
Screen clipping taken: 25-11-2021 10:49

$$\alpha = \frac{R_1 - R_0}{R_0 t_1}$$

$$R_1 = R_0[1 + \alpha t_1]$$

$$R_2 = R_0[1 + \alpha t_2]$$

$$\alpha = \frac{1}{R_1} \frac{(R_2 - R_1)}{(t_2 - t_1)}$$



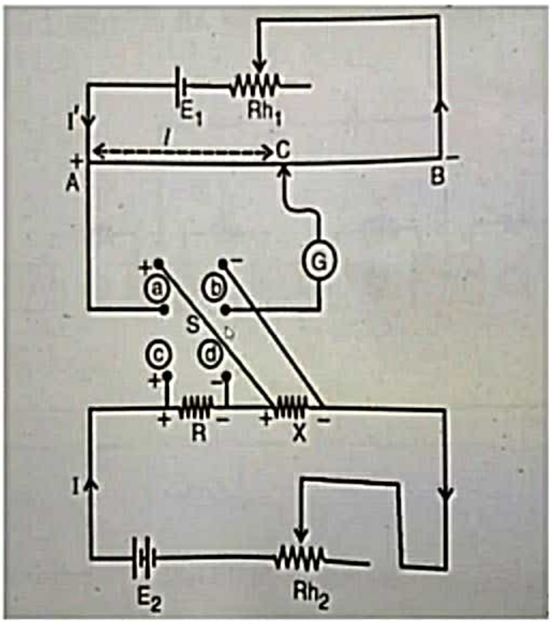
The circuit used to send steady current through the wire is called primary circuit.

The p.d across a length AC = current X Resistance

The p.d across a length AC= I **(ρl)/A**

R= (ρl)/A is the resistance of AC and A is the area of cross section of the wire ,then V=IR=I**(ρl)/A**

When a study current flows through a long wire of uniform area of cross section the p.d across any section of the wire is directly proportional to the length of that section.This is the Principle of Potentiometer



By the principle of potentiometer

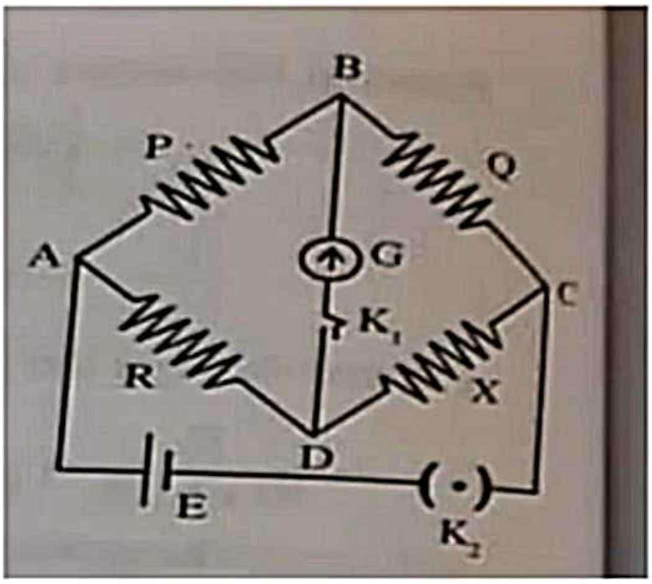
$IR \propto l_1$ ....(1)

Now the gaps (a) and (b) are closed while gaps (c) and (d) are opened.The p.d IX across the unknown resistance X is balanced by moving J over AB.

Let the balancing length be l_2 IX $\propto l_2$.................. (2)

(1)÷(2) $\frac{R}{X} = \frac{l_1}{l_2}$ $X = R\frac{l_2}{l_1}$

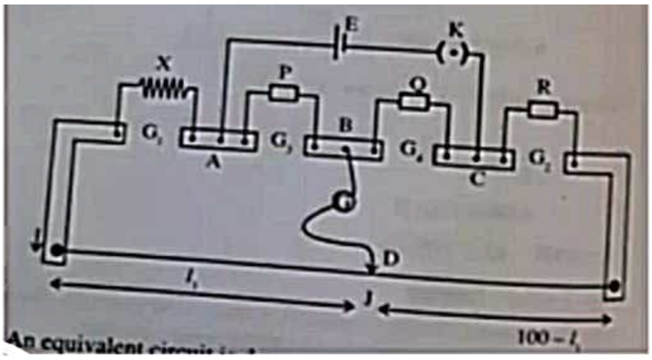
It is the modified form of wheatstone's bridge and working principle of wheatstone's bridge



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

$$\frac{P}{Q} = \frac{\text{(Resistance of arm AD)}}{\text{Resistance of Arm CD}}$$

ie $$\frac{P}{Q} = \frac{(X+\alpha+l_1\rho)}{R+\beta+(100-l_1)\rho}$$



Since P=Q we have $(X + \alpha + l_1\rho) = R + \beta + (100 - l_1)\rho$

Now Interchange X and R $(R + \alpha + l_2\rho) = X + \beta + (100 - l_2)\rho$

$$X = R + \rho(l_2 - l_1)$$

$$\frac{x+\alpha+l_1\rho}{R+\beta+(100-l_1)\rho} = \frac{R+\alpha+l_2\rho}{x+\beta+(100-l_2)\rho}$$

$$1+\frac{x+\alpha+l_1\rho}{R+\beta+(100-l_1)\rho} = 1+\frac{R+\alpha+l_2\rho}{x+\beta+(100-l_2)\rho}$$

$$\frac{R+\beta+(100-l_1)\rho+x+\alpha+l_1\rho}{R+\beta+(100-l_1)\rho} = \frac{x+\beta+(100-l_2)\rho+R+\alpha+l_2\rho}{x+\beta+(100-l_2)\rho}$$

$$\frac{R+\beta+100\rho-\cancel{l_1\rho}+x+\alpha+\cancel{l_1\rho}}{R+\beta+(100-l_1)\rho} = \frac{x+\beta+100\rho-\cancel{l_2\rho}+R+\alpha+\cancel{l_2\rho}}{x+\beta+(100-l_2)\rho}$$

$$\frac{R+\beta+x+\alpha+100\rho}{R+\beta+(100-l_1)\rho} = \frac{R+\beta+x+\beta+100\rho}{x+\beta+(100-l_2)\rho}$$

Numerators are equal.

then $R+\beta+(100-l_1)\rho = x+\beta+(100-l_2)\rho$

$\Longrightarrow$ $R+(100-l_1)\rho = x+(100-l_2)\rho$

$$x = R+(100-l_1)\rho-(100-l_2)\rho$$

$$= \underline{R+(l_2-l_1)\rho}$$

$$0 = R + \rho\,(l_4 - l_3)$$

$$\rho = \frac{R}{(l_3 - l_4)}$$

ρ is the resistance per unit length