CURRENT ELECTRICITY

Electric Current: The time rate of flow of charge through any cross-section is called current. It is denoted by i. Current is a scalar quantity. It's S.I unit is ampere (A).

i.e $\boxed{i = \dfrac{q}{t}}$ where q is net amount of charge passing through any cross-sectional area. and $q = q_+ - q_-$, if flow is uniform.

also $i = \lim\limits_{\Delta t \to 0} \dfrac{\Delta Q}{\Delta t}$ if flow is non-uniform. or $i = \dfrac{dQ}{dt}$

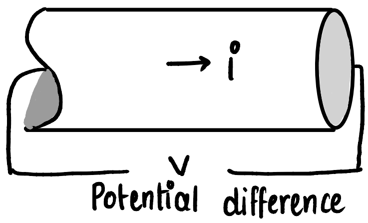
Note:→ if the moving charges are +ve, the current is in the direction of motion.
if the moving charges are −ve, the current is opposite to the direction of motion.

CURRENT CARRIERS

- **Solid:** In solid conductors like metals current carriers are free electrons.
- **Liquids:** In liquids current carriers are positive and negative ions.
- **Gases:** In gases current carriers are positive ions and free electrons.
- **Semiconductor:** In semiconductors current carriers are holes and free electrons.

OHM'S LAW

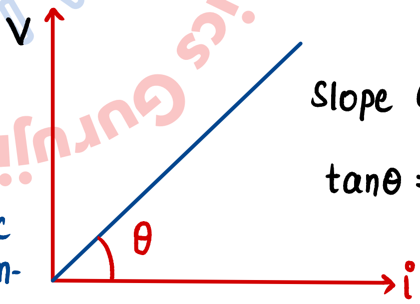
The current flowing through the conductor is directly proportional to the potential difference across it's two ends. (if the physical condition of conductor (length, temperature, mechanical strain) remain same.



i.e $V \propto i$ or $\boxed{V = iR}$

where R is constant of proportionality called as Resistance of the conductor.
SI unit of Resistance is ohm (Ω).

$\boxed{R = \dfrac{V}{i}}$ Resistance = Slope of V−i graph.



Slope of the line

$\tan\theta = \dfrac{V}{i} = R$

Note:→ The devices or substances which don't obey ohm's law e.g gases, crystal rectifiers, thermionic valve, transistors etc are called non-ohmic or non-linear conductor. and which obey ohm's law called as Ohmic Conductor. e.g All metals.

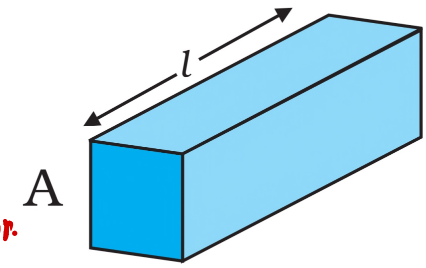
RESISTANCE

- The property of a substance by virtue of which it opposes the flow of current through it, is known as the resistance. The resistance of a conductor is directly proportional to the length of the conductor and inversely proportional to the cross-sectional area of conductor.

$R \propto l$ —(1)

$\propto \dfrac{1}{A}$ —(2).

$R \propto \dfrac{l}{A} \Rightarrow \boxed{R = \rho\dfrac{L}{A}}$ ρ = Proportionality constant called as Resistivity of Conductor.



NOTE:→ ρ depend upon the material of conductor.

Question:→ Show that one ampere is equivalent to a flow of 6.25×10^{18} elementary charges per second.

Solution:→ Given $i = 1A$ $t = 1s$, $e = 1.6 \times 10^{-19}C$ $\quad i = \dfrac{q}{t} = \dfrac{ne}{t}$

Number of electrons $n = \dfrac{it}{e}$

$= \dfrac{1 \times 1}{1.6 \times 10^{-19}} = 6.25 \times 10^{18}$ Answer

Thermal Velocity: Free electrons in a metal move randomly with a very high speed of the order of 10^5 m/s (when no external electric field is applied). This speed is called thermal velocity of free electrons. As there is a large number of free electrons moving in random directions, the number of electrons crossing an area ΔS from one side very nearly equals the number crossing from the other side in any given time interval.

i.e average thermal velocity $\vec{u}_{avg} = 0$

Drift Velocity

When a potential difference is applied across the ends of a conductor, the free electrons in it move with an average velocity opposite to the direction of electric field, which is called drift velocity of free electrons.

Drift velocity is very small, it is of the order of 10^{-4} m/s.

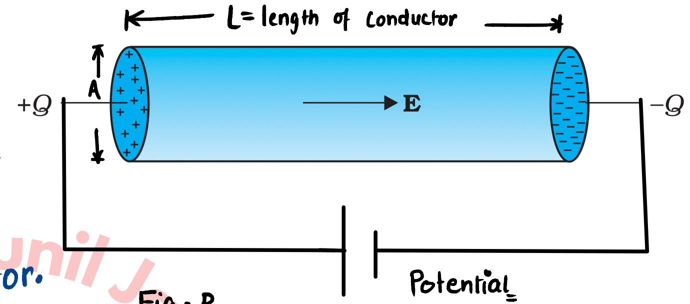


Fig. P

For a conductor n = no. of e^- per unit volume of the conductor.

A = Area of cross-section V = Potential diff. across conductor.

E = Electric field inside conductor

The magnitude of electric field setup is $\boxed{E = \frac{V}{l}}$

• if m is the mass of an electron, the acceleration of each electron is $a = -\frac{e\vec{E}}{m}$ [−ve shows that the direction of force is opposite to that of electric field applied).

The average drift velocity is given by

$$\vec{V}_d = \vec{u}_{avg} + at$$

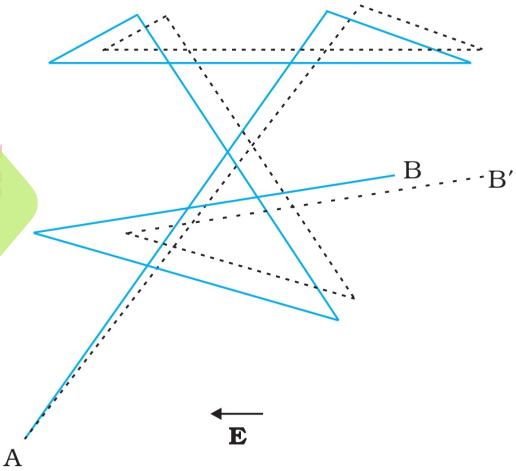
Here $\vec{u}_{avg} = 0$

so $\vec{V}_d = \vec{a}t \Rightarrow \vec{V}_d = -\frac{e\vec{E}}{m}\tau$

$t = \tau$ (Average relaxation time).

In magnitude $\boxed{V_d = \frac{eE}{m}\tau}$

Fig. shows movement of electron from to A to B' on application of electric field. And movement from A to B without electric field.



Relation between Current & Drift velocity

we know that

$i = \frac{q}{t}$ & $q = NAe$

$q = nlAe$ from fig P.

and

$t = \frac{L}{V_d}$ Now $i = \frac{nAle}{l} \times V_d \Rightarrow \boxed{i = AneV_d}$ $e = 1.6 \times 10^{-19}$ C n = number density.

• Deduction of OHM'S Law from idea of Drift Velocity.

we know that $i = AneV_d$ — ① and $V_d = \frac{eE}{m}\tau$ Put value of V_d in eq ① we get $i = \frac{Ane^2E\tau}{m}$

and $E = \frac{V}{l}$ from fig P.

so $i = \frac{Ane^2}{m}\frac{V}{l}\tau$

$V = \frac{iml}{Ane^2\tau}$ or $\boxed{\frac{V}{i} = \frac{ml}{Ane^2\tau} = R \text{ (Costant)}}$ i.e $R = \frac{ml}{Ane^2\tau} \Rightarrow R = \frac{l}{A} \times \frac{m}{ne^2\tau}$ Constant

$\boxed{\rho = \frac{m}{ne^2\tau}}$, Called as Resistivity and depend upon material of conductor.

• Important Definitions

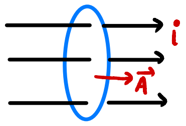
• **Relaxation Time :– (τ)** The time interval between two successive collisions of electrons with the positive ions in the metallic lattice is defined as Relaxation Time.

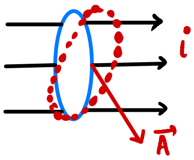
$$\tau = \frac{\text{mean free Path}}{\text{rms velocity of electrons}} = \frac{\lambda}{V_{rms}}$$

• **Mobility** :→ It is defined as the magnitude of drift velocity of charge per unit electric field applied. i.e

$$\mu = \frac{|\vec{V_d}|}{E} \Rightarrow \frac{eE\tau}{m} \times \frac{1}{E} \Rightarrow \boxed{\mu = \frac{e\tau}{m}}$$ SI unit $m^2 s^{-1} V^{-1}$

• **Current density : (J).** ⇒ Current density at a point inside a conductor is defined as the amount of current flowing per unit cross-sectional area surrounding that point.
(NOTE :→ Area is normal to the direction of current (charge) through that point.)





so $J = \frac{i}{A}$

$J = \frac{i}{A\cos\theta}$ $\qquad$ $i = JA\cos\theta$

$i = \vec{J} \cdot \vec{A}$

• Current density is a vector quantity.
• its direction is same as the direction of current.

• **Conductance** : It is the reciprocal of Resistance. It is denoted by G.
so $\quad G = \frac{1}{R}$ $\quad$ SI unit = Ω^{-1} (Siemen) (S)
(NOTE:→ Conductance is measure of ease with which the charges flow through the conductor.)

• Conductivity (σ)
It is the reciprocal of resistivity of a conductor, denoted by σ.
$\sigma = \frac{1}{\text{Resistivity}} \Rightarrow \sigma = \frac{1}{\rho}$ $\qquad$ SI unit $\Omega^{-1} m^{-1}$ or mho m^{-1} or Sm^{-1}.

Temperature Dependence of Resistivity / Resistance

• For Conductor $\qquad$ Resistance ∝ Temperature

or $R = \frac{ml}{ne^2\tau}$ or $R = \rho\frac{L}{A}$ where $\rho = \frac{m}{ne^2\tau}$ i.e $\rho \propto \frac{1}{\tau}$

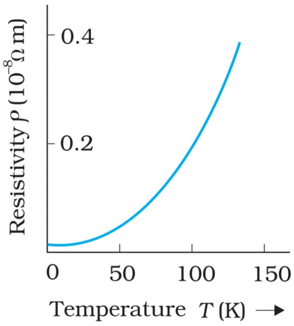
When Temp ↑es ⇒ τ ↓es ⇒ ρ ↑es or R ↑es

also $\quad R = R_0(1 + \alpha\Delta T)$ $\quad$ where $\Delta T = T - T_0$ $\quad$ OR $\quad \rho = \rho_0(1 + \alpha\Delta T)$

where R = resistance of Conductor at T°C or Final Temp
R_0 = " " " at 0°C or initial "

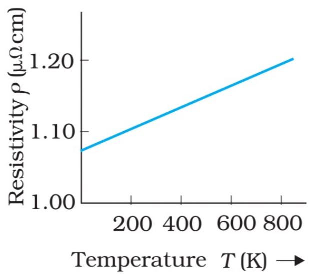
T = Final Temp
T_0 = initial Temp

α = Temp. Coefficient.
unit of α = °C^{-1}
α is +ve for metals.



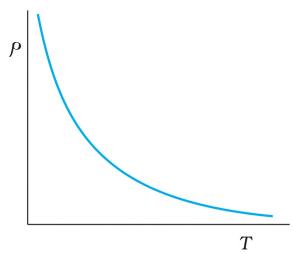
Resistivity ρ_T of copper as a function of temperature T.

α is +ve (large)



Resistivity ρ_T of nichrome as a function of absolute temperature T.

α is small +ve
T ↑es but small change (↑es) in ρ.



Temperature dependence of resistivity for a typical semiconductor.

α is –ve
Here T ↑es ρ ↓es

[CELL]

The device which converts chemical energy into electrical energy is known as electric cell.

- Cell is a source of constant emf but not constant current.
- Symbol of Cell

EMF of Cell (E) :→ The potential difference across the terminal of a cell when it is not supplying any current is called it's emf.

$$E = V + Ir.$$

- **Potential difference (V) :→** The voltage across the terminal of a cell when it is supplying current to external resistance is called potential difference or terminal voltage. denoted by V.
- it is always less than emf E. i.e $V = E - Ir.$

- **Internal resistance (r) :→** The obstruction offered by the electrolyte of a cell in the path of electric current is called internal resistance (r) of the cell.

Internal resistance of a cell depends on the

a) distance between electrodes ($r \propto d$)

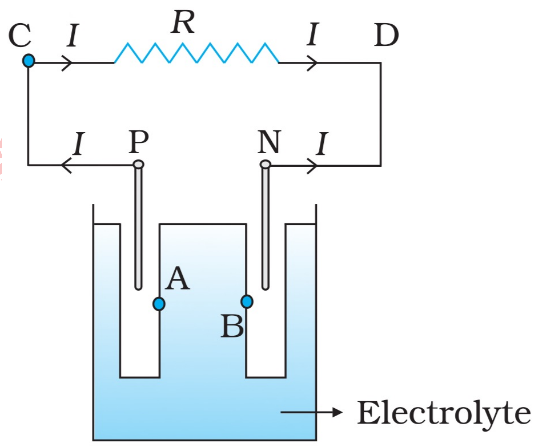
b). area of electrodes ($r \propto 1/A$)

c) nature, concentration of electrolyte ($r \propto C$)

d). Temp of electrolyte ($r \propto 1/Temp$)

Relation between E, V and r.

Consider first the situation when R is infinite so that I = V/R = 0, where V is the potential difference between P and N. Now,



V = Potential difference between P and A
+ Potential difference between A and B + Potential difference between B and N

$V = \varepsilon$ (emf of cell)

If however R is finite, I is not zero. In that case the potential difference between P and N is

$$V = V_+ + V_- - Ir$$

$$V = \varepsilon - Ir \quad \text{— (1)} \qquad \text{or} \qquad r = \left(\frac{\varepsilon}{V} - 1\right)R$$

Note the negative sign in the expression (I r) for the potential difference between A and B. This is because the current I flows from B to A in the electrolyte.

since V is the potential difference across R, we have from Ohm's law

$V = IR$ so eq (1) become as $IR = \varepsilon - Ir$

$Ir = \varepsilon - IR \Rightarrow I(R+r) = \varepsilon \Rightarrow I = \dfrac{\varepsilon}{R+r}$

I is maximum when R=0 then $\boxed{I_{max} = \dfrac{\varepsilon}{r}}$

Grouping of Cells

(1). Series Combination of Cell.

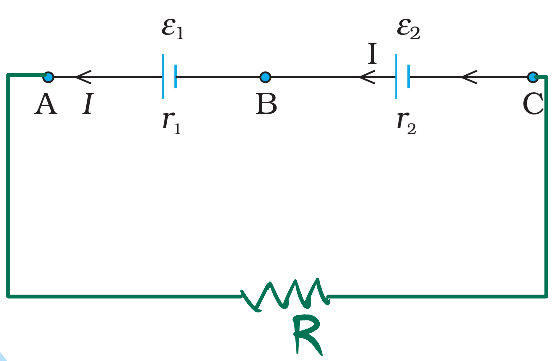
$\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2$

$r_{eq} = r_1 + r_2$

$R_{eq} = R + r_{eq}$

so $i = \dfrac{\varepsilon_{eq}}{R_{eq}} = i = \dfrac{\varepsilon_1 + \varepsilon_2}{R + r_1 + r_2}$

For n-Series $i = \dfrac{nE}{R + nr}$ ← For identical cell

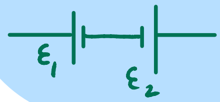


Maximum Current

if $R >> nr$

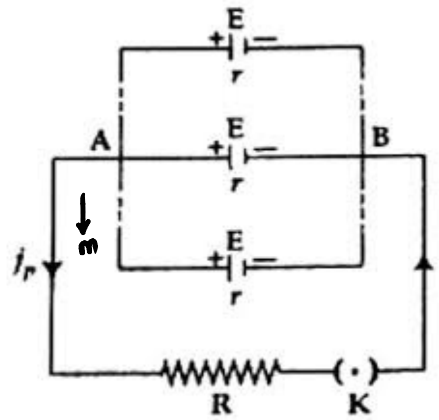
$i = \dfrac{nE}{R}$ n times the current (ε/R) that can be drawn from one cell.

if Similar plates of Cells are connected i.e



if $\varepsilon_1 > \varepsilon_2$ then $\varepsilon = \varepsilon_1 - \varepsilon_2$

• Parallel Combination of Cell



Here

$E_{eq} = E$ (in Parallel emf/voltage remain Same)

& $r_{eq} = \frac{r}{m}$

and $R_{eq} = R + \frac{r}{m} = \frac{mR + r}{m}$

so $i = \frac{mE}{mR + r}$ or $i = \frac{E}{R + r/m}$

$i_{max} = \frac{mE}{r}$ when $R << \frac{r}{m}$

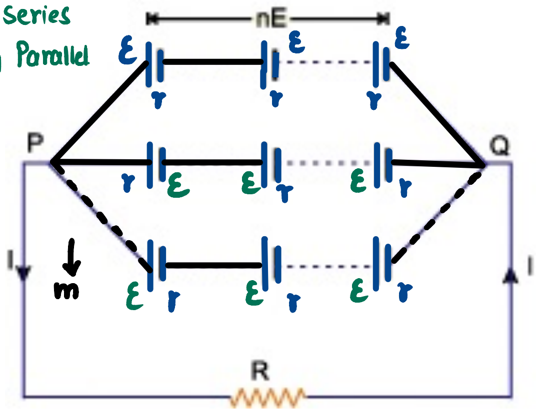
Mixed Grouping of Cell

Here n Cells are connected in series and m rows are connected in Parallel. Here equivalent emf of the Combination is

$E_{eq} = nE$

$r_{eq} = \frac{nr}{m}$ $\quad R_{eq} = R + \frac{nr}{m}$

$i = \frac{nE}{R + \frac{nr}{m}}$



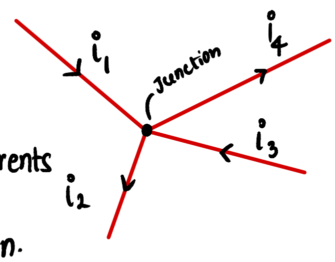
Current will be maximum when $R = \frac{nr}{m}$

Kirchhoff's Law

1). Kirchhoff's Law

This law is also known as junction Rule or Current law.

At any junction the sum of the currents entering the junction must equal to the sum of current leaving the junction.



from figure $i_1 + i_3 = i_2 + i_4$

i.e $i_1 + i_3 + (-i_2) + (-i_4) = 0$

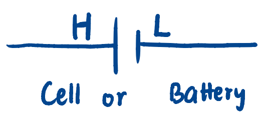
2). Kirchhoff's 2nd Law

The algebraic sum of all the potential differences in any closed circuit is zero.

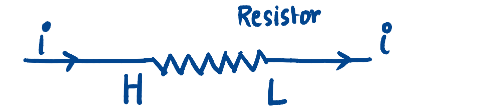
i.e $\Sigma \Delta V = 0$, This law represents "Conservation of energy".

Sign Convention for the application of Kirchhoff's

•



For Both Cell / Battery or Resistor if we traverse From H (+ve) to L (-ve) then we will Consider it negative & if we traverse from L to H, then we will consider it +ve.



H = High (+)ve $\quad$ L = Low (-ve)

• WHEAT STONE BRIDGE

• Wheat stone bridge is an arrangement of four resistances in which one resistance is unknown but rest are known.

Principle of Wheat stone Bridge

$\boxed{\frac{P}{Q} = \frac{R}{S}}$ at Balanced Condition

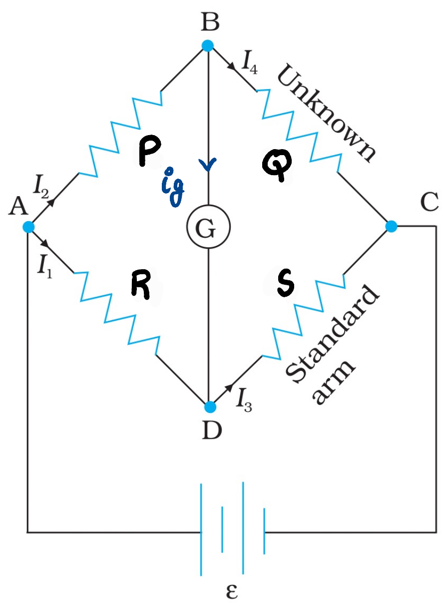
The bridge is said to be balanced when deflection in galvanometer is ZERO. i.e $i_g = 0$

At Balanced Condition

$PS = RS$

At unbalanced Condition

$PS \neq RS$



METER BRIDE/SLIDE WIRE BRIDGE

It is the practical form of wheat stone Bridge. It is specially useful for comparing resistance more accurately and for measuring an unknown resistance.

At balancing situation of bridge

$$\frac{l}{(100-l)} = \frac{R}{S}$$

where l is the length of wire from one end and where null point is obtained.

- It consist of a wire of 1m (100 cm)

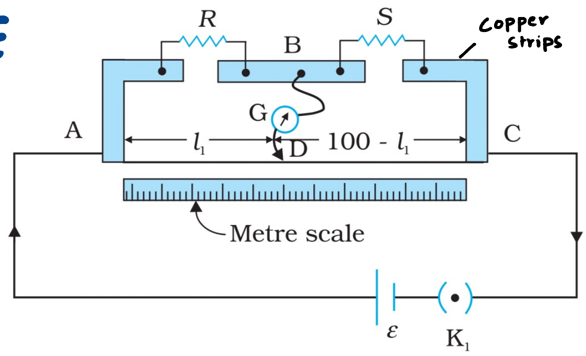


FIGURE A meter bridge. Wire AC is 1 m long. R is a resistance to be measured and S is a standard resistance.

Potentiometer

Potentiometer :- Potentiometer is a device mainly used to measure emf of a cell of a given cell and to compare emf's of two cells. It is also used to measure internal resistance of a given cell.

- The principle of potentiometer states that when a constant amount of current flows through a wire of uniform cross section, then the potential drop across the wire is directly proportional to its length. $V \propto l \Rightarrow V = kl$ k is potential gradient (Voltage drop per unit length)

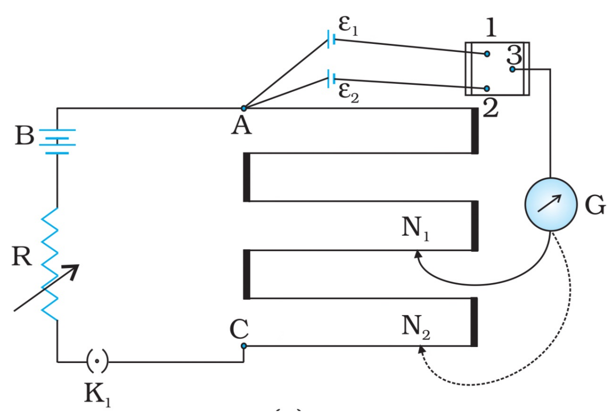
SI unit of $k = \frac{V}{m} = Vm^{-1}$

- It consists of a long resistance wire of uniform cross-section in which a steady direct current is set up by means of a battery.

Note: Sensitivity of potentiometer is increased by increasing length of Potentiometer wire.

Application of Potentiometer

• To Compare EMF of two Cells



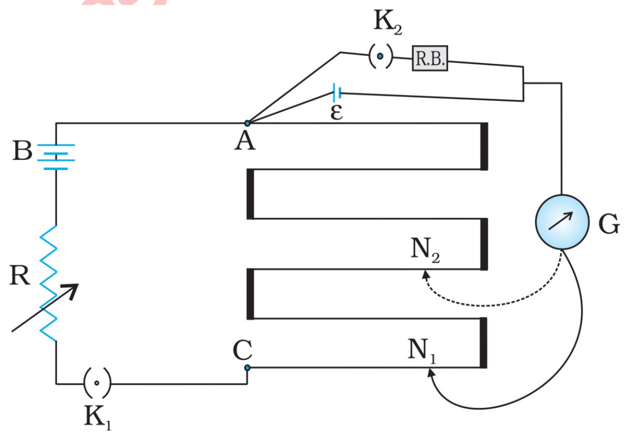
- If the plug is put in the gap between 1 & 3, we get $\varepsilon_1 = kl_1$ —(1).

Similarly, when the plug is put in the gap between 2 and 3, we get $\varepsilon_2 = kl_2$ —(2)

From eq (1) and (2) we get

$$\boxed{\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}}$$

• To Find internal resistance of a Cell.



- When K_2 is open & K_1 is closed, then $\varepsilon = kl_1$ — (1).

But if by inserting key K_2 and introducing some resistances S, then potential difference V is balanced by a length l_2, where

$V = kl_2$ — (2)

divide eq (1) ÷ (2)

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

we know that $r = \left(\frac{\varepsilon}{V} - 1\right)R$

$$r = \left(\frac{l_1}{l_2} - 1\right)R$$

Electric Energy

The work done by any source in maintaining the current in the electric circuit is called electric enegy consumed by the electric Circuit.

Electric Enegy = Potential x Charge

$$E = Vq = VIt = I^2Rt = \frac{V^2}{R}t$$

SI unit is joule (J) another unit is watt-hour. The bigger unit of energy is kilowatt hour. (Also known as Board of Trade (BOT).

1 kilowatt hour = 3.6×10^6 J

1 Horse Power = 746 Watt

Electric Power

It is defined as the rate of doing Work by any source. It is denoted by P.

$$\text{Power} = \frac{\text{Work}}{\text{Time}} \Rightarrow P = \frac{W}{t} \Rightarrow P = V\frac{q}{t} \Rightarrow P = VI$$

- SI unit is watt (W)
- kilowatt
- horse Power

Heating effect of Current (Joule's Law)

When Current I flows through a conductor of resistance R for a time t, then heat generated in it is given by

$$H = i^2Rt \text{ joule}$$

$$H = \frac{i^2Rt}{4.18} \text{ cal}$$

Important Topics

- Drift velocity
- Temperature Dependence of Resistance
- Combination of Cells
  - Series
  - Parallel

- Potentiometer
- Application of Potentiometer.
- Slide wire bridge.

Numerical asked from

- Potentiometer
  - $\frac{\varepsilon_1}{\varepsilon_2} = \frac{l_1}{l_2}$
  - $r = \left(\frac{\varepsilon}{V} - 1\right)R$
- Drift velocity
  - $V_d = \frac{eE}{m}\tau$
  - $i = AneV_d$
- Wheat Stone Bridge
  - $\frac{l}{(100-l)} = \frac{R}{S}$
- Kirchhoff's Law