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# CURRENT ELECTRICITY

flow (of) electric charges

## Introduction

"Electric current is net charge flowing through area per time."

→ **Steady current** is the constant flow of free electrons

→ **Conventional current**; it was assumed before the electron theory that current flows from positive terminal to negative terminal.

→ **Electronic current**; actual direction of current is from negative terminal to positive terminal

→ **Why is current scalar?** Because it does not follow vector law of addition.

→ **When do electrons flow?** When free electrons present in a conductor are exposed to a potential difference, they flow.

**Mathematically**: $I = \frac{Q}{t}$ where I = current, t = time, Q = charge

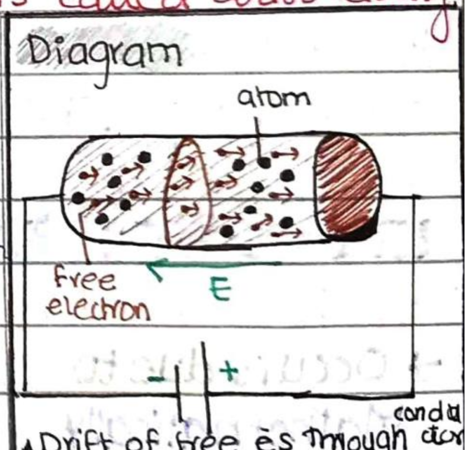
**SI unit**: Ampere $(Cs^{-1})$

## Drift Velocity

"The net velocity which ēs acquire within a conductor upon connection w/ a battery is called drift velocity"

→ **Why is drift velocity called as 'drift' velocity?**

When upon connection, with a battery, of conductor electric field $\vec{E}$ is set up at every point within the conductor. The electrons (free) acquire some path through the conductor with some drift velocity but ēs face opposition from atoms of conductor and thus they deviate from their straight path and move along a tilted drift path.



Drift of free ēs through conductor

only the "free" electrons within a conductor cause electric current. in a conductor

**Mathematically**

$$\vec{V_d} = \frac{\vec{j}}{nq}$$ where $j$ = current density = $I/A$

$$V_d = \frac{I/A}{nq} \quad \text{or} \quad V_d = \frac{I}{nAq}$$

→ **Important point**: In absence of battery net effect/velocity of ēs is zero.

## 11, Ohm's Law: "Current and voltage show a linear relationship as long as the temprature of conductor is kept constant."

→ **Constant temprature** is important for obeying this law as with increase in temprature, effective collisions between atoms start which offer resistance to the flow of current.

· **Mathematically** $V \alpha I$ or $V = IR$

→ **Non ohmic materials** are those having variable slope for I versus V graph

→ **Ohmic materials** are those having a constant slop for I versus V graph.

→ **Limitations of Ohm's law**



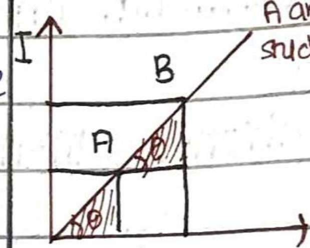
- not appliciable to insulators
- valid at only constant temprature.
- not appliciable on semiconductors and gaseous conductors like Hydrogen

→ **Graph**

We plot a graph between I and V to observe their behaviour with respect to each other and to study change. The curve tells us about resistance since $I/V = I/R$ or $V/I = R$

Graph

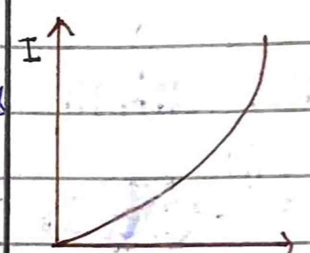
we take points A and B to study change.




$\tan\theta = \frac{Perp}{Base} = \frac{I}{V} = \frac{1}{R}$ V

↑ slope

∴ change is uniform, ohm law obeyed




∴ change isn't uniform, ohm law disobeyed

ohmic graph → straight line

non-ohmic graph → curved.

## 11, Electrical Resistance: "Resistance is the opposition offered by the substance to the flow of free electrons".

→ **Occurs due to** collision of free electrons with atoms. This Liberates heat.

**Mathematically** symbol's $\Omega$ $1\Omega = 1V/1A$ **SI unit** Ohm. $(\Omega)$

## 12, Factors affecting;

REASONS

→ **Length** $R \alpha L$ → Greater length means greater no. of atoms for collision.

→ **Cross Section A** $R \alpha 1/A$ → Small C.S.A means greater resistance to passage of charge

→ **Nature of material** → Specific resistance varies from material to material

→ **Temprature** $R \alpha T$ → Temprature increases the collisions b/w atoms.

**Combined equation** $R \propto \frac{L}{A}$, $R = \rho \times \frac{L}{A}$ where $\rho$ is called specific resistance of material (keeping T constant)

→ **Specific resistance or resistivity** of a material is the resistance offered by 1m length of wire of material having an area of cross section of $1m^2$.

→ **Resitivity of metals** is very less thus they are good conductors.

→ **Resistivity of insulators** is very large thus they hardly conduct any current.

## → effect of temprature on:

→ **Resistance of conductor** increases with increase in temprature due to collisions which offer hindrance to free és $\uparrow T \propto R \uparrow$

→ **Resistance of an insulator** decreases w/ increase in temprature. This is because the electrons which otherwise do not flow due to not being free, gain enough energy from heat to jump from their orbits and start flowing. $\uparrow T \propto 1/R \downarrow$

## → Conductance:

"The reciprocal of resistance of a conductor is called conductance (G)."

**Mathematically** $G = \frac{1}{R}$ **SI unit** mho **Common unit** Siemen (S).

| → Conductance / Resistance | VS | → Resistivity / conductivity |
| --- | --- | --- |
| • These terms are general which describe the phenomenon of either conductance or resistance | | • These terms are specific to the materials which offer either conductance or resistance. All materials have their specified values for these phenomenon thus when specifying conductance or resistance to specific material, we use resistivity or conductivity |

## → conductivity:

Reciprocal of resistivity of a conductor is called its conductivity

**Mathematically** $\sigma = 1/\rho = \frac{L}{RA}$

**Unit** $mho\,m^{-1}$ or siemen meter$^{-1}$ $(Sm^{-1})$

## III) Temprature Coefficient of Resitance/Resitivity:

→ Consider a conductor having resistance $R_0$ at 0°C and resistance $R_T$ at T°C.

→ Change in resistance will be (final - initial) $R_T - R_0$

→ Change will depend on initial resistance and rise in temp.

- $R_T - R_0 \propto R_0$ → Greater the initial value of resistance, greater will be the change.
- $R_T - R_0 \propto T$ → Greater the rise in T, greater will be increase & change in resistance

**Mathematically** $R_T - R_0 = \alpha R_0 T$ ① or $\alpha = \frac{R_T - R_0}{R_0 T}$ ②

where 'α' is temprature coefficient of resistance.

→ **What does 'α' tell us?** α tells us how much change in resistance will occure with respect to the original ohm resistance per degree rise in temprature. **unit of α** $= K^{-1}$

→ Every conductor has it's own value of 'α'.

→ **Positive and Negative temprature coefficient of R**

→ Resistance of metals increases w/ temprature. They have Positive temprature coefficient of R. {PTC}

→ Resistance of semiconductors decreases with temprature. They have Negative temprature coefficient of R. {NTC}

→ **Temprature coefficient of 'resistivity'**

Equation ① can be stated in terms of specific resistance of material aswell. If specific resistance $\rho_0$ is at 0°C and $\rho_T$ is at T°C then

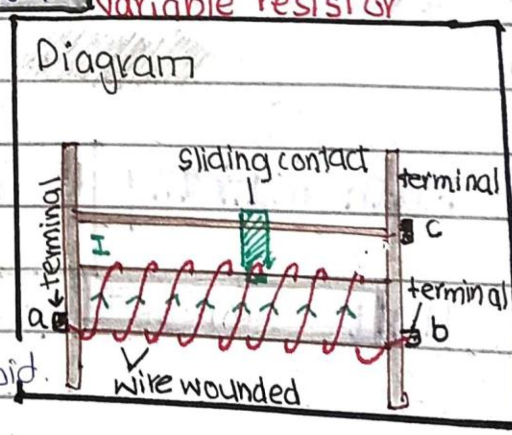
**Mathematically** $\rho_T = \rho_0(1 + \alpha T)$ or $\alpha = \frac{\rho_T - \rho_0}{\rho_0 T}$

## II) Rheostat:

Rheostat is a wire-bound variable resistor usually cylindrical in appearance.

→ **Symbol-** its symbol is ⍁

→ **Construction** wire is wounded over some ceramic material. Rheostat has three terminals, two are fixed (a and b) and one is variable (c). A sliding contact is present which slides over the wires or solenoid.



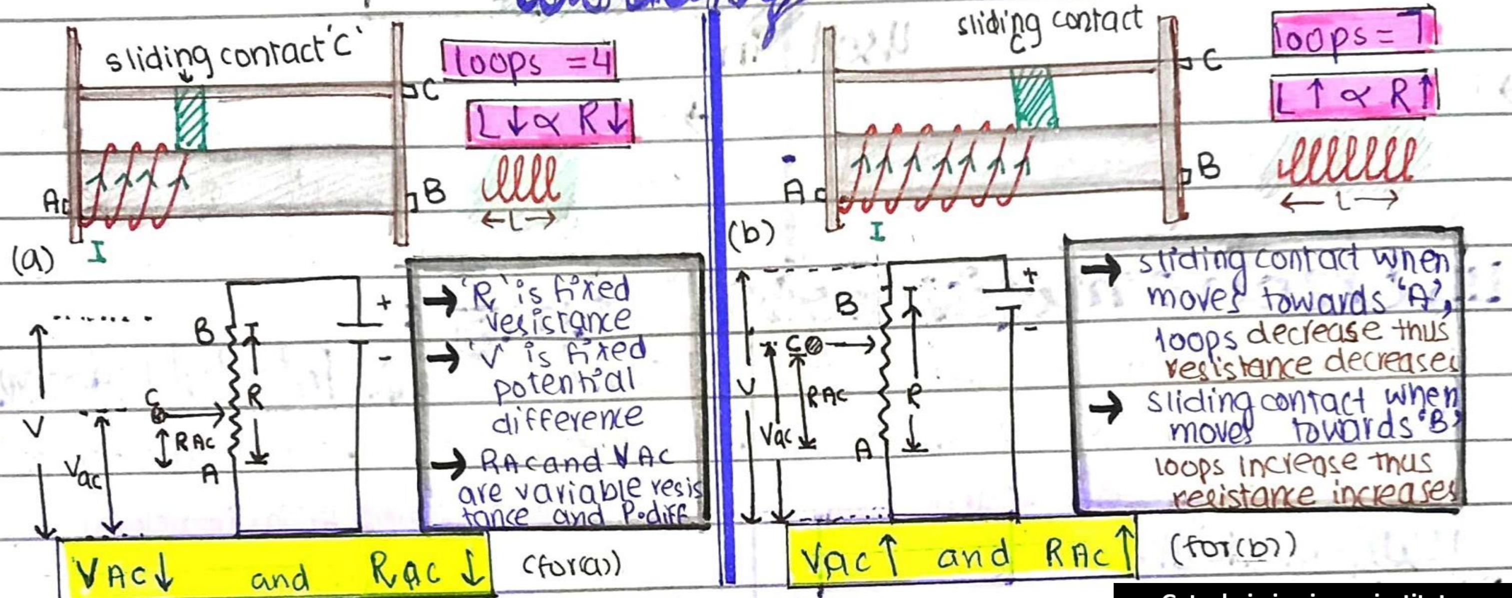
→ **Function** Rheostat is a current controlling device. It acts as a potential divider in the circuit. If the fixed terminals are connected in the circuit it acts as a fixed resistor. If the variable terminal along with one fixed terminal are connected, it acts as variable resistor.

**Potential Divider:** "Rheostat helps us to get a variable potential difference hence it acts as a potential divider."

→ **Connection in circuit** we will connect either a or b and the c terminals in the circuit to get rheostat work like a potential divider. (series connection will be effective)

→ **Working Principle** works on the principle **Resistance ∝ Length of wire**

## Working






## Mathematically

$V_{AB} = IR$ (fixed potential difference of circuit)

$V_{AC} = IR_{AC}$ (variable potential difference due to sliding contact C)

$V_{AC} = \frac{V}{R} \times R_{AC}$

$V_{AC} = \frac{R_{AC}}{R} \times V$

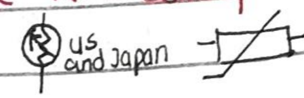
→ **What does ratio $R_{AC}/R$ tell us?** This ratio tells us about what portion the variable resistance '$R_{AC}$' is of the total resistance 'R'. Then in order to find potential difference for that part having variable resistance '$R_{AC}$' we multiply the ratio $R_{AC}$ with total potential difference.

**Conclusion:** Depending on the position of the sliding contact 'C' the value of fraction $R_{AC}/R$ can be varied from 0 to 1.

## ii) Thermistor:

"Thermistor is a temprature sensing device whose function is to exhibit change in electrical resistance with corresponding change in temprature."



Symbol 


| → NTC Thermistor | → PTC Thermistor |
|---|---|
| **Increase in Temp** | |
| → Its resistance decreases | → Its resistance increases. |
| **Decrease in Temprature** | |
| → It resistance increases | → Its resistance decreases |
| **Mathematically** | |
| $\uparrow R \propto 1/T \downarrow$ | $\uparrow R \propto T \uparrow$ |
| **Used in** | |
| → hair dryers, ovens, toasters, A-C fire alarm, thermostats washing machines, freezers etc | → automotive industry as heaters. timing devices in TVs. They are generally used for fuse purposes. |

## iii) Electromotive Force Emf ::

Emf 'E' of a source equals the work done in carrying 1 coulomb of charge through the source

**Mathematically** $E = W/q$

**PKMZ:** Emf motivates the ēs to move across the circuit. It's similar to motivating students to bunk a class. Thus to memorize, we can call emf as electron bunk force.

→ **Sources:** Battery, Thermocouples, generators, Radiant.

→ **Unit** volt V

### Emf vs Potential Difference

| Emf | Potential Difference |
|---|---|
| • Emf is maximum potential difference b/w battery terminals in an open circuit | • Is the difference of two points' potential in a closed circuit |
| • It's independent of the resistance of circuit. | • It's dependent on the resistance of circuit |
| • Responsible for steady current | • Not responsible for steady current |
| • It's a cause | • It is an effect |
| • Greater than potential difference | • Smaller than emf |
| • Remains constant | • varies with resistance |
| • Causes electric and magnetic field. | • only causes electric field. |
| • Symbol E | • Symbol V |

## iii) Maximum Power Output:- "Maximum power output is obtained when load resistance equals internal resistance of the source of emf. This is also called **maximum power transfer theorem**."

→ **Minimum power** will be delivered to load when load resistance is less or greater than the source resistance.

**Mathematically** — Expression can be derived in two ways

$P_{out} = VI$

$P_{out} = (IR)I$

$P_{out} = I^2R \quad (1)$

$\mathcal{E} = Ir + IR, \quad \mathcal{E} = I(r+R)$

$\mathcal{E}/r+R = I \quad (2)$

Put eq (2) in (1), $P_{out} = \left(\frac{\mathcal{E}}{r+R}\right)^2 \times R$

$P_{out} = \frac{\mathcal{E}^2}{r^2+R^2+2Rr} \times R$

condition → $R = r$

$P_{out} = \frac{\mathcal{E}^2}{(R^2+R^2+2R^2)} \times R, \quad P_{out} = \frac{\mathcal{E}^2}{4R^2} \times R$

$$\boxed{P_{out} = \frac{\mathcal{E}^2}{4R}}$$

**Important point:** Both derivations are correct for exam.

→ Usually when we consider the factor 'R' to be equal to 'r', we talk on theoretical ideal basis. In actual practice, it's usually not possible to get these factors equal.

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$P_{out} = VI$

$P_{out} = (IR)I$

$P_{out} = I^2R$

$\mathcal{E} = Ir + IR, \quad \mathcal{E} = I(r+R)$

$P_{out} = \left(\frac{\mathcal{E}}{r+R}\right)^2 \times R$

$P_{out} = \frac{\mathcal{E}^2}{(r+R)^2} \times R$

$P_{out} = \frac{\mathcal{E}^2}{r^2+R^2+2Rr} \times R$

adding and subtracting (2Rr) at RHS

$P_{out} = \frac{\mathcal{E}^2}{r^2+R^2+2Rr-2Rr+2Rr} \times R$

$P_{out} = \frac{\mathcal{E}^2}{(r-R)^2+4Rr} \times R$

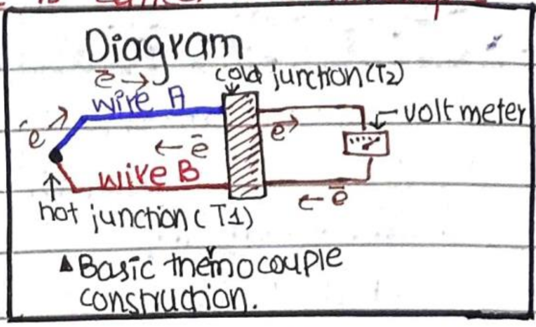
factor $(r-R)^2$ shows us that when they are equal, they cancel each other's effect.

$P_{out} = \frac{\mathcal{E}^2}{(r-r)+4r^2} \times r$ (Putting $r = R$)

$$\boxed{P_{out} = \frac{\mathcal{E}^2}{4r}}$$

## m, Thermocouples:

"Temprature sensor that generates a potential difference through temprature change is called Thermocouple"




→ **Working principle / seebeck effect**

Working principle of Thermocouple is the 'seebeck effect'; which states that when two metals are joined at two ends, there is a temprature difference across the junction and a voltage is generated. → **Types** J, K, E, T } Base metal T.cs . R, S, B } Noble metal thermocouples.

→ **Construction** two dissimilar wires 'A' and 'B' are joined at one end T1 — the "hot" junction (variable temprature) the other end $T_2$ (cold junction) is maintained at a constant reference temprature i.e., 0°C

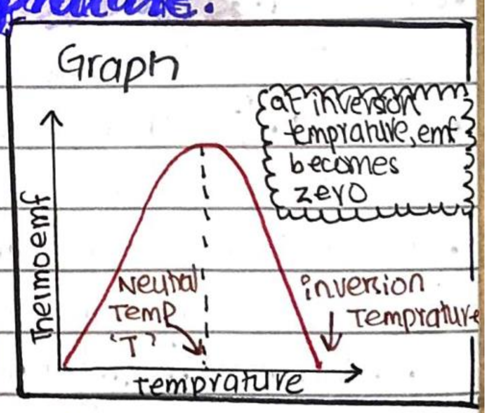
→ **Reason behind using dissimilar metals** Metal combination like Cu-Fe might be used. This is because due the different nature and conductivity of metals, charges get a direction to flow when temprature gradient is applied.

→ **emf generation and its direction** hot and cold junction together work as an emf source. The seebeck effect is reversible; if hot and clod junctions are interchange, the direction of emf reverses. usually, Hot junction → +ve terminal (high potential) and cold junction → -ve terminal (low potential)

**Mathematically** $\mathcal{E} = \alpha T + \frac{1}{2} \beta T^2$

and Distance b/w metals ∝ Thermo emf

## → Variation in thermo emf with temprature:



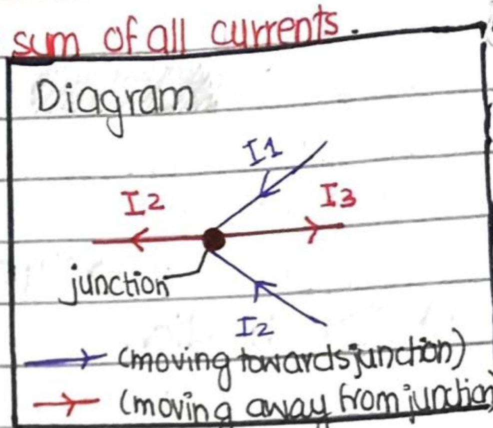

→ **If junctions are in thermal equilibrium** no thermo emf will be produced.

→ **If junctions are at different temp (hot and cold)** Thermo emf will be generated and increased upon increasing temp of hot junction and maximum at neutral Temprature T [value of neutral temprature depends on nature of material & is constant for a t.c]

→ **Further increase in temprature** will cause decrease in thermo emf because high temprature above 'T' will alter the nature of material used. At a certain high temprature, emf becomes zero. This is the inversion temprature

## iii, KIRCHHOFF'S LAW: Robert Kirchhoff gave two laws for complex circuits where ohm's law can't be applied

→ **LAW(1); Kirchhoff's Current Law:** "The sum of all the currents flowing towards a junction is equal to sum of all currents moving away from it."




**Mathematically** (with respect to the diagram →)

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

[Current moving towards junction will have +ve sign and the current moving away from junction will -ve negative sign)

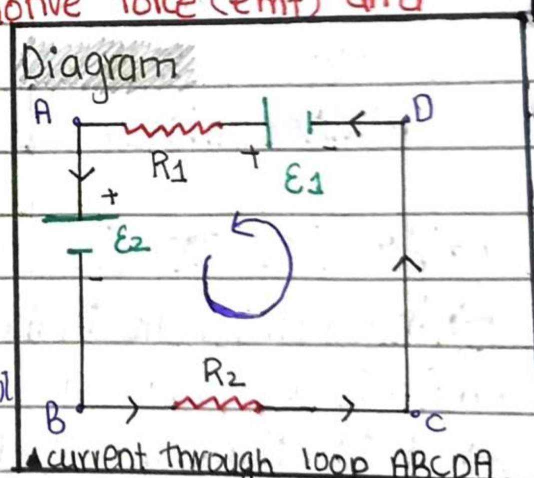
$$\underbrace{I_1 + I_4}_{\text{towards}} = \underbrace{I_3 + I_2}_{\text{away}}$$

or

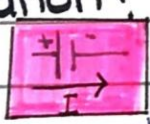
$$\Sigma I = 0$$

→ **KCL is a manifestation of** law of conservation of charge to a junction which implements; If there's no sink or source of charge at a point, the total charge flowing towards the point must be equal to the total charge flowing away from it.

→ **LAW(2); Kirchhoff's Voltage Law:** "In any closed electrical circuit, the algebriac sum of all electromotive force (emf) and voltage drops in resistor is equal to zero".




→ **How to assign signs to ε and IR in equation?** (consider the diagram →)

• When  there will be a fall in potential represented by a -ve sign i.e, $-\varepsilon_2$

• When  there will be a rise in potential represented by a +ve sign i.e., $+\varepsilon_2$

• As voltage always **drops** due to resistance, $IR_2$ & $IR_1$ will be both -ve (Here resistors are traversed in the direction of current thus Potential drop is -ve)

**Mathematically** Energy gained through $\varepsilon_1 = E_1 \Delta Q$, Energy loss through $\varepsilon_2 = -E_2 \Delta Q$

Energy lost through $R_1 = -IR_1 \Delta Q$, Energy loss through $R_2 = -IR_2 \Delta Q$

According to law of conservation of energy, total energy change must be zero so

$$E_1\Delta Q - IR_1\Delta Q - E_2\Delta Q - IR_2\Delta Q = 0$$ [take ΔQ common]

$$E_1 - IR_1 - E_2 - IR_2 = 0$$ [∵ ΔQ ≠ 0]

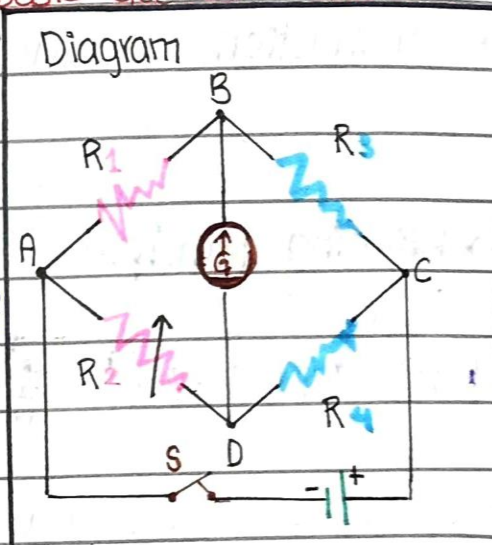
$$E_1 - E_2 = IR_1 + IR_2$$

$$\Sigma \mathcal{E} = \Sigma IR$$



→ **KVL is a manifestation of** law of conservation of Energy.

## iii, Wheatstone Bridge:: "It is basic electrical circuit which is used to measure the value of unknown resistance."




▲Basic construction of wheatstone bridge.

→ **Construction** 4 resistances joined together value of two is fixed and known ($R_1$ and $R_3$) value of one is variable ($R_2$) and known. The remaining '$R_4$' is unknown. These are connected to Emf source

→ **Working principle** When the potential at point B and D becomes equal, no current flows through the galvanometer. This is called as null or balanced condition.

→ **How is null condition achieved?** To achieve the null condition, resistances $R_1, R_3$ and $R_2, R_4$ should have equal ratios. As $V \propto R$, when ratios of resistances become equal, the ratio of potential at point B to D becomes equal. In this condition, no potential difference is present for current to flow through galvanometer and it points at 0. This is achieved by varying value of $R_2$ (variable resistor)

**Mathematically** at null condition $R_2 : R_4 = R_1 : R_3$

or $\frac{R_2}{R_4} = \frac{R_1}{R_3}$ but '$R_4$' is not known to us thus,

$$\frac{R_1}{R_3} \times \frac{1}{R_2} = R_4 \quad \text{or} \quad \boxed{\frac{R_2 \times R_3}{R_1} = R_4}$$

Grab the concept ◡̈ suppose $R_2 = 2\Omega$ and $R_4 = 4\Omega$ ratio becomes 1:2 and $R_1 = 6\Omega$, $R_3 = 12\Omega$ ratio becomes 1:2 under this condition, potential drop at B becomes equal to potential drop at D.

**Potentiometer:** A device used to measure or compare the potentials without drawing any current from the circuit

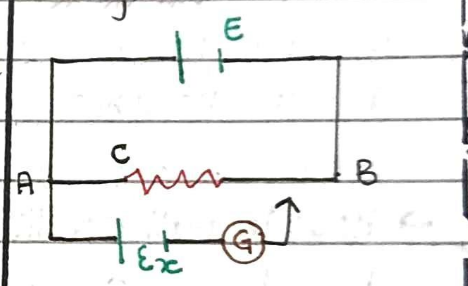
→ **Drawbacks of voltmeter covered by Potentiometer** The potential difference can be measured using voltmeter but the voltmeter draws some current towards itself unless it has infinite resistance which is impossible. Thus the measurement of p.diff. won't be accurate, to overcome this and to get a precise value, we use potentiometer as it draws no current towards itself and circuit current remains unchanged.

→ **Construction** consists of a resistive wire on which a terminal C can slide, a power source (known) and unknown emf source along with a galvanometer.

→ **Working principle** the potential difference across wire is directly proportional to its length. $V \propto l$ when $I$ = constant

**measurement of emf:** Let $E_x$ be unknown emf of the cell. The positive terminal of $E_{known}$ and slider are connected at same point A.

Diagram

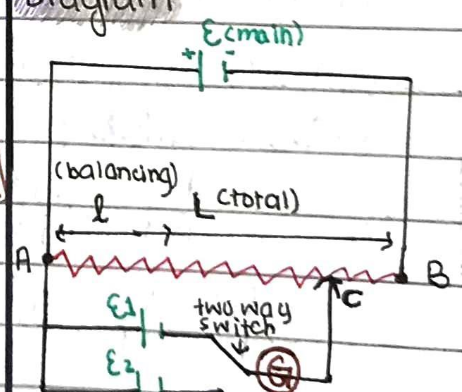



→ **Balancing length** when potential provided by $\varepsilon_x$ becomes equal to potential drop due to resistance provided by wire, the galvanometer points at zero. This is balancing length and is found by sliding the slider across A and C. Thus $E_x = V_{AC} = \frac{l}{L} \times \varepsilon$

→ **Uses of Potentiometer**
- calculate internal resistance of the cell
- To determine emf of a cell
- To compare emf of two cells
- as a continuously potential divider

**comparison of two cell's emf:** The upper method can also be used to compare the $\varepsilon_1$ and $\varepsilon_2$ of two cells

Diagram




**Mathematically** [let $l_2$ and $l_1$ be balancing lengths for $\varepsilon_2$ and $\varepsilon_1$ respectively]

$$E_1 = \frac{l_1}{L} \times \varepsilon(\text{main battery})$$

[where $\frac{l_2}{L} \times \varepsilon = V_{ac}$]

$$\varepsilon_2 = \frac{l_2}{L} \times \varepsilon$$

dividing $\varepsilon_1$ by $\varepsilon_2$

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