SPECTRUM
CAREER INSTITUTE
JEE/NEET EXPERT

PHYSICS
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ELECTRIC CURRENT (SP-12)

Student's Name: ____________________
Batch: ____________________

2
CHAPTER

Current Electricity

JEE/NEET Syllabus

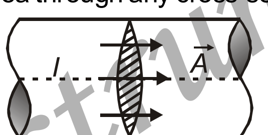
Electric current, Drift velocity, Ohm's law, Electrical resistance, Resistances of different materials, V-I characteristics of Ohmic and nonohmic conductors, Electrical energy and power, Electrical resistivity, Colour code for resistors; Series and parallel combinations of resistors; Temperature dependence of resistance. Electric Cell and its Internal resistance, potential difference and emf of a cell, combination of cells in series and in parallel. Kirchhoff's laws and their applications. Wheatstone bridge, Metre bridge. Potentiometer - principle and its applications

ELECTRIC CURRENT

1. The rate of flow of electric charge across any cross-section is called electric current.
   (a) Instantaneous electric current $I = \frac{dq}{dt}$
   (b) Average electric current $I_{av} = \frac{\Delta q}{\Delta t}$
   (c) **Unit** : ampere or A (SI)
2. Although electric current is denoted with direction in dc circuits but it is a scalar quantity. Direction merely represents the sense of charge flow.

Current Density

Current flowing per unit area through any cross-section is called current density.



$J = \frac{I}{A}$

Unit : A/m^2.

It is a vector quantity and directed along the motion of positive charge.

$I = \vec{J}.\vec{A} = JA\cos\theta$ (where θ is the angle between $\vec{J}$ & $\vec{A}$)

Factors on which Current Depends

1. **Free Charge Density** : Number of free electrons per unit volume (n).
   (in case of conductors, charge carriers are free electrons only)
2. **Drift Velocity** : Average velocity with which electrons drift from low potential end to high potential end of the conductor (v_d). Drift velocity is given by

   $\vec{v}_d = -\frac{e\tau}{m}\vec{E}$ (in terms of applied electric field)

   $v_d = \frac{I}{neA}$ (in terms of current through the conductor)

THIS CHAPTER COVERS :

- Electric Current
- Ohm's law
- Grouping of resistors
- Sources of emf : Cell
- Grouping of Cells
- Kirchhoff's law
- Wheatstone Bridge
- Potentiometer
- RC Circuit
- Heating Effect
  - Joule's Law
  - Power in Electric Circuits
  - Maximum Power Transfer Theorem
  - Fuse Wire

From second relation

$\boldsymbol{I = neAv_d}$. where A is the area of cross-section and "Av_d" represents the rate of flow.

The term $\frac{v_d}{E}$ is called mobility of charge carriers, represented by $\mu = \frac{v_d}{E} = \frac{e\tau}{m}$.

(here $\tau \to$ mean relaxation time depends on temp. $\tau \propto \frac{1}{\sqrt{T}}$, $T \to$ absolute temperature of the conductor)

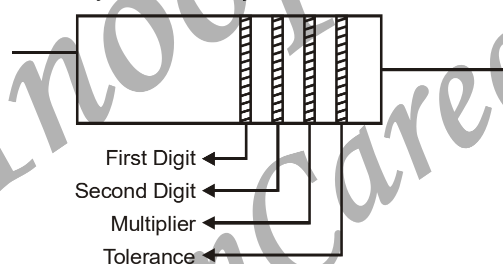
OHM'S LAW

According to Ohm's law,

1. Current Density $\propto$ Electric Field
   i.e., $\vec{J} \propto \vec{E}$ or $\vec{J} = \sigma\vec{E}$
   where σ is a constant of proportionality called Conductivity (unit $\Omega^{-1}m^{-1}$ or mho/m or siemen/m).
2. $I = \frac{V}{R}$ where $R = \frac{1}{\sigma}\frac{l}{A} = \frac{\rho l}{A}$ where ρ (resistivity) $= \frac{1}{\sigma}$.
   Hence according to Ohm's law when R is constant $I \propto V$
   $\Rightarrow$ I~V curve is a straight line (at constant temperature)
3. **Ohmic conductors** are those for which I-V curve is a straight line or $R_s = R_d$ and
   Non-ohmic conductors are those for which $R_s \neq R_d$ at every point on I-V curve

Colour Code for Resistors

[Colour code : B B ROY Great **B**ritain **V**ery **G**ood **W**ife}



Colour	Digit	Multiplier	Tolerance
Black	0	1	-
Brown	1	10	-
Red	2	10^2	-
Orange	3	10^3	-
Yellow	4	10^4	-
Green	5	10^5	-
Blue	6	10^6	-
Violet	7	10^7	-
Gray	8	10^8	-
White	9	10^9	-
Gold	-	0.1	5%
Silver	-	0.01	10%
No Colour	-		20%

Electrical Resistance and Resistivity

1. Resistance of a conductor is given by

$$R = \frac{\rho l}{A} = \frac{ml}{ne^2\tau A}$$

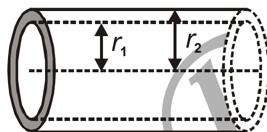
where ρ is resistivity. Its units is Ω m.

2. Resistivity of a conductor, $\rho = \frac{m}{ne^2\tau}$ (where m is mass of an electron, n is number density of electrons, τ is average relaxation time).

3. Resistivity is the property of material and does not depend on the dimensions of conductor but depends on nature and temperature of conductor.

4. For a hollow cylinder of inner radius r_1 and outer radius r_2, length l and material of resistivity ρ

$$R = \frac{\rho l}{\pi(r_2^2 - r_1^2)}$$



Dependence of Drift Velocity

1. For same strength of current, $v_d \propto \frac{1}{A}$ [$I = neAv_d$ = constant]

2. For same potential difference, $v_d \propto \frac{1}{l}$ [It is independent of area]

Temperature Dependence of Resistivity

1. **For Conductors :**

$\rho_t = \rho_0(1 + \alpha t)$, where '$\alpha$' is temperature

Coefficient of resistivity. As $R \propto \rho$

$\Rightarrow$ $R = R_0(1 + \alpha t)$

At temperature t_1, $R_1 = R_0\,(1 + \alpha t_1)$

At temperature t_2, $R_2 = R_0\,(1 + \alpha t_2)$

$$\Rightarrow \quad \alpha = \frac{R_2 - R_1}{R_0(t_2 - t_1)},\ R_0 = \frac{R_2 - R_1}{\alpha(t_2 - t_1)},\ \alpha = \frac{R_2 - R_1}{R_1 t_2 - R_2 t_1}$$

2. **For Semiconductors :** Their resistivity decreases exponentially with temperature.

3. **For Insulators :** Their resistivity is very high and does not vary appreciably with change in temperature.

Note : *If two wires having resistances R_1 and R_2 and temperature coefficients of resistance a_1 and a_2 then the equivalent temperature coefficients of their combination.*

(a) In series $\alpha_s = \frac{R_1\alpha_1 + R_2\alpha_2}{R_1 + R_2}$

(b) In parallel $\alpha_p = \frac{R_1\alpha_2 + R_2\alpha_1}{R_1 + R_2}$

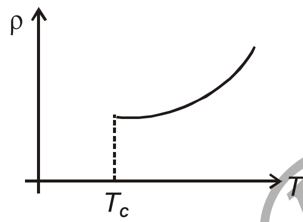
Effect of Current in Human Body

1. The resistance of a normal human body is 10 kΩ
2. Current of the order of 0.1 A are fatal.
3. Cause of death on receiving a shock is not the heating effect, but interfering of electrical signals with human nervous system.

Super Conductors

The phenomenon in which resistance of a conductor becomes zero at very low temperatures.

(In graph T_C is critical temperature and for Hg. T_C = 4.2 K)



Superconductors are found to show perfect diamagnetism ($X_m = -1$). This is known as Meissner's Effect. This effect is used for running of magnetically Leviated Superfast train.

Variation of Resistance with Dimensions of Conductor

1. **Variation with length:**

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

(a) If a wire is cut to alter its length, then area remains same.

$\therefore \quad R \propto l$

(b) If a wire is stretched or folded, area varies but volume remains constant.

$\Rightarrow \quad R \propto l^2$

For small percentage changes in length by stretching or folding, then,

$$\frac{\Delta R}{R} = \frac{2\Delta l}{l}$$

2. **Variation with area of cross-section or thickness :**

(a) If area is increased / decreased but length is kept same.

$\therefore \quad R \propto \frac{1}{A}$ or $R \propto \frac{1}{r^2}$ (r = radius / thickness)

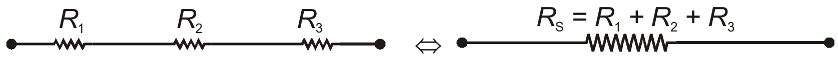
(b) If area is increased / decreased but volume remains same.

$$R \propto \frac{1}{A^2} \text{ or } R \propto \frac{1}{r^4}$$

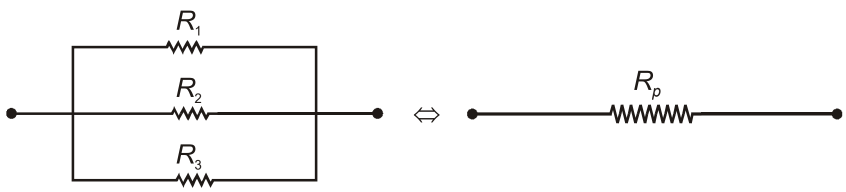
(c) A resistance wire has a resistance R. Half of this wire is stretched to double its length and half is twisted to double its thickness, then $R' = \left(\frac{R}{2}\right) \times 4 + \frac{R}{2} \times \frac{1}{16} = \frac{65R}{32}$

GROUPING OF RESISTORS (SERIES AND PARALLEL COMBINATION)

1. **Series Grouping**

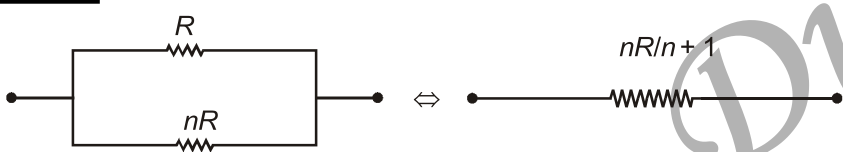


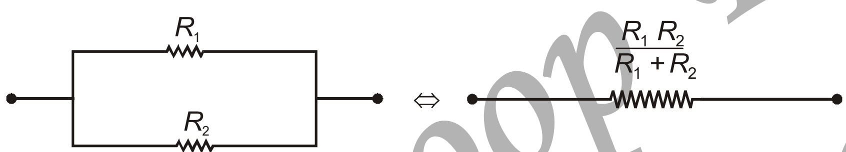
2. **Parallel Grouping**

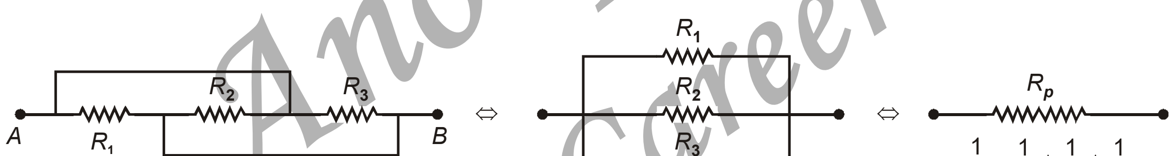


$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Illustrations :

1. 

2. 

3. 

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Cause of flow of Current

The cause of flow of current through a conductor is potential difference applied across its ends. This is achieved by connecting a source of electric energy (or emf) across the conductor, called cell.

CELL

1. **Primary cell :**
   - (a) A cell in which electric energy is produced due to chemical reaction in it during the use of cell.
   - (b) Chemical reactions are irreversible.
   - (c) These cannot be charged (exception $\rightarrow$ lithium cells are primary cells but can be charged)
   - (d) *Examples :* Daniel cell, Leclanche cell, Dry cell.
2. **Secondary cell :**
   - (a) A cell in which electric energy is first stored in the form of chemical energy and this chemical energy converts into electrical energy during the use of cell.
   - (b) Chemical reactions are reversible.
   - (c) These are charged before use.
   - (d) These are also known as storage cells.
   - (e) *Examples :* Lead-acid accumulator, Ni-Fe alkaline accumulator.

Defects in Cells

1. Polarisation : Problem arises due to accumulation of hydrogen gas around a positive electrode.
   Remedy - Use of depolariser which is basically an oxidising reagent.
2. Local actions : It is due to the presence of impurities in electrodes.
   Remedy - Use of amalgamated electrodes.

Type of Cells

1. Daniel cell :

Electrolyte $\rightarrow$ dil H_2SO_4; depolariser $\rightarrow$ $CuSO_4$ solution

positive electrode $\rightarrow$ Cu and negative electrode $\rightarrow$ Zn

emf = 1.08 V but not constant due to defects.

2. Leclanche cell :

Electrolyte $\rightarrow$ NH_4Cl (solution); depolariser $\rightarrow$ MnO_2 powder

positive electrode $\rightarrow$ carbon; negative electrode $\rightarrow$ Zn

emf = 1.5 V when just prepared.

3. Dry cell :

Electrolyte $\rightarrow$ NH_4Cl (paste); depolariser $\rightarrow$ MnO_2 powder

positive electrode $\rightarrow$ carbon; negative electrode $\rightarrow$ Zn

emf = 1.5 V when just prepared.

4. Weston cadmium cell :

Used as standard cell. Electrolyte $\rightarrow$ $CdSO_4$(solution), depolariser $\rightarrow$ Hg_2SO_4 paste,

Positive electrode $\rightarrow$ Hg with Hg_2SO_4 paste.

Negative electrode $\rightarrow$ amalgam of Cd with Hg

emf = 1.0183 V at 20ºC.

5. Lead Accumulator :

Electrolyte $\rightarrow$ dil H_2SO_4, positive electrode $\rightarrow$ Lead dioxide in grids of hard Pb-Sb alloy

Negative electrode $\rightarrow$ spongy lead in grids of hard Pb-Sb alloy, emf = 2.1/2.0 V.

(a) Standard cell : A cell whose emf is precisely specified and remains constant w.r.t. time is known as standard cell. e.g., Weston cadmium cell.

(b) Ideal cell : A cell whose internal resistance is zero.

Cell Terminology

1. EMF (*E*)

The potential difference across the terminals of a cell when no current is being drawn from it.

2. Internal Resistance (*r*)

The opposition of flow of current inside the cell.

It depends on

(i) Distance between electrodes ($r \propto d$)

(ii) Area of electrodes $\left(r \propto \frac{1}{A}\right)$

(iii) Concentration of electrolyte ($r \propto$ conc.)

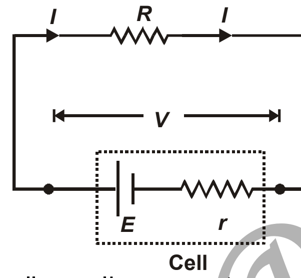
(iv) Temperature

3. Terminal Potential Difference

The potential difference across the terminals of a cell when current is supplied by it.

$E = IR + Ir$, $V = IR$

$E - V = Ir$ .... (i)



$$r = \left(\frac{E-V}{V}\right)R$$

from (i)

when $r = 0$, $E = V$

Here E is emf and V is potential difference. Clearly $V < E$ when the cell supplies current.

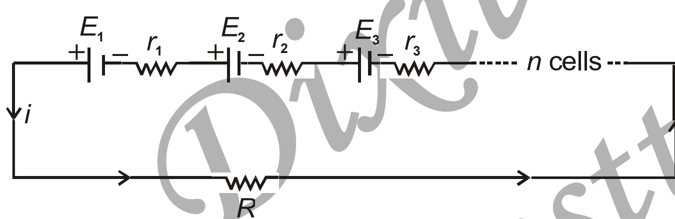
Grouping of Cells (Series and Parallel Combination)

1. Series grouping :

(a) $E_{\text{equivalent}} = E_1 + E_2 + E_3 + \ldots\ldots\ E_n$

(b) $r_{\text{equivalent}} = r_1 + r_2 + r_3 + \ldots\ldots\ r_n$

(c) Current $i = \dfrac{\sum E_i}{\sum r_i + R}$



(d) (s) If all cells have equal emf E and equal internal resistance r then

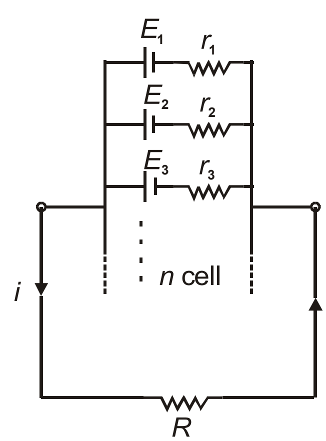
$$i = \frac{nE}{nr + R}$$

Cases : (i) If $nr >> R$ $\Rightarrow$ $i = \dfrac{E}{r}$

(ii) If $nr << R$ $\Rightarrow$ $i = \dfrac{nE}{R}$

2. Parallel Grouping :

(a) $E_{\text{equivalent}} = \dfrac{\dfrac{E_1}{r_1} + \dfrac{E_2}{r_2} + \dfrac{E_3}{r_3} + \ldots\ldots}{\dfrac{1}{r_1} + \dfrac{1}{r_2} + \dfrac{1}{r_3} + \ldots\ldots\ldots}$



(b) $r_{\text{equivalent}} = \dfrac{1}{\dfrac{1}{r_1} + \dfrac{1}{r_2} + \dfrac{1}{r_3} + \ldots\ldots}$

(c) If all cells have equal emf. E and internal resistance r then

$E_{\text{equivalent}} = E$

$r_{\text{equivalent}} = \dfrac{r}{n}$

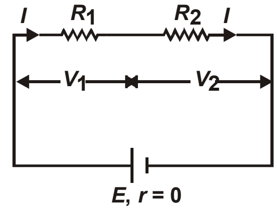
$\Rightarrow$ Current $i = \dfrac{E}{\dfrac{r}{n} + R}$

Cases : (i) If $\dfrac{r}{n} >> R$ $\Rightarrow$ $i = \dfrac{nE}{r}$

(ii) If $\dfrac{r}{n} << R$ $\Rightarrow$ $i = \dfrac{E}{R}$

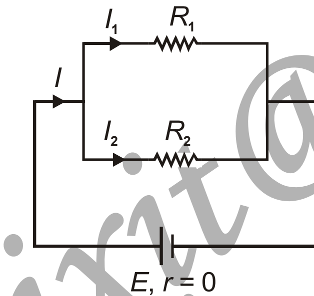
> ***Note :*** *If polarity of m cells are made reverse in the series combination of n identical cells then equivalent emf* $E_{\text{equivalent}} = (n - 2m)E$ *and internal resistance* $r_{\text{equivalent}} = nr$

Illustrations :



1. $I = \dfrac{E}{R_1 + R_2}$, $V_1 = IR_1 = \dfrac{ER_1}{R_1 + R_2}$, $V_2 = \dfrac{ER_2}{R_1 + R_2}$

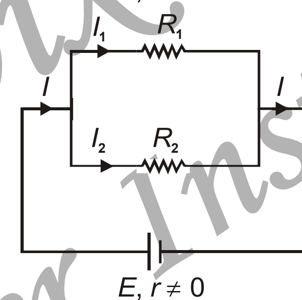
$\Rightarrow \dfrac{V_1}{V_2} = \dfrac{R_1}{R_2}$



2. $E = I_1R_1 = I_2R_2$

$I_1 = \dfrac{E}{R_1}$, $I_2 = \dfrac{E}{R_2}$

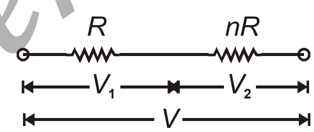
$\Rightarrow$ If cell is ideal, I_1 and I_2 are independent of each other.



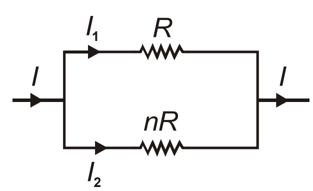
3. $I = \dfrac{E}{\dfrac{R_1R_2}{R_1 + R_2} + r}$, $I_1R_1 = I_2R_2$, $I = I_1 + I_2$

$\Rightarrow I_1 = \dfrac{IR_2}{R_1 + R_2}$, $I_2 = \dfrac{IR_1}{R_1 + R_2}$

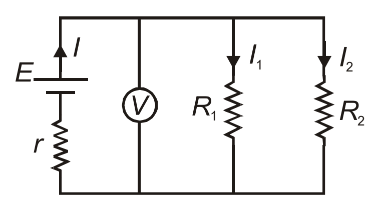
$\Rightarrow \dfrac{I_1}{I_2} = \dfrac{R_2}{R_1}$



4. $V = V_1 + V_2$, $V_1 = \dfrac{V}{n+1}$, $V_2 = \dfrac{nV}{n+1}$



5. $I = I_1 + I_2$, $I_1 = \dfrac{nI}{n+1}$, $I_2 = \dfrac{I}{n+1}$



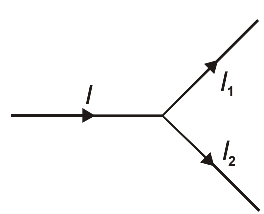
6. $I = \dfrac{E}{r + \dfrac{R_1R_2}{R_1 + R_2}}$, $V = E - Ir$

$I_1 = \dfrac{V}{R_1}$, $I_2 = \dfrac{V}{R_2}$

If R_2 is increased, I will decrease, I_2 will decrease, V will increase, I_1 will increase.

KIRCHHOFF'S LAWS

1. **Junction Rule :** It is based on conservation of charge.



$I = I_1 + I_2$

2. Loop Rule : It is based on conservation of energy.

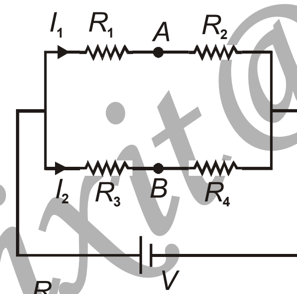
(a) For any closed loop, total rise in potential + total fall in potential = 0.

(b) For any open part from a point *A* to point *B*, if V_A is potential at *A* and V_B is potential at *B*, then as we move from *A* to *B*.

V_A + total rise in potential + total fall in potential = V_B.

Note : *By convention rise in potential is taken as positive and fall in potential is taken as negative.*

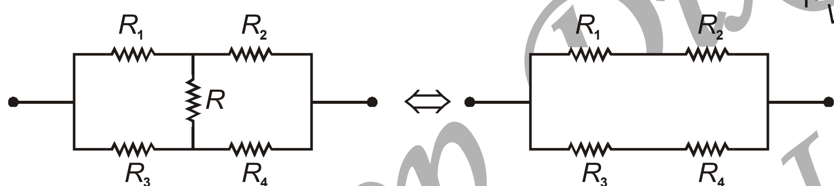
Principle of Wheatstone Bridge



$$I_1 = \frac{V}{R_1 + R_2}, I_2 = \frac{V}{R_3 + R_4}$$

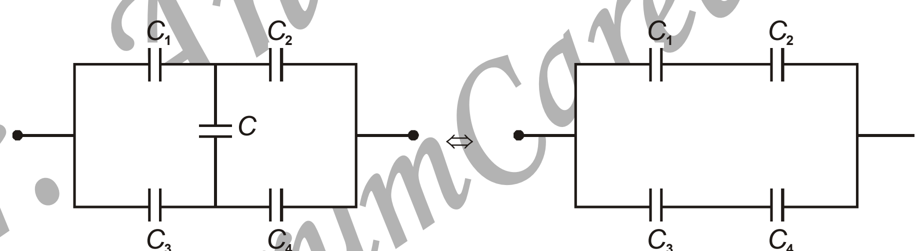
Hence if $\frac{R_1}{R_2} = \frac{R_3}{R_4}$ or $\frac{R_1}{R_3} = \frac{R_2}{R_4}$ or $R_1R_4 = R_2R_3$, then

No current through *R* so



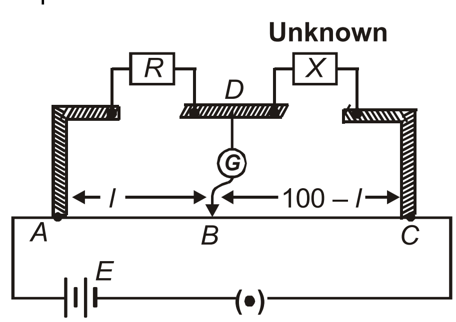
Similarly, for a capacitive circuit shown here,

If $\frac{C_1}{C_2} = \frac{C_3}{C_4}$



METER BRIDGE

Based on Wheatstone bridge principle. It is used to find unknown resistance.



When there is no deflection in *G* bridge is called balanced and for balanced bridge $\frac{P}{Q} = \frac{R}{S}$, $\frac{R}{l} = \frac{X}{100 - l}$

$\Rightarrow$ Unknown $X = R\left(\frac{100 - l}{l}\right)$

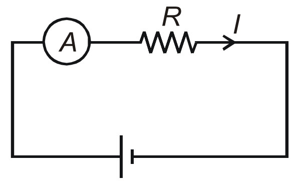
Note : *Location of null point is independent of resistivity or area of cross-section of wire AB.*

INSTRUMENTS

1. Ammeter

(a) Ammeter is a current measuring device.

(b) It is connected in series in the branch in which current is to be measured.

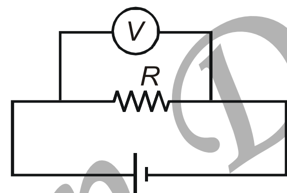


(c) An ideal ammeter has zero resistance.

2. Voltmeter

(a) Device to measure potential difference.

(b) Connected in parallel in between the points between which potential difference is required.



(c) An ideal voltmeter has infinite resistance.

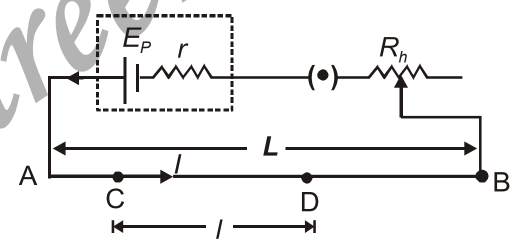
3. Potentiometer

It can measure potential difference without drawing a current from the circuit. Thus it gives accurate reading and it can measure emf of a cell.

AB = Potentiometer wire of resistance *R* and length *L*.

(It has two properties high resistivity and low α)

Any two point *C* and *D* are separated by length 'l'.

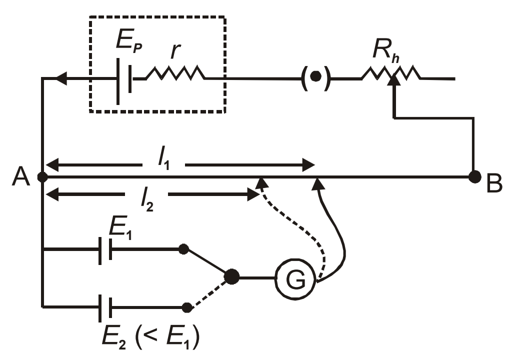


Potential gradient $x = \left[\frac{E_P}{r+R+R_h}\right]\frac{R}{L} = \frac{iR}{L} = \frac{i\rho}{A} = \frac{V_{AB}}{L}$

(here ρ - resistivity and *A* - Area of cross section of potentiometer wire)

Applications

1. Find the emf of a Cell or comparison of emf of two cells



$$\frac{E_1}{E_2} = \frac{l_1}{l_2}$$

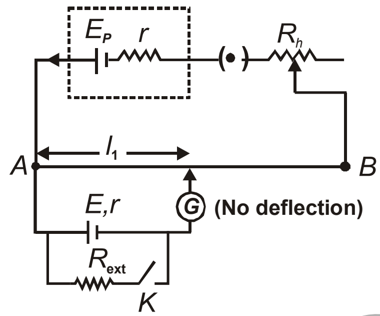
If one of the emf is known then unknown $E_2 = \left(\frac{l_2}{l_1}\right)E_1$

2. Find Internal Resistance of a Cell

Case I :

Key K is kept open, balance point is at length l_1.

$\Rightarrow \quad E \propto l_1$



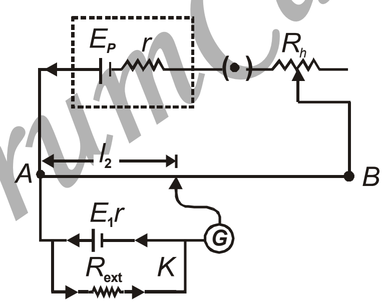
Case II :

Key K is closed, balance point is at length l_2.

$V \propto l_2 \Rightarrow \dfrac{E}{V} = \dfrac{l_1}{l_2}$

$\therefore$ internal resistance of given cell is

$$= \left(\frac{E-V}{V}\right) R_{ext} = \left(\frac{l_1 - l_2}{l_2}\right) R_{ext}$$



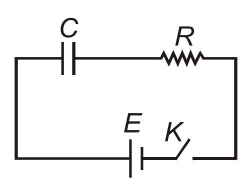
Sensitivity of a potentiometer

Smaller the potential drop per unit length better is the sensitivity. *i.e.*, $\dfrac{V_{AB}}{L} = x$ should be small.

This can be achieved by increasing the length of potentiometer wire or decreasing the current through it.

R-C CIRCUIT

1. Charging



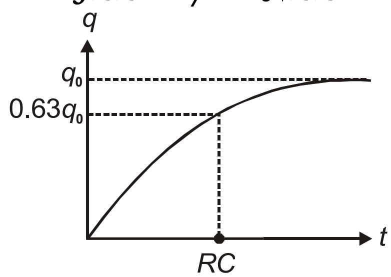
Key K is closed at t = 0. Current starts flowing and charging of capacitor starts.

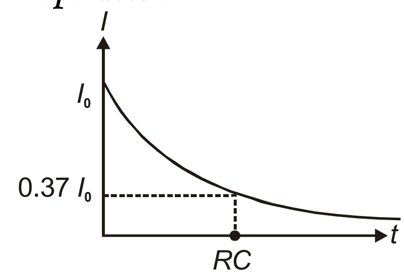
At any instant t, q is charge on capacitor. I is current in the circuit.

(a) $q = q_0\,[1 - e^{-t/jRC}]$ where $q_0 = EC$ is maximum charge

(b) $I = \frac{E}{R}e^{-t/RC} = I_0 e^{\frac{-t}{RC}}$

$\Rightarrow$ At $t = 0$, $I = E/R$



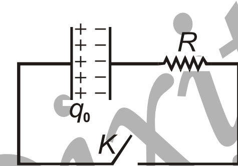


(c) RC = time constant. During charging, in $t = RC$, $q = 0.63q_0$.

(d) A capacitor behaves like closed switch at $t = 0$ and open switch at $t = \infty$.

2. Discharging

Key K is closed at $t = 0$



(a) $q = q_0 e^{-t/RC}$

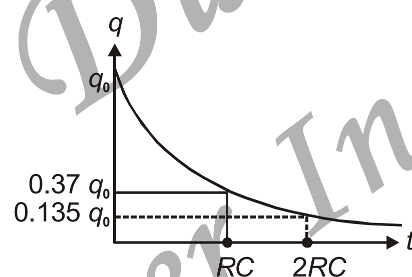
(b) $I = -I_0 e^{-t/RC}$ where, $I_0 = \frac{q_0}{RC}$

(c) RC = time constant (τ)

at $t = 0$, $q = q_0$

at $t = RC$, $q = 0.37\ q_0$

at $t = 2RC$, $q = 0.135\ q_0$



(d) The charge and potential difference both decay exponentially like radio-active decay with half life = 0.693 RC

HEATING EFFECT OF CURRENT

Joule's Law

When I current is passed through a device having resistance R, then the amount of heat produced in time t

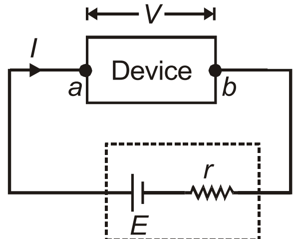
$H = I^2Rt$ in joules

$\Rightarrow$ $H = \frac{I^2Rt}{J}$ in calories

where J = mechanical equivalent of heat = 4.186 or 4.2 J/cal

Electric Power

Let a charge dq flows through a device from a to b, (from higher potential to lower potential).



Decrease in potential energy $dU = Vdq = VIdt$

Power associated with this flow = $\frac{dU}{dt} = VI$

Rate of electrical energy transferred to the device = VI

Unit of power is volt-ampere (V × A).
$\therefore$ 1 watt = 1V × A

Rating of an Appliance : A device is rated as P watt, V volts. This means that when the device is connected to V volt, it will consume a power P.

Resistance of the device $R = \dfrac{V^2}{P}$ is constant, while both P and V are variable.

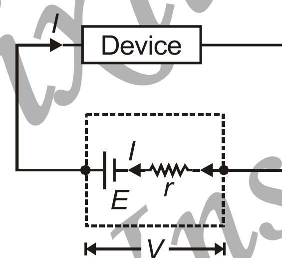
Generally if a voltage more than the rated voltage is applied, the device may get destroyed (like a bulb may fuse).

Power in a D.C. Circuit

V = Potential difference across the device

I = Current through the device

Results

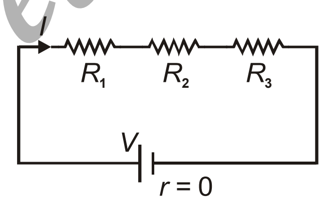


1. Total power supplied by the cell = EI
   (equals to rate of consumption of chemical energy)
2. Source of power is chemical energy stored in the cell.
3. Rate of heat loss inside the cell = I^2r
4. Net power output = $EI - I^2r = (E - Ir)\,I = VI$
5. Power delivered to device = VI
6. When the device is purely resistive like a bulb, then

   $V = IR, \quad \therefore\ P = VI = I^2R = \dfrac{V^2}{R}$

Applications

1. Series combination



$P_1 = I^2R_1,\ P_2 = I^2R_2,\ P_3 = I^2R_3$

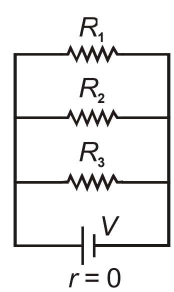
$\therefore \quad P_1 : P_2 : P_3 :: R_1 : R_2 : R_3$

$P_{Total} = P_1 + P_2 + P_3 = I^2\,[R_1 + R_2 + R_3]$

$= \dfrac{V^2}{R_1 + R_2 + R_3}$

***Note :** For n identical resistors,* $P_{Total} = \dfrac{nV^2}{R}$

2. Parallel combination



$P_1 = \dfrac{V^2}{R_1},\ P_2 = \dfrac{V^2}{R_2},\ P_3 = \dfrac{V^2}{R_3}$

$P_1 : P_2 : P_3 :: \dfrac{1}{R_1} : \dfrac{1}{R_2} : \dfrac{1}{R_3}$

$P_{Total} = \dfrac{V^2}{R_1} + \dfrac{V^2}{R_2} + \dfrac{V^2}{R_3}$

$= V^2\left[\dfrac{1}{R}\right]$ where $\dfrac{1}{R} = \dfrac{1}{R_1} + \dfrac{1}{R_2} + \dfrac{1}{R_3}$

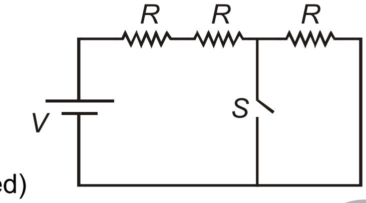
***Note :** For n identical resistors,* $P_{Total} = \dfrac{nV^2}{R}$

3. Short circuit

   (a) When switch 'S' is open $I = \dfrac{V}{3R}$

   Total power = $\dfrac{V^2}{3R}$

   Power dissipated in each resistor is $\dfrac{V^2}{9R}$

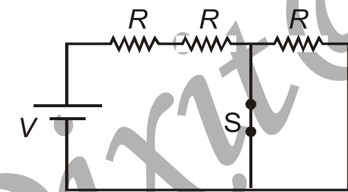


   (b) When switch S is closed (third resistor's short circuited)

   $I = \dfrac{V}{2R}$

   Total power = $\dfrac{V^2}{2R}$

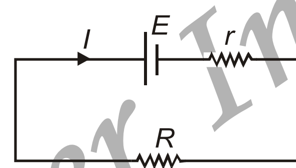
   Power dissipated in each resistor is $\dfrac{V^2}{4R}$



Maximum Power Transfer Theorem

In an electrical circuit, the maximum power can be drawn from the battery when external resistance is same as the internal resistance of the battery. Power drawn in the external resistor is

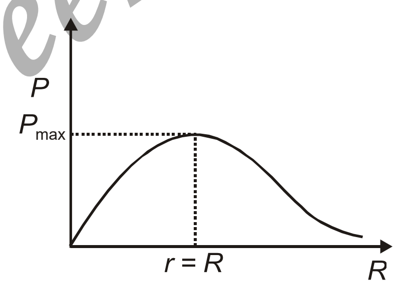
$$P = I^2R = \frac{E^2R}{(R+r)^2} \Rightarrow \frac{dP}{dR} = E^2\frac{(R+r)^2 - 2R(R+r)}{(R+r)^4} = 0$$



$\Rightarrow \quad R = r$

Results :

1. Power in external resistor is $\dfrac{E^2}{4r}$.
2. Dissipated power in internal resistance is $\dfrac{E^2}{4r}$.
3. Total power supplied by the cell is $\dfrac{E^2}{2r}$.
4. Efficiency of the circuit is 50 %.



Fuse Wire

1. Made of lead and tin alloy.
2. Has low melting point.
3. Current capacity (current at which it blows)

   $I^2 = \dfrac{r^3}{\rho}$

   (a) $I \propto r^{3/2}$,

   (b) $I \propto \dfrac{1}{\sqrt{\rho}}$,

   (c) I is independent of length of fuse wire.
4. Time taken to melt the fuse wire $t \propto A^2$ or $t \propto r^4$, 't' is also independent of length.
5. A fuse wire is connected in series with main supply.

❑ ❑ ❑