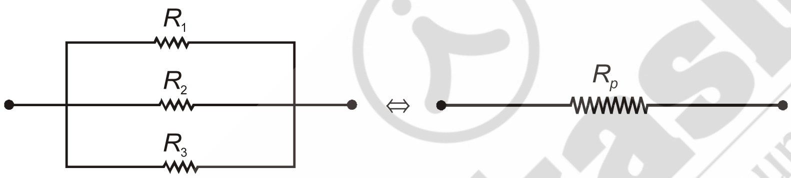
Chapter 11

Current Electricity

GROUPING OF RESISTORS (SERIES AND PARALLEL COMBINATION)

1. **Series Grouping**

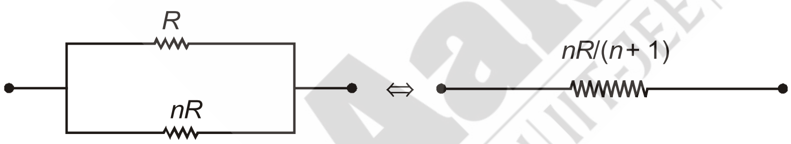
2. **Parallel Grouping**



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

Illustrations :

1.



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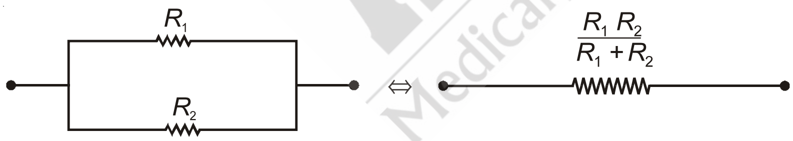

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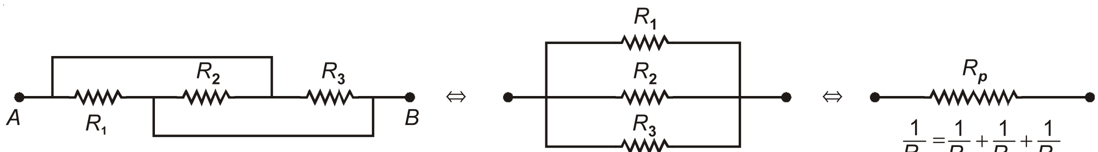


$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Cell Terminology

1. **EMF (*E*)**

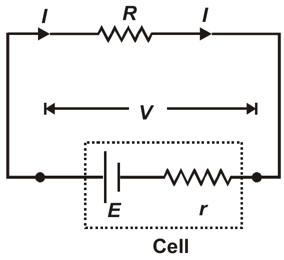
   The potential difference across the terminals of a cell when no current is being drawn from it.

2. **Internal Resistance (*r*)**

   The opposition to flow of current inside the cell.

3. Terminal Potential Difference

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



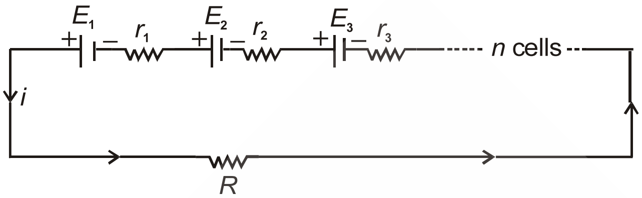
$E = IR + Ir, \quad V = IR$

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

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

Grouping of Cells (Series and Parallel Combination)

1. Series Grouping :



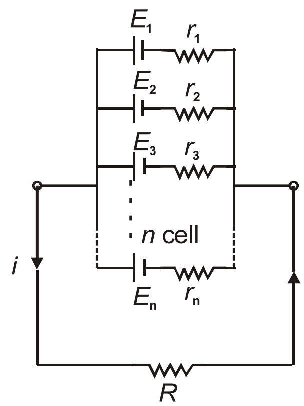
(a) $E_{\text{equivalent}} = E_1 + E_2 + E_3 + \ldots\ldots\ E_n$

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

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

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

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

3. Mixed Grouping of Cell :

Let n cells be connected in series in one row and m rows of cells in parallel. If cells are identical each of emf E.

Total number of cells = mn

Total emf = nE

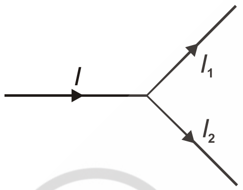
Let i to be current through external load R.

$$i = \frac{mnE}{mR + nr}$$

i will be maximum if $mR = nr$

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.

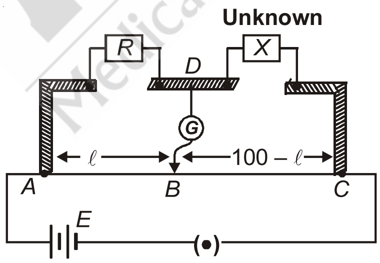
   (b) For any open part from a point A to point B, if V_A is potential at A and V_B is potential at B, then as we move from A to B.

   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.*

METER BRIDGE

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



When there is no deflection in galvanometer then bridge is called balanced and for balanced bridge $\frac{P}{Q} = \frac{R}{S}$,

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

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

INSTRUMENTS

1. Ammeter

(a) Shunt resistance is added in parallel to the galvanometer coil to make it into an ammeter.

Shunt resistance $S = \left(\dfrac{i_g}{i - i_g}\right)G$.

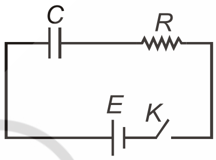
2. Voltmeter

(a) A large resistance is added in series to the galvanometer coil to make it into a voltmeter.

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

R-C CIRCUIT

1. Charging



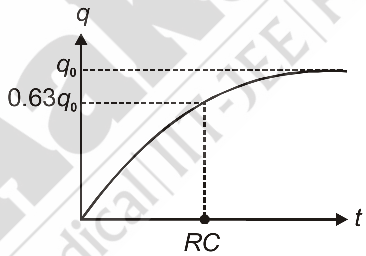
Key K is closed at $t = 0$.

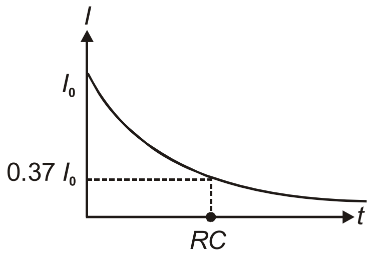
Current starts flowing and charge of capacitor starts increasing.

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

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

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



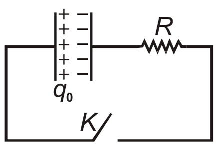


$\Rightarrow$ At $t = 0$, $I = E/R$

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

(d) In RC circuit an uncharged capacitor behaves like closed switch at $t = 0$ and open switch at $t = \infty$.

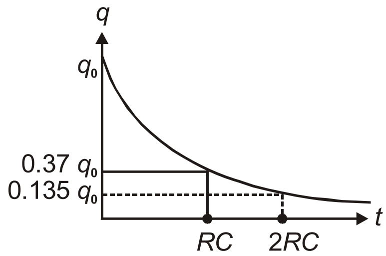
2. Discharging RC Circuit



Key K is closed at $t = 0$

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

(b) $I = -\frac{dq}{dt} \Rightarrow I = +I_0 e^{-t/RC}$ 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 radioactive decay with half-life = 0.693 RC

HEATING EFFECT OF CURRENT

Joule's Law

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

$H = I^2Rt$ in joules

$\Rightarrow \quad H = \frac{I^2Rt}{J}$ in calories, where J = mechanical equivalent of heat = 4.186 or 4.2 J/cal

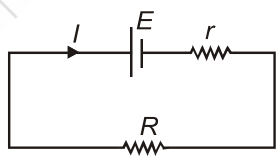
In general of a variable current I passes through a resistor, heat produced across R in time t is $H = \int_0^t I^2 R\,dt$

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

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

$\Rightarrow \quad R = r$



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