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# PHYSICS

## NEET and JEE Main 2020 : 45 Days Crash Course

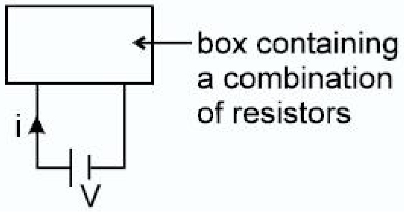
# Current Electricity and Electrical Instruments

By,
Ritesh Agarwal, B. Tech. IIT Bombay

# Combination of Resistances

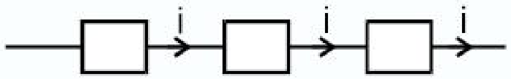
A number of resistances can be connected and all the complicated combinations can be reduced to two different types, namely series and parallel.

The equivalent resistance of a combination is defined as $R_{eq} = \frac{V}{i}$



# Resistances in Series

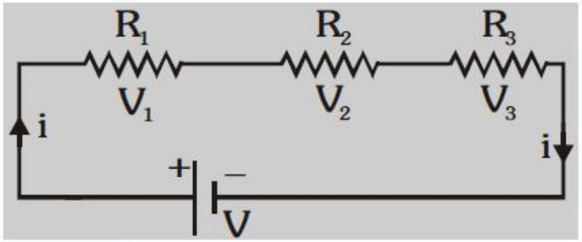
When the resistances (or any type of elements) are connected end to end then they are said to be in series. The current through each element is same.




Resistances in series carry equal current but reverse may not be true.

$$R = R_1 + R_2 + R_3$$

Where R = equivalent resistance



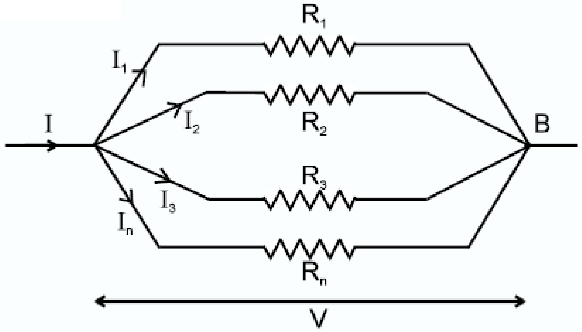

$$V = V_1 + V_2 + V_3$$

$$V_1 = IR_1$$

# Resistances in Parallel

A parallel circuit of resistors is one in which the same voltage is applied across all the components in a parallel grouping of resistors $R_1$, $R_2$, $R_3$,........, $R_n$.

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots\ldots + \frac{1}{R_n}$$

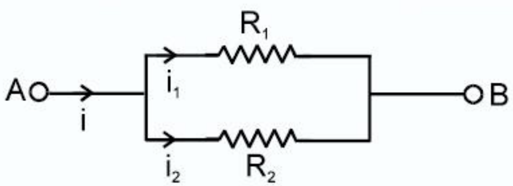



**Division of Current in two parallel Resistors**

$i_1R_1 = i_2R_2$ or $\frac{i_1}{i_2} = \frac{R_2}{R_1}$

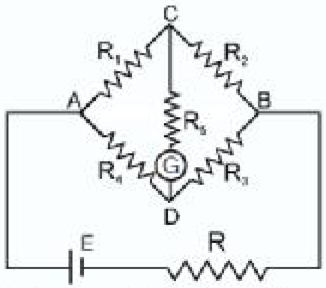
$$i_1 = \frac{R_2 i}{R_1 + R_2}$$

$$i_2 = \frac{R_1 i}{R_1 + R_2}$$

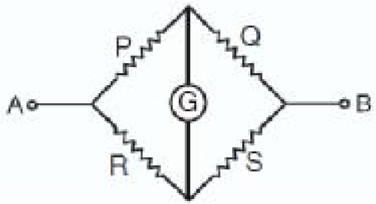


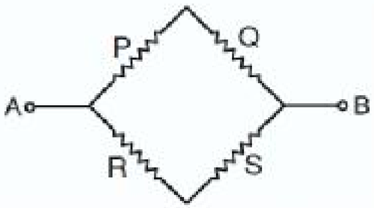

$$R_{eq.} = \frac{R_1 R_2}{R_1 + R_2}$$

# Wheatstone Network (4 Terminal Network)




In this circuit if $R_1 R_3 = R_2 R_4$ then $V_C = V_D$ and current in $R_5 = 0$ this is called balance point or null point




When current through the galvanometer is zero (null point or balance point) $\frac{P}{Q} = \frac{R}{S}$.

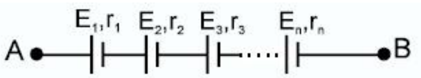
The null point is not affected by resistance $R_5$, E and R.

**It is not affected even if the positions of Galvanometer and battery (E) are interchanged.**

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

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

# Cells in Series

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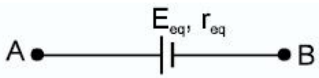



Equivalent EMF

$$E_{eq} = E_1 + E_2 + ....... + E_n$$

[write EMF's with polarity]

Equivalent internal resistance

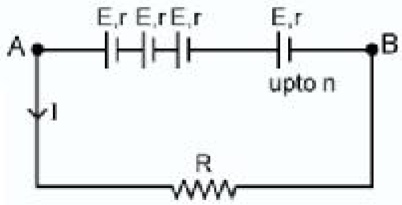
$$r_{eq} = r_1 + r_2 + r_3 + r_4 + .... + r_n$$

If n cells each of emf E, arranged in series and if r is internal resistance of each cell, then total emf = n E so current in the circuit

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

$E_{eq} = nE$

$r_{eq} = nr$

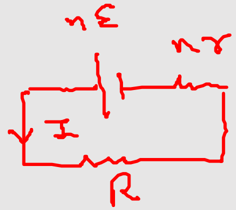


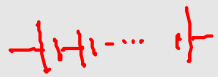

**Note :**

If polarity of m cells is reversed, then equivalent emf = (n-2m)E while the equivalent resistance is still nr+R, so current in R will be $i = \frac{(n-2m)E}{nr + R}$

$\varepsilon_1$ $\varepsilon_2$ $\varepsilon_3$

$\varepsilon_{eq} = \varepsilon_1 + \varepsilon_2 - \varepsilon_3$



If polarity of one cell is reversed

$E_{eq} = (n-1)E - E$

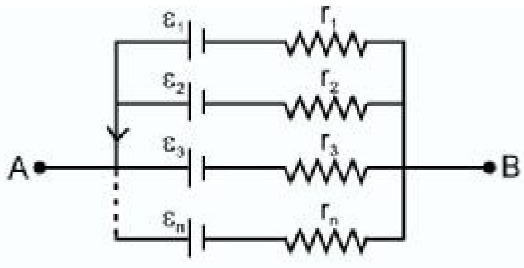
$= (n-2)E$

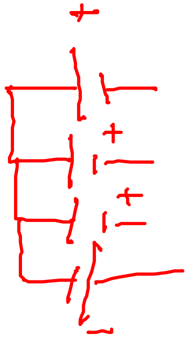
$r_{eq} = nr$

# Cells in Parallel

$$E_{eq} = \frac{\varepsilon_1/r_1 + \varepsilon_2/r_2 + \ldots + \varepsilon_n/r_n}{1/r_1 + 1/r_2 + \ldots + 1/r_n}$$

[Use emf's with polarity]

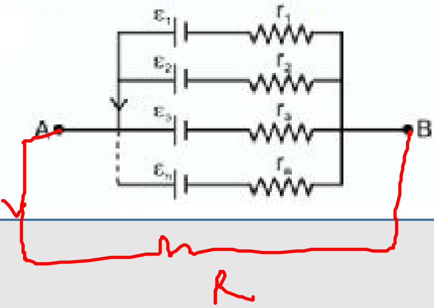



$$\frac{1}{r_{eq}} = \frac{1}{r_1} + \frac{1}{r_2} + \ldots + \frac{1}{r_n}$$

If m cells each of emf E and internal resistance r be connected in parallel

$$E_{eq} = E \qquad r_{eq} = \frac{r}{m}$$

and $$I = \frac{E}{R + \frac{r}{m}} = \frac{mE}{mR + r}$$



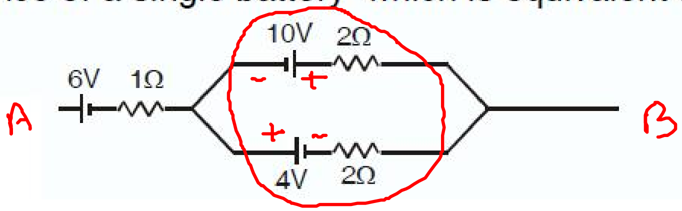

$$E_{eq} = \frac{mE/r}{m \cdot \frac{1}{r}} = E$$

$$r_{eq} = r/m$$

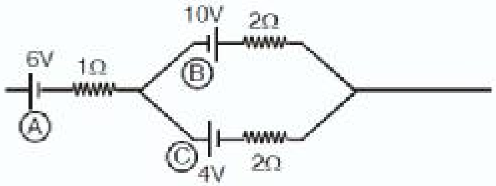
$$I = \frac{E_{eq}}{R + r_{eq}} = \frac{E}{R + r/m}$$

# Example

Find the emf and internal resistance of a single battery which is equivalent to a combination of three batteries as shown in figure.




**Sol.**




Battery (B) and (C) are in parallel combination with opposite polarity. So, their equivalent

$$\epsilon_{BC} = \frac{\frac{10}{2} + \frac{-4}{2}}{\frac{1}{2} + \frac{1}{2}} = \frac{5-2}{1} = 3V \quad \Rightarrow \quad r_{BC} = 1\Omega.$$

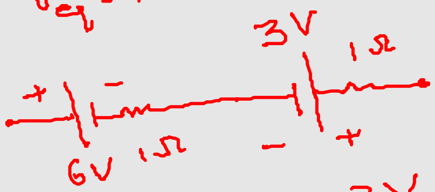
Now,


$\epsilon_{ABC} = 6 - 3 = 3V$

$r_{ABC} = 2\Omega.$ **Ans.**

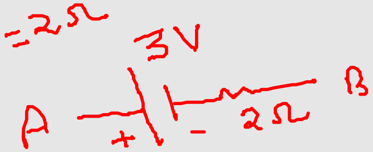
$$\varepsilon_{1,eq.} = \frac{\frac{10}{2} - \frac{4}{2}}{\frac{1}{2} + \frac{1}{2}} = \frac{5-2}{1} = 3V$$

$r_{eq} = 1\Omega$




$\varepsilon_{eq} = 6 - 3 = 3V$

$r_{eq} = 1 + 1 = 2\Omega$



# Galvanometer

Galvanometer is represented as follow : 



It consists of a pivoted coil placed in the magnetic field of a permanent magnet. Attached to the coil is a spring. In the equilibrium position, with no current in the coil, the pointer is at zero and spring is relaxed. When there is a current in the coil, the magnetic field exerts a torque on the coil that is proportional to current. As the coil turns, the spring exerts a restoring torque that is proportional to the angular displacement. Thus, the angular deflection of the coil and pointer is directly proportional to the coil current and the device can be calibrated to measure current.

When coil rotates the spring is twisted and it exerts an opposing torque on the coil.

There is a resistive torque also against motion to damp the motion. Finally in equilibrium

$$\tau_{magnetic} = \tau_{spring} \Rightarrow BINA \sin\theta = C\phi$$

But by making the magnetic field radial $\theta = 90^o$.

$\therefore$ $BINA = C\phi$

$I \propto \phi$

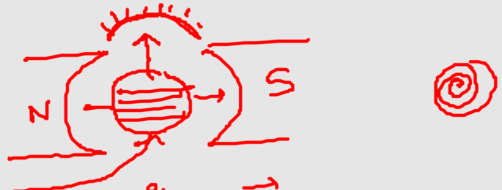
$I \propto \phi$

here
- $B$ = magnetic field
- $I$ = Current
- $N$ = Number of turns
- $A$ = Area of the coil
- $C$ = torsional constant
- $\phi$ = angle rotate by coil.

- **Current sensitivity**

  The ratio of deflection to the current i.e. deflection per unit current is called current sensitivity (C.S.) of the galvanometer $CS = \frac{\phi}{I} = \frac{BNA}{C}$

The galvanometer coil has some resistance represented by $R_g$ . It is of the order few ohms. It also has a maximum capacity to carry a current known as $I_g$. $I_g$ is also the current required for full scale deflection. This galvanometer is called moving coil galvanometer.





Soft iron core

$\tau_{mag} = \vec{M} \times \vec{B}$

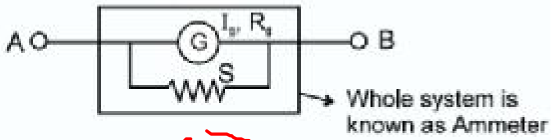
$= NIAB \sin\theta$

$\tau_{spring} = C\phi$

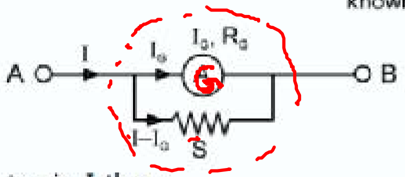
# Ammeter

A shunt (small resistance) is connected in parallel with galvanometer to convert into ammeter; An ideal ammeter has zero resistance

Ammeter is represented as follow -








If maximum value of current to be measured by ammeter is I then

$$I_G \cdot R_G = (I - I_G)S$$

$$S = \frac{I_G R_G}{I - I_G}$$

$$\boxed{S = \frac{I_G \times R_G}{I}} \quad \text{when} \quad I >> I_G.$$

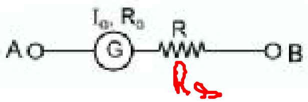
where I = Maximum current that can be measured using the given ammeter.

For measuring the current the ammeter is connected is series.

# Voltmeter

A high resistance is put in series with galvanometer. It is used to measure potential difference across a resistor in a circuit.






For maximum potential difference

$$V = I_G \cdot R_S + I_G R_G \qquad R_S = \frac{V}{I_G} - R_G$$

$$\text{If } R_G << R_S \quad \Rightarrow \quad R_S \approx \frac{V}{I_G}$$

For measuring the potential difference a voltmeter is connected across that element in parallel

A good voltmeter has high value of resistance.

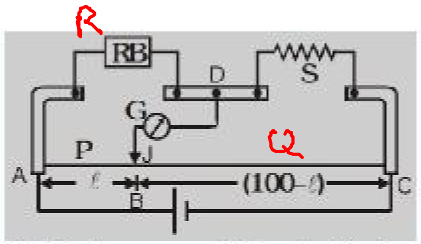
Ideal voltmeter → which has high value of resistance. $R \to \infty$

10000

9995 ✓

# Metre Bridge

It is based on principle of wheatstone bridge. It is used to find out unknown resistance of wire. AC is 1 m long uniform wire R.B. is known resistance and S is unknown resistance. A cell is connected across 1 m long wire and Galvanometer is connected between jockey and midpoint of R & S.



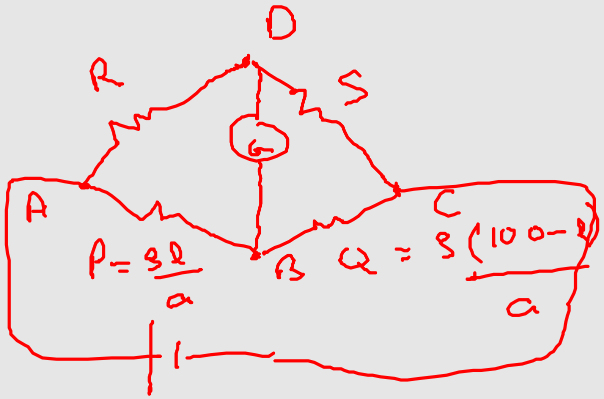

To find out unknown resistance we touch jockey from A to C and find balance condition. Let balance is at B point on wire.

AB = $\ell$ cm. P = r $\ell$

BC = (100 - $\ell$ ) cm. Q = r(100 - $\ell$) r = resistance per unit length on wire.

At balance condition :

$$\frac{P}{Q} = \frac{R}{S} \Rightarrow \frac{r\ell}{r(100-\ell)} = \frac{R}{S} \Rightarrow S = \frac{(100-\ell)}{\ell} R$$




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

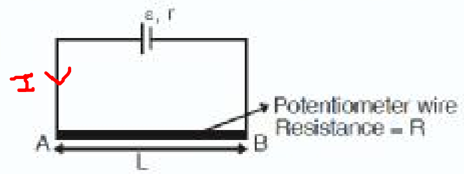
$$\frac{R}{S} = \frac{l}{100-l}$$

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

# Potentiometer

A potentiometer is a linear conductor of uniform cross-section with a steady current set up in it. This maintains a uniform potential gradient along the length of the wire. Any potential difference which is less then the potential difference maintained across the potentiometer wire can be measured using this.

The wire should have high resistivity and low expansion coefficient for example. Manganin or, Constantine wire etc.




$$I = \frac{\varepsilon}{r+R}$$

$$V_A - V_B = \frac{\varepsilon}{R+r}.R$$

Potential gradient (x) → Potential difference per unit length of wire

$$x = \frac{V_A - V_B}{L} \quad = \frac{\varepsilon}{R+r} \cdot \frac{R}{L}$$

# Applications of Potentiometer

**(a) To find emf of unknown cell and compare emf of two cells.**

**In case** I,

In figure (3) is joint to (1) then balance length = $\ell_1$

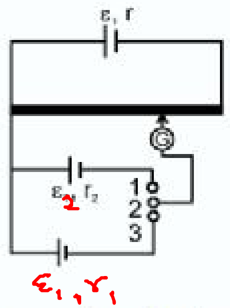
$\varepsilon_1 = x\ell_1$ ....(1)

**in case** II,

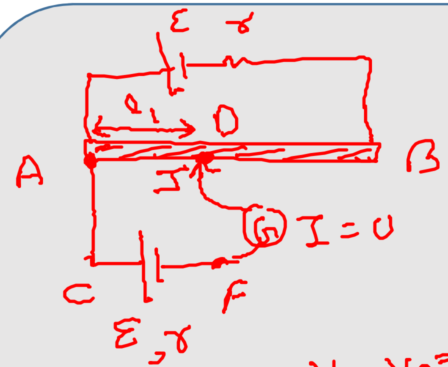
In figure (3) is joint to (2) then balance length = $\ell_2$

$\varepsilon_2 = x\ell_2$ ....(2)

$$\frac{\varepsilon_1}{\varepsilon_2} = \frac{\ell_1}{\ell_2}$$




If any one of $\varepsilon_1$ or $\varepsilon_2$ is known the other can be found. If x is known then both $\varepsilon_1$ and $\varepsilon_2$ can be found




$V_A - V_D = V_C - V_F$

$V_A = V_C$

$V_D = V_F$

$x l_1 = \varepsilon$

$\varepsilon = x l_1$

$\varepsilon_1 = x l_1$

$\varepsilon_2 = x l_2$

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

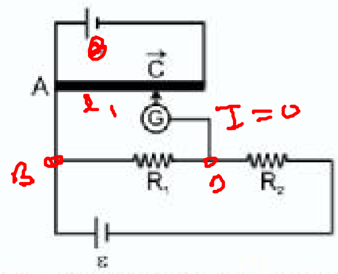
# Applications of Potentiometer

**(b) To find current if resistance is known**

$V_A - V_C = x\ell_1$

$IR_1 = x\ell_1$

$$I = \frac{x\ell_1}{R_1}$$




Similarly, we can find the value of $R_2$ also.

Potentiometer is ideal voltmeter because it does not draw any current from circuit, at the balance point.

$V_A - V_C = V_B - V_D$

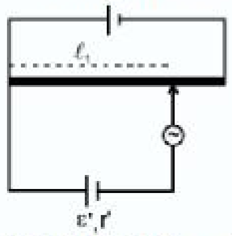
$x\ell_1 = V_{R_1}$

$I = \frac{V_{R_1}}{R_1}$

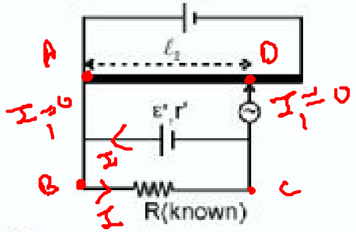
# Applications of Potentiometer

**(c) To find the internal resistance of cell.**

I[st] arrangement




2[nd] arrangement




by first arrangement $\varepsilon' = x\ell_1$ ...(1)

by second arrangement $IR = x\ell_2$

$$I = \frac{x\ell_2}{R},$$

also $I = \dfrac{\varepsilon'}{r'+R}$ $\Rightarrow$ $\dfrac{\varepsilon'}{r'+R} = \dfrac{x\ell_2}{R}$

$\Rightarrow$ $\dfrac{x\ell_1}{r'+R} = \dfrac{x\ell_2}{R}$ $\Rightarrow$ $r' = \left[\dfrac{\ell_1 - \ell_2}{\ell_2}\right]R$ $= \left(\dfrac{l_1}{l_2} - 1\right) R$

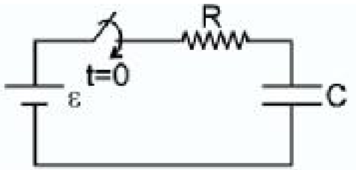
$l_1 > l_2$

$V_A - V_D = V_B - V_C$

$x l_2 = IR$

$x l_2 = \dfrac{\varepsilon'}{R + r'} \cdot R$

# Charging of Capacitor




initially capacitor is uncharged.

at any time

$$q = \varepsilon C(1 - e^{-t/RC})$$

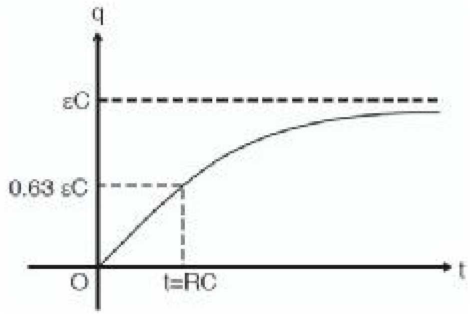
RC = time constant of the RC series circuit.

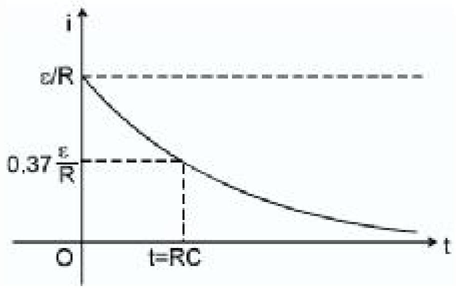
**After one time constant**

$$q = \varepsilon C\left(1 - \frac{1}{e}\right) = \varepsilon C\,(1 - 0.37) = 0.63\,\varepsilon C$$

**Current at any time t**

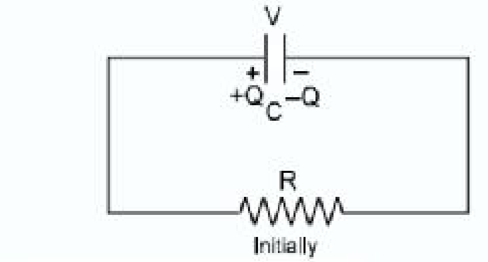
$$i = \frac{dq}{dt} = \varepsilon C\left(-e^{-t/RC}\left(-\frac{1}{RC}\right)\right) = \frac{\varepsilon}{R}e^{-t/RC}$$

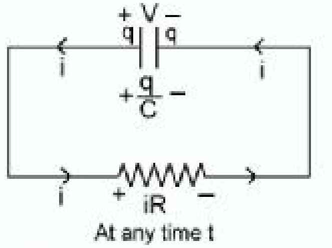



$\tau = RC$
$= 1k\Omega \times 1\mu F$
$= 10^{-3}\,s$

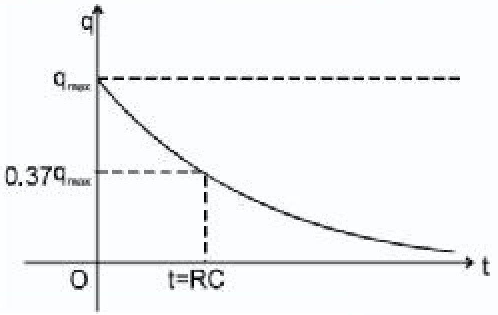
# Discharging of Capacitor

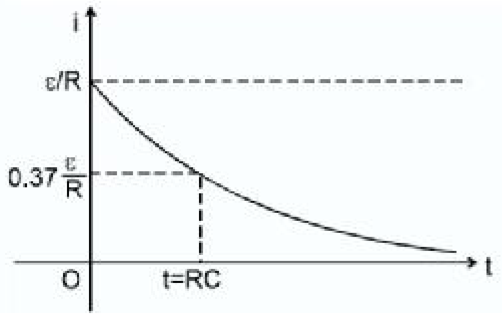



$$q = Q \, . \, e^{-t/RC}$$

$$i = -\frac{dq}{dt} = \frac{Q}{RC} e^{-t/RC}$$



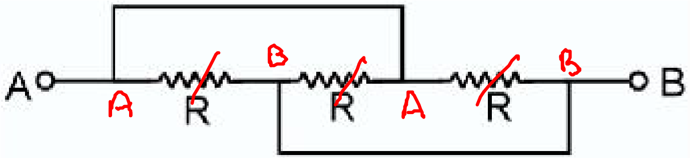

$E = \frac{V}{d}$

$= \frac{Q}{C}$

$E_{max}$ of air $\simeq 3.6 \times 10^6$ V/m

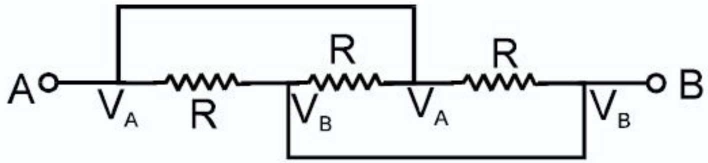
# Example

Find equivalent Resistance





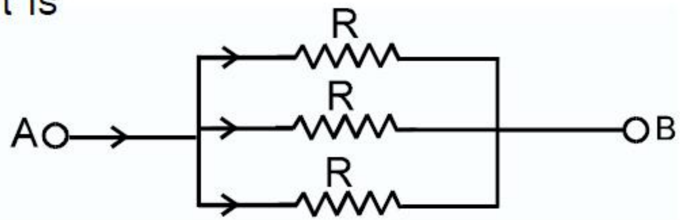
Sol.




Here all the Resistance are connected between the terminals A and B

Modified circuit is

So $R_{eq} = \frac{R}{3}$

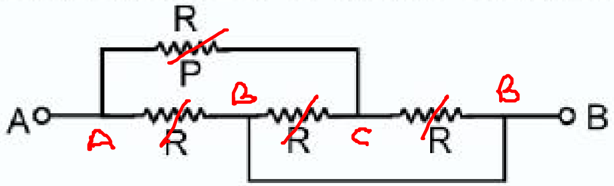




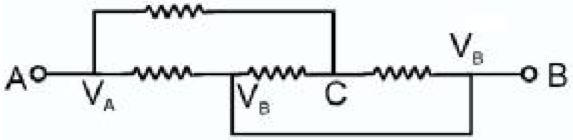
$R_{AB} = R/3$

# Example

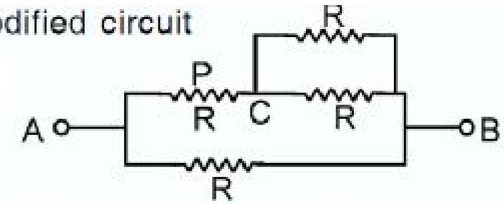
Find the current in Resistance P if voltage supply between A and B is V volts




Sol.

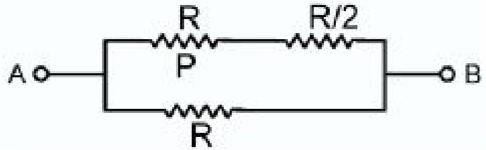


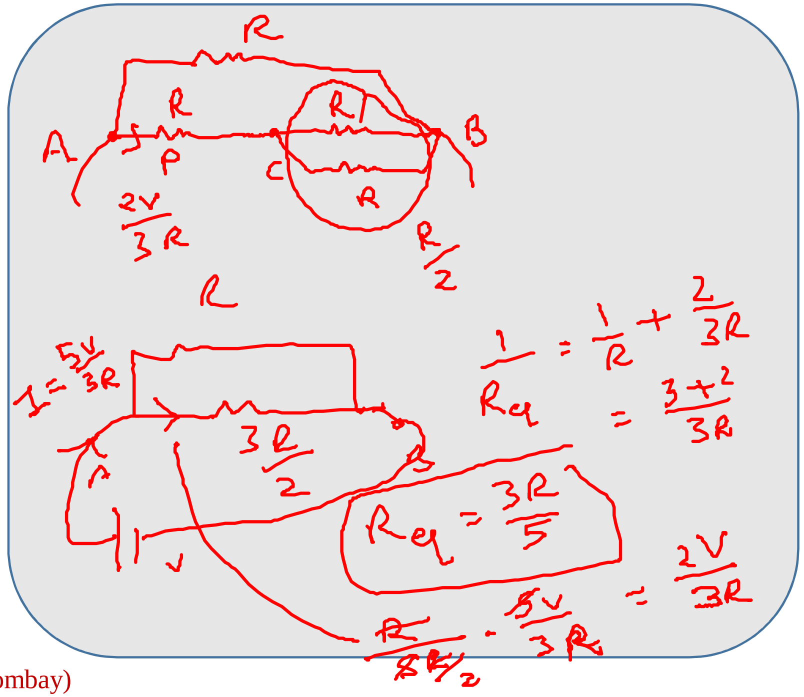

Modified circuit




$$R_{eq} = \frac{3R}{5} \qquad I = \frac{5V}{3R}$$

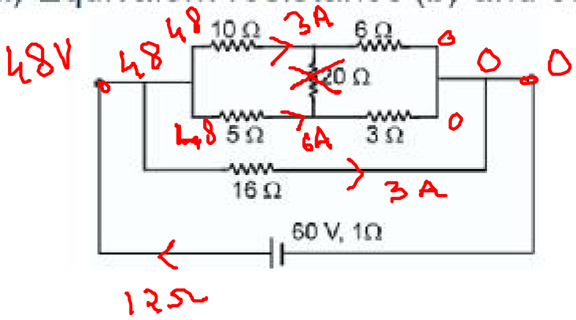
$$\text{Current in P} = \frac{R \times \frac{5V}{3R}}{1.5R + R} = \frac{2V}{3R}$$



# Example

Find (a) Equivalent resistance (b) and current in each resistance




Sol.

(a) $R_{eq} = \left(\frac{1}{16}+\frac{1}{8}+\frac{1}{16}\right)^{-1}+1=5\Omega$

(b) $i = \frac{60}{4+1} = 12\text{ A}$

Hence 12 A will flow through the cell.

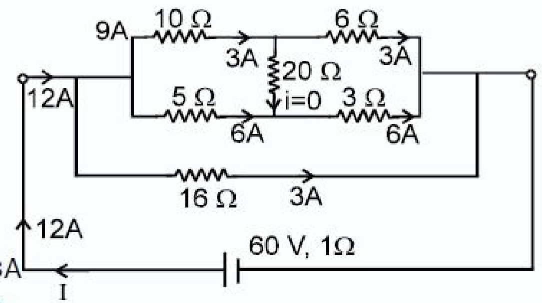
By using current distribution law.

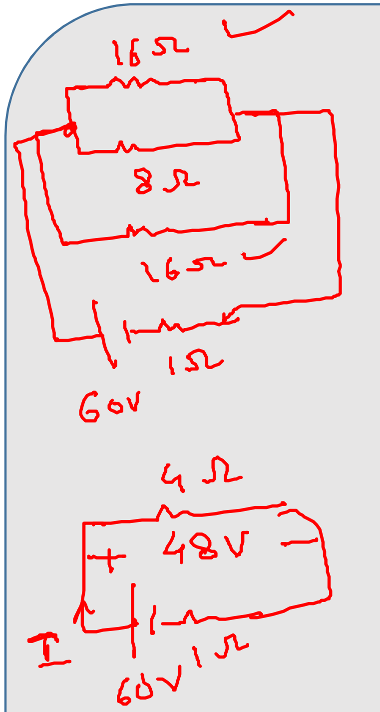
Current in resistance 10Ω and 6Ω = 3A

Current in resistance 5Ω and 3Ω = 6A

Current in resistance 20Ω = 0

Current in resistance 16Ω = 3A



$R_{eq} = 5\Omega$

$I = \frac{60}{5} = 12A$