Chapter 3. Current Electricity

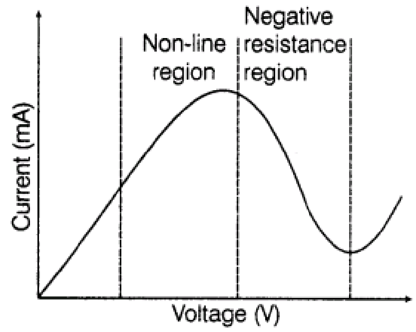
Resistance and Ohm'sLaw

1 Mark Questions

1.Plot a graph showing variation of current versus voltage for the material GaAs. [Delhi 2014]

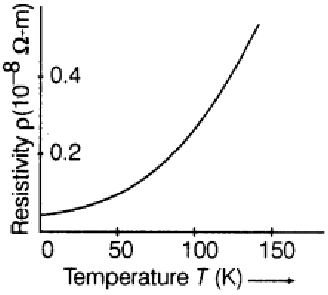
Ans.

Variation of current *versus* voltage for the material GaAs.



2.Show variation of resistivity of copper as a function of temperature in graph. [Delhi 2014; All India 2014]

Ans.Graph of resistivity of copper as a function of temperature is given below (resistivity of metals increases with increase in temperature)



3.Define the term drift velocity of charge carriers in a conductor and write its relationship with the current flowing through it. [Delhi 2014]

Ans.The term drift velocity of charge carriers in a conductor is defined as the average velocity acquired by the free electrons along the length of a metallic conductor under a potential difference applied across the conductor.Its relationship is expressed as

$$v_d = \frac{I}{neA}$$

where, I is current flowing through the conductor,n is concentration of free electrons
e is electron i.e.charge
A is cross-sectional area

4.Define the term electrical conductivity of a metallic wire. Write its SI unit. [Delhi 2014]

Ans.

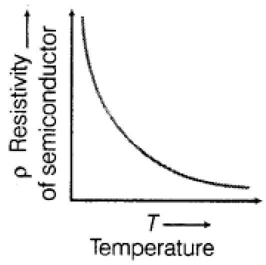
The electrical conductivity (σ) of a metallic wire is defined as the ratio of the current density to the electric field it creates. Its SI unit is mho per metre.

5.Show variation of resistivity of Si with temperature in graph.[Delhi 2014]

Ans.

The resistivity of a semiconductor decreases exponentially with temperature.

The variation of resistivity with temperature for semiconductor is shown in figure below.



(1)

6.Define the term mobility of charge carriers in a conductor. Write its SI unit. [Delhi 2014]

Ans.

The mobility of charge carriers in a conductor is defined as the magnitude of drift velocity (in a current carrying conductor) per unit electric field. **(1/2)**

$$\mu = \frac{\text{Drift velocity } (v_d)}{\text{Electric field } (E)} = \frac{q\tau}{m}$$

where, τ is the average relaxation time and m is the mass of the charged particle.

Its SI unit is $m^2/V\text{-}s$ or $ms^{-1}N^{-1}C$. **(1/2)**

7.Write a relation between current and drift velocity of electrons in a conductor. Use this relation to explain how the resistance of a conductor changes with the rise in temperature ? [Compartment 2013]

Ans.Relation between current and drift velocity of electrons in a conductor is given by $I = Anev_d$

where I = current, A = area of conductor, n = number density of electrons and v_d = drift velocity.

with the increase in temperature of a metallic conductor, resistance increases and hence, drift velocity decreases

8.When electrons drift in a metal from lower to higher potential, does it mean that all the free electrons of the metal are moving in the same direction? [Delhi 2012]

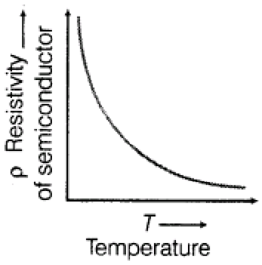
Ans. No, the drift speed of electrons is superposed over the random velocities of the electrons

9.Show on a graph, the variation of resistivity with temperature for a typical semiconductor. [Delhi 2012]

Ans.

The resistivity of a semiconductor decreases exponentially with temperature.

The variation of resistivity with temperature for semiconductor is shown in figure below.



(1)

10.Two wires of equal length, one of copper and the other of manganin have the same resistance. Which wire is thicker? [All India 2012]

Ans.

Given that resistance of both the wire is same.

i.e. $R_{Mn} = R_{Cu}$

$$\frac{\rho_{Mn} l_{Mn}}{A_{Mn}} = \rho_{Cu} \frac{l_{Cu}}{A_{Cu}} \quad \text{...(i)}$$

According to the question, both the wires are of equal length, so

$$l_{Mn} = l_{Cu}$$

∴ From Eq. (i), we get

$$\frac{\rho_{Mn}}{A_{Mn}} = \frac{\rho_{Cu}}{A_{Cu}} \text{ or } \frac{\rho}{A} = \text{constant}$$

or $$\frac{A_{Cu}}{A_{Mn}} = \frac{\rho_{Cu}}{\rho_{Mn}} \text{ or } \rho \propto A$$

We know that copper is better conductor than manganin, therefore, copper will have less resistivity.

i.e. $\rho_{Cu} < \rho_{Mn}$

So, $A_{Mn} > A_{Cu}$ $(\because \rho \propto A)$

That means wire of manganin will be thicker than that of copper. **(1)**

11.Define resistivity of a conductor. Write its SI unit. [All India 2011]

Ans.

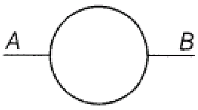
The resistivity of the material of conductor is equal to the resistance offered by the conductor of same material of unit length and unit cross-sectional area.

The resistivity of a material of the conductor does not depend on the geometry of the conductor.

SI unit of resistivity is ohm-metre (Ω -m).

(1/2 + 1/2 = 1)

12. A wire of resistance 8 Ω is bent in the form of a circle. What is the effective resistance between the ends of a diameter *AB*? **[Delhi 2010]**

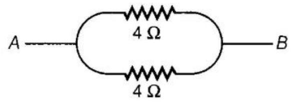


Ans.

The resistance of the whole wire is 8 Ω, which is bent in the form of a circle. We have to find the effective resistance between the ends of diameter *AB*. Diameter of the circle divides the circle into two equal parts. The resistance of each such part will be $\frac{8}{2} = 4\,\Omega$.

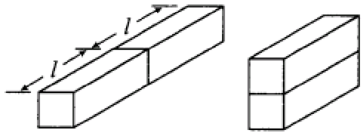
(Resistance $R \propto$ length of wire l, if length is halved then resistance will also become half).
From the figure, it is clear that both the parts are in parallel combination. So, effective resistance between *A* and *B* is given by

$$\frac{1}{R_{AB}} = \frac{1}{R_1} + \frac{1}{R_2} \Rightarrow \frac{1}{R_{AB}} = \frac{1}{4} + \frac{1}{4}$$



$$\Rightarrow \qquad R_{AB} = \frac{4}{1+1} = 2\,\Omega$$ **(1)**

13.Two identical slabs, of a given metal, are joined together, in two different ways, as shown in figures
(a) and (b). What is the ratio of the resistances of these two combinations? [Delhi 2010 c]



(a) (b)

Ans.

In these types of questions, first of all, identify the combination in which the metal slabs are connected and then apply the formula for equivalent resistance accordingly.

Let each conductor is of resistance *R*.
Case I According to Fig. (a) the resistances are connected in series combination, so equivalent resistance of slab

$$R_1 = R + R = 2R$$

Case II According to Fig. (b), the resistances are connected in parallel combination, so equivalent resistance

$$\frac{1}{R_2} = \frac{1}{R} + \frac{1}{R} \Rightarrow \frac{1}{R_2} = \frac{2}{R} \Rightarrow R_2 = \frac{R}{2}$$

Ratio of the equivalent resistance in two combinations is

$$\therefore \quad \frac{R_1}{R_2} = \frac{2R}{(R/2)} = 4 \Rightarrow \frac{R_1}{R_2} = 4$$ **(1)**

14.Two conducting wires X and Y of same diameter but different materials are joined in series across a battery. If the number density of electrons in X is twice than that in Y, then find the ratio of drift velocity of electrons in the two wires.[All India 2010]
Ans.

Given that number density in *X*
= 2 × Number density in *Y*

$$\Rightarrow \qquad n_X = 2n_Y$$

As current is common for the entire circuit

i.e. $$I = n_X A_X\, e\, (v_d)_X = n_Y A_Y\, e\, (v_d)_Y$$

Also, the diameters of the wires are same

$$A_X = A_Y$$

$$\Rightarrow \quad \frac{(v_d)_X}{(v_d)_Y} = \frac{n_Y}{n_X} = \frac{n_Y}{2n_Y} = \frac{1}{2}$$

15.The three coloured bands, on a carbon resistor are red, green and yellow, respectively. Write the value of its resistance. [All India 2009c]

Ans.

According to the colour code of resistances.

Code for red = 2

Code for green = 5

Code for yellow = 4

$\therefore$ Resistance of the wire $= 25 \times 10^4 \Omega \pm 20\%$

16.Write an expression for the resistivity of a metallic conductor showing its variation over a limited range of temperatures. [Delhi 2008 C]

Ans.

Required expression $\rho = \rho_0 [1 + \alpha (T_2 - T_1)]$

where, ρ_0 = resistivity of conductor at lower reference temperature,

α = temperature coefficient of resistivity,

and ρ = resistivity of material of conductor. **(1)**

17.Define ionic mobility. Write its SI Unit.[Foreign 2008]

Ans.

Ionic Mobility The ionic mobility is the drift speed acquired by ions per unit applied electric field.

Ionic mobility,

$$\mu = \frac{v_d}{E}$$

where, v_d = drift speed,

E = applied electric field.

Its SI unit is m^2/V-s. **(1)**

18. A physical quantity, associated with electrical conductivity, has the SI unit Ω-m. Identify this physical quantity. **[All India 2008C]**

Ans.

The physical quantity resistivity (ρ) of material of conductor has the SI unit Ω-m. **(1)**

2 Marks Questions

19. Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area $1.0 \times 10^{-7} m^2$ carrying a current of 1.5 A. Assume the density of conduction electrons to be $9 \times 10^{28} m^{-3}$. **[All India 2014]**

Ans.

Given, cross sectional area, $A = 1.0 \times 10^{-7} m^2$

Current, $I = 1.5A$

Electron density, $n = 9 \times 10^{28} m^{-3}$

Drift velocity, $v_d = ?$

We know that,

$$I = neAv_d \quad ($$

$$\Rightarrow v_d = \frac{I}{neA}$$

$$= \frac{1.5}{9 \times 10^{28} \times 1.6 \times 10^{-19} \times 1.0 \times 10^{-7}}$$

$$= 1.042 \times 10^{-3} \text{ m/s} \quad ($$

20. Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area 2.5×10^{-7} m^2 carrying a current of 1.8 A. Assume the density of conduction electrons to be $9 \times 10^{28} m^{-3}$. **[All India 2014]**

Ans.

Refer to ans. 19. (Ans. 5×10^{-4} m/s).

21. Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area $2.5 \times 10^{-7} m^2$ carrying a current of 2.7 A. Assume the density of conduction electrons to be $9 \times 10^{28} m^{-3}$. **[All India 2014]**

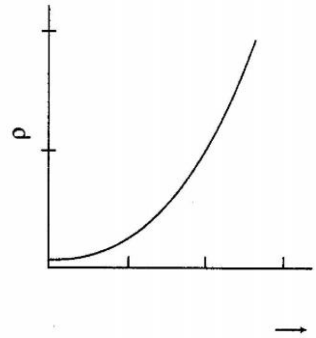
Ans.

Refer to ans. 19. (Ans. 7.5×10^{-4} m/s).

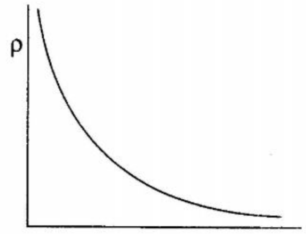
22.Draw a plot showing the variation of resistivity of a (i) conductor and (ii) semiconductor, with the increase in temperature. How does one explain this behaviour in terms of number density of charge carriers and the relaxation time? [Delhi 2014 C]

Ans.

(i) **Conductor**



(ii) **Semiconductor**



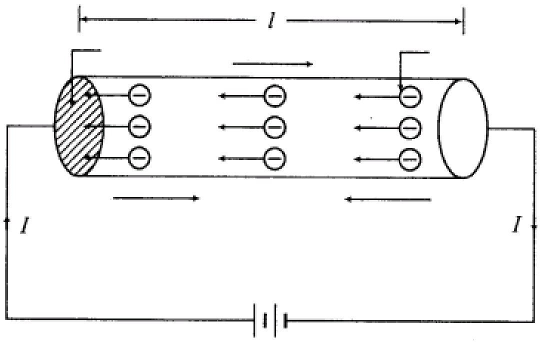
The relation between resistivity and relaxation time $\rho = \frac{m}{ne^2\tau}$

In conductors, average relation time decreases with increase in temperature, resulting in an increase in resistivity. In semiconductors, the increase in number density (with increase in temperature) is more than the decrease in relaxation time, the net result is therefore a decrease in resistivity.

23.Derive an expression for the current density of a conductor in terms of the drift speed of electrons. [Foreign 2014]

Ans. Let potential difference V is applied across a conductor of length / and hence, an electric field E produced inside the conductor.

$$\therefore \qquad E = \frac{V}{l} \qquad \ldots(i)$$



Let n = number density of free electrons
A = cross-sectional area of conductor
e = electrons charge

$\therefore$ Number of free electrons present in l length of conductor = nAl

$\therefore$ Total charge contained in length l which can contribute in current

$$q = (nAl)e \quad \text{...(i)} \quad \textbf{(1/2)}$$

The time taken by free electron to cross the l length of conductor is

$$t = \frac{l}{v_d} \quad \text{...(ii)}$$

(1/2)

where, v_d = drift speed of electron

$\therefore$ Current through the conductor

$$I = \frac{q}{t}$$

$$I = \frac{(nAl)\,e}{t} = \frac{(nAl)\,e}{\left(\frac{l}{v_d}\right)} = neAv_d$$

$\therefore$ Current density $(j) = \frac{I}{A} = \frac{neAv_d}{A} = nev_d$

$\therefore \quad j = nev_d$ i.e. $j \propto v_d)$ **(1)**

Thus, current density of conductor is proportional to drift speed.

24.A conductor of length / is connected to a DC source of potential V. If the length of the conductor is tripled by gradually stretching it, keeping V constant, how will

(i)drift speed of electrons and

(ii)resistance of the conductor be affected? Justify your answer.[HOTS; Foreign 2012]

Ans.

When a wire is stretched, then there is no change in the matter of the wire hence, its volume remains constant.

NOTE There is a difference between the two length changed by stretching and length mode changes. Ist means that volume will not change but IInd means that volume will change.

The potential V = constant, $l' = 3l$

(*i*) Drift speed of electrons $= \frac{V}{nel\rho}$

where, n is number of electrons, e is charge on electron, l is the length of the conductor and ρ is the resistivity of conductor.

$$\therefore \quad v \propto \frac{1}{l}$$

($\because$ Other factors are constants)

So, vhen length is tripled, drift velocity gets one-third. **(1)**

(*ii*) Resistance of the conductor is given as

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

Here, wire is stretched to triple its length, that means the mass of the wire remains same in both the conditions.

Mass before stretching = Mass after stretching

(Volume × Density) before stretching

= (Volume × Density) after stretching.

(Area of cross-section × Length) before stretching

= (Area of cross-section × Length) after stretching

(∵ Density is same in both cases)

$$\therefore \quad A_1 l_1 = A_2 l_2$$

$$A_1 l = A_2 (3l)$$

(∵ Length is tripled after stretching)

$$\therefore \quad A_2 = \frac{A_1}{3}$$

i.e. when length is tripled area of cross-section is reduced to $\frac{A}{3}$.

Hence, $R = \rho \frac{l'}{A'} = \rho \frac{3l}{\frac{A}{3}} = 9\rho \frac{l}{A} = 9R$ **(1)**

Thus, new resistance will be 9 times of its original value.

25.Plot a graph showing temperature dependence of resistivity for a typical semiconductor. How is this behaviour explained? [Delhi 2011]

Ans.

> To plot the graph between the two quantities, first of all identify the relation between them.

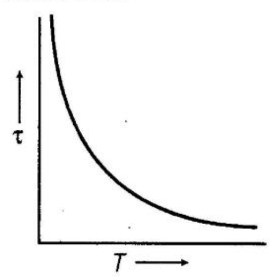
Since, resistivity of material of conductor (ρ) is given by

$$\rho = \frac{m}{ne^2\tau}$$

where, n = number density of electrons,

τ = relaxation time.

With the rise of temperature of semiconductor, number density of free electrons increases, whereas τ remains constant and hence resistivity decreases. **(1)**



Resistivity of a semiconductor decreases rapidly with temperature

(1)

26. (*i*) You are required to select a carbon resistor of resistance 47 k $\Omega \pm 10\%$ from a large collection. What should be the sequence of colour bands used to code it?

(*ii*) Write two characteristics of manganin which make it suitable for making standard resistances. **[Delhi 2011]**

Ans.

(*i*) Given, resistance $= 47\,k\Omega \pm 10\%$

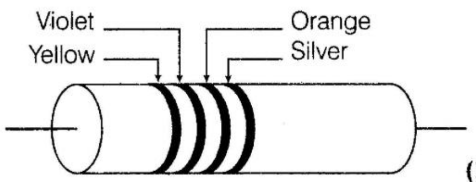
$$= 47 \times 10^3\ \Omega \pm 10\%$$

$\therefore$ Ist colour band should be yellow as code for it is 4.

IInd colour band should be violet as code for it is 7.

IIIrd colour band should be orange as code for it is 3.

IVth colour band should be silver because approximation is $\pm 10\%$



(1)

(*ii*) Two properties of manganin are

(*a*) Low temperature coefficient of resistance.

(*b*) High value of resistivity of material of manganin make it suitable for making a standard resistor. **(1)**

27.The sequence of coloured bands in two carbon resistors R_t and R_2 is

(i)brown, green, blue and

(ii)orange, black, green.

Find the ratio of their resistances.[Delhi 2010 C]

Ans.

According to colour codes, resistance of two wires are

(*i*) Code of brown = 1

Code of green = 5

Code of blue = 6

$R_1 = 15 \times 10^6\,\Omega \pm 20\%$

(*ii*) Code of orange = 3

Code of black = 0

Code of green = 5

$R_2 = 30 \times 10^5\,\Omega \pm 20\%$

$$\therefore \text{ Ratio of resistances } \frac{R_1}{R_2} = \frac{15 \times 10^6}{30 \times 10^5} = 5$$

$$\Rightarrow \qquad \frac{R_1}{R_2} = 5$$

(1)

28. A wire of 15 Ω resistance is gradually stretched to double its original length. It is then cut into two equal parts. These parts are then connected in parallel across a 3.0 V battery. Find the current drawn from the battery. **[All India 2009]**

Ans.

Let original cross-sectional area and length of 15 Ω resistance are A and l after stretching they become A' and l', respectively.

Initial resistance, $R = \rho \frac{l}{A} \Rightarrow 15 = \rho \frac{l}{A}$ ...(i)

∴ In case of stretching, volume of the wire remains same, so

$$Al = A'l'$$

$$\because \quad l' = 2l \Rightarrow A' = \frac{A}{2} \qquad \text{...(ii)}$$

∴ Resistance after stretching

$$R' = \rho \frac{l'}{A'} = \rho\left(\frac{2l}{A/2}\right) = 4\left(\rho \frac{A}{l}\right)$$

$$R' = 4 \times 15 \qquad \text{(from Eq. (i))}$$

Now resistance, $R' = 60\ \Omega$ **(1/2)**

After dividing into two parts, resistance of each part = 30 Ω

∴ Effective resistance after connecting them into parallel combination

$$R_{eff} = \frac{30}{2} = 15\ \Omega \qquad \textbf{(1/2)}$$

∵ Applied potential difference, $V = 3$ V

∴ Current drawn from the battery, $I = \frac{V}{R}$

(from Ohm's law)

$$\Rightarrow \quad I = \frac{3}{15} \Rightarrow I = \frac{1}{5}\text{ A} \qquad \textbf{(1)}$$

29.Derive an expression for drift velocity of free electrons in a conductor in terms of relaxation time. [Delhi 2009]

Ans.

When a conductor is subjected to an electric field **E**, each electron experiences a force

$\mathbf{F} = -e\mathbf{E}$, and free electron acquires an acceleration

$$\mathbf{a} = \frac{\mathbf{F}}{m} = -\frac{e\mathbf{E}}{m} \quad \text{...(i)}$$

where, m = mass of electron, e = electronic charge and $\mathbf{E}$ = electric field.

Free electron starts accelerating and gains velocity and collide with atoms and molecules of the conductor. The average time difference between two consecutive collisions is known as relaxation time of electron and

$$\bar{\tau} = \frac{\tau_1 + \tau_2 + \ldots + \tau_n}{n} \quad \text{...(ii)} \ \mathbf{(1)}$$

where, $\tau_1, \tau_2, \ldots, \tau_n$ are the average time difference between 1st, 2nd, ..., nth collisions.

$\therefore$ $\mathbf{v}_1, \mathbf{v}_2, \ldots, \mathbf{v}_n$, are velocities gained by electron in 1st, 2nd ..., nth collisions with initial thermal velocities $\mathbf{u}_1, \mathbf{u}_2, \ldots, \mathbf{u}_n$, respectively.

$$\therefore \quad \mathbf{v}_1 = \mathbf{u}_1 + \mathbf{a}\tau_1$$
$$\mathbf{v}_2 = \mathbf{u}_2 + \mathbf{a}\tau_2$$
$$\vdots \quad \vdots \quad \vdots$$
$$\mathbf{v}_n = \mathbf{u}_n + \mathbf{a}\tau_n$$

The drift speed $\mathbf{v}_d$ may be defined as

$$\mathbf{v}_d = \frac{\mathbf{v}_1 + \mathbf{v}_2 + \ldots + \mathbf{v}_n}{n}$$

$$\mathbf{v}_d = \frac{(\mathbf{u}_1 + \mathbf{u}_2 + \ldots + \mathbf{u}_n) + \mathbf{a}(\tau_1 + \tau_2 + \ldots + \tau_n)}{n}$$

$$\mathbf{v}_d = \frac{(\mathbf{u}_1 + \mathbf{u}_2 + \ldots + \mathbf{u}_n)}{n} + \frac{\mathbf{a}(\tau_1 + \tau_2 + \ldots + \tau_n)}{n}$$

$$\mathbf{v}_d = 0 + \mathbf{a}\tau \quad (\because \text{Average thermal velocity in } n \text{ collisions} = 0)$$

$$\mathbf{v}_d = -\left(\frac{e\mathbf{E}}{m}\right)\tau \quad \text{(from Eq. (i))}$$

(1)

This is the required expression of drift speed of free electrons.

30.Two metallic wires of the same material have the same length but cross-sectional area is in the ratio 1: 2. They are connected

(i)in series and

(ii)in parallel.

Compare the drift velocities of electrons in the two wires in both the cases. [All India 2008]

Ans.

In series, current is same, $I = neA_d$

$$v_d = \frac{I}{neA}$$

$$\Rightarrow \quad v_d \propto \frac{l}{A}$$

$$\frac{v_{d_1}}{v_{d_2}} = \frac{A_2}{A_1} = \frac{2}{1}$$

In parallel, voltage is same.

As, $v_d = \dfrac{e\tau}{m}\tau = \dfrac{ev}{ml}\tau$, $v_d \propto \dfrac{1}{l}$

$$\frac{v_{d_1}}{v_{d_2}} = \frac{l_2}{l_1} = \frac{1}{1}$$

31.Derive an expression for the resistivity of a good conductor, in terms of the relaxation time of electrons. [All India 2008]

Ans.

When a potential difference V is applied across l length of a conductor then drift speed of electron is given by

$$v_d = \frac{eE\tau}{m} = \frac{eV\tau}{lm} \quad ...(i) \quad \left(\because E = \frac{V}{l}\right)$$

(1/2)

Also, the electric current through the conductor and drift speed are linked as

$$I = neAv_d \quad ...(ii)$$ **(1/2)**

where, n = number density of electrons

e = electronic charge

A = cross-sectional area of conductor

v_d = drift speed of electron

$$\therefore \quad I = neA\left(\frac{eV\tau}{lm}\right)$$

(substituting the value of v_d)

$$\Rightarrow \quad \frac{V}{I} = \frac{ml}{ne^2\tau A} \quad ...(iii)$$

Also, at constant temperature

$$\frac{V}{I} = R \quad ...(iv)$$

(from Ohm's law)

$$\Rightarrow \quad R = \left(\frac{m}{ne^2\tau}\right)\frac{l}{A}$$

(from Eqs. (iii) and (iv))

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

where, ρ is specific resistance or resistivity of conductor.

$$\therefore \quad \rho = \frac{m}{ne^2\tau} \quad ...(v)$$

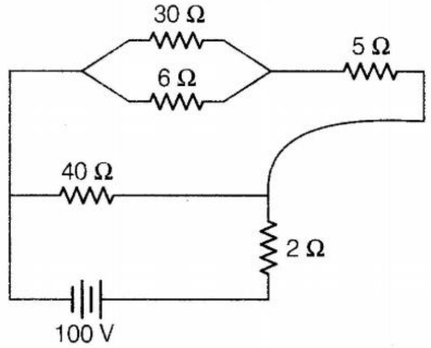
(1)

Thus, resistivity of material of conductor is inversely proportional to relaxation time (τ).

3 Marks Questions

32. (a) Define the term 'drift velocity' of charge carriers in a conductor. Obtain the expression for the current density in terms of relaxation time.

(b) A 100 V battery is connected to the electric network is shown in the figure. If the power consumed in the 2 Ω resistor is 200 W, determine the power dissipated in the 5 Ω resistor. **[Foreign 2014]**



Ans.(i)The term drift velocity of charge carriers in a conductor is defined as the average velocity acquired by the free electrons along the length of a metallic conductor under a potential difference applied across the conductor.Its relationship is expressed as

$$v_d = \frac{I}{neA}$$

where, I is current flowing through the conductor,n is concentration of free electrons
e is electron i.e.charge
A is cross-sectional area

Let original cross-sectional area and length of 15 Ω resistance are A and l after stretching they become A' and l', respectively.

Initial resistance, $R = \rho\frac{l}{A} \Rightarrow 15 = \rho\frac{l}{A}$ ...(i)

$\therefore$ In case of stretching, volume of the wire remains same, so

$$Al = A'l'$$

$\because \quad l' = 2l \Rightarrow A' = \frac{A}{2}$ ...(ii)

$\therefore$ Resistance after stretching

$$R' = \rho\frac{l'}{A'} = \rho\left(\frac{2l}{A/2}\right) = 4\left(\rho\frac{A}{l}\right)$$

$R' = 4 \times 15$ (from Eq. (i))

Now resistance, $R' = 60\ \Omega$ **(1/2)**

After dividing into two parts, resistance of each part = 30 Ω

$\therefore$ Effective resistance after connecting them into parallel combination

$R_{eff} = \frac{30}{2} = 15\ \Omega$ **(1/2)**

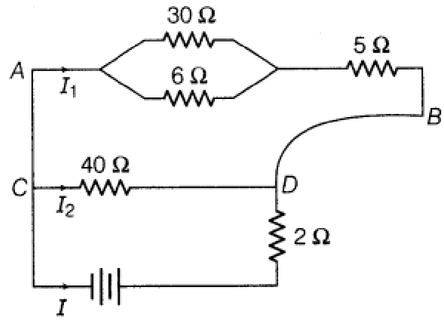
$\because$ Applied potential difference, $V = 3$ V

$\therefore$ Current drawn from the battery, $I = \frac{V}{R}$

(from Ohm's law)

$\Rightarrow \quad I = \frac{3}{15} \Rightarrow I = \frac{1}{5}$ A **(1)**

(ii) Total current, $I = \sqrt{\frac{P}{R}} = \sqrt{\frac{200}{2}} = 10$A



Resistance across AB

$$= \left(\frac{1}{30} + \frac{1}{6}\right) + 5$$

$$R_{AB} = 10\ \Omega = R_1$$

Potential difference across AB = potential difference across CD

$\Rightarrow \quad I_1R_1 = I_2R_2 \Rightarrow I_1R_1 - I_2R_2 = 0$

$\therefore \quad 10I_1 - 40I_2 = 0$

$I_1 - 4I_2 = 0$ ...(i)

$\because \quad I_1 + I_2 = I \Rightarrow I_1 + I_2 = 10$ ...(ii)

From Eq. (i)

$$I_2 = \frac{I_1}{4}$$ ...(iii)

Put the value of I_2 from Eq. (iii) to Eq. (ii), we get

$$I + \frac{I_1}{4} = 10 \Rightarrow I_1 = 8A$$

Power dissipated in 5 Ω resistor

$= 5 \times$ [(current through 5 Ω resistor)^2]

$= 5 \times (8)^2$

$P = 320$ W

33.Define relaxation time of the free electrons drifting in a conductor. How it is related to the drift velocity of free electrons? Use this relation to deduce the expression for the electrical resistivity of the material.[All India 2012]

Ans.

Relaxation Time The average time difference between two successive collisions of drifting electrons inside the conductor under the influence of electric field applied across the conductor, is known as relaxation time. **(1)**

Drift speed and relaxation time

$$v_d = -\frac{eE\tau}{m}$$ **(1/2)**

where, E = electric field due to applied potential difference

τ = relaxation time

m = mass of electron

e = electronic charge

$\because$ Electron current, $I = -neAv_d$ **(1/2)**

$$I = -neA\left(-\frac{eE\tau}{m}\right)$$ **(1/2)**

$$I = \frac{ne^2A\tau}{m}\left(\frac{V}{l}\right) \qquad \left(\because E = \frac{V}{l}\right)$$

$$\Rightarrow \quad \frac{V}{I} = \frac{mI}{ne^2A\tau} = \rho\frac{l}{A} = R$$

$$\Rightarrow \quad \rho = \frac{m}{ne^2\tau}$$ **(1/2)**

This is required expression.

34. (*i*) Derive the relation between current density j and potential difference V across a current carrying conductor of length l, area of cross-section A and the number density n of free electrons.

(*ii*) Estimate the average drift speed of conduction electrons in a copper wire of cross-sectional area 1.0×10^{-7} m^2 carrying a current of 1.5 A. [Assume that the number density of conduction electrons is 9×10^{28} m^{-3}]. **[Delhi 2012 C]**

Ans.

(*i*) The current in the conductor having length l_1 cross-sectional area A and number density n is

$$I = neAv_d \qquad ...(i)$$

Electric field inside the wire is given by

$$E = \frac{V}{l} \qquad ...(ii)$$

If relaxation time is τ, the drift speed

$$v_d = \frac{e\tau E}{m} \qquad \textbf{(1)}$$

where,

m = mass of electron

τ = relaxation charge

e = electronic charge

E = electric field.

Put the value of Eq. (i), we get

$$\Rightarrow \quad I = \frac{ne^2\tau}{m} AE \qquad ...(ii)$$

From Eqs. (ii) and (iii), we get

$$I = \frac{ne^2\tau AV}{ml} \Rightarrow J = \frac{I}{A} = \frac{ne^2\tau V}{ml} \qquad \textbf{(1)}$$

(*ii*) Given, $I = 1.5$ A, $n = 9 \times 10^{28}$ m^{-3},

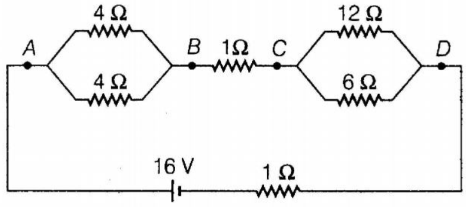
$$A = 1.0 \times 10^{-7} \text{ m}^2$$

$$\because \quad v_d = \frac{I}{neA}$$

$$\therefore \ v_d = \frac{1.5}{9 \times 10^{28} \times 1.6 \times 10^{-19} \times 1.0 \times 10^{-7}}$$

$$\Rightarrow v_d = 1.04 \times 10^{-3} \text{ m/s} \qquad \textbf{(2)}$$

35. A network of resistors is connected to a 16 V battery of internal resistance of 1 Ω as shown in the figure.



(*i*) Compute the equivalent resistance of the network.

(*ii*) Obtain the voltage drops V_{AB} and V_{CD}. **[Foreign 2010]**

Ans.

> To calculate the equivalent resistance of complex network (network having multiple branches), calculate the equivalent resistance of smaller part of network and finally calculate the equivalent resistance of the network.

(*i*) ∵ 4 Ω and 4 Ω are in parallel combination.

∴ Equivalent resistance, $R_{AB} = \frac{1}{4} + \frac{1}{4}$

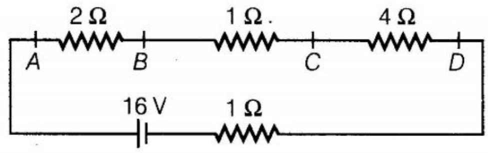
$$\frac{1}{R_{AB}} = \frac{2}{4} \Rightarrow R_{AB} = 2\ \Omega$$

Similarly, equivalent resistance of 12 Ω and 6 Ω is

$$\frac{1}{R_{BC}} = \frac{1}{12} + \frac{1}{6} \Rightarrow \frac{1}{R_{BC}} = \frac{1+2}{12}$$

$\Rightarrow \quad R_{BC} = 4\ \Omega$

Now, the circuit can be redrawn as shown in figure below



Now, 2 Ω, 1Ω and 4Ω, 1Ω are in series combination.

∴ Equivalent resistance of the network

$R_{eq} = 2\ \Omega + 1\Omega + 4\Omega + 1\Omega = 8\ \Omega$ **(1)**

(*ii*) ∴ Current drawn from the battery,

$$I = \frac{V}{R} = \frac{16}{8} = 2\ \text{A}$$

This current will flow from *A* to *B* and *C* to *D*. So, the potential difference in between *AB* and *CD* can be calculated as

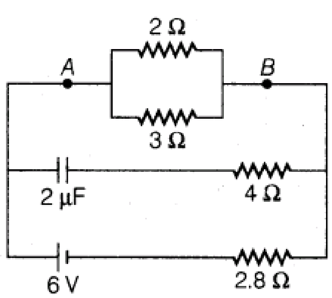
Now,

$V_{AB} = IR_{AB} = 2 \times 2 = 4\ \text{V}$ **(1)**

and $V_{CD} = I\,R_{CD} = 2 \times 2 = 8\ \text{V}$ **(1)** **3**

36. Calculate the steady current through the 2 Ω resistor in the circuit shown in the figure.

[HOTS; Foreign 2010]



Ans.

To calculate the current through a particular resistance first we have to find the potential difference across that resistance.

In DC circuit, capacitor offers infinite resistance. Therefore, no current flows through capacitor and through $4\,\Omega$ resistance, so resistance will produce no effect.

∴ Effective resistance between A and B

$$R_{AB} = \frac{2 \times 3}{2+3} = 1.2\ \Omega$$

$$\left(\because \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \Rightarrow R = \frac{R_1 R_2}{R_1 + R_2}\right) \quad \textbf{(1)}$$

Total resistance of the circuit $= 1.2 + 2.8 = 4\,\Omega$

(∵ These two are in series)

Net current drawn from the cell,

$$I = \frac{V}{R\,(\text{total resistance})}$$

$$= \frac{6}{4} = \frac{3}{2} = 1.5\ \text{A} \quad \textbf{(1/2)}$$

∴ Potential difference between A and B

$$V_{AB} = IR_{AB} = 1.5 \times 1.2$$

$$V_{AB} = 1.80\ \text{V} \quad \textbf{(1/2)}$$

Current through $2\,\Omega$ resistance,

$$I' = \frac{V_{AB}}{2\,\Omega} = \frac{1.8}{2} = 0.9\ \text{A} \quad \textbf{(1)}$$

37.Three resistors R_1, R_2 and R_3 are connected in parallel, across a source of emf E and negligible internal resistance. Obtain a formula for the equivalent expressions for the current through each of the three resistors. [All India 2009 c]

Ans.

Let the equivalent resistance of parallel combination of R_1, R_2 and R_3 is R.

$$\therefore \quad \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

$$\frac{1}{R} = \frac{R_2R_3 + R_1R_3 + R_1R_2}{R_1R_2R_3}$$

$$R = \frac{R_1R_2R_3}{R_1R_2 + R_2R_3 + R_3R_1} \quad \left(1\frac{1}{2}\right)$$

Effective current, $I = \dfrac{E}{R}$

$$I = \frac{E}{\dfrac{R_1R_2R_3}{R_1R_2 + R_2R_3 + R_3R_1}}$$

$$I = \frac{E(R_1R_2 + R_2R_3 + R_3R_1)}{R_1R_2R_3} \quad \left(1\frac{1}{2}\right)$$

38.Prove that the current density of a metallic conductor is directly proportional to the drift speed of electrons.[Delhi 2008]

Ans.

Since, the relationship between electric current density (j) and drift velocity (v_d) is given by

$$j = ne v_d \quad \text{...(i)} \quad \textbf{(2)}$$

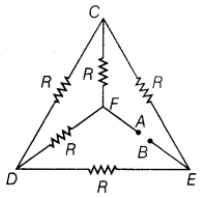
where, n = number of free electrons per unit volume, e = charge on each electron

For detailed proof, refer ans 31.

$\because$ For a given conductor ne is constant.

$\therefore \quad j \propto v_d$ **(1)**

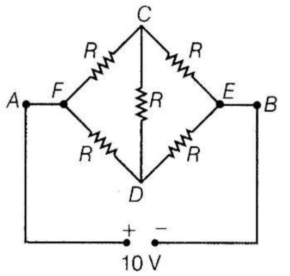
39. (*i*) Calculate the equivalent resistance of the given electrical network between points A and B.



(*ii*) Also, calculate the current through CD and ACB, if a 10 V DC source is connected between A and B and the value of R is assumed as $2\,\Omega$. **[All India 2008]**

Ans.

(*i*) The circuit can be redrawn as shown in figure below



(1)

As combination is balanced Wheatstone bridge.

$\therefore$ Equivalent resistance between the points A and B

$$R_{eq} = \frac{2R \times 2R}{2R + 2R} = R \quad \textbf{(1)}$$

(*ii*) If $R = 2\Omega$, then $R_{eq} = 2\,\Omega$

There is no current through resistor across CD.

$\therefore$ Current through arm $AFCEB = \frac{V}{2R}$

$$= \frac{10}{2 \times 2} = 2.5 \text{ A} \quad \textbf{(1)}$$

Potentiometer, Celland their Combinations

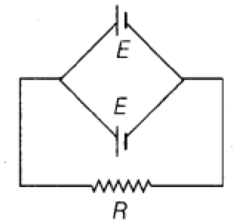
1 Mark Questions

1.State the underlying principle of a potentiometer? [Delhi 2014 c]

Ans.The potentiometer works on the principle that potential difference across any two points of uniform current carrying conductor is directly proportional to the length between the two points.

2.Two identical cells, each of emf E, having negligible internal resistance, are connected in parallel with each other across an external resistance What is the current through this resistance? [All India 2013]

Ans.The cells are arranged as shown in the circuit

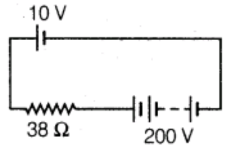


As the internal resistance of cells is negligible, so total resistance of the circuit = R

So. current through the resistance. **I=E/R**

(In parallel combination, potential is same as the single cell)

3. A 10 V battery of negligible internal resistance is connected across a 200 V battery and a resistance of 38 Ω as shown in the figure. Find the value of the current in circuit.



[Delhi 2013]

Ans. Since, the positive terminal of the batteries are connected together, so the equivalent emf of the batteries is given by £ = 200 -10 = 190 V

Hence, the current in the circuit is given by I=E/R=190/38=5 A

4.The emf of a cell is always greater than its terminal voltage. Why? Give reason. [Delhi 2013]

Ans.The emf of a cell is greater than its terminal voltage because there is some potential drop across the cell due to its small internal resistance

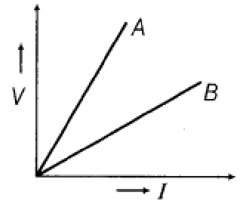
5.A cell of emf E and internal resistance r draws a current Write the relation between terminal voltage V in terms of E, I and r.[Delhi 2013]

Ans. When a current Idraws from a cell of emf E and internal resistance r, then the terminal voltage is

V = E − Ir.

6.A resistance R is connected across a cell of emf E and internal resistance r. Now, a potentiometer measures the potential difference between the terminals of the cells as V.

Write the expression for r in terms of E, V and R.



[Delhi 2011, 2010]

Ans.

Internal resistance, $r = R\left(\frac{E}{V} - 1\right)$

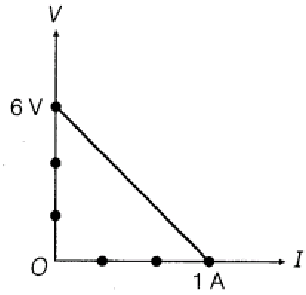
where, signs are as usual.

7.A (i) series (ii) parallel combination of two given resistors is connected, one-by-one, across a cell. In which case, will the terminal potential difference across the cell have a higher value?[All India 2008 C]

Ans.The equivalent resistance combination of resistances is (i) greater than the greatest resistance in series combination and (ii) smaller than the least value of resistance in parallel combination.

The terminal potential difference across the cell is higher in series combination as V = E – Ir and due to higher resistance, current I is less in series combination.

8.The plot of the variation of potential difference across a combination of three identical cells in series versus current is as shown in figure. What is the emf of each cell?



[Delhi 2008]

Ans. Terminal potential difference across a cell can be obtained by subtracting potential drop across internal resistance of the cell from the emf of the cell.

v Terminal voltage across cell combination,

V = E – Ir

when current I=0

=> V = E

From graph, when I = 0, V = 6 V

=> emf E = 6 V

2 Marks Questions

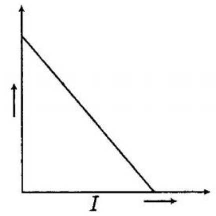
9.A cell of emf E and internal resistance r is connected across a variable resistor Plot a graph showing variation of terminal voltage V of the cell versus the current I. Using the plot, show the emf of the cell and its internal resistance can be determined.[All India 2014]

Ans.

We know that,

$$V = E - Ir$$

The plot between V and I is a straight line of positive intercept and negative slope as shown in figure below



(i) The value of potential difference corresponding to zero current gives emf of the cell. **(1)**

(ii) Maximum current is drawn when terminal voltage is zero, so

$$V = E - Ir$$

$$\Rightarrow \quad 0 = E - I_{max} r \Rightarrow r = \frac{E}{I_{max}}$$ **(1)**

10. A potentiometer wire of length 1 m has a resistance of 10 Ω. Determine the emf of the primary cell which gives a balance point at 40 cm. **[Delhi 2014]**

Ans.

Given, length of wire, $l = 1 \text{ m} = 100 \text{ cm}$

Resistance, $R = 10\ \Omega$

Emf of a battery, $E_1 = 6$ V

$R_1 = 5\ \Omega$

$x = 40$ cm

$$\therefore \text{ Current, } I = \frac{E_1}{R + R_1} = \frac{6}{10 + 5} = \frac{6}{15} \text{ A}$$

$$V_{AB} = IR = \frac{6}{15} \times 10 = \frac{60}{15} = 4 \text{ V}$$

$$\therefore \text{ Emf of the primary cell } = \frac{V_{AB}}{l} \times x$$

$$= \frac{4}{100} \times 40 = 1.6 \text{ V}$$

11. A potentiometer wire of length 1 m has a resistance of 5 Ω. It is connected to a 8 V battery in series with a resistance of 15 Ω. Determine the emf of the primary cell which gives a balance point at 60 cm. **[Delhi 2014]**

Ans.Refer to ans. 10. (Ans. 1.2V).

12. A potentiometer wire of length 1.0 m has a resistance of 15 Ω. It is connected to a 5 V battery in series with a resistance of 5 Ω. Determine the emf of the primary cell which gives a balance point at 60 cm.
[Delhi 2014]

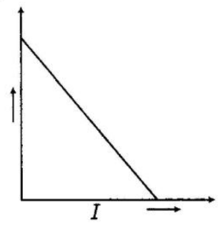
Ans.Refer to ans. 10. (Ans. 2.25 V).

13. Distinguish between emf (ε) and terminal voltage (*V*) of a cell having internal resistance *r*. Draw a plot showing the variation of terminal voltage (*V*) *versus* the current (*I*) drawn from the cell. Using this plot, show how does one can determine the internal resistance of the cell?
[All India 2014 C]

Ans.

Difference between emf (ε) and terminal voltage (*V*)

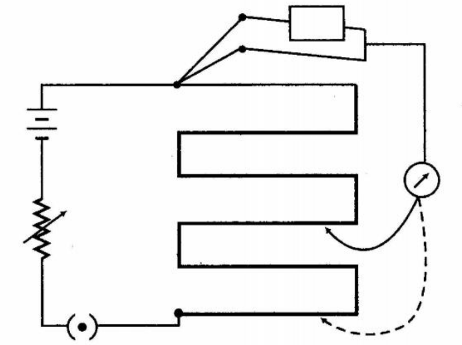
S. No.	Emf	Terminal voltage
1.	It is the potential difference between two terminals of the cells when no current is flowing through it.	1. It is the potential difference between two terminals when current passes through it.
2.	It is the cause.	2. It is the effect.



Negative slope gives internal resistance. **(2)**

14.Describe briefly with the help of a circuit diagram, how a potentiometer is used to determine the internal resistance of a cell.[All India 2013]
Ans.

Measurement of internal resistance of a cell using potentiometer.



(1)

The cell of emf, E (internal resistance r) is connected across a resistance box (R) through key K_2.

$$E = \phi\, l_2 \quad \text{...(i)}$$

When K_2 is open balance length is obtained at length $AN_1 = l_1$

$$\therefore \quad V = \phi\, l_2$$

From Eqs. (i) and (ii), we get

$$\frac{E}{V} = \frac{l_1}{l_2} \quad \text{...(iii)}$$

$$E = I(r + R)$$

$$V = IR$$

$$\frac{E}{V} = \frac{r+R}{R} \quad \text{...(iv)}$$

From Eqs. (iii) and (iv) we get

$$\frac{R+r}{R} = \frac{l_1}{l_2}$$

$$\therefore \quad \frac{E}{V} = \frac{l_1}{l_2}$$

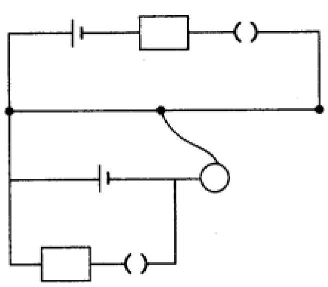
$$\because \quad r = R\left(\frac{E}{V} - 1\right)$$

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

We known l_1, l_2 and E, so we can calculate r.

(1)

15.Two students X and Y perform an experiment on potentiometer separately using the circuit given below



Keeping other parameters unchanged, how will the position of the null point be affected if

(i)X increases the value of resistance R in the set up by keeping the key closed and the key K_2 open?

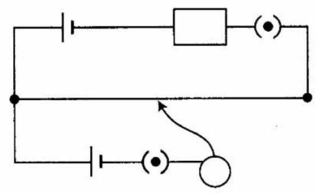
(ii)Y decreases the value of resistance S in the set up, while the key K_2 remains open and then K_t closed?

Justify your answer.[HOTS; Foreign 2012]

Ans.

When K_1 is closed and K_2 is open, then only the cell connected in upper part branch will work.
When K_2 is closed and K_1 is open, then only the cell connected in lower branch will work.

(*i*) $K_1 \rightarrow$ closed, $K_2 \rightarrow$ open



Suppose null point occurs at *J*.
Apply KVL in smaller loop,

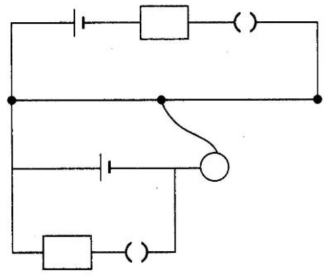
$$E - IR = 0 \quad \text{...(i)}$$

where, R = resistance

$$E = IR \Rightarrow I = \frac{E}{R}$$

As, X increases the value of resistance R. So, current in the circuit (wire) decreases. Hence, R will be increased. Then I will decrease.
We can say, as X increases the value of R, null point decrease. **(1)**

(*ii*) $K_2 \rightarrow$ open, $K_1 \rightarrow$ closed.
Then the circuit will be same as shown earlier.



We see that resistance S is not involved in the circuit because K_2 is open.
So, from Eq. (i)

$$E = RI \Rightarrow I = \frac{E}{R}$$

Here, R does not depend on the value of resistance S.
So, R null point is not affected by decreasing the value of resistance S. **(1)**

16.Two cells of emf 2E and E and internal resistances 2r and r respectively, are connected in parallel. Obtain the expressions for the equivalent emf and the internal resistance of the combination.[All India 2010 C]
Ans.

Given,

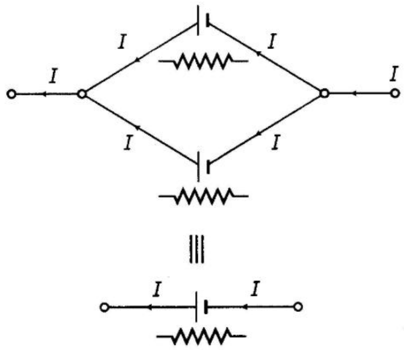
Emf of first cell = $2E$

Emf of second cell = E

Internal resistance of first cell = $2r$

Internal resistances of second = r

Net current $\quad I = I_1 + I_2 \quad$ ...(i) **(1/2)**



For cell-I

$V = V_A - V_B = 2E - I_1(2r) \Rightarrow I_1 = \dfrac{2E - V}{2r}$ ...(ii)

For cell-II,

$$V = V_A - V_B = E - I_2 r$$

$\Rightarrow \quad I_2 = \dfrac{E - V}{r}$ ...(iii)

∵ From Eqs. (ii) and (iii), substituting in Eq. (i),

$$I = \frac{2E - V}{2r} + \frac{E - V}{r}$$

On rearranging the term, we get

$$V = \frac{4E}{3} - I\left(\frac{2r}{3}\right)$$ **(1)**

But for equivalent of combination,

$$V = E_{eq} - I(r_{eq})$$

On comparing,

$$E_{eq} = \frac{4E}{3},$$ **(1/2)**

$$r_{eq} = \frac{2r}{3}$$ **(1/2)**

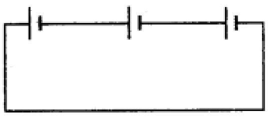
NOTE Two cells of emfs E_1 and E_2 and internal resistances r_1 and r_2 connected in parallel combination, then equivalent emf

$$E_{eq} = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$$

Equivalent resistance, $r_{eq} = \dfrac{r_1 r_2}{r_1 + r_2}$

17.Three cells of emf E,2E and 5 Eh aving internal resistances r, 2r and 3r, variable resistance R as shown in the figure. Find the expression for the current. Plot a graph for variation of current with R.

[All India 2010 C]



Ans.

In these type of questions, we have to look out the connections of different cells, if the opposite terminals of all the cells are connected, then they support each other, i.e. these individual emf's are added up. If the same terminals of the cells are connected, then the equivalent emf is obtained by taking the difference of emf's.

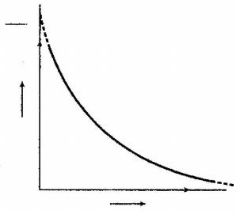
Net emf of combination $= E_1 - 2E_1 + 5E_1 = 4E_1$

Net resistance of current $= r + 2r + 3r + R$

$= 6r + R$

$\therefore$ Current, $I = \frac{V}{R}$ (from Ohm's law)

$$I = \frac{4E_1}{6r + R} \quad \textbf{(1)}$$



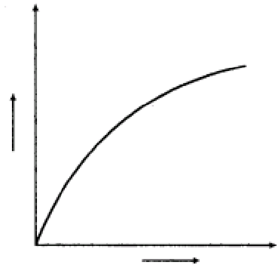
(1)

18.A cell of emf E and internal resistance r is connected across a variable resistor R. Plot a graph showing the variation of terminal potential V with resistance!?.[Delhi 2009]

Ans.

$$\because \quad V = \left(\frac{E}{R+r}\right)R = \frac{E}{1 + r/R} \quad \textbf{(1/2)}$$

$\Rightarrow$ with the increase of R, V increases



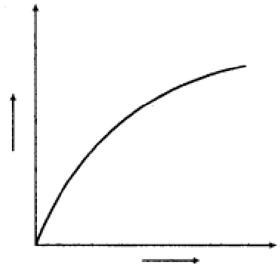
$\left(1\frac{1}{2}\right)$

19.Plot a graph showing the variation of terminal potential difference across a cell of emf E and internal resistance r with current drawn from it. Using this graph, how does one determine the emf of the cell? [Delhi 2009 c]

Ans.

$$\because \quad V = \left(\frac{E}{R+r}\right)R = \frac{E}{1 + r/R} \quad \textbf{(1/2)}$$

$\Rightarrow$ with the increase of R, V increases

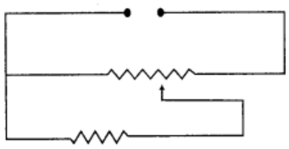


$\left(1\frac{1}{2}\right)$

3 Marks Questions

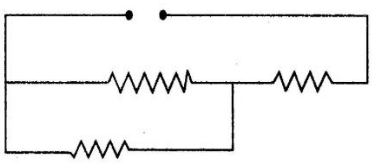
20. A resistance of $R\,\Omega$ draws current from a potentiometer as shown in the figure. The potentiometer has a total resistance $R_0\ \Omega$. A voltage V is supplied to the potentiometer. Derive an expression for the voltage across R when the sliding contact is in the middle of the potentiometer.

[All India 2014]



Ans.

The equivalent circuit is redrawn as shown in figure below



So, the equivalent resistance of the circuit is given by

$$R_{eq} = \frac{R_0}{2} + \frac{R \cdot \frac{R_0}{2}}{R + \frac{R_0}{2}} \qquad \textbf{(1)}$$

$\therefore$ Current in the circuit,

$$I_{circuit} = \frac{V}{R_{eq}} \qquad \textbf{(1)}$$

$$\Rightarrow \quad V = I\,R_{eq}$$

$$= I\left[\frac{R_0}{2} + \frac{R \cdot \frac{R_0}{2}}{R + \frac{R_0}{2}}\right]$$

$$= I\left(\frac{R_0}{2} + \frac{RR_0}{2R + R_0}\right)$$

$$= \frac{IR_0}{2}\left(1 + \frac{2R}{2R + R_0}\right) \qquad \textbf{(1)}$$

21.(i) State the underlying principle of a potentiometer. Why is it necessary to (i) use a long wire, (ii) have uniform area of cross-section of the wire and (iii) use a driving cell whose emf is taken to be greater than the emfs of the primary cells?

(ii) In a potentiometer experiment, if the area of the cross-section of the wire increases uniformly from one end to the other, draw a graph showing how potential gradient would vary as the length of the wire increases from one end.[All India 2014 C]

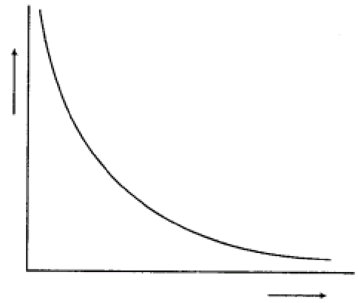
Ans.(i) Principle of Potentiometer The potential drop across the length of a steady current carrying wire of uniform cross-section is proportional to the length of the wire.

(a)We use a long wire to have a lower value of potential gradient (i.e a lower "least count" or greater sensitivity of the potentiometer.

(b)The area of cross-section has to be uniform to get a 'uniform wire' as per the principle of the potentiometer.

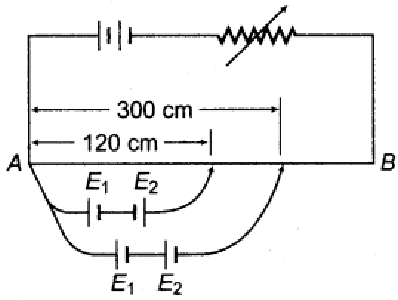
(c)The emf of the driving cell has to be greater than the emf of the primary cells as otherwise, no balance point would be obtained (*ii*) Potential gradient, $K = \frac{V}{L}$

∴ The required graph is as shown below



(1)

22.In the figure, a long uniform potentiometer wire AB is having a constant potential gradient along its length. The null points for the two primary cells of emfs E_x and E_2 connected in the manner shown, are obtained at a distance of 120 cm and 300 cm from the end A



Find (i) E1 / E_2 and

(ii) position of null point for the cell E1

How is the sensitivity of a potentiometer increased? [Foreign 2014; Delhi 2012]

Ans.

(*i*) Let potential gradient be K.

$\because \quad E_1 - E_2 = K \times 120$ ...(i)

(cells are connected in opposite order)

$E_1 + E_2 = K \times 300$ ...(ii)

(cells are connected in supporting order)

$\left(2 \times \frac{1}{2} = 1\right)$

$$\frac{E_1 + E_2}{E_1 - E_2} = \frac{K \times 300}{K \times 120} = \frac{5}{2}$$

Now, apply componendo and dividendo

$$\frac{(E_1 + E_2) + (E_1 - E_2)}{(E_1 + E_2) - (E_1 - E_2)} = \frac{5+2}{5-2}$$

$$\frac{E_1}{E_2} = \frac{7}{3}s$$

(1/2)

(ii) $\because$ $\frac{E_1}{E_2} = \frac{7}{3}$, $E_2 = \frac{3}{7}E_1$

From Eq. (i)

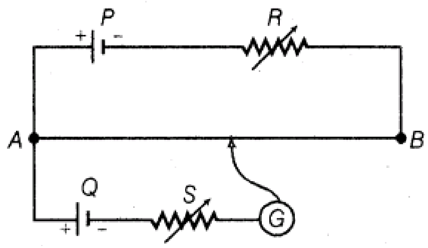
$E_1 - \frac{3}{7}E_1 = K \times 120$, $\frac{4}{7}E_1 = K \times 120$

$$DE_1 = K \times 120 \times \frac{7}{4}$$

$$E_1 = K \times 210$$

Null point for E_1 is obtained at 210 cm. **(1)**
The sensitivity of potentiometer be increased by increasing the length of wire. **(1/2)**

23.State the underlying principle of a potentiometer. Write two factors on which the sensitivity of a potentiometer depends.



In the potentiometer circuit shown in the figure, the balance point is at X. State, giving reason, how the balance point is shifted when

(i)resistance R is increased

(ii)resistance S is increased, keeping R constant?[Compartment 2013]

Ans. We use a long wire to have a lower value of potential gradient (i.e a lower "least count" or greater sensitivity of the potentiometer The two factors on which the sensitivity of a potentiometer depends are

(a)the value of potential gradient (K)

(b)by increasing the length of potentiometer wire. From the circuit diagram,

(i) if R is increased, the current through the potentiometer wire will decrease. Due to it, the potential gradient of potentiometer wire will also decrease. Thus, the position of **J** will shift towards **B.**

(ii) if S is increased, keeping R constant, the position of J will shift towards A.

24. An ammeter of resistance 0.80 Ω can measure current upto 1.0 A.

(*i*) What must be the value of shunt resistance to enable the ammeter to measure current upto 5.0 A?

(*ii*) What is the combined resistance of the ammeter and the shunt?

[Delhi 2013]

Ans.

Here, resistance of ammeter $R_A = 0.80\ \Omega$ and maximum current across ammeter, $I_A = 1.0$ A.
So, voltage across ammeter,

$$V = IR = 1.0 \times 0.80 = 0.8 \text{ V}$$

Let the value of shunt be x.

(*i*) Resistance of ammeter with shunt,

$$R = \frac{R_A x}{R_A + x} = \frac{0.8x}{0.8 + x}$$

when current through ammeter, $I = 5$ A. **(1)**

Now for $V = IR$, $\left(\frac{0.8\,x}{0.8 + x}\right) \times 5 = 0.8$

$$\Rightarrow 0.8x \times 5 = 0.8\,(0.8 + x)$$

$$\Rightarrow \quad 4x = 0.64 + 0.8x$$

$$\therefore \quad x = \frac{0.64}{3.2} = 0.2$$

Hence, the value of resistance must be 0.2 Ω. **(1)**

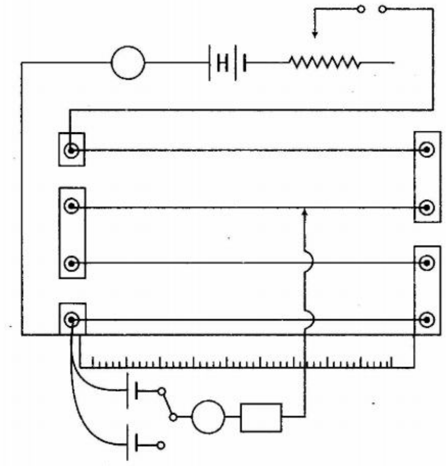
(*ii*) With the help of value of shunt resistance combined resistance of the ammeter and the shunt,

$$R = \frac{0.8x}{0.8 + x} = \frac{0.8 \times 0.2}{0.8 + 0.2} = 0.16\ \Omega$$ **(1)**

25.With the help of circuit diagram, explain how a potentiometer can be used to compare emf of two primary cells? [Delhi 2011]

Ans.

The required circuit diagram is shown in the figure below.



The main circuit comprises of battery of emf E, key (K) and rheostat (R_h). The auxiliary circuit comprises of two primary cells of emfs E_1 and E_2, galvanometer, jockey and resistance box (RB) to prevent large current flowing through the galvanometer.

When key K_1 is closed and K_2 kept open, the cell, E_1 comes into action. The jockey J is moved on the wire AB till null point is obtained in galvanometer. Let null point is obtained at length l_1 then emf of first cell is given by

$$E_1 = kl_1 \quad \ldots\text{(i)}$$

(1)

where, k is the potential gradient along the wire AB due to battery E.

Now, key K_2 is closed and K_1 kept open and null point is obtained at length l_2, then

$$E_2 = kl_2 \quad \ldots\text{(ii)}$$ **(1)**

Therefore, $\frac{E_1}{E_2} = \frac{kl_1}{kl_2} = \frac{l_1}{l_2} \Rightarrow \frac{E_1}{E_2} = \frac{l_1}{l_2}$ **(1)**

NOTE The null point is obtained only when

(*i*) emf of battery E must be greater than emfs of two primary cells E_1 and E_2 each.

(*ii*) all the positive terminals of cells and battery must be connected at the same point.

26.State the underlying principle of a potentiometer. Describe briefly, giving the necessary circuit diagram, how a potentiometer is used to measure the internal resistance of a given cell?[Foreign 2011]

Ans. Principle of Potentiometer The potential difference across any two points of current carrying , wire, having uniform cross-sectional area and material of the potentiometer is directly proportional to the length between the two points

i.e. $V \propto l$

$$\because \quad V = IR = I\left(\rho \frac{l}{A}\right)$$

(from Ohm's law)

$$V = \left(\frac{l\rho}{A}\right) I$$

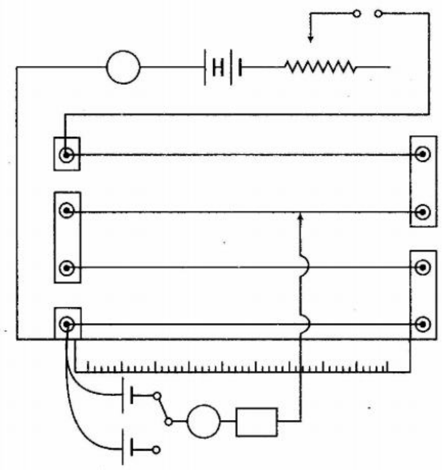
For uniform current and cross-sectional area

$$\frac{l\rho}{A} = \text{constant}$$

$$\Rightarrow \quad V \propto I \qquad \textbf{(1)}$$

The circuit diagram of potentiometer for determining internal resistance of a given cell is shown

The required circuit diagram is shown in the figure below.



The main circuit comprises of battery of emf E, key (K) and rheostat (R_h). The auxiliary circuit comprises of two primary cells of emfs E_1 and E_2, galvanometer, jockey and resistance box (RB) to prevent large current flowing through the galvanometer.

When key K_1 is closed and K_2 kept open, the cell, E_1 comes into action. The jockey J is moved on the wire AB till null point is obtained in galvanometer. Let null point is obtained at length l_1 then emf of first cell is given by

$$E_1 = kl_1 \qquad \text{...(i)}$$

(1)

where, k is the potential gradient along the wire AB due to battery E.

Now, key K_2 is closed and K_1 kept open and null point is obtained at length l_2, then

$$E_2 = kl_2 \qquad \text{...(ii)} \quad \textbf{(1)}$$

Therefore, $\frac{E_1}{E_2} = \frac{kl_1}{kl_2} = \frac{l_1}{l_2} \Rightarrow \frac{E_1}{E_2} = \frac{l_1}{l_2}$ **(1)**

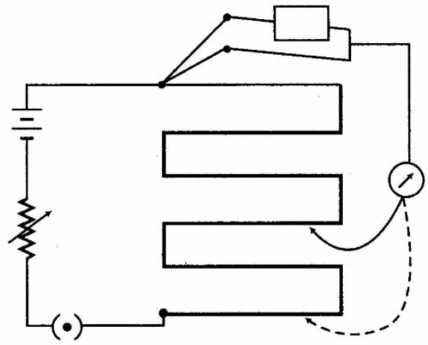
NOTE The null point is obtained only when

(*i*) emf of battery E must be greater than emfs of two primary cells E_1 and E_2 each.

(*ii*) all the positive terminals of cells and battery must be connected at the same point.

Measurment of Internal Resistance of a Cell Using Potentiometer

Measurement of internal resistance of a cell using potentiometer.



(1)

The cell of emf, E (internal resistance r) is connected across a resistance box (R) through key K_2.

$$E = \phi\, l_2 \qquad \text{...(i)}$$

When K_2 is open balance length is obtained at length $AN_1 = l_1$

$$\therefore \quad V = \phi\, l_2$$

From Eqs. (i) and (ii), we get

$$\frac{E}{V} = \frac{l_1}{l_2} \qquad \text{...(iii)}$$

$$E = I(r + R)$$

$$V = IR$$

$$\frac{E}{V} = \frac{r + R}{R} \qquad \text{...(iv)}$$

From Eqs. (iii) and (iv) we get

$$\frac{R + r}{R} = \frac{l_1}{l_2}$$

$$\therefore \quad \frac{E}{V} = \frac{l_1}{l_2}$$

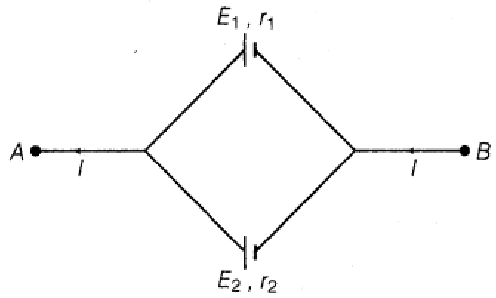
$$\because \quad r = R\left(\frac{E}{V} - 1\right)$$

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

We known l_1, l_2 and E, so we can calculate r.

(1)

27.Two cells of emf E_x, E_2 and internal resistances r_a and r_2 respectively are connected in parallel as shown in the figure.



Deduce the expressions for

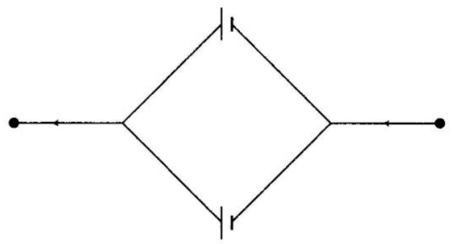
(i)the equivalent emf of the combination.

(ii)the equivalent resistance of the combination and

(iii)the potential difference between the points A and [Foreign 2010]

Ans.

Let, I_1 and I_2 be the currents in two cells with emfs, E_1 and E_2 and internal resistances, r_1 and r_2.



So, $$I = I_1 + I_2$$

Now, let V be the potential difference between the points, A and B. Since, the first cell is connected between the points A and B.

V = potential difference across first cell

$V = E_1 - I_1 r_1$

or $I_1 = \frac{E_1 - V}{r_1}$ **(1)**

Now, the second cell is also connected between the points, A and B. So,

$$I_2 = \frac{E_2 - V}{r_2}$$

Thus, substituting for I_1 and I_2

$$I = \frac{E_1 - V}{r_1} + \frac{E_2 - V}{r_2}$$

or $$I = \left(\frac{E_1}{r_1} + \frac{E_2}{r_2}\right) - V\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$$

$$V = \left(\frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}\right) - I\left(\frac{r_1 r_2}{r_1 + r_2}\right) \quad \text{...(i)}$$

If E is effective emf and r, the effective internal resistance of the parallel combination of the two cells, then

$$V = E - Ir \quad \text{...(ii)}$$ **(1)**

Comparing Eqs. (i) and (ii), we get

(*i*) $E = \frac{E_1 r_2 + E_2 r_1}{r_1 + r_2}$

This is equivalent emf of the combination.

(*ii*) $r = \frac{r_1 r_2}{r_1 + r_2}$

This is equivalent resistance of the combination.

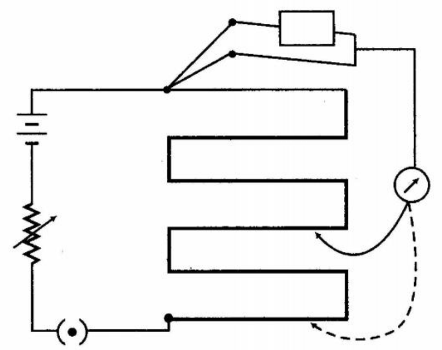
(*iii*) the potential difference between the points A and B is **(1)**

$$V = E - Ir$$

28.Draw the circuit diagram of a potentiometer which can be used to determine the internal resistance r of a given cell of emf Explain briefly how the internal resistance of the cell is determined? [Delhi 2010,2008 C]

Ans.

Measurement of internal resistance of a cell using potentiometer.



(1)

The cell of emf, E (internal resistance r) is connected across a resistance box (R) through key K_2.

$$E = \phi\, l_2 \qquad \text{...(i)}$$

When K_2 is open balance length is obtained at length $AN_1 = l_1$

$$\therefore \quad V = \phi\, l_2$$

From Eqs. (i) and (ii), we get

$$\frac{E}{V} = \frac{l_1}{l_2} \qquad \text{...(iii)}$$

$$E = I(r + R)$$

$$V = IR$$

$$\frac{E}{V} = \frac{r+R}{R} \qquad \text{...(iv)}$$

From Eqs. (iii) and (iv) we get

$$\frac{R+r}{R} = \frac{l_1}{l_2}$$

$$\therefore \quad \frac{E}{V} = \frac{l_1}{l_2}$$

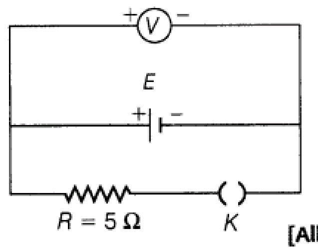
$$\because \quad r = R\left(\frac{E}{V} - 1\right)$$

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

We known l_1, l_2 and E, so we can calculate r.

(1)

29.Write any two factors on which internal resistance of a cell depends. The reading on a high resistance voltmeter, when a cell is connected across it, is 2.2 V. When the terminals of the cell are also connected to a resistance of 5 ohms as shown in the circuit, the voltmeter reading drops to 1.8 V. Find the internal resistance of the cell.



[All India 2010]

Ans. The high resistance voltmeter means that no current with flow through it hence, there is no potential difference across it. So, the reading shown by the high resistance voltmeter can be taken as the emf of the cell.

The internal resistance of a cell depends on

(i) the concentration of electrolyte and

(ii) distance between the two electrodes

The emf of cell $(E) = 2.2$ V

The terminal voltage across cell when 5 Ω resistance (R) connected across it $(V) = 1.8$ V

Let internal resistance $= r$

$\because$ Internal resistance,

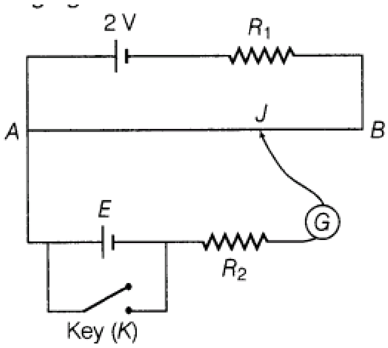
$$r = R\left(\frac{E}{V} - 1\right)$$ **(1)**

$$\therefore \quad r = 5\left(\frac{2.2}{1.8} - 1\right) = 5 \times \frac{0.4}{1.8} = \frac{2}{1.8} = \frac{10}{9}\,\Omega$$

$$\Rightarrow r = \frac{10}{9}\,\Omega$$ **(1)**

30.(i)State the principle of working of a potentiometer.

(ii)Figure shows the circuit diagram of a potentiometer for determining the emf of E cell of negligible internal resistance.



(a)What is the purpose of using high resistance ?

(b)How does the position of balance point (J) change when the resistance i?$_x$ is decreased?

(c)Why cannot the balance point be obtained

- **when the emf E is greater than 2 V.**
- **when the key (K) is closed?[Foreign 2009]**

Ans.(i) Principle of Potentiometer The potential drop across the length of a steady current carrying wire of uniform cross-section is proportional to the length of the wire.

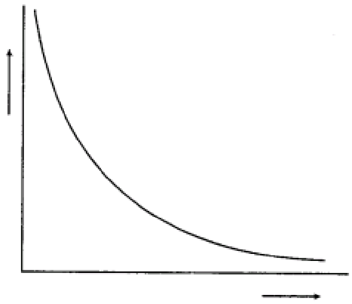
(a)We use a long wire to have a lower value of potential gradient (i.e a lower "least count" or greater sensitivity of the potentiometer.

(b)The area of cross-section has to be uniform to get a 'uniform wire' as per the principle of the potentiometer.

(c)The emf of the driving cell has to be greater than the emf of the primary cells as otherwise, no balance point would be obtained

(*ii*) Potential gradient, $K = \frac{V}{L}$

$\therefore$ The required graph is as shown below



(1)

(ii) (a) To protect the galvanometer from flow of high current.

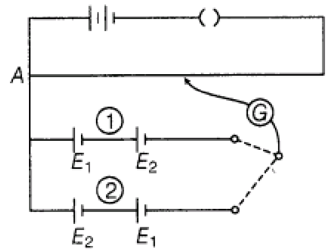
(b) Balance point, J shift towards **A**

(c)Potential drop across the cell cannot become equal to potential difference across any two point of the curve. Potential difference across cell become zero

31.A circuit using a potentiometer and battery of negligible internal resistance is set up as shown to develop a constant potential gradient along the wire Two cells of emfs E_1 and E_2 are connected in series as shown in combinations (1) and (2). The balance points are obtained respectively at 400 cm and 240 cm from the point A. Find

(i)E_1 / E_2.

(ii)balancing length for the cell E1 only.



[Delhi 2009]

Ans.

In combination 1, net emf of combination is $E_1 + E_2$, whereas for combination 2 net emf is $E_2 - E_1$.

$$E_1 + E_2 = Kl_1 \quad \text{...(i)}$$

where, K = potential gradient

$$l_1 = 400 \text{ cm}$$

For combination 2,

$$E_2 - E_1 = Kl_2 \quad \text{...(ii)}$$

where, $l_2 = 240$ cm **(1/2)**

$$\because \frac{E_1 + E_2}{E_2 - E_1} = \frac{Kl_1}{Kl_2} = \frac{400}{240} = \frac{5}{3}$$

$$\frac{E_1 + E_2}{E_2 - E_1} = \frac{5}{3}$$

Applying componendo and dividendo theorem, we get

$$\frac{(E_1 + E_2) + (E_2 - E_1)}{(E_1 + E_2) - (E_2 - E_1)} = \frac{5+3}{5-3}$$

$$\frac{E_2}{E_1} = \frac{8}{2} \Rightarrow \frac{E_1}{E_2} = \frac{1}{4}$$ **(1)**

(ii) $\because \frac{E_1}{E_2} = \frac{1}{4} \Rightarrow E_1 = E$ (say)

Then, $E_2 = 4E$

$$\Rightarrow E_1 + E_2 = K \times 400 \Rightarrow 5E = K \times 400$$

$$K = \frac{5E}{400} = \frac{E}{80}$$ **(1/2)**

Now, let balancing length for E_1 is l_1

$$\therefore E_1 = Kl_1 \Rightarrow E = \frac{E}{80} \times l_1$$

$$\Rightarrow l_1 = 80 \text{ cm}$$ **(1)**

32.A number of identical cells, n each of emf E, internal resistance r, connected in series are charged by a DC source of emf E', using a resistor, R.

(i)Draw the circuit arrangement.

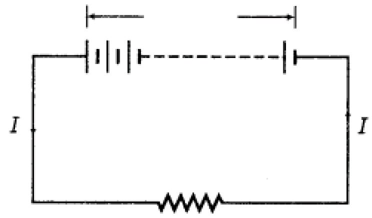
(ii)Deduce the expressions for

(a)the changing current and

(b)the potential difference across the combination of the cells. [Delhi 2008]

Ans.

(i) Net emf = $E' - nE$ **(1)**



(ii) (a) Net internal resistance of the combination of cells = nr

Net resistance = $nr + R$

where, R = external resistance

$\therefore$ Charging current, $I = \dfrac{\text{Net emf}}{\text{Net resistance}}$

$$I = \frac{E' - nE}{nr + R}$$ **(1)**

(b) Potential difference across the combination of cells

$$V = nE + I\,(nr) = nE + \left(\frac{E' - nE}{nr + R}\right) nr$$

$$= \frac{nE\,(nr + R) + (E' - nE)\,nr}{nr + R}$$

$$= \frac{n^2Er + nER + E'nr - n^2Er}{nr + R} = \frac{n(ER + E'r)}{nr + R}$$ **(1)**

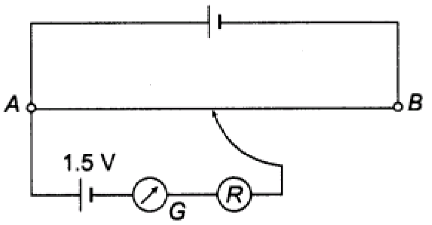
NOTE Here, series cell combination is being charged.

$$V_A - nE - (nr)\,I = V_B$$

$\Rightarrow$ $V_A - V_B = nE + (nr)\,I$

$\therefore$ Terminal voltage, $V = V_A - V_B = nE + Inr$

33.A potentiometer wire of length lm is connected to a driver cell of emf 3 V as shown in the figure. When a cell of 1.5 V emf is used in the secondary circuit, the balance point is found to be 60 cm. On replacing this cell and using a cell of unknown emf, the balance point shifts to 80 cm.



(i)Calculate unknown emf of the cell.

(ii)Explain with reason, whether the circuit works, if the driver cell is replaced with a cell of emf 1 V.

(iii)Does the high resistance R, used in the secondary circuit affect the balance point? Justify your answer.[Delhi 2008]

Ans.

(*i*) For comparing emfs of two cells using potentiometer, we have

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

Here, $E_1 = 1.5$ V, $l_1 = 60$ cm,

$E_2 = ?$, $l_2 = 80$ cm,

$$\therefore \quad \frac{1.5}{E_2} = \frac{60}{80} \Rightarrow E_2 = \frac{80}{60} \times 1.5 = 2 \text{ V}$$

$$E_2 = 2 \text{ V}$$ **(1)**

34. Four identical cells, each of emf 8 V and internal resistance 2.5 Ω are connected in series and charged by a 100 V DC supply, using a 24 Ω resistor in series. Calculate the following

(*i*) Changing current in the circuit.

(*ii*) Potential difference across the cells during recharging. **[Foreign 2008]**

Ans. (i) Net emf applied in the circuit = Applied potential difference – Total emf of all cells = 100 V-4 x 8 V = 68 V

NOTE During changing of the current, positive terminal of the battery is connected to positive terminal of the series combination of the cells.

Net resistance of the circuit = Internal resistance of charging cell + Total internal resistance of cells.

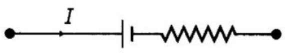
$$= 24 + 4 \times 2.5 = 34\,\Omega$$

$$\therefore \text{ Charging current, } I = \frac{V}{R} = \frac{68}{34} = 2 \text{ A}$$

(1½)

(*ii*) ∴ Potential difference across the cell combination $V = E + Ir$

During charging of the cell.



$V_A - E - Ir = V_B$

$\Rightarrow \quad V = V_A - V_B = E + Ir; \quad V = E + Ir$

$\Rightarrow \quad V = 4 \times 8 + 2 \times (4 \times 2.5) = 32 + 20$

$V = 52$ V **(1½)**

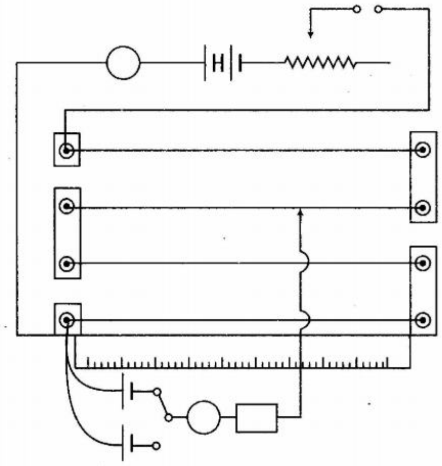
5 Marks Questions

35.(i) State the working principle of a potentiometer. With the help of the circuit diagram, explain how a potentiometer is used to compare the emf's of two primary cells. Obtain the required expression used for comparing the emfs.

(ii) Write two possible causes for one sided deflection in a potentiometer experiment.[Delhi 2013]

Ans.(i) **Working principle of potentiometer** When a constant current is passed through a wire of uniform area of cross-section, the potential drop across any portion of the wire is directly proportional to the length of that portion.

The required circuit diagram is shown in the figure below.



The main circuit comprises of battery of emf E, key (K) and rheostat (R_h). The auxiliary circuit comprises of two primary cells of emfs E_1 and E_2, galvanometer, jockey and resistance box (RB) to prevent large current flowing through the galvanometer.

When key K_1 is closed and K_2 kept open, the cell, E_1 comes into action. The jockey J is moved on the wire AB till null point is obtained in galvanometer. Let null point is obtained at length l_1 then emf of first cell is given by

$$E_1 = kl_1 \qquad \ldots(i)$$

(1)

where, k is the potential gradient along the wire AB due to battery E.

Now, key K_2 is closed and K_1 kept open and null point is obtained at length l_2, then

$$E_2 = kl_2 \qquad \ldots(ii)$$ **(1)**

Therefore, $\frac{E_1}{E_2} = \frac{kl_1}{kl_2} = \frac{l_1}{l_2} \Rightarrow \frac{E_1}{E_2} = \frac{l_1}{l_2}$ **(1)**

NOTE The null point is obtained only when

(*i*) emf of battery E must be greater than emfs of two primary cells E_1 and E_2 each.

(*ii*) all the positive terminals of cells and battery must be connected at the same point.

(ii) (a) The emf of the cell connected in main circuit may not be more than the emf of the primary cells whose emfs are to be compared.

(b) The positive ends of all cells are not connected to the same end of the wire

36.State the working principle of a potentiometer. Draw a circuit diagram to compare emf of two primary cells. Derive the formula used.

(i)Which material is used for potentiometer wire and why?

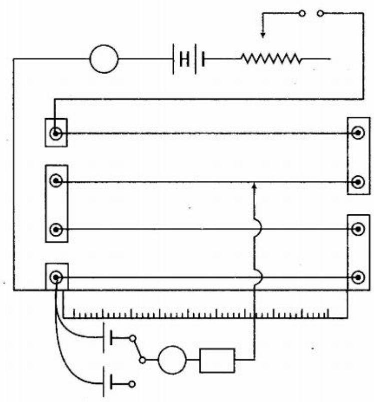
(ii)How can the sensitivity of a potentiometer be increased? [Delhi 2011]

Ans.(i) **For working principle of potentiometer**

We use a long wire to have a lower value of potential gradient (i.e a lower "least count" or greater sensitivity of the potentiometer.

For circuit diagram to compare emf of two cells

The required circuit diagram is shown in the figure below.



The main circuit comprises of battery of emf E, key (K) and rheostat (R_h). The auxiliary circuit comprises of two primary cells of emfs E_1 and E_2, galvanometer, jockey and resistance box (RB) to prevent large current flowing through the galvanometer.

When key K_1 is closed and K_2 kept open, the cell, E_1 comes into action. The jockey J is moved on the wire AB till null point is obtained in galvanometer. Let null point is obtained at length l_1 then emf of first cell is given by

$$E_1 = kl_1 \quad \text{...(i)}$$

(1)

where, k is the potential gradient along the wire AB due to battery E.

Now, key K_2 is closed and K_1 kept open and null point is obtained at length l_2, then

$$E_2 = kl_2 \quad \text{...(ii)}$$ **(1)**

Therefore, $\frac{E_1}{E_2} = \frac{kl_1}{kl_2} = \frac{l_1}{l_2} \Rightarrow \frac{E_1}{E_2} = \frac{l_1}{l_2}$ **(1)**

NOTE The null point is obtained only when

(*i*) emf of battery E must be greater than emfs of two primary cells E_1 and E_2 each.

(*ii*) all the positive terminals of cells and battery must be connected at the same point.

(ii) Constantan or manganin (alloy) as they have low temperature coefficient of resistance.

(iii) The sensitivity of potentiometer can be increased by increasing the number of wires of potentiometer and hence, decreasing the value of potential gradient

Kirchhoff's Laws andElectric Devices

1 Mark Questions

1.A heating element is marked 210 V, 630 What is the value of the current drawn by the element when connected to a 210 V DC Source? [Delhi 2013]

Ans.

Given that $P = 630$ W and $V = 210$ V. In DC source $P = VI$. Therefore, $I = \frac{P}{V} = \frac{630}{210} = 3$ A. **(1)**

2.In an experiment on meter bridge, if the balancing length AC is X, what would be its value, when the radius of the meter bridge wire AB is doubled? Justify your answer.[All India 2011 C]

Ans.

The balancing length continue to be X even on doubling the radius of meter bridge wire as it does not affect the ratio of length of two parts of meter bridge wire. **(1)**

NOTE $\because$ Resistance of wire $= \left(\frac{\rho}{A}\right) l$

For uniform wire, $\left(\frac{\rho}{A}\right)$ is constant even on doubling the radius of meter bridge wire.

$\therefore$ Resistance of wire $\propto l$.

3.In a meter bridge, two unknown resistances R and S when connected in the two gaps, give a null point at 40 cm from one end. What is the ratio of R and S?[Delhi 2010]

Ans.

$\because$ Null point is obtained at 40 cm from one end

$$l = 40 \text{ cm},$$

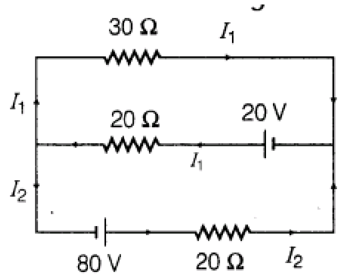
$$100 - l = 60 \text{ cm}.$$

$\because$ For meter bridge ratio of unknown resistances

$$\frac{R}{S} = \frac{l}{(100 - l)} = \frac{40}{60} = \frac{2}{3}$$

$\Rightarrow R:S = 2:3$ **(1)**

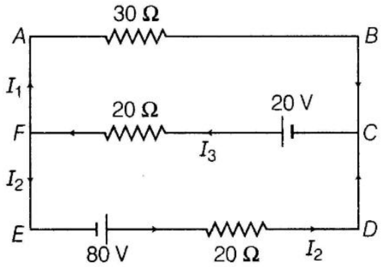
4.Use Kirchhoff's rules to determine the value of the current I_x flowing in the circuit shown in the figure.



[Delhi 2013C]

Ans.

According to the question,



Applying Kirchhoff's junction rule at F node

$$I_3 = I_1 + I_2 \quad \text{...(i)}$$

Applying Kirchhoff's second rule in loop $ABCF$,

$$-30I_1 + 20 - 20I_3 = 0$$

$$3I_1 + 2I_3 = 2 \quad \text{...(ii)}$$

In loop $ABDE$, **(1)**

$$-30I_1 + 20I_2 - 80 = 0$$

$$-3I_1 + 2I_2 = 8 \quad \text{...(iii)}$$

From Eq. (i) put the value of I_3 in Eq. (ii),

$$3I_1 + 2I_1 + 2I_2 = 2$$

$$5I_1 + 2I_2 = 2 \quad \text{...(iv)}$$

$$-3I_1 + 2I_2 = 8 \quad \text{...(v)}$$

$$\quad + \quad - \quad -$$

subtract $\quad 8I_1 = -6, I_1 = -\frac{3}{4}$ A

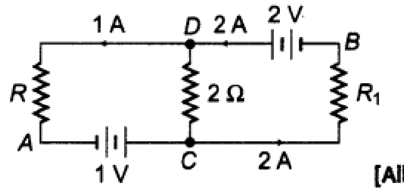
Put I_1 in Eq. (iv)

$$-5 \times \frac{3}{4} + 2I_2 = 2, \; 2I_2 = \frac{23}{4}, I_2 = \frac{23}{8} \text{ A}$$

From Eq. (i)

$$I_3 = -\frac{3}{4} + \frac{23}{8} = \frac{-6 + 23}{8} \text{ or } I_3 = \frac{17}{8} \text{ A.}$$ **(1)**

5.In the given circuit, assuming point A to be at zero potential, use Kirchhoff's rules to determine the potential at point B

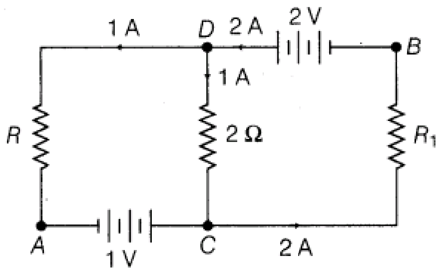


[All India 2011]

Ans.

By Kirchhoff's first law at D

$$I_{DC} = 1\text{A} \qquad (I_{DC} + 1 = 2)$$



(1)

Along $ACDBA$,

$$V_A + 1\text{V} + 1 \times 2 - 2 = V_B$$

But $V_A = 0,$

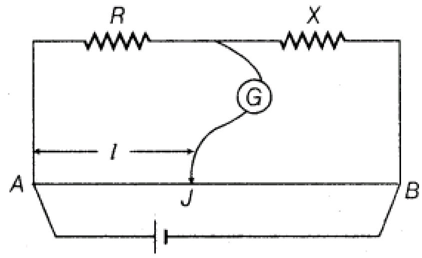
$$V_B = 1 + 2 - 2 = 1\text{V}$$

$$V_B = 1\text{ V}$$ (1)

6.In the meter bridge experiment, balance point was observed at J with AJ =l.

(i)The values of R and X were doubled and then interchanged. What would be the new position of balance point?

(ii)If the galvanometer and battery are interchanged at the balanced position, how will the balance point get affected?



[All India 2011]

Ans.

(i) The balancing condition state that

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

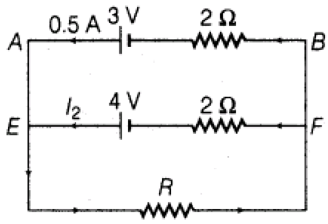
When X and R both are doubled, then

$$\frac{2X}{2R} = \frac{X}{R} = \frac{100 - l}{l}$$

Balancing length would be at $(100 - l)$ cm. **(1)**

(ii) On changing the position of galvanometer and battery, the meter bridge continue to be balanced and hence, no change occur in the balance point. **(1)**

7.Using Kirchhoff's rules in the given circuit, determine
(i)the voltage drop across the unknown resistor R and
(ii)the current I_2 in the arm EF



[All India 2011]

Ans.

(i) Applying Kirchhoff's second rule in the closed mesh $ABFEA$

$$V_B - 0.5 \times 2 + 3 = V_A \Rightarrow V_B - V_A = -2$$

$$V = V_A - V_B = +2\text{ V}$$

Potential drop across R is 1 V as R, EF and upper row are in parallel. **(1)**

or

Potential across AB = potential across EF

$$3 - 2 \times 0.5 = 4 - 2I_2$$

$$2I_2 = 2\ I_2\text{ A}$$

Potential across R = potential across AB = potential accross EF

$$= 3 - 2 \times 0.5 = 2\text{ V}$$

(ii) Applying Kirchhoffs first rule at E

$$0.5 + I_2 = I$$

where, I is current through R.

Now, Kirchhoff's second rule in closed mesh $AEFB$, $\Sigma E + \Sigma IR = 0$

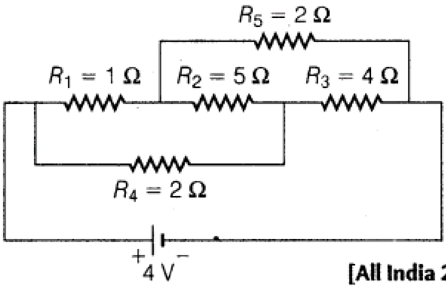
$$-4 + 2I_2 - 0.5 \times 2 + 3 = 0$$

$$2I_2 - 2 = 0$$

$$I_2 = 1\text{ A}$$

The current in arm $EF = 1\text{ A}$ **(1)**

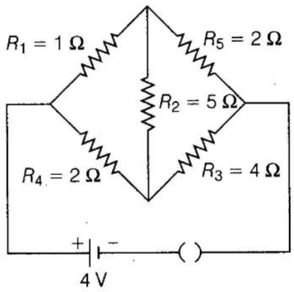
8.Calculate the current drawn from the battery in the given network



[All India 2009]

Ans.

The given circuit can be redrawn as given below.



Here, $\frac{R_1}{R_5} = \frac{R_4}{R_3} \Rightarrow \frac{1}{2} = \frac{2}{4}$

Wheatstone bridge is balanced. So, there will no current in the diagonal resistance R_2 or it can be withdrawn from the circuit.

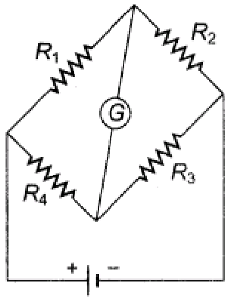
The equivalent resistance would be equivalent to a parallel combination of two rows which consists of series combination of R_1 and R_5 and R_4 and R_3, respectively.

$$\frac{1}{R} = \frac{1}{1+2} + \frac{1}{2+4} = \frac{1}{3} + \frac{1}{6}$$

$$R = \frac{18}{9} = 2\,\Omega$$

$$\therefore\ I = \frac{V}{R} = \frac{4}{2} = 2\text{ A} \text{ or } I = 2\text{ A}$$

9. For the circuit diagram of a Wheatstone bridge shown in the figure, use Kirchhoff's laws to obtain its balance condition.

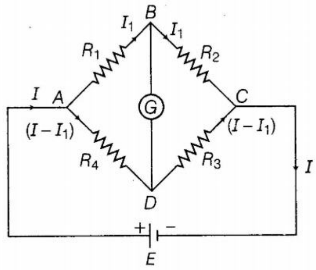


[Delhi 2009]

Ans.

In balanced Wheatstone bridge to current flow through galvanometer, that means while applying Kirchhoff's law, we can neglect this path.

No current flows through the galvanometer G when circuit is balanced.



(1)

On distributing currents as per Kirchhoff's first rule.

Applying Kirchhoff's second rule

(i) In mesh $ABDA$,

$\therefore -I_1R_1 + (I - I_1)R_4 = 0$

$\Rightarrow \quad I_1R_1 = (I - I_1)R_4$ ...(i)

(ii) In mesh $BCDB$,

$-I_1R_2 + (I - I_1)R_3 = 0$

$\Rightarrow \quad I_1R_2 = (I - I_1)R_3$ ...(ii)

On dividing Eq. (i) by Eq. (ii), we get

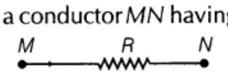
$$\frac{I_1R_1}{I_1R_2} = \frac{(I-I_1)R_4}{(I-I_1)R_3}; \quad \frac{R_1}{R_2} = \frac{R_4}{R_3}$$

This is necessary and required balanced condition of balanced Wheatstone bridge. **(1)**

10.Obtain the formula for the power loss (i.e. power dissipated) in a conductor of resistance R, carrying a current.[Delhi 2009 C]

Ans.

Consider a conductor MN having resistance R.



The potentials of the two terminals are suppose V_M and V_N.

Such that, $V_M - V_N = V$ (As, $V_M > V_N$)

At any time interval Δt, current through the conductor will be

$$I = \frac{\Delta q}{\Delta t}$$ **(1)**

where, Δq = charge drifted through the conductor.

The electrical potential energies of the charge Δq at M and N are $\Delta U_m = \Delta q V_M$ and $\Delta U_N = \Delta q V_N$, respectively.

$\therefore$ Change in potential energy

$$\Delta U = \Delta U_N - \Delta U_M$$

As loss of potential energy = gain in kinetic energy.

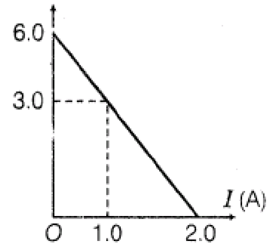
$\Rightarrow \quad \Delta K = -\Delta U = IV\Delta t$ **(1)**

$\therefore$ Energy dissipated per unit time (called power loss) is,

$$P = \frac{IV\Delta t}{\Delta t} = VI = I^2R$$

$(\because V = IR)$

11.The adjoining graph shows the variation of terminal potently difference V, across a combination o three cells in series to a resistor vers[1] the current I.



(i)Calculate the emf of each cell.

(ii)For what current I, will the power dissipation of the circuit be maximum? [All India 2008]

Ans.

(i) As, terminal potential,

$$V = \varepsilon_0 - Ir$$

When current drawn through the cell is zero (i.e. $I = 0$) then voltage is 6 V.

The battery is a combination of three cells. Thus, in open circuit its terminal potential is equal to its emf.

$\therefore$ The emf of each cell, $\varepsilon = \frac{6.0}{3} = 2$ V

(ii) From the graph,

$V = 0$ when $I_s = 2$ A

$$\therefore \quad 0 = \varepsilon_0 - I_s r$$

where, r_2 is internal resistance of the cell combination

$$\Rightarrow \quad r = \frac{\varepsilon_0}{I_s} = \frac{6}{2} = 3\ \Omega$$ **(1)**

Power is maximum when internal resistance is equal to the external resistance and the current drawn,

$$I = \frac{\varepsilon}{r+R} = \frac{\varepsilon}{2r} = \frac{6}{2 \times 3} = 1\text{A}$$ **(1)**

3 Marks Questions

12.Answer the following

(i)Why are the connections between the resistor in a meter bridge made of thick copper strips?

(ii)Why is it generally preferred to obtain the balance point in the middle of the meter bridge wire?

(iii)Which material is used for the meter bridge wire and why?[All India 2014]

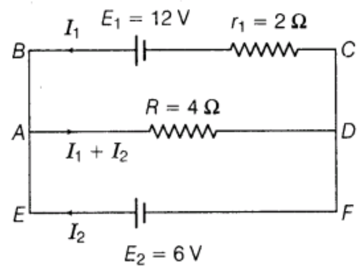
Ans.(i)The connections between the resistors in a meter bridge are made of thick copper strips because of their negligible resistance.

(ii) It generally preferred to obtain the balance point in the middle of the meter bridge wire because meter bridge is most sensitive when all four resistances are of same order

(iii)Alloy, magnanin or constantum are used for making meter bridge wire due to low temperature coefficient of resistance and high resistivity

13. In the electric network shown in the figure, use Kirchhoff 's rules to calculate the power consumed by the resistance $R = 4\ \Omega$.

[Delhi 2014 C]



Ans.

According to Kirchhoff's rule in loop *ABCDA*.

$$+12 - 2I_1 - 4(I_1 + I_2) = 0$$

$$3I_1 + 2I_2 = 6 \qquad \text{...(i)}$$

For loop *ADFEA*

$$+4(I_1 + I_2) - 6 = 0$$

$$\therefore \qquad 2I_1 + 2I_2 = 3 \qquad \text{...(ii)}$$

On solving Eqs. (i) and (ii), we get

$$I_1 = 3\text{A}$$

$$I_2 = -1.5\ \text{A}$$

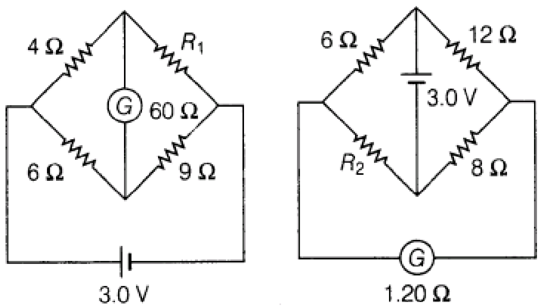
Hence, power consumed by resistor *R*

$$= (I_1 + I_2)^2 R = (3 - 1.5)^2 \times 4$$

$$= (1.5)^2 \times 4$$

$$= 9$$

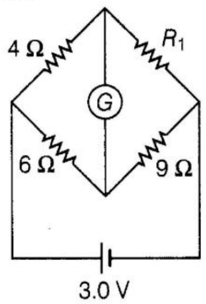
14.Define the current sensitivity of a galvanometer. Write its SI unit.Figure shows two circuits each having a galvanometer and a battery of 3 V.When the galvanometer in each arrangement do not show any deflection, obtain the ratio R_1 / R_2.



[All India 2013]

Ans.

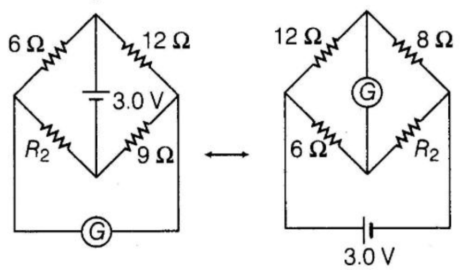
Current sensitivity of a galvanometer is defined as the deflection produed in galvanometer per unit current flowing through it. Its SI unit is radian/ampere.



(1)

For balanced Wheatstone bridge, there will be no deflection in the galvanometer.

$$\frac{4}{R_1} = \frac{6}{9} \Rightarrow R_1 = \frac{4 \times 9}{6} = 6\Omega$$



(1)

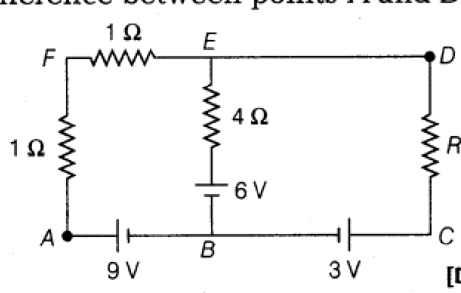
For the equivalent circuit, when the Wheatstone bridge is balanced, there will be no deflection in the galvanometer.

$$\therefore \quad \frac{12}{8} = \frac{6}{R_2}$$

$$\Rightarrow \quad R_2 = \frac{6 \times 8}{12} = 4\,\Omega$$

$$\therefore \quad \frac{R_1}{R_2} = \frac{6}{4} = \frac{3}{2}$$

15. Using Kirchhoff's rules, determine the value of unknown resistance R in the circuit, so that no current flows throu h $4\,\Omega$ resistance. Also, find the potential difference between points A and D.



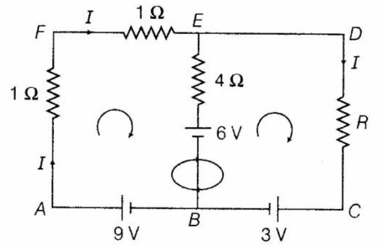
[Delhi 2012]

Ans.

Applying Kirchhoff's second law in mesh *AFEBA*

$$-1\times I-1\times I-6+9=0$$
$$-2I+3=0$$
$$I=\frac{3}{2}\text{ A} \qquad \text{...(i)}$$

(1/2)



(1/2)

Applying Kirchhoff's IInd law in mesh *AFDCA*

$$-1\times I-1\times I-I\times R-3+9=0$$
$$-2I-IR+6=0 \qquad \textbf{(1/2)}$$
$$2I+IR=6 \qquad \text{...(ii)}$$

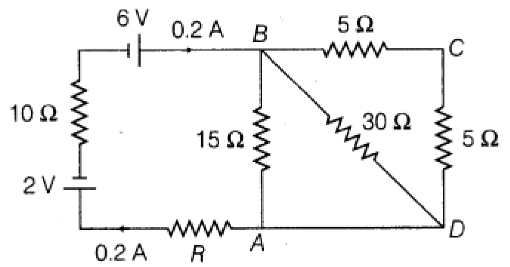
From Eqs. (i) and (ii), we get

$$\left(2\times\frac{3}{2}\right)+\frac{3}{2}R=6$$
$$\Rightarrow \qquad R=2\ \Omega \qquad \textbf{(1/2)}$$

For potential difference across *A* and *D* along *AFD*

$$V_A-\frac{3}{2}\times1-\frac{3}{2}\times1=V_D$$
$$V_A-V_D=3\text{ V} \qquad \textbf{(1)}$$

16.Calculate the value of the resistance R in the circuit shown in the figure, so that the current in the circuit is 0.2A. What would be the potential difference between points A and B ?



[All India 2012]

Ans.

For *BCD*, equivalent resistance

$$R_1=5\Omega+5\Omega=10\ \Omega \qquad \textbf{(1/2)}$$

Across *BA*, equivalent resistance R_2

$$\frac{1}{R_2}=\frac{1}{10}+\frac{1}{30}+\frac{1}{15}$$
$$=\frac{3+1+2}{30}=\frac{6}{30}=\frac{1}{5} \qquad \textbf{(1/2)}$$
$$\Rightarrow \qquad R_2=5\Omega$$

Potential difference,

$$V_{BA}=I\times R_2$$
$$=0.2\times5$$
$$V_{BA}=1\text{V}$$
$$\Rightarrow \qquad V_{AB}=-1\text{V}$$

17.Two heating elements of resistances R1 and R_2 when operated at a constant supply of voltage V, consume powers P1 and P_2, respectively. Deduce the expressions for the power of their combination when they are, in turn, connected in (i)series and

(ii)parallel across their same voltage supply.[All India 2011]

Ans.

To deduce the expression for the power of the combination, first find the equivalent resistance of the combination in the given conditions.

$$\because \quad P_1 = \frac{V^2}{R_1} \Rightarrow R_1 = \frac{V^2}{P_1}$$

$$P_2 = \frac{V^2}{R_2}$$

$$\Rightarrow \quad R_2 = \frac{V^2}{P_2}$$

(1/2 × 2 = 1)

(i) In series combination,

$$R_s = R_1 + R_2 = \frac{V^2}{P_1} + \frac{V^2}{P_2}$$

$$R_s = R_1 + R_2 = V^2\left(\frac{1}{P_1} + \frac{1}{P_2}\right) = V^2\left(\frac{P_1 + P_2}{P_1 P_2}\right)$$

Now, let the power of heating element in series combination be P_s.

$$\therefore \; P_s = \frac{V^2}{R_1 + R_2} = \frac{V^2}{V^2\left(\frac{P_1 + P_2}{P_1 P_2}\right)} = \frac{P_1 P_2}{P_1 + P_2}$$

$$P_s = \frac{P_1 P_2}{P_1 + P_2}$$

(1)

(ii) In parallel combination,

$$\frac{1}{R_p} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{\frac{V^2}{P_1}} + \frac{1}{\frac{V^2}{P_2}} = \frac{P_1}{V^2} + \frac{P_2}{V^2}$$

$$\frac{1}{R_p} = \frac{1}{V^2}(P_1 + P_2)$$

Now, power consumption in parallel combination

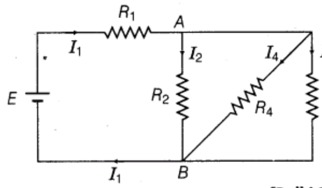
$$P_p = \frac{V^2}{R_p} = V^2\left(\frac{1}{R_p}\right)$$

$$P_p = V^2\left[\frac{1}{V^2}(P_1 + P_2)\right]$$

$$P_p = P_1 + P_2$$

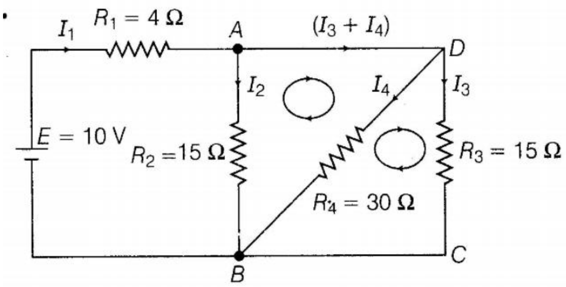
(1)

18. In the circuit shown, $R_1 = 4\,\Omega$, $R_2 = R_3 = 15\,\Omega$, $R_4 = 30\,\Omega$ and $E = 10$ V. Calculate the equivalent resistance of the circuit and the current in each resistor.



[Delhi 2011]

Ans.



According to figure $15\Omega, 30\Omega$ and 15Ω are in parallel, their equivalent resistance (R_{eq}) is

$$\frac{1}{R_{eq}} = \frac{1}{15} + \frac{1}{30} + \frac{1}{15} = \frac{2+1+2}{30} = \frac{5}{30}$$

$$\frac{1}{R_{eq}} = \frac{1}{6}$$

$$R_{eq} = 6\ \Omega$$

Now, $R_{eq} = 6\Omega$ and 4Ω are in series their equivalent resistance R'_{eq} is

$$R'_{eq} = R_{eq} + 4\Omega = 6\Omega + 4\Omega = 10\Omega$$

By junction rule at node A

$$I_1 = I_2 + I_3 + I_4 \quad \text{...(i)}$$ (1/2)

Applying Kirchhoff's second rule in

(*i*) In mesh ADB,

$$-I_4 \times 30 + 15 I_2 = 0$$

$$I_2 = 2I_4$$

$$\Rightarrow \quad I_4 = \frac{I_2}{2}$$ **(1/2)**

(*ii*) In mesh BDC,

$$30 I_4 - 15 I_3 = 0$$

$$\Rightarrow \quad I_3 = 2I_4 \Rightarrow I_4 = \frac{I_3}{2}$$

(*iii*) In mesh ABE (containing battery), **(1/2)**

$$-4I_1 - 15 I_2 + 10 = 0$$

$$4I_1 + 15 I_2 = 10 \quad \text{...(ii)}$$

(*iv*) In mesh $ABCD$, **(1/2)**

$$-15 I_2 + 15 I_3 = 0$$

$$I_2 = I_3$$

$$I_1 = I_2 + I_2 + \frac{I_2}{2}$$

$$I_1 = \frac{5}{2} I_2$$

From Eq. (ii), we get

$$4\left(\frac{5}{2} I_2\right) + 15 I_2 = 10$$

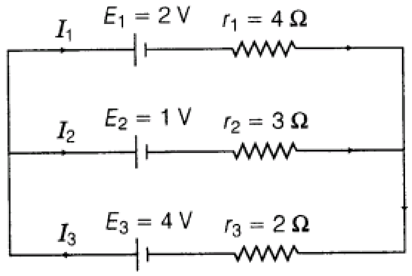
$$I_2 = \frac{10}{25}\text{ A} = \frac{2}{5}\text{ A} = I_3$$

$$\Rightarrow \quad I_2 = I_3 = \frac{2}{5}\text{ A}$$

$$I_4 = \frac{I_2}{2} = \frac{1}{5}\text{ A}$$

$$\therefore \quad I_1 = \frac{5}{2} I_2 = \frac{5}{2} \times \frac{2}{5} = 1\text{ A}$$

19. State Kirchhoff's rules. Use these rules to write the expressions for the currents I_1, I_2 and I_3 in the circuit diagram shown in figure below.



[All India 2010]

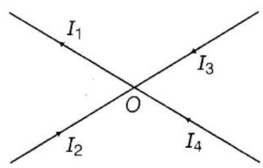
Ans.

Kirchhoff's first rule or junction rule The algebraic sum of electric currents at any junction of electric circuit is equal to zero i.e. the sum of current entering into a junction is equal to the sum of current leaving the junction

$\Rightarrow \quad \Sigma I = 0$

At junction O,

$$I_1 + I_2 = I_3 + I_4$$



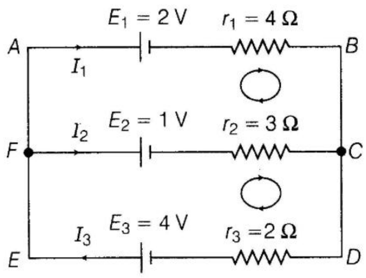
(1)

Kirchhoff's second rule In any closed mesh of electrical circuit, the algebraic sum of emfs of cells and the product of currents and resistances is always equal to zero.

i.e. $\quad \Sigma E + \Sigma IR = 0$

Kirchhoff's second law is a form of law of conservation of energy. **(1)**

For given circuit,



At F, applying junction rule

$$I_3 = I_1 + I_2 \qquad \text{...(i)}$$

In mesh $ABCFA$,

$$-2 - 4I_1 + 3I_2 + 1 = 0$$
$$4I_1 - 3I_2 = -1$$

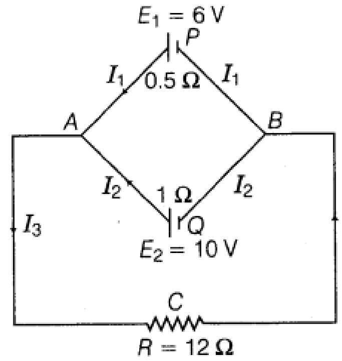
In mesh $FCDEF$,

$$-1 - 3I_2 - 2I_3 + 4 = 0$$
$$3I_2 + 2I_3 = 3$$

On solving, we get I_1, I_2 and I_3.

$$I_1 = \frac{2}{13}\text{ A} \quad \text{or} \quad I_2 = \frac{7}{13}\text{ A}$$
$$I_3 = \frac{9}{13}\text{ A}$$

20.State Kirchhoff's rules. Apply Kirchhoff's rules to the loops ACBPA and ACBQA to write the expressions for the currents I1,I_2 and I_3 in the network.



[All India 2010]

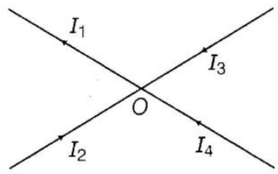
Ans.

Kirchhoff's first rule or junction rule The algebraic sum of electric currents at any junction of electric circuit is equal to zero i.e. the sum of current entering into a junction is equal to the sum of current leaving the junction

$\Rightarrow \qquad \Sigma I = 0$

At junction O,

$$I_1 + I_2 = I_3 + I_4$$



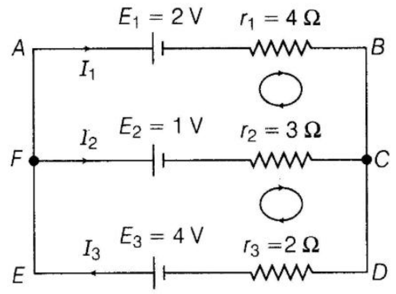
(1)

Kirchhoff's second rule In any closed mesh of electrical circuit, the algebraic sum of emfs of cells and the product of currents and resistances is always equal to zero.

i.e. $\qquad \Sigma E + \Sigma IR = 0$

Kirchhoff's second law is a form of law of conservation of energy. **(1)**

For given circuit,



At F, applying junction rule

$$I_3 = I_1 + I_2 \qquad \text{...(i)}$$

In mesh $ABCFA$,

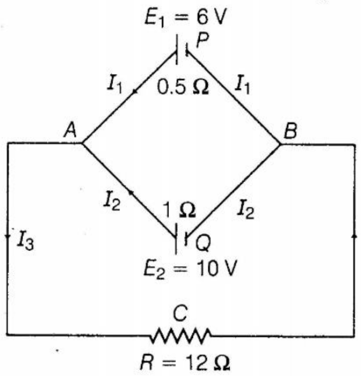
$$-2-4I_1+3I_2+1=0$$
$$4I_1-3I_2=-1$$

In mesh $FCDEF$,

$$-1-3I_2-2I_3+4=0$$
$$3I_2+2I_3=3$$

On solving, we get I_1, I_2 and I_3.

$$I_1=\frac{2}{13}\text{ A} \quad \text{or} \quad I_2=\frac{7}{13}\text{ A}$$
$$I_3=\frac{9}{13}\text{ A}$$



Applying Kirchhoff's second rule in loop $ACBPA$,

$$-12I_3+6-0.5\,I_1=0$$
$$5I_1+120\,I_3=60 \qquad \text{...(i)}$$

In loop $ACBQA$,

$$-12\,I_3+10-I_2\times 1=0$$
$$12I_3+I_2=10 \qquad \text{...(ii)} \textbf{ (1/2)}$$

Also Kirchhoff's junction rule,

$$I_1+I_2=I_3 \qquad \text{...(iii)} \textbf{ (1/2)}$$

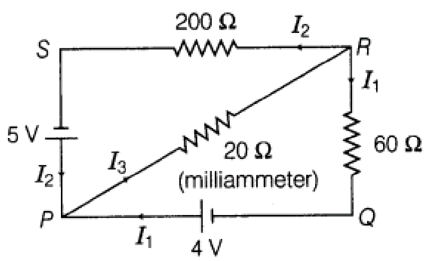
(Here, three equations are the expressions for I_1, I_2 and I_3)

On solving Eqs. (i), (ii) and (iii), we get

$$I_1=-\frac{84}{37}\text{ A}$$
$$I_2=\frac{106}{37}\text{ A}$$
$$I_3=\frac{22}{37}\text{ A}$$

(1/2)

21.State Kirchhoff's rules. Apply these rules to the loops PRSP and PRQP to write the expressions for the currents I_1, I_2 and I_3 in given circuit.



[All India 2010]

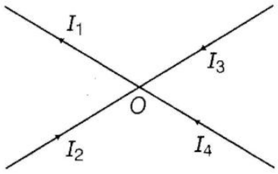
Ans.

Kirchhoff's first rule or junction rule The algebraic sum of electric currents at any junction of electric circuit is equal to zero i.e. the sum of current entering into a junction is equal to the sum of current leaving the junction

$\Rightarrow \quad \Sigma I = 0$

At junction O,

$$I_1 + I_2 = I_3 + I_4$$



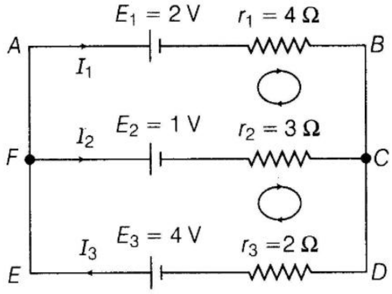
(1)

Kirchhoff's second rule In any closed mesh of electrical circuit, the algebraic sum of emfs of cells and the product of currents and resistances is always equal to zero.

i.e. $\quad \Sigma E + \Sigma IR = 0$

Kirchhoff's second law is a form of law of conservation of energy. **(1)**

For given circuit,



At F, applying junction rule

$$I_3 = I_1 + I_2 \quad \text{...(i)}$$

In mesh $ABCFA$,

$$-2 - 4I_1 + 3I_2 + 1 = 0$$

$$4I_1 - 3I_2 = -1$$

In mesh $FCDEF$,

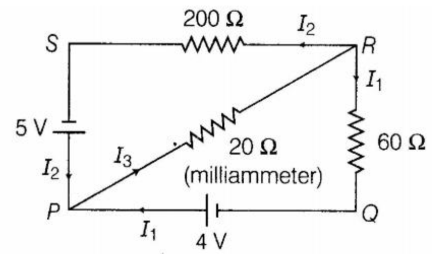
$$-1 - 3I_2 - 2I_3 + 4 = 0$$

$$3I_2 + 2I_3 = 3$$

On solving, we get I_1, I_2 and I_3.

$$I_1 = \frac{2}{13}\text{ A} \quad \text{or} \quad I_2 = \frac{7}{13}\text{ A}$$

$$I_3 = \frac{9}{13}\text{ A}$$



Applying Kirchhoff's second rule to the loop *PRSP*,

$$\Sigma E + \Sigma IR = 0$$

$$-I_3 \times 20 - I_2 \times 200 + 5 = 0$$

$$4I_3 + 40I_2 = 1 \quad \text{...(i)}$$

For loop *PRQP*,

$$-20I_3 - 60I_1 + 4 = 0$$

$$5I_3 + 15I_1 = 1 \quad \text{...(ii)}$$

Applying Kirchhoff's first rule at *P*

$$I_3 = I_1 + I_2 \quad \text{...(iii)}$$

(1)

From Eqs. (i) and (iii), we have

$$4I_1 + 44I_2 = 1 \quad \text{...(iv)}$$

From Eqs. (ii) and (iii), we have

$$20I_1 + 5I_2 = 1 \quad \text{...(v)}$$

On solving the above equations, we get

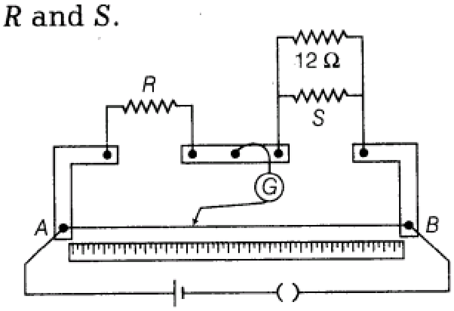
$$I_3 = \frac{11}{172} \text{ A} = \frac{11000}{172} \text{ mA}$$

$$I_2 = \frac{4}{215} \text{ A} = \frac{4000}{215} \text{ mA}$$

$$I_1 = \frac{39}{860} \text{ A} = \frac{39000}{860} \text{ mA}$$

(1)

22. In a meter bridge, the null point is found at a distance of 40 cm from *A*. If a resistance of 12 Ω is connected in parallel with *S*, then null point occurs at 50.0 cm from *A*. Determine the values of *R* and *S*.



[HOTS; Delhi 2010]

Ans.

In case of meter bridge at null point condition, the bridge is balanced, i.e. we can apply the condition of balanced Wheatstone bridge.

Applying the condition of balanced Wheatstone bridge,

$$\frac{R}{S} = \frac{l}{100 - l} = \frac{40}{100 - 40} = \frac{40}{60} = \frac{2}{3}$$

$$\frac{R}{S} = \frac{2}{3} \qquad \text{...(i)}$$

(1)

The equivalent resistance of 12 Ω and S Ω in parallel is $\frac{12S}{12 + S}$ Ω.

(1/2)

Again, applying the condition

$$\frac{R}{\left(\frac{12S}{12+S}\right)} = \frac{50}{50} = 1$$

(1/2)

$$\Rightarrow \qquad R = \frac{12S}{12 + S} \qquad \text{...(ii)}$$

From Eqs. (i) and (ii), we get

$$\frac{2}{3}S = \frac{12S}{12 + S}$$

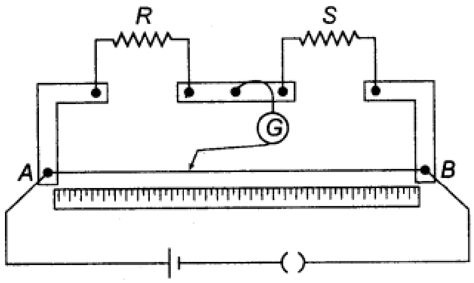
$$12 + S = 18 \quad \text{or} \quad S = 6\,\Omega$$

$$R = \frac{2}{3}S = \frac{2}{3} \times 6 = 4\,\Omega$$

$$R = 4\,\Omega$$

(1/2 × 2 = 1)

23. In a meter bridge, the null point is found at a distance of 60 cm from A. If a resistance of 5 Ω is connected in series with S, then null point occurs at 50.0 cm from A. Determine the values of R and S.



[Delhi 2010]

Ans.

The condition of balanced meter bridge

$$\frac{R}{S} = \frac{60}{100-60} = \frac{60}{40} = \frac{3}{2}$$

$$\frac{R}{S} = \frac{3}{2} \qquad \text{...(i)}$$

(1)

Again, applying the condition,when S and $5\ \Omega$ are connected in series

$$\frac{R}{S+5} = \frac{50}{50} \Rightarrow \frac{R}{S+5} = 1 \qquad \text{...(ii)}$$

(1)

From Eqs. (i) and (ii), we get

$$\frac{3}{2}S = S+5 \quad \Rightarrow \frac{3}{2}S - S = 5$$

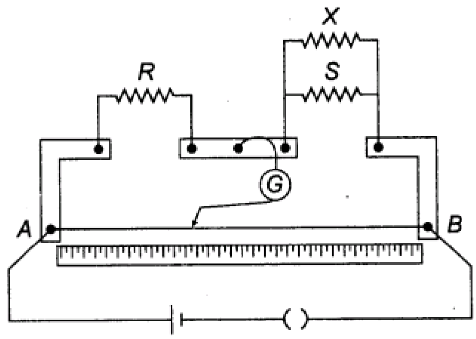
$$S = 10\ \Omega$$

$$R = \frac{3}{2}S = \frac{3}{2} \times 10 = 15\ \Omega$$

$$R = 15\ \Omega, S = 10\ \Omega$$

(1)

24.In a meter bridge, the null point is found at a distance of l1 cm from A. If a resistance of X is connected in parallel with S, then null point occurs at a distance l2 cm from A Obtain the formula for X in terms of l1,l2 and S.



[Delhi 2010]

Ans.

Initially, for balanced Wheatstone bridge,

$$\frac{R}{S} = \frac{l_1}{100 - l_1}$$

$$\Rightarrow \qquad R = \frac{l_1}{100 - l_1} S \qquad \text{...(i)}$$

(1)

When X is connected in parallel with S, then

$$\left(\frac{R}{\frac{SX}{S+X}} \right) = \frac{l_2}{(100 - l_2)}$$

(1)

$$\Rightarrow \quad \frac{SX}{S+X} = \left(\frac{100 - l_2}{l_2}\right)R$$

$$= \left(\frac{100 - l_2}{l_2}\right) \times \left(\frac{l_1}{100 - l_1}\right)S$$

(from Eq. (i))

$$\frac{X}{S+X} = \left(\frac{l_1}{l_2}\right)\left(\frac{100 - l_2}{100 - l_1}\right)$$

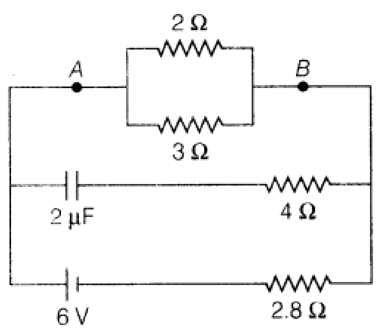
$$\frac{S+X}{X} = \left(\frac{l_2}{l_1}\right)\left(\frac{100 - l_1}{100 - l_2}\right)$$

$$\frac{S}{X} + 1 = \frac{l_2(100 - l_1)}{l_1(100 - l_2)}$$

$$\frac{S}{X} = \frac{l_2}{l_1}\left(\frac{100 - l_1}{100 - l_2}\right) - 1$$

$$\frac{S}{X} = \frac{100(l_2 - l_1)}{l_1(100 - l_2)} \Rightarrow X = \frac{l_1(100 - l_2)}{100(l_2 - l_1)}S$$ **(1)**

25. Calculate the steady current through the $2\,\Omega$ resistor in the circuit shown in the figure below.



[Foreign 2010]

Ans.

No current flows through $4\,\Omega$ resistor as capacitor offers infinite resistance in DC circuits.

Also, $2\,\Omega$ and $3\,\Omega$ are in parallel combination

$$\therefore \quad R_{AB} = \frac{2 \times 3}{2+3} = \frac{6}{5} = 1.2 \text{ A}$$

Applying Kirchhoff's second rule in outer loop AB and cell.

Let I current flow through outer loop in clockwise direction.

$$-1.2I - 2.8I + 6 = 0$$

$$4I = 6$$

$$I = \frac{3}{2} \text{ A} \qquad \left(1\frac{1}{2}\right)$$

$\therefore$ Potential difference across AB

$$V_{AB} = IR_{AB} = \frac{3}{2} \times 1.2$$

$$V_{AB} = 1.8 \text{ V}$$

$\therefore$ $3\,\Omega$ and $2\,\Omega$ are in parallel combination.

$\therefore$ Potential difference across $2\,\Omega$ resistor is 1.8 V.

$\therefore$ Current I' through $2\,\Omega$ resistor is given by

$$I' = \frac{V}{R} = \frac{1.8}{2} = 0.9 \text{ A}$$

$$I' = 0.9 \text{ A} \qquad \left(1\frac{1}{2}\right)$$

The current through $2\,\Omega$ resistor is 0.9 A.

26. (*i*) State Kirchhoff's rules.

(*ii*) A battery of 10 V and negligible internal resistance is connected across the diagonally opposite corners of a cubical network consisting of 12 resistors each of $1\,\Omega$ resistance. Use Kirchhoff's rules to determine

(*a*) the equivalent resistance of the network and

(*b*) the total current in the network.

[All India 2010]

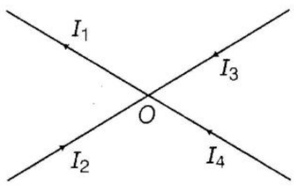
Ans.(i)

Kirchhoff's first rule or junction rule The algebraic sum of electric currents at any junction of electric circuit is equal to zero i.e. the sum of current entering into a junction is equal to the sum of current leaving the junction

$\Rightarrow \quad \Sigma I = 0$

At junction O,

$$I_1 + I_2 = I_3 + I_4$$



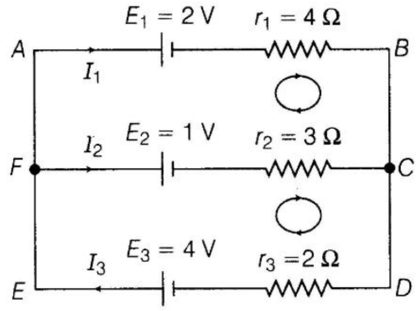
(1)

Kirchhoff's second rule In any closed mesh of electrical circuit, the algebraic sum of emfs of cells and the product of currents and resistances is always equal to zero.

i.e. $\quad \Sigma E + \Sigma IR = 0$

Kirchhoff's second law is a form of law of conservation of energy. **(1)**

For given circuit,

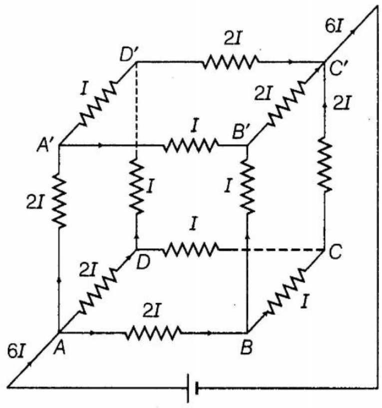


At F, applying junction rule

$$I_3 = I_1 + I_2 \quad \text{...(i)}$$

(*ii*) Let $6I$ current be drawn from the cell. Since, the paths AA', AD and AB are symmetrical, current through them is same. **(1)**

As per Kirchhoff's junction rule, the current distribution is shown in the figure. **(1)**



Let the equivalent resistance across the combination be R.

$$E = V_A - V_B = (6I)R$$

$\Rightarrow \quad 6IR = 10 \quad (\because E = 10\text{ V}) \quad ...(i)$

Applying Kirchhoff's second rule in loop $AA'B'C'A$

$$-2I \times 1 - I \times 1 - 2I \times 1 + 10 = 0$$

$\Rightarrow \quad 5I = 10$

$$I = 2\text{ A}$$

Total current in the network $= 6I$

$$= 6 \times 2 = 12\text{ A}$$

From Eq. (i), $6IR = 10$

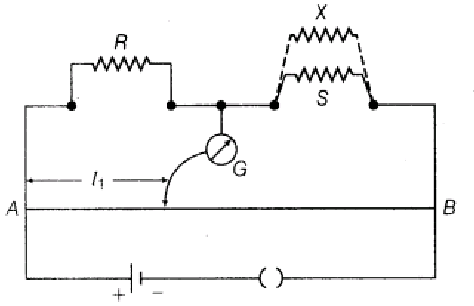
$$6 \times 2 \times R = 10$$

$$R = \frac{10}{12} = \frac{5}{6}\,\Omega$$

$$R = \frac{5}{6}\,\Omega$$

27.(i) State the principle of working of a meter bridge.

(ii) In a meter bridge balance point is found at a distance l1 with resistances R and S as shown in the figure. When an unknown resistance X is connected in parallel with the resistance S, the balance point shifts to a distance l_2. Find expression for X in terms of l1 , l_2 and S. [All India 2009]



Ans.

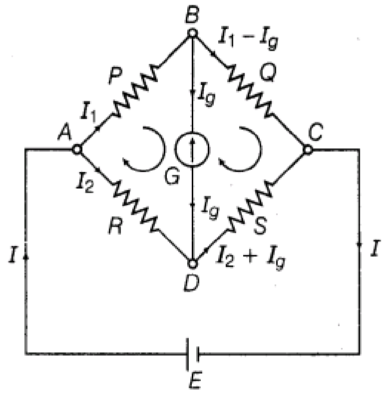
(*i*) Meter bridge works on the principle of balanced Wheatstone bridge.

In balanced Wheatstone bridge,

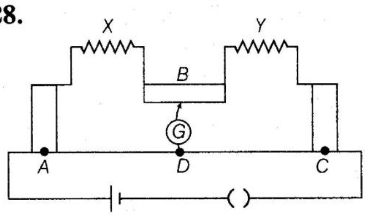
(a) no current flow through the galvanometer.

(b) $V_B = V_D$ (c) $\frac{P}{Q} = \frac{R}{S}$ $\left(1\frac{1}{2}\right)$

where, P, Q are ratio arms.
R = known resistance and
S = unknown resistance.



28.



The figure shows experimental set up of a meter bridge. When the two unknown resistances X and Y are inserted, the null point D is obtained 40 cm from the end A. When a resistance of 10 Ω is connected in series with X, the null point shifts by 10 cm.

Find the position of the null point when the 10 Ω resistance is instead connected in series with resistance Y. Determine the values of the resistances X and Y.

[Delhi 2009]

Ans.

Applying the condition of balanced Wheatstone bridge $\frac{X}{Y} = \frac{l}{100 - l}$, where l is the balancing length from end A.

Initially, $l = 40$ cm

$$\Rightarrow \quad \frac{X}{Y} = \frac{40}{100 - 40} = \frac{40}{60} = \frac{2}{3}$$

$$X = \frac{2}{3}Y \quad \text{...(i)}$$

(1/2)

When 10 Ω resistance connected in series with X, null points shift to 40 + 10 = 50 cm.

$$\therefore \quad \frac{X + 10}{Y} = \frac{50}{50} = 1$$

$$\Rightarrow \quad X + 10 = Y$$

$$\Rightarrow \quad Y - X = 10 \quad \text{...(ii)}$$

(1/2)

From Eqs. (i) and (ii), we get

$$\frac{Y}{3} = 10\ \Omega$$

$$\Rightarrow \quad Y = 30\ \Omega$$

$$X = 20\ \Omega$$

(1)

Now, 10 Ω resistance connected in series with Y and let null point is obtained at length l cm.

$$\frac{X}{Y + 10} = \frac{l}{100 - l}$$

$$\frac{20}{30 + 10} = \frac{l}{100 - l}$$

$(\because X = 20\ \Omega, Y = 30\ \Omega)$

$$\frac{1}{2} = \frac{l}{100 - l}$$

$$100 - l = 2l$$

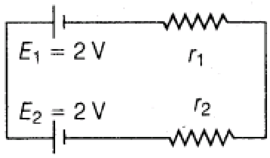
$$3l = 100$$

$$l = \frac{100}{3}\text{ cm} = 33.33\text{ cm}$$

(1)

So, null point is obtained at length 33.33 cm.

29.State Kirchhoff's rules. Use Kirchhoff's rules to show that no current flows in the given circuit



[Foreign 2009]

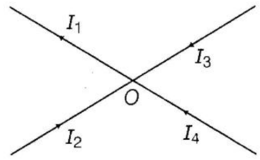
Ans.

Kirchhoff's first rule or junction rule The algebraic sum of electric currents at any junction of electric circuit is equal to zero i.e. the sum of current entering into a junction is equal to the sum of current leaving the junction

$\Rightarrow \quad \Sigma I = 0$

At junction O,

$$I_1 + I_2 = I_3 + I_4$$



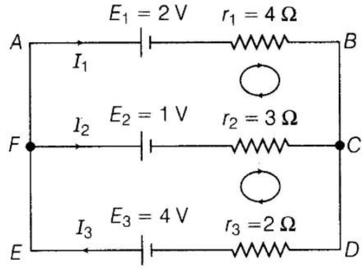
(1)

Kirchhoff's second rule In any closed mesh of electrical circuit, the algebraic sum of emfs of cells and the product of currents and resistances is always equal to zero.

i.e. $\Sigma E + \Sigma IR = 0$

Kirchhoff's second law is a form of law of conservation of energy. **(1)**

For given circuit,



At F, applying junction rule

$$I_3 = I_1 + I_2 \quad \text{...(i)}$$

In mesh ABCFA,

$$-2 - 4I_1 + 3I_2 + 1 = 0$$

$$4I_1 - 3I_2 = -1$$

In mesh FCDEF,

$$-1 - 3I_2 - 2I_3 + 4 = 0$$

$$3I_2 + 2I_3 = 3$$

On solving, we get I_1, I_2 and I_3.

$$I_1 = \frac{2}{13}\text{ A} \quad \text{or} \quad I_2 = \frac{7}{13}\text{ A}$$

$$I_3 = \frac{9}{13}\text{ A}$$

Let I current flows clockwise in the circuit.
Applying Kirchhoff's voltage rule

$$-2 - Ir_1 - Ir_2 + 2 = 0 \quad \textbf{(1/2)}$$

$$Ir_1 + Ir_2 = 0$$

$$I(r_1 + r_2) = 0$$

$\therefore \quad r_1 + r_2 \neq 0$

$\Rightarrow \quad I = 0$ **(1/2)**

Thus, no current flows through the circuit.

30. A battery of five lead acid accumulators, each of emf 4 V and internal resistance 1 Ω, connected in series is charged by 100 V DC source.

Calculate the following.

(*i*) The series resistance to be used in the circuit to have a current of 5 A.

(*ii*) Power supplied by the source.

(*iii*) Chemical energy stored in the battery in 10 min. **[Foreign 2008]**

Ans.

(*i*) Net emf = 100 − 5 × 4 = 80 V

Net resistance = Net internal resistance + External resistance (*R*)

Net resistance = 5 × 1 + *R* = (5 + *R*) Ω

$\therefore \quad I = \frac{V}{R}$ (Ohm's law)

$\Rightarrow \quad 5 = \frac{80}{5+R}$

$\Rightarrow \quad 5 + R = \frac{80}{5} = 16$

or $\quad R = 11\,\Omega$

(*ii*) As, $P = VI$ **(1)**

$= 100 \times 5 = 500$ W **(1)**

(*iii*) Chemical energy stored

= Net energy consumed by external battery − Energy loss in resistance

$= 500 \times (10 \times 60) - (5)^2 \times 16 \times (60 \times 10)$

$= 100 \times 10 \times 60 = 6 \times 10^4$ J

or $W = EIt = (5 \times 4) \times (5) \times (10 \times 60)$

$= 6 \times 10^4$ J **(1)**

31.Draw a circuit showing a Wheatstone bridge. Use Kirchhoff's rule to obtain the balance condition in terms of the values of the four resistors for the galvanometer to give null deflection. [Delhi 2008 CI

Ans.

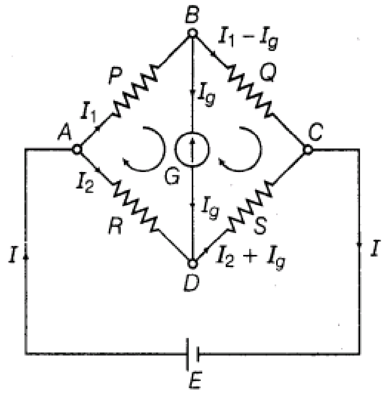
(*i*) Meter bridge works on the principle of balanced Wheatstone bridge.

In balanced Wheatstone bridge,

(a) no current flow through the galvanometer.

(b) $V_B = V_D$ (c) $\frac{P}{Q} = \frac{R}{S}$ $\left(1\frac{1}{2}\right)$

where, P, Q are ratio arms.
R = known resistance and
S = unknown resistance.



32.Draw a circuit diagram for a Wheatstone bridge. Explain briefly how the balance condition for the galvanometer to give null deflection provides a practical method for the determination of an unknown resistance? [Delhi 2008]

Ans.

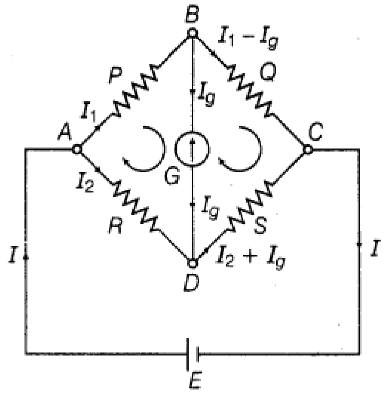
(i) Meter bridge works on the principle of balanced Wheatstone bridge.

In balanced Wheatstone bridge,

(a) no current flow through the galvanometer.

(b) $V_B = V_D$ (c) $\frac{P}{Q} = \frac{R}{S}$ $\left(1\frac{1}{2}\right)$

where, P, Q are ratio arms.
R = known resistance and
S = unknown resistance.



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

where, S is unknown resistance.

$$S = \frac{Q}{P} \times R = \frac{l}{(100 - l)} \times R \quad \textbf{(1)}$$

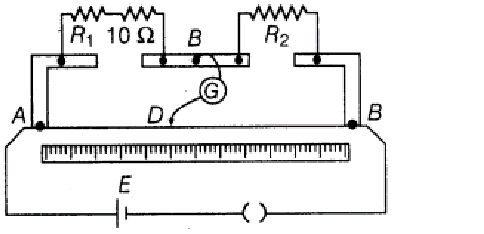
(using meter bridge)

5 Marks Questions

33.(i) State Kirchhoff's rules for an electric network. Using Kirchhoff's rules, obtain the balance condition in terms of the resistances of four arms of Wheatstone bridge.

(ii) In the meter bridge experimental set up, shown in the figure, the null point D is obtained at a distance of 40 cm from end A of the meter bridge wire.

If a resistance of 10 Ω is connected in series with R_1, null point is obtained at $AD = 60$ cm. Calculate the values of R_1 and R_2.



[Delhi 2013]

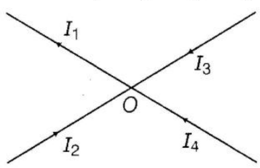
Ans.

Kirchhoff's first rule or junction rule The algebraic sum of electric currents at any junction of electric circuit is equal to zero i.e. the sum of current entering into a junction is equal to the sum of current leaving the junction

$\Rightarrow \quad \Sigma I = 0$

At junction O,

$$I_1 + I_2 = I_3 + I_4$$



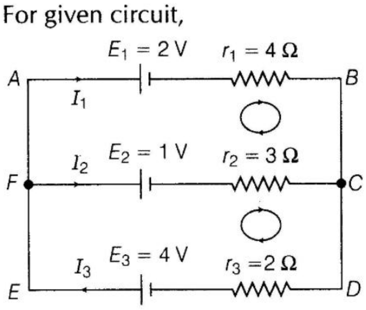
(1)

Kirchhoff's second rule In any closed mesh of electrical circuit, the algebraic sum of emfs of cells and the product of currents and resistances is always equal to zero.

i.e. $\quad \Sigma E + \Sigma IR = 0$

Kirchhoff's second law is a form of law of conservation of energy. **(1)**

For given circuit,



At F, applying junction rule

$$I_3 = I_1 + I_2 \qquad ...(i)$$

In mesh $ABCFA$,

$$-2 - 4I_1 + 3I_2 + 1 = 0$$
$$4I_1 - 3I_2 = -1$$

In mesh $FCDEF$,

$$-1 - 3I_2 - 2I_3 + 4 = 0$$
$$3I_2 + 2I_3 = 3$$

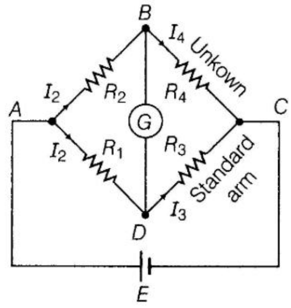
On solving, we get I_1, I_2 and I_3.

$$I_1 = \frac{2}{13}\text{ A} \quad \text{or} \quad I_2 = \frac{7}{13}\text{ A}$$

$$I_3 = \frac{9}{13}\text{ A}$$

Wheatstone Bridge

The Wheatstone bridge is an arrangement of four resistances as shown in the following figure.



(1)

R_1, R_2, R_3 and R_4 are the four resistances. Galvanometer (G) has a current I_g flowing through it at balanced condition,

$$I_g = 0$$

Applying junction rule at B,

$$\therefore \quad I_2 = I_4$$

Applying junction rule at D,

$$\therefore \quad I_1 = I_3$$

Applying loop rule to closed loop $ADBA$,

$$-I_1R_1 + 0 + I_2R_2 = 0$$

$$\therefore \quad \frac{I_1}{I_2} = \frac{R_2}{R_1}$$

...(i)

Applying loop rule to closed loop $CBDC$,

$$I_2R_4 + 0 - I_1R_3 = 0$$

$$\because \quad I_3 = I_1$$

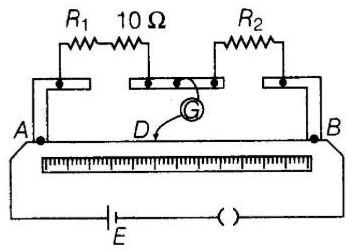
$$I_4 = I_2$$

$$\therefore \quad \frac{I_1}{I_2} = \frac{R_4}{R_3} \quad \text{...(ii)}$$

From Eqs. (i) and (ii), $\frac{R_2}{R_1} = \frac{R_4}{R_3}$

This is the required balanced condition of Wheatstone bridge.

(*ii*) Considering both the situations and writing them in the form of equations



Let R' be the resistance per unit length of the potential meter wire

$$\frac{R_1}{R_2} = \frac{R' \times 40}{R'(100-40)} = \frac{40}{60} = \frac{2}{3}$$

$$\frac{R_1+10}{R_2} = \frac{R' \times 60}{R'(100-60)}$$

$$= \frac{60}{40} = \frac{3}{2}$$

$$\frac{R_1}{R_2} = \frac{2}{3} \quad \text{...(i)}$$

$$\frac{R_1+10}{R_2} = \frac{3}{2} \quad \text{...(ii)}$$

Putting the value of R_1 from Eq. (i) and substituting in Eq. (ii).

$$\frac{2}{3} + \frac{10}{R_2} = \frac{3}{2}$$

$\Rightarrow$ $R_2 = 12\ \Omega$

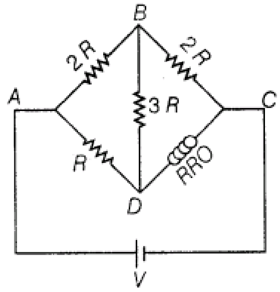
Recalling Eq. (i) again

$$\frac{R_1}{12} = \frac{2}{3}$$

$\Rightarrow$ $R_1 = 8\ \Omega$ **(3)**

34.(i) Use Kirchhoff's rules to obtain the balance condition in a Wheatstone bridge.

(ii) Calculate the value of R in the balance condition of the Wheatstone bridge, if the carbon resistor connected across the arm CD has the colour sequence red, red and orange, as shown in the figure.



(iii) If now the resistance of the arms BC and CD are interchanged, to obtain the balance condition, another carbon resistor is connected in place or R. What would now be sequence of colour bands of the carbon resistor?[Delhi 2012]

Ans.

(*i*) The balance condition is

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

$$\Rightarrow \quad \frac{P}{R} = \frac{Q}{S} \quad \textbf{(1)}$$

(*ii*) Let a carbon resistor S is given to the bridge

$$\Rightarrow \quad \frac{R}{S} = 1 \Rightarrow R = S = 22 \times 10^3\ \Omega \quad \textbf{(1)}$$

(iii) After interchanging the resistances the balanced bridge would be

$$\frac{2R}{X} = \frac{2 \times 10^3}{2 \times 22 \times 10^3} = \frac{1}{2}$$

$$\Rightarrow X = 4R = 4 \times 22 \times 10^3 = 88\ \text{k}\Omega \quad \textbf{(1)}$$

Thus, equivalent resistances of Wheatstone bridge

$$\frac{1}{R_{eq}} = \frac{1}{3R} + \frac{1}{6R} = \frac{3}{6R} \quad \textbf{(1)}$$

$$\Rightarrow \quad R_{eq} = 2R \quad \textbf{(1)}$$

$\therefore$ Current through it $I = \frac{1}{3} \times \frac{V}{2R} = \frac{V}{6R}$ A

35.(i) State with the help of a circuit diagram, the working principle of a meter bridge. Obtain the expression used for determining the unknown resistance.

(ii)What happens if the galvanometer and cell are interchanged at the balance point of the bridge?

(iii)Why is it considered important to obtain the balance point near the mid-point of the wire? [Delhi 2011 c]

Ans.(i)

(*i*) Meter bridge works on the principle of balanced Wheatstone bridge.

In balanced Wheatstone bridge,

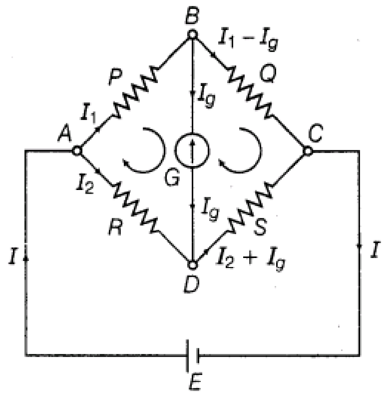
(a) no current flow through the galvanometer.

(*b*) $V_B = V_D$ (c) $\frac{P}{Q} = \frac{R}{S}$ $\left(1\frac{1}{2}\right)$

where, P, Q are ratio arms.

R = known resistance and

S = unknown resistance.



(ii)

(*i*) The balancing condition state that

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

When X and R both are doubled, then

$$\frac{2X}{2R} = \frac{X}{R} = \frac{100 - l}{l}$$

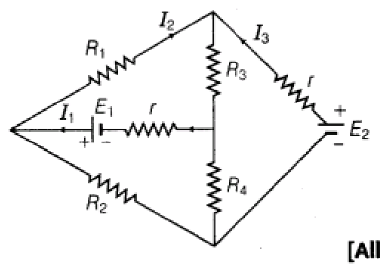
Balancing length would be at $(100 - l)$ cm.

(1)

(*ii*) On changing the position of galvanometer and battery, the meter bridge continue to be balanced and hence, no change occur in the balance point. **(1)**

(iii)It is because of the fact that meter bridge is most sensitive when null point occur nc the mid-point of wire and all the four resistances are of same order.

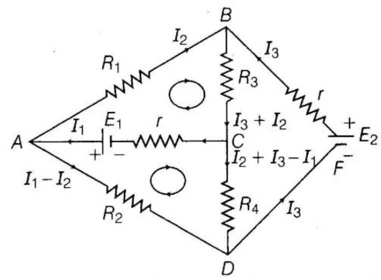
36.State the two rules that serves as general rules for analysis of electrical circuits.Use these rules to write the three equations that may be used to obtain the values of the three unknown currents in the branches (shown) of the circuit given below. [All India 2008 C]



[All India 2008C]

Ans.

The two rules that serves as general rules for analysis of electrical circuits are Kirchhoff's rules.



For statement of Kirchhoff's rule refer to ans. 19. **(2)**

In loop $ABCA$ (clockwise),

$$-I_2R_1 - (I_2 + I_3)R_3 - I_1 r + E_1 = 0$$

$$I_1 r + I_2(R_1 + R_3) + I_3 R_3 = E_1 \quad \text{...(i)}$$

(1)

In loop $ACDA$ (clockwise),

$$-(I_1 - I_2)R_2 - I_1 r + E_1 + (I_2 + I_3 - I_1)R_1 = 0$$

$$\Rightarrow I_1(r + R_2 + R_4) - I_2(R_2 + R_4) - I_3 R_4 = E_1$$

(1)

In loop $ABFDA$ (anti-clockwise)

$$-I_2R_1 + I_3 r_1 - E_2 + (I_1 - I_2)R_2 = 0$$

$$I_1 R_2 - I_2(R_1 + R_2) + I_3 r_1 = E_2 \quad \text{...(iii)}$$

(1)