Current electricity(CBSE)-Solutions

Explanations

1. The mobility of electrons in a conductor is given by

$$\mu = \frac{e\tau}{m}$$

where, e = charge on electron, m = mass of electrons and τ = relaxation time.

Also, $\tau \propto T$.

But here temperature (T) is kept constant. As mobility is independent of potential difference, so there is no change in it. **(1)**

2. Average drift velocity,

$$v_d = \frac{eE}{m}\tau$$

where, e = charge on electron,
m = mass of electron,
E = electric potential or field across conductor
and τ = relaxation time. **(1)**

3. The average drift velocity, $v_d = \frac{eE}{m}\tau$

where, τ = relaxation time.

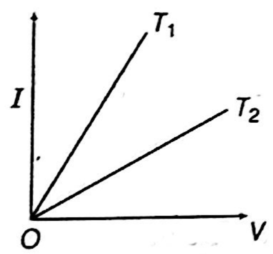
The relaxation time is directly proportional to the temperature of conductor i.e.

$$\tau \propto T$$

$\therefore$ $v_d \propto T$

So, the drift velocity increases with rise in temperature. **(1)**

4. Consider the figure,



Since, slope of 1 > slope of 2.

$$I_1/V_1 > I_2/V_2 \Rightarrow V_2/I_2 > V_1/I_1$$

$\therefore$ $R_2 > R_1$

$\because$ $V/I = R$ **(1/2)**

Also, we know that resistance is directly proportional to the temperature.

Therefore, $T_2 > T_1$. **(1/2)**

5. (i) DE is the region of negative resistance because the slope of curve in this part is negative. **(1/2)**

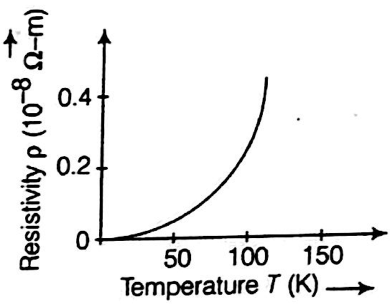
(ii) BC is the region where Ohm's law is obeyed because in this part, the current varies linearly with the voltage. **(1/2)**

6. The resistivity of a metallic conductor is given by

$$\rho = \rho_0\,[1 + \alpha(T - T_0)]$$

where, ρ_0 = resistivity at reference temperature,
T_0 = reference temperature
and α = coefficient of resistivity.

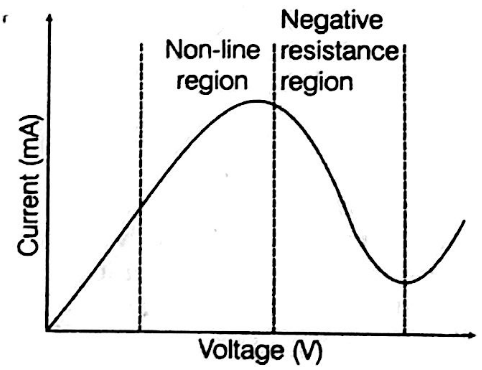
From the above relation, we can say that the graph between resistivity of a conductor with temperature is straight line. But, at temperatures much lower than 273 K (i.e. 0°C), the graph deviates considerably from a straight line as shown in the figure.



(1)

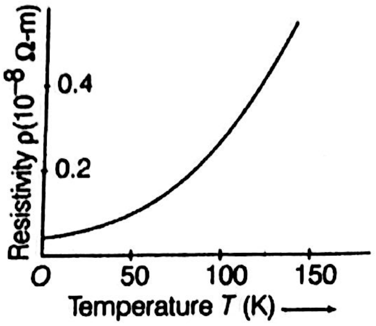
7. Conductors contain free electrons. In the absence of any external electric field, the free electrons are in random motion just like the molecules of gas in a container and the net current through wire is zero. If the ends of the wire are connected to a battery, an electric field (E) will setup at every point within the wire. Due to electric effect of the battery, the electrons will experience a force in the direction opposite to E. **(1)**

8. Variation of current *versus* voltage for the material GaAs is as follows



(1)

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



(1)

10. Drift velocity 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. (1/2)

Its **relationship is expressed** as

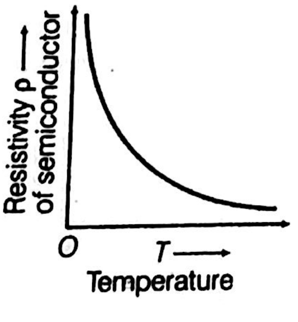
$$v_d = \frac{I}{neA}$$

where, I is current flowing through the conductor, n is concentration of free electrons, e is electronic charge and A is cross-sectional area. (1/2)

11. 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 $(\Omega\text{-m})^{-1}$. (1)

12. The resistivity of a semiconductor decreases exponentially with temperature.

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



(1)

13. 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.

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

where, τ is the average relaxation time and m is the mass of the charged particle. (1/2)

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

14. Increasing temperature causes greater electron scattering due to increased thermal vibrations of atoms and hence, resistivity ρ (reciprocal of conductivity) of metals increases linearly with temperature. (1)

15. Relation between current and drift velocity of electrons in a conductor is given by

$$I = Ane\,v_d \Rightarrow V/R = Anev_d$$

$$\therefore \quad v_d \propto \frac{1}{R}$$

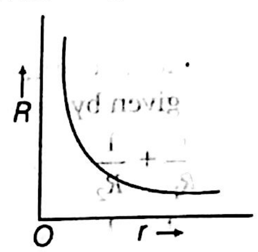
where, I = current,
A = area of conductor,
n = number density of electrons
and v_d = drift velocity.

with the increase in temperature of a metallic conductor, resistance increases and hence drift velocity decreases. (1)

16. Resistance of a conductor of length l and radius r is given by

$$R = \rho\frac{l}{\pi r^2}, \text{ i.e. } R \propto \frac{1}{r^2}$$

∴ *The variation of resistance of a conducting wire as a function of its radius is given as,*



(1)

17. In silicon, the resistivity increases with decrease in temperature. (1/2)

In copper, the resistivity decreases with decrease in temperature. (1/2)

18. No, the drift speed of electrons is superposed over the random velocities of the electrons. (1)

19. Refer to Sol. 12 (1)

20. Given that resistance of both the wires are of equal length, so

$$R_{Mn} = R_{Cu}$$

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

According to the question, both the wires are of equal length, so $l_{Mn} = l_{Cu}$

∴ From Eq. (i), we get

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

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)**

21. 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)

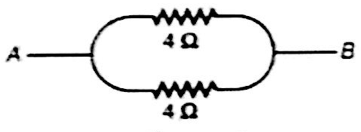
22. The resistance of the whole wire is 8Ω, which is bent in the form of a circle. We have to find the effective resistance between the ends of diameter AB. Diameter of the circle divides the circle into two equal parts. The resistance of each such part will be $8/2 = 4\Omega$.

(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

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

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



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

23. Given that number density in X

$= 2 \times$ Number density in Y

$\Rightarrow \quad n_X = 2n_Y$ ...(i)

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

$$A_X = A_Y$$

$$\Rightarrow \quad \frac{(v_d)_X}{(v_d)_Y} = \frac{n_Y}{n_X} = \frac{n_Y}{2n_Y} \quad \text{[From Eq. (i)]}$$

$$= \frac{1}{2}$$ **(1)**

24. 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 the resistance each of conductor is 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

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

$$\Rightarrow \quad \frac{R_1}{R_2} = 4$$ **(1)**

25. From Ohm's law, we have

$$V = IR \Rightarrow V = I\rho\frac{l}{A} \quad [\because R = \rho(l/A)] \ \ldots\text{(i)}$$ **(1)**

When the rod is cut parallel, and rejoined by length, the length of the conductor becomes $2\,l$, whereas the area decrease to $\frac{A}{2}$. If the current remains the same, the potential changes as

$$V' = I\rho\frac{2l}{A/2} = 4 \times I\rho\frac{l}{A} = 4V \quad \text{[using Eq. (i)]}$$

The new potential applied across the metal rod will be four times the original potential (V). **(1)**

26. As we know that, $I = neAv_d$

Also, current density J is given by

$$J = I/A$$ **(1)**

$$\therefore \quad |\mathbf{J}| = \frac{ne^2}{m}\tau|\mathbf{E}| \quad \left[\because v_d = \frac{e\tau E}{m}\right]$$

or $\quad J = (1/\rho)E \quad [\because \rho = m/ne^2\tau]$

(1)

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

Current, $I = 1.5\text{A}$

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

Drift velocity, $v_d = ?$

We know that, $I = neAv_d$ **(1)**

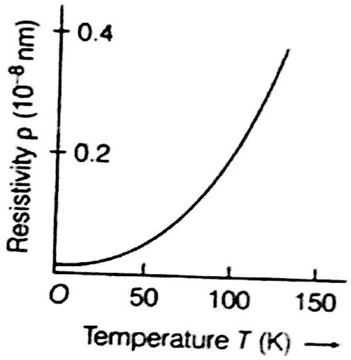
$$\Rightarrow \quad v_d = \frac{I}{neA} = \frac{1.5}{9 \times 10^{28} \times 1.6 \times 10^{-19} \times 1.0 \times 10^{-7}}$$

$$= 1.042 \times 10^{-3}\,\text{m/s}$$ **(1)**

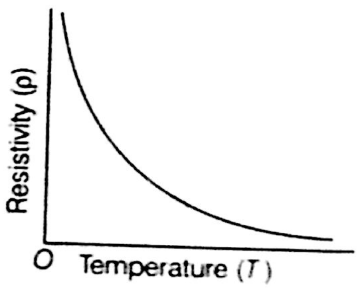
Or **Ans.** $= 5 \times 10^{-4}$m/s

Or **Ans.** $= 7.5 \times 10^{-4}$m/s **(2)**

28. **(i) For conductor**



(ii) For semiconductor



(1)

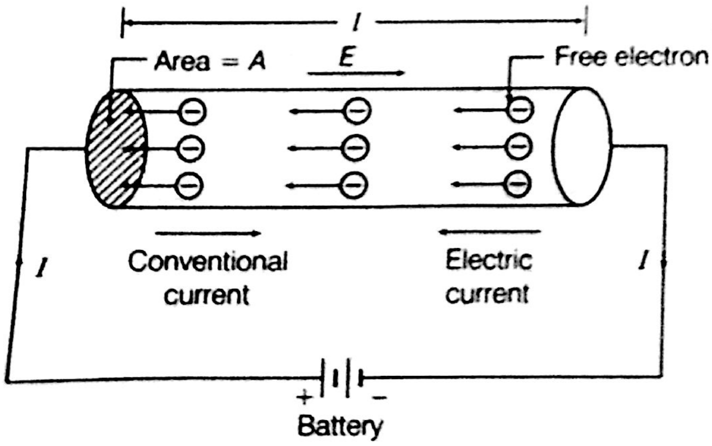
The relation between resistivity and relaxation time, $\rho = \frac{m}{ne^2\tau}$

In conductors, average relaxation 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. **(1)**

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

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



Let n = number density of free electrons

A = cross-sectional area of conductor

e = electrons charge.

∴ Number of free electrons present in length l of conductor = nAl

∴ Total charge contained in length l which can contribute in current,

$$q = (nAl)e \quad \ldots(i) \; \mathbf{(1/2)}$$

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

$$t = l/v_d \quad \ldots(ii) \; \mathbf{(1/2)}$$

where, v_d = drift speed of electron.

∴ Current through the conductor [from Eqs. (i) and (ii)]

$$I = q/t$$

$$I = \frac{(nAl)e}{t} = \frac{(nAl)e}{(l/v_d)} = neAv_d$$

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

$$\therefore \quad J = nev_d, \text{ i.e. } J \propto v_d$$

Thus, current density of conductor is proportional to drift speed. **(1)**

30. Mobility of a charge carrier is defined as the drift velocity of the charge carrier per unit electric field. It is generally denoted by μ.

$$\therefore \quad \mu = v_d/E \quad \ldots(i)$$

The SI unit of mobility is $m^2 V^{-1} s^{-1}$. **(1)**

Drift velocity in term of relaxation time,

$$\mathbf{v}_d = \frac{-e\mathbf{E}}{m}\tau$$

In magnitude, $v_d = \frac{eE}{m}\tau$ or $\frac{v_d}{E} = \frac{e\tau}{m}$

$$\mu = \frac{e\tau}{m} \quad \text{[From Eq. (i)]}$$

(1)

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

Here, 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.

$$\therefore \quad v \propto \frac{1}{l} \quad [\because \text{ other factors are constants}]$$

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

(ii) Resistance of the conductor is given as

$$R = \rho\,(l/A)$$

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

$\therefore$ 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

($\because$ Density is same in both cases)

$\therefore \quad A_1 l_1 = A_2 l_2 \Rightarrow A_1 l = A_2 (3l)$

[$\because$ length is tripled after stretching]

$\therefore \quad A_2 = A_1/3$

i.e. When length is tripled area of cross-section is reduced to $A/3$

Hence, $\quad R = \rho \dfrac{l'}{A'} = \rho \dfrac{3l}{A/3} = 9\rho \dfrac{l}{A} = 9R$

Thus, new resistance will be 9 times of its original value. **(1)**

32. (i) Given, resistance = 47 kΩ ± 10%

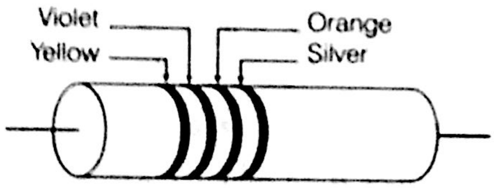
$= 47 \times 10^3\ \Omega \pm 10\%$

$\therefore$ 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 ± 10%.



(1)

(ii) *Two properties of manganin are*

(a) low temperature coefficient of resistance.

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

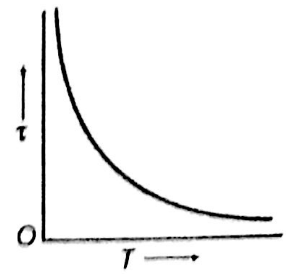
33. To plot the graph between the two quantities, first of all identify the relation between them.

Since, resistivity of material of conductor (ρ) is given by, $\rho = m/ne^2\tau$

where, n = number density of electrons

and $\quad \tau$ = 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)**

34. According to colour codes, resistance of two wires are

(i) Code of brown = 1, Code of green = 5

Code of blue = 6

$R_1 = 15 \times 10^6\ \Omega \pm 20\%$ **(1)**

(ii) Code of orange = 3

Code of black = 0

Code of green = 5

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

$\therefore$ Ratio of resistances, $\dfrac{R_1}{R_2} = \dfrac{15 \times 10^6}{30 \times 10^5} = 5 \Rightarrow \dfrac{R_1}{R_2} = 5$ **(1)**

35. Refer to Sol. 28 **(3)**

36. (a) **Conductivity** The reciprocal of resistivity of a conductor is known as conductivity. It is expressed as

$$\sigma = \frac{1}{\rho}$$ **(1/2)**

The SI unit of conductivity is mho per metre ($\Omega^{-1}\text{m}^{-1}$). **(1/2)**

(b) We know that, drift velocity is given by

$$v_d = \frac{eE\tau}{m} \quad \ldots \text{(i)}$$

where, e = electric charge,

E = applied electric field, τ = relaxation time

and $\quad m$ = mass of electron.

But $\quad E = \dfrac{V}{l} \quad$ (i.e. potential gradient)

$$\therefore \quad v_d = \left(\frac{e\tau}{m}\right)\left(\frac{V}{l}\right) \quad \ldots \text{(ii)}$$

From the relation between current and drift velocity,

$$I = neAv_d \quad \ldots \text{(iii)}$$

(where, n = number of density of electrons)

Putting the value of Eq. (ii) in Eq. (iii), we get

$$I = neA\left(\frac{e\tau V}{ml}\right) \text{ or } I = \left(\frac{ne^2A\tau}{ml}\right)V$$

or $$V = \left(\frac{ml}{ne^2A\tau}\right) I \quad \text{... (iv)}$$

But according to Ohm's law,

$$V = IR \quad \text{... (v)}$$

From Eqs. (iv) and (v), we get

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

Also, $$R = \rho\frac{l}{A} \quad \text{... (vii)}$$

From Eqs. (vi) and (vii), we get

$\rho = \frac{m}{ne^2\tau}$ = resistivity of conductor.

As reciprocal of resistivity of conductor is known as conductivity.

$\therefore$ Conductivity, $\sigma = \frac{1}{\rho} = \frac{ne^2\tau}{m}$ (1)

Now, we know that, current density, $J = \frac{I}{A}$

or $$J = \frac{neAv_d}{A} = nev_d = \left(\frac{ne^2\tau}{m}\right)E \left(\because v_d = \frac{eE\tau}{m}\right)$$

$$\therefore \quad J = \sigma E \quad \left(\because \sigma = \frac{ne^2\tau}{m}\right)$$ (1)

37. (i) **Drift velocity** Refer to Sol. 10 (1)

(ii) Specific resistance or resistivity of the material of a conductor is defined as the resistance of a unit length with unit area of cross-section of the material of the conductor.

The unit of resistivity is ohm-metre or Ω-m.

Since, we know that $R = \rho(l/A)$

$$\Rightarrow \quad \rho = RA/l \quad \text{....(i)}$$

From Ohm's law, $V = IR \Rightarrow El = neAv_dR$

$\Rightarrow R = El/neAv_d$ and $v_d = eE\tau/m$

So, $R = \frac{El \times m}{ne^2 AE\tau} = \frac{ml}{ne^2 A\tau}$

Substituting the value of $R = \frac{ml}{ne^2 A\tau}$ in Eq. (i),

we have, $\rho = (ml/ne^2A\tau).A/l$

$\therefore$ Resistivity of the material, $\rho = m/ne^2\tau$

From the above formula, it is clear that resistivity of a conductor depends upon the following factors:

(a) $\rho \propto \frac{1}{n}$, i.e. the resistivity of material is inversely proportional to the number density of free electrons (number of free electrons per unit volume). As the free electron density depends upon the nature of material, so resistivity of a conductor depends on the nature of the material.

(b) $\rho \propto 1/\tau$, i.e. the resistivity of a material is inversely proportional to the average relaxation time τ of free electrons in the conductor. As the value of τ depends on the temperature as temperature increases, τ decreases, hence ρ increases. (1)

(iii) Alloys like Constantan and Manganin are used for making standard resistors because the resistivity of these alloys has lesser dependence on the temperature. (1)

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

F = $-e$**E**, and free electron acquires an acceleration, $\mathbf{a} = \mathbf{F}/m = -e\mathbf{E}/m$ ...(i)

where, m = mass of electron, e = electronic charge and **E** = electric field.

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

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

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

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

$\therefore$ $$\mathbf{v}_1 = \mathbf{u}_1 + \mathbf{a}\tau_1$$

Similarly, $$\mathbf{v}_2 = \mathbf{u}_2 + \mathbf{a}\tau_2$$

$$\vdots \quad \vdots \quad \vdots$$

$$\mathbf{v}_n = \mathbf{u}_n + \mathbf{a}\tau_n$$

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

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

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

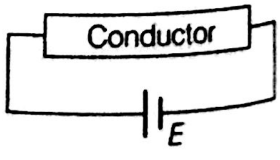
$$\mathbf{v}_d = \frac{(\mathbf{u}_1 + \mathbf{u}_2 + ... + \mathbf{u}_n)}{n} + \frac{\mathbf{a}(\tau_1 + \tau_2 + ... + \tau_n)}{n}$$

$\mathbf{v}_d = 0 + \mathbf{a}\tau$ [$\because$ Average thermal velocity in n collisions = 0]

$\mathbf{v}_d = -(e\mathbf{E}/m)\tau$ [from Eq. (i)]

This is the required expression of drift speed of free electrons. (1)

The conductor connected to DC source of emf E is shown in the figure below:



Suppose, initial length of the conductor, $l_i = l_0$.

New length, $l_f = 3l_0$

We know that,

Drift velocity, $v_d \propto E_0$ [electric field]

Thus, $\frac{(v_d)_f}{(v_d)i} = \frac{(E_0)_f}{(E_0)i} = \frac{E/l_f}{E/l_i} = \frac{l_i}{l_f} = \frac{l_0}{3l_0} = \frac{1}{3}$

Thus, $(v_d)_f = (v_d)_i/3$

Thus, drift velocity decreases three times. **(1)**

39. In first circuit,

Reading of ideal voltmeter = 6V

Net potential difference = 9 + 6 = 15 V

Total resistance = $1+1=2\,\Omega$

Current in ammeter = V/R = 15/2 = 7.5A **(1)**

In second circuit,

Reading of ideal voltmeter = 6V

Net potential difference = 9 − 6 = 3V **(1)**

Total resistance = $1+1=2\,\Omega$

Current in ammeter = V/R = 3/2 = 1.5A **(1)**

40. When an electric field is applied across a conductor, then the charge carriers inside the conductor move with an average velocity which is independent of time. This velocity is known as drift velocity (v_d). **(1)**

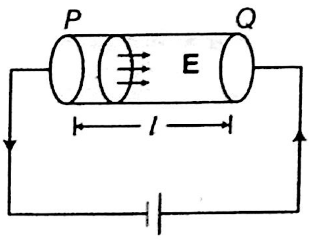
(i) Relationship between current (I) and velocity (v_d) is, $I = neAv_d$

where, ne = amount of charge inside the conductor and A = area of cross-section of conductor.

Total number of free electrons in a conductor PQ of length l, cross-sectional area A having n free electrons per unit volume is

$N = n\times$ volume of conductor PQ

or $N = nAl$



(1)

Time t in which an electron moves from P to Q, all N free electrons pass through cross-section Q.

$$t = l/v_d$$

where, v_d is the drift velocity of electrons in the conductor. So, electric current flowing through conductor is given by

$$I = \frac{q}{t} = \frac{Ne}{t} = \frac{nAle}{l/v_d} \Rightarrow I = neAv_d$$

This gives the relation between electric current and drift velocity.

(ii) Area under I-t curve on t-axis is charge flowing through the conductor

$$Q = \frac{1}{2}\times 5\times 5 + (10+5)\times 5 = 87.5\text{C}$$ **(1)**

41. 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,

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

where, E = electric field due to applied potential difference, τ = relaxation time,

m = mass of electron and e = electronic charge.

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

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

$$I = ne^2A\tau/m\,(V/l) \quad [\because E = V/l]$$

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

$$\therefore R = \rho\frac{l}{A}\left[\because \frac{V}{I} = R_s \text{ and } \rho = \frac{m}{ne^2\tau}\right]$$

This is the required expression. **(1/2)**

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

$$I = neAv_d \quad \text{...(i)}$$

Electric field inside the wire is given by

$$E = V/l \quad \text{...(ii)}$$

If relaxation time is τ, the drift speed

$$v_d = e\tau E/m$$ **(1)**

where, m = mass of electron

τ = relaxation charge

e = electronic charge

and E = electric field.

Putting the value of V_d in Eq. (i), we get

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

$$I = ne^2\tau AV/ml \quad \text{[From Eqs. (ii)]}$$

$$\Rightarrow J = I/A = ne^2\tau V/ml$$ **(1)**

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

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

$\because v_d = I/neA$

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

$$\Rightarrow v_d = 1.04\times 10^{-3}\ \text{m/s}$$ **(1)**

43. 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) $\because$ 4 Ω and 4 Ω are in parallel combination.

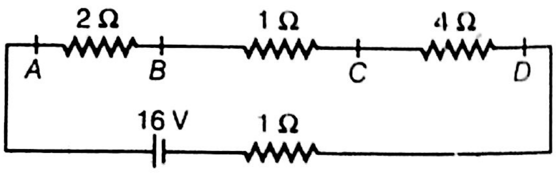
$\therefore$ Equivalent resistance,

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

Similarly, equivalent resistance of 12 Ω and 6 Ω is

$$\frac{1}{R_{CD}} = \frac{1}{12} + \frac{1}{6} \Rightarrow \frac{1}{R_{BC}} = \frac{1+2}{12} \Rightarrow R_{BC} = 4\,\Omega$$ **(1)**

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



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

$\therefore$ Equivalent resistance of the network,

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

(ii) $\therefore$ 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, $V_{AB} = IR_{AB} = 2 \times 2 = 4$ V

and $V_{CD} = I R_{CD} = 2 \times 4 = 8$ V **(1)**

44. 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 Ω resistance, so resistance will produce no effect.

$\therefore$ Effective resistance between A and B

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

$$= 1.2\,\Omega \quad \left[\because \frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \Rightarrow R = \frac{R_1 R_2}{R_1 + R_2}\right]$$ **(1)**

Total resistance of the circuit = 1.2 + 2.8 = 4Ω

[$\because$ these two are in series]

Net current drawn from the cell,

$$I = \frac{V}{R\,(\text{total resistance})} = \frac{6}{4} = \frac{3}{2} = 1.5\,\text{A}$$ **(1/2)**

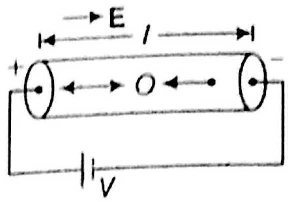
$\therefore$ Potential difference between A and B

$$V_{AB} = IR_{AB} = 1.5 \times 1.2 \Rightarrow V_{AB} = 1.80\,\text{V}$$ **(1/2)**

Current through 2Ω resistance,

$$I' = V_{AB}/2\Omega = 1.8/2 = 0.9\,\text{A}$$ **(1)**

45. (i) Let v_d be the drift velocity.



Electric field produced inside the wire is

$$E = V/l \quad \text{...(i)}$$

Force on an electron, $a = -E\,e$ **(1)**

Acceleration of each electron $= -Ee/m$

[$\because$ from Newton's law, $a = F/m$]

where, m is mass of electron.

Velocity created due to this acceleration $= \frac{Ee}{m}\tau$.

where, τ is the time span between two consecutive collision. This ultimately becomes the drift velocity in steady state.

So, $$v_d = \frac{Ee}{m}\tau = \frac{e}{m}\tau \times \frac{V}{l} \quad [\text{from Eq. (i)}]$$

We know that current in the conductor

$i = n\,e\,A\,v_d$ (where, n is number of free electrons in a conductor per unit volume)

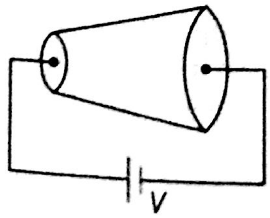
$$i = n\,e\,A \times \frac{e}{m}\tau\frac{V}{l} \Rightarrow i = \frac{n\,e^2 A\,\tau\,V}{m\,l}$$

$$\Rightarrow \quad i = V/R \quad [\because R = m\,l/n\,e^2 A\tau]$$

$$i \propto V.$$

This is Ohm's law. **(1½)**

(ii) The setup is shown in the figure. Here, electric current remains constant throughout the length of the wire. Electric field also remains constant which is equal to V/l.



Current density and hence drift speed change. **(2½)**

Explanations

1. According to question, maximum potential of three cells (cells in series) each of emf E is given in graph (i.e. 6 V)

So, $3E = 6\text{ V}$

$\Rightarrow \quad E = 6/3 = 2\text{ V}$

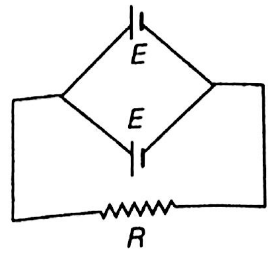
Internal resistance of three cells each of resistance r can be calculated as

$V = I \times 3r$ [all are in series]

$\Rightarrow \quad 3r = \frac{V}{I} = \frac{6}{1}$

$\Rightarrow \quad r = 2\Omega$ **(1)**

2. The cells are arrange... the circuit diagram given below.



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) **(1)**

3. Since, the positive terminal of the batteries are connected together, so the equivalent emf of the batteries is given by

$$E = 200 - 10 = 190\text{ V}.$$

Hence, the current in the circuit is given by

$$I = E/R = 190/38 = 5\text{ A}$$

(1)

4. 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. **(1)**

5. When a current I draws from a cell of emf E and internal resistance r, then the terminal voltage is $V = E - Ir$. **(1)**

6. Here, $E_1 = E$, $E_2 = -2E$ and $E_3 = 5E$, $r_1 = r$, $r_2 = 2r$ and $r_3 = 3r$

Equivalent emf of the cell is $E = E_1 + E_2 + E_3$

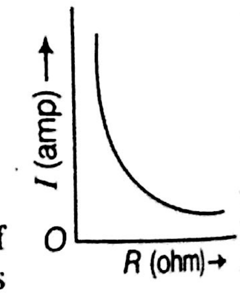
$= E - 2E + 5E = 4E$

Equivalent resistance

$= r_1 + r_2 + r_3 + R$

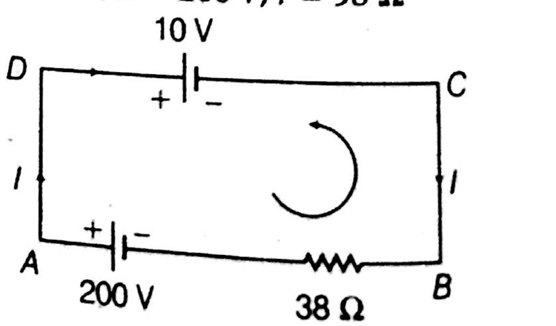
$= r + 2r + 3r + R = 6r + R$

$\therefore$ Current, $I = \frac{4E}{6r + R}$



The graph for variation of current I with resistance R is shown above. **(1)**

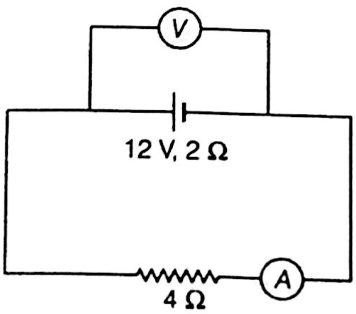
7. Given, $\varepsilon = 10\text{ V}$, $E = 200\text{ V}$, $r = 38\ \Omega$



Now, using Kirchhoff's loop law in given figure, in loop $ABCDA$,

$$200 - 38I - 10 = 0$$
$$190 = 38I$$
$$\therefore \quad I = \frac{190}{38} = 5\text{ A}$$
(1)

8. According to question,



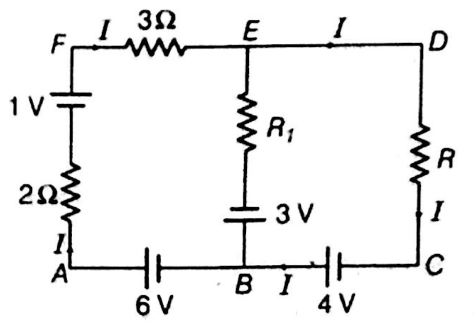
$$R = 2 + 4 = 6\Omega$$

(i) Net current in the circuit $= \frac{12}{6} = 2\text{A}$

Voltage across the battery,
$$V_b = 12 - 2 \times 2 = 8\text{V}$$
Voltage across the resistance,
$$V_r = IR = 2 \times 4 = 8\text{V}$$
(1)

(ii) In order to measure the device's voltage by a voltmeter, it must be connected in parallel to that device. This is necessary because device in parallel experiences the same potential difference. An ammeter is connected in series with the circuit because the purpose of the ammeter is to measure the current through the circuit. Since, the ammeter is a low impedance device, connecting in parallel with the circuit would cause a short-circuit, damaging the ammeter of the circuit. (1)

9. Consider the given figure,



Applying Kirchhoff's second law in mesh AFEBA,
$$2I - 1 + 3I - 6 = 0$$
(since, no current flows in the arm BE of the circuit)
$$5I = 7$$
$$\Rightarrow \quad I = \frac{7}{5}\text{A} \quad \text{...(i)}$$

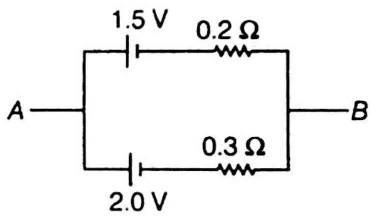
Applying Kirchhoff's second law in mesh AFDCA,
$$3I + RI - 4 - 6 + 2I - 1 = 0$$
$$5I + RI = 11 \quad \text{...(ii)}$$

Now, substitute the value of I from Eq. (i) to Eq. (ii), we get
$$5 \times \frac{7}{5} + R \times \frac{7}{5} = 11 \Rightarrow 7 + \frac{7R}{5} = 11$$
$$\Rightarrow \quad \frac{7R}{5} = 4 \Rightarrow R = \frac{20}{7}\Omega$$
(1)

For potential difference across A and D, along AFD,
$$V_A - \frac{7}{5} \times 2 + 1 - 3 \times \frac{7}{5} = V_D \Rightarrow V_A - \frac{14}{5} + 1 - \frac{21}{5} = V_D$$
$$\Rightarrow V_A - V_D = \frac{14}{5} + \frac{21}{5} - 1 \Rightarrow (V_A - V_D) = 7 - 1 = 6\text{ V}$$
(1)

10. Two cells of emfs E_1 and E_2 and internal resistances r_1 and r_2 connected in parallel combination, then equivalent emf,
$$E_{eq} = E_1 r_2 + E_2 r_1 / r_1 + r_2$$
Equivalent resistance, $r_{eq} = r_1 r_2 / (r_1 + r_2)$

According to question,



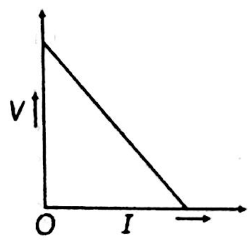
Equivalent emf $= E_1 r_2 + E_2 r_1 / (r_1 + r_2)$

i.e. $= \frac{(1.5 \times 0.3) + (2 \times 0.2)}{0.2 + 0.3} = \frac{0.45 + 0.4}{0.5} = \frac{0.85}{0.5} = 1.7\text{ V}$ (1)

Equivalent internal resistance
$$= \frac{r_1 r_2}{r_1 + r_2} = \frac{0.2 \times 0.3}{0.2 + 0.3} = \frac{0.06}{0.5} = \frac{6}{50} = 0.12\,\Omega$$
(1)

11. 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.



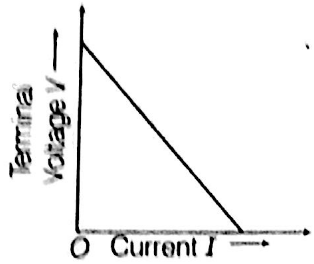
(i) The value of potential difference corresponding to zero current gives emf of the cell. (1)

(ii) Maximum current is drawn when terminal voltage is zero, so $V = E - Ir$
$$\Rightarrow 0 = E - I_{max} r \Rightarrow r = E / I_{max}$$
(1)

12. Difference between emf (ε) and terminal voltage (V)

emf	Terminal voltage
It is the potential difference between two terminals of the cells when no current is flowing through it cell is in the open circuit.	It is the potential difference between two terminals when current passes through it, in a closed circuit.
It is the cause.	It is the effect. **(1)**

Following plot is showing variation of terminal voltage versus the current



Note Negative slope gives internal resistance. **(1)**

13. In closed loop $ABEFCDA$, $-80+20I_2-30I_1=0$

$$20I_2-30I_1=80 \quad \text{...(i)}$$

In closed loop $BEFCB$,

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

$$20I_2+20I_1=100 \quad \text{...(ii) (1)}$$

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

$$I_1=\frac{2}{5}=0.4\text{ A}$$ **(1)**

14. Given, $R_1=12\,\Omega$, $R_2=25\Omega$

$I_1=0.5\text{A}$, $I_2=0.25\text{A}$

For the 1st case

$$r=\frac{E}{I_1}-R_1=\frac{E}{0.5}-12 \Rightarrow r=\frac{E-6}{0.5} \quad \text{...(i)}$$

Now, for the 2nd case

$$r=\frac{E}{0.25}-25;\ r=\frac{E-6.25}{0.25} \quad \text{...(ii)}$$

Compare the Eqs. (i) and (ii), we get

$$\frac{E-6}{0.5}=\frac{E-6.25}{0.25}$$

$$0.25E-1.5=0.5E-3.125$$

$$\Rightarrow \quad -0.25E=-1.625$$

$$E=\frac{1.625}{0.25} \Rightarrow E=6.5\text{V}$$ **(1)**

Putting the value of E in Eq. (i), we get

$$r=\frac{6.5-6}{0.5}=\frac{0.5}{0.5} \Rightarrow r=1\Omega$$ **(1)**

15. *The current relating to corresponding situations are as follows:*

(i) Without any external resistance, $I_1=E/R$

In this case, effective resistance of circuit is minimum, so current is maximum.

Hence, $I_1=4.2\text{A}$.

(ii) With resistance R_1 only, $I_2=\dfrac{E}{r+R_1}$ **(1/2)**

In this case, effective resistance of circuit is more than situations (i) and (iv) but less than

So, $I_2=1.05\text{A}$. **(1/2)**

(iii) With R_1 and R_2 in series combination.

$$I_3=E/r+R_1+R_2$$

In this case, effective resistance of circuit is maximum, so current is minimum.

Hence, $I_3=0.42\text{A}$. **(1/2)**

(iv) $I_4=\dfrac{E}{r+R_1R_2/R_1+R_2}$

In this case, the effective resistance is more than (i) but less than (ii) and (iii). So, $I_4=1.4\text{A}$. **(1/2)**

16. Given, $E=10\text{V}$, $r=3\Omega$, $I=0.5\text{A}$

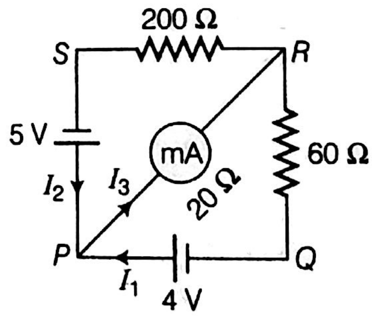
Total resistance of circuit,

$$R+r=\frac{E}{I}=\frac{10}{0.5}=20\Omega$$

(i) External resistance, $R=20-r=20-3=17\Omega$ **(1)**

(ii) Terminal voltage, $V=IR=0.5\times17=8.5\text{V}$ **(1)**

17. The given diagram is shown below



Applying Kirchhoff's second law to the loop $PRSP$,

$$-I_3\times20-I_2\times200+5=0$$

$$4I_3+40I_2=1 \quad \text{...(i)}$$ **(1)**

For loop $PRQP$,

$$-20I_3-60I_1+4=0$$

$$5I_3+15I_1=1 \quad \text{...(ii)}$$

Applying Kirchhoff's first law,

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

From Eqs. (i) and (iii), we have

$$\Rightarrow \quad 4I_1+44I_2=1$$

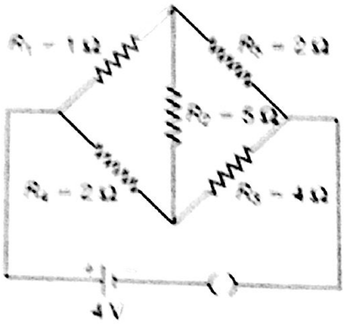
On solving, we get

$$I_1 = \frac{11}{172}\text{ A} = \frac{11000}{172}\text{ mA}$$

$$I_2 = \frac{4000}{215}\text{ mA},\ I_3 = \frac{30000}{860}\text{ mA}$$

$\therefore$ The reading in the milliammeter will be $\frac{11000}{172}$ mA **(1)**

18. 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.

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

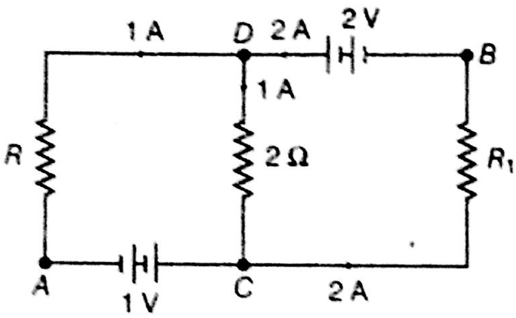
$$R = \frac{18}{9} = 2\,\Omega$$ **(1½)**

$\therefore$ $I = \frac{V}{R} = \frac{4}{2} = 2\text{A}$ or $I = 2\text{A}$ **(1/2)**

19. By Kirchhoff's first law at D,

$$I_{DC} + 1 = 2$$

$$I_{DC} = 1\text{A}$$



(1)

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

But $V_A = 0, V_B = 1 + 2 - 2 = 1\text{V}$

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

20. (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.

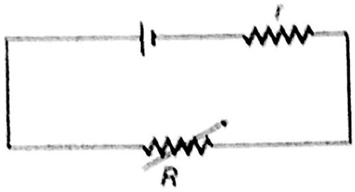
$\therefore$ Potential across AB = potential across EF

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

$$2I_2 = 2\text{A} \Rightarrow I_2 = 1\text{ A}$$ **(1)**

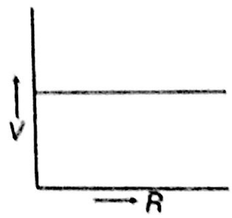
(ii) Potential across R = potential across AB
= potential across EF
$= 3 - 2 \times 0.5 = 2\text{V}$ **(1)**

21. From the following circuit and graph



(i) The value of potential difference corresponding to zero current gives the emf of cell. This value is 1.4 V. **(1)**

(ii) Maximum current is drawn from the cell when the terminal potential difference is zero. The current corresponding to zero value of terminal potential difference is 0.28 A. This is maximum value of current.



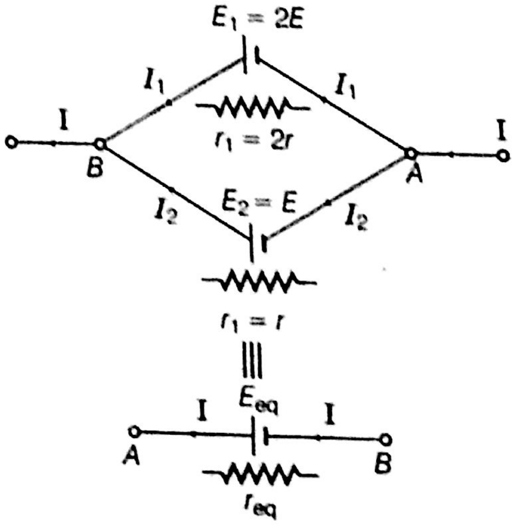
$\therefore$ $r = \frac{E}{I} = \frac{1.4}{0.28}\,\Omega;\ r = 5\,\Omega.$ **(1)**

22. Given, emf of first cell = $2E$, emf of second cell = E

Internal resistance of first cell = $2r$

Internal resistance of second cell = r

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



For cell I

$$V = V_A - V_B = 2E - I_1(2r)$$

$$\Rightarrow \quad I_1 = \frac{2E - V}{2r} \quad \text{...(ii)}$$

For cell II, $V = V_A - V_B = E - I_2 r$

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

$\because$ From Eqs. (ii) and (iii), substituting in Eq. (i), we get

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

On rearranging the term, we get

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

But for equivalent of combination,

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

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

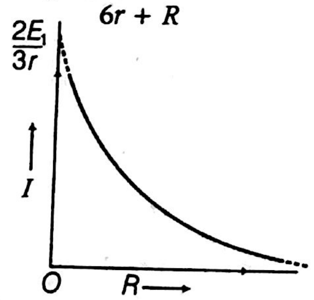
23. In these type of questions, we have to look out the connections of different cells, if the opposite terminals of all the cells are connected, then they support each other, i.e. these individual emfs are added up. If the same terminals of the cells are connected, then the equivalent emf is obtained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

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

Net resistance of current $= r + 2r + 3r + R = 6r + R$

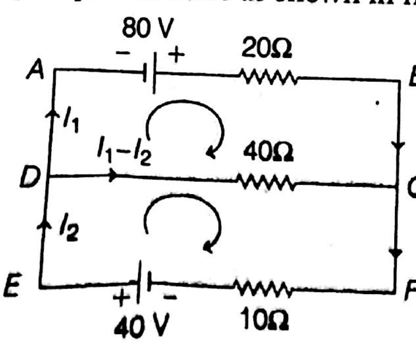
$\therefore$ Current, $I = \frac{V}{R}$ [from Ohm's law]

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



(1)

24. Taking loops clockwise as shown in figure.



(1)

Using KVL in $ABCDA$,

$$-80 + 20I_1 + 40(I_1 - I_2) = 0$$

$$\Rightarrow \quad 3I_1 - 2I_2 = 4 \quad \text{...(i)}$$

Using KVL in $DCFED$,

$$-40(I_1 - I_2) + 10I_2 - 40 = 0$$

$$\Rightarrow \quad -4I_1 + 5I_2 = 4 \quad \text{...(ii) (1)}$$

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

$$I_1 = 4\text{ A}$$

and $I_2 = 4$ A

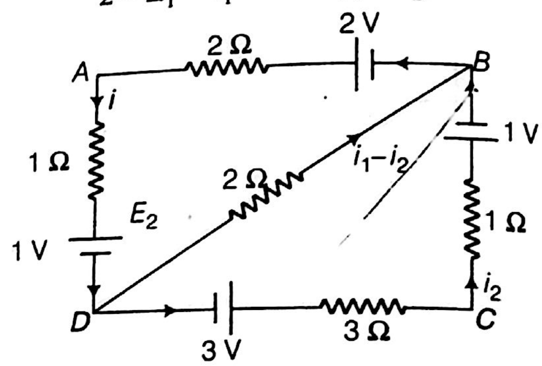
Thus, $I_{40} = I_1 - I_2 = 0$ A

$I_{20} = I_1 = 4$ A **(1)**

25. Refer to Sol. 22 **(3)**

26. Applying Kirchhoff's second law in loop $BADB$,

$$2 - 2i_1 - i_1 - 1 - 2(i_1 - i_2) = 0 \quad \text{...(i)}$$



(1)

Similarly, applying Kirchhoff's second law in loop $BDCB$,

$$2(i_1 - i_2) + 3 - 3i_2 - i_2 - 1 = 0 \quad \text{...(ii)}$$

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

$$i_1 = \frac{5}{13}\text{ A}, \; i_2 = \frac{6}{13}\text{ A}$$

and $i_1 - i_2 = -\frac{1}{13}$ A **(1)**

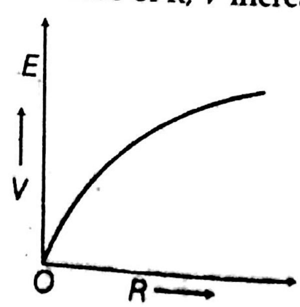
Potential difference between B and D,.

$$V_B + 2(i_1 - i_2) = V_D$$

$$\therefore \quad V_B - V_D = -2(i_1 - i_2) = \frac{2}{13}\text{ V} \quad \text{(1)}$$

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

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



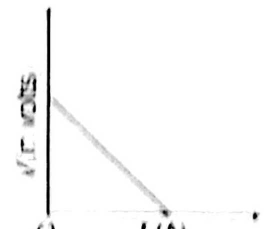
(1)

When $R = 4\ \Omega$ and $I = 1$ A.

We know that, terminal voltage, $V = E - Ir$

$\Rightarrow \quad V = IR = 4 = E - Ir$

$\Rightarrow \quad E - r = 4 \quad \text{...(i)} \quad \textbf{(1)}$



Graph between terminal voltage (V) and current (I)

When $R = 9\,\Omega$ and $I = 0.5$ A, then

$$V = IR = 0.5 \times 9 = E - 0.5r$$

$\Rightarrow \quad E - 0.5r = 4.5 \quad \text{...(ii)}$

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

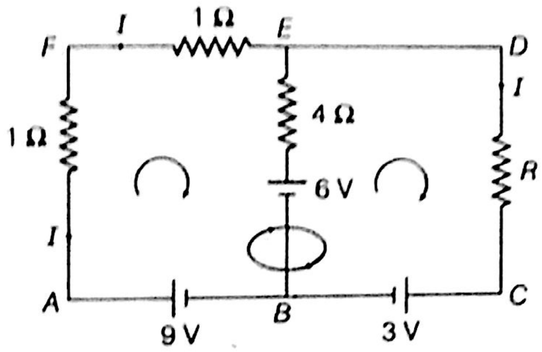
$r = 1\,\Omega$ and $E = 5$ V **(1)**

28. Applying Kirchhoff's second law in mesh $AFEBA$,

$$-1 \times I - 1 \times I - 6 + 9 = 0$$

$$-2I + 3 = 0$$

$$I = \frac{3}{2}\text{ A} \quad \text{...(i)}$$ **(1/2)**



(1/2)

Applying Kirchhoff's second law in mesh $AFDCA$,

$$-1 \times I - 1 \times I - I \times R - 3 + 9 = 0$$

$$-2I - IR + 6 = 0$$

$$2I + IR = 6 \quad \text{...(ii)}$$ **(1/2)**

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

$$\left(2 \times \frac{3}{2}\right) + \frac{3}{2}R = 6$$

$\Rightarrow \quad R = 2\,\Omega$ **(1/2)**

For potential difference across A and D along AFD,

$$V_A - \frac{3}{2} \times 1 - \frac{3}{2} \times 1 = V_D$$

$$V_A - V_D = 3\text{ V}$$ **(1)**

29. For BCD, equivalent resistance

$$R_1 = 5\,\Omega + 5\,\Omega = 10\,\Omega$$ **(1/2)**

Across BA, equivalent resistance R_2

$$\frac{1}{R_2} = \frac{1}{10} + \frac{1}{30} + \frac{1}{15}$$

$$= \frac{3 + 1 + 2}{30} = \frac{6}{30} = \frac{1}{5}$$ **(1/2)**

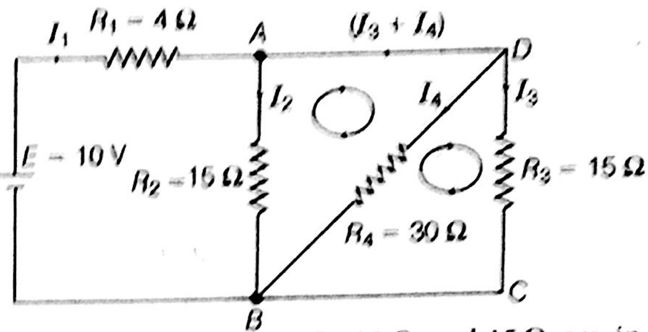
$\Rightarrow \quad R_2 = 5\,\Omega$

Potential difference between points A and B,

$$V_{BA} = I \times R_2 = 0.2 \times 5$$ **(1)**

$$V_{BA} = 1\text{ V} \Rightarrow V_{AB} = -1\text{ V}$$ **(1)**

30.



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

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

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

$\therefore \quad R_{eq} = 6\,\Omega$

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

(a) In mesh ADB,

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

$$I_2 = 2I_4$$

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

(b) In mesh BDC,

$$30I_4 - 15I_3 = 0$$

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

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

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

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

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

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

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

From Eq. (ii), we get

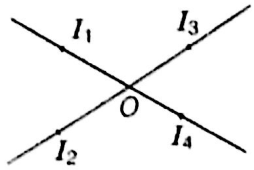
$$4\left(\frac{5}{2}I_2\right) + 15I_2 = 10$$

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

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

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

31. 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



$$\Rightarrow \quad \Sigma I = 0$$

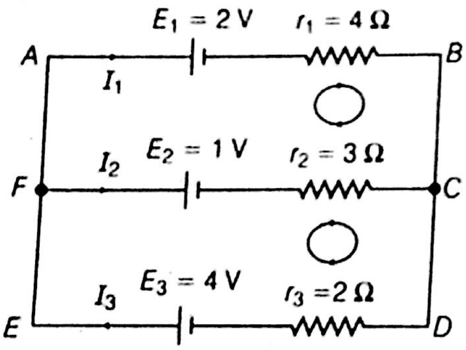
At junction O, $I_1 + I_2 = I_3 + I_4$ (1)

Kirchhoff's second rule or loop 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,

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

$$4I_1 - 3I_2 = -1 \quad \text{...(ii)}$$

In mesh FCDEF,

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

$$3I_2 + 2I_3 = 3 \quad \text{...(iii)}$$

On solving, I_1, I_2 and I_3, we get

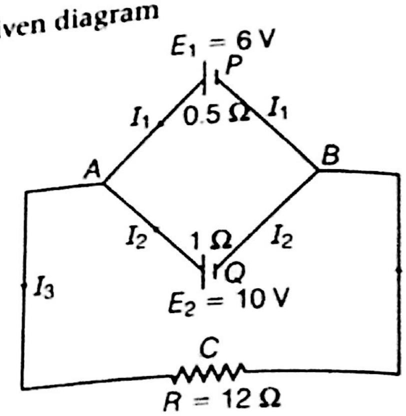
$$I_1 = \frac{2}{13}\text{ A}, \quad I_2 = \frac{7}{13}\text{ A}$$

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

(1)

32. For Kirchhoff's rules Refer to Sol. 31

The given diagram



(1½)

Applying Kirchhoff's second rule in loop ACBPA,

$$-12I_3 + 6 - 0.5I_1 = 0$$

$$5I_1 + 120I_3 = 60 \quad \text{...(i)}$$

In loop ACBQA, $-12I_3 + 10 - I_2 \times 1 = 0$

$$12I_3 + I_2 = 10 \quad \text{...(ii)}$$

Also kirchhoff's junction rule,

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

[Here, three equations are the expressions for I_1, I_2 and I_3]

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

$$I_1 = -\frac{84}{37}\text{ A} \Rightarrow I_2 = \frac{106}{37}\text{ A} \Rightarrow I_3 = \frac{22}{37}\text{ A}$$ (1½)

33. For statement of Kirchhoff's rules Refer to Sol. 31 (1)

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

$$I_3 = \frac{11}{172}\text{ A} = \frac{11000}{172}\text{ mA},$$

$$I_2 = \frac{4}{215}\text{ A} = \frac{4000}{215}\text{ mA}$$

and $$I_1 = \frac{39}{860}\text{ A} = \frac{39000}{860}\text{ mA}$$ (1)

34. The high resistance voltmeter means that no current will 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.

(1/2 × 2 = 1)

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)

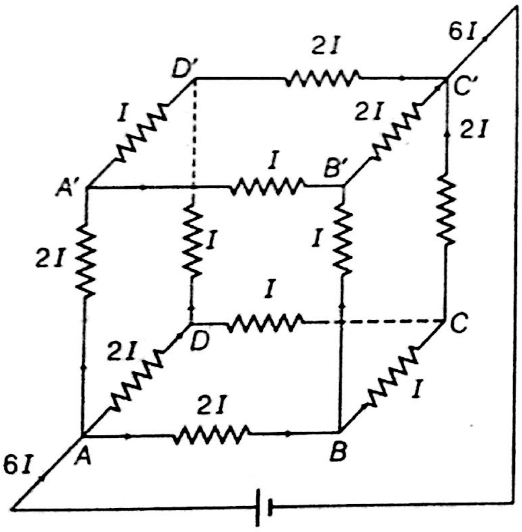
35. (i) **For kirchhoff's rules** Refer to Sol. 31

(1)

(ii) (a) Let $6I$ current be drawn from the cell. Since, the paths AA', AD and AB are symmetrical, current through them is same.

As per Kirchhoff's junction rule, the current distribution is shown in the figure.

(1)



Let the equivalent resistance across the combination be R.

$$E = V_A - V_B = (6I)\,R$$

$\Rightarrow \quad 6IR = 10 \qquad$ [given $E = 10\,\text{V}$] ...(i)

Applying Kirchhoff's second rule in loop $AA'B'C'A$,

$$-2I \times 1 - I \times 1 - 2I \times 1 + 10 = 0$$

$\Rightarrow \qquad 5I = 10$

$I = 2\text{A}$

Total current in the network = $6I$

$= 6 \times 2 = 12$ A

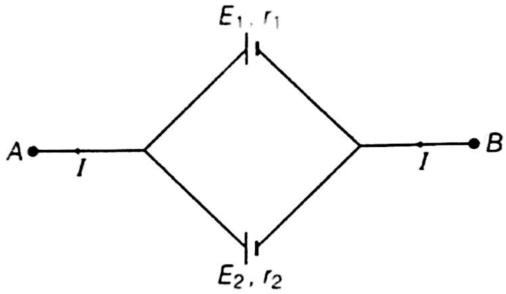
From Eq. (i), we get

$6IR = 10 \Rightarrow 6 \times 2 \times R = 10$

$R = \frac{10}{12} = \frac{5}{6}\,\Omega \Rightarrow R = \frac{5}{6}\,\Omega$

(b) The current through 2Ω resistor is 0.9 A. **(1)**

36. 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, $\qquad I = I_1 + I_2$

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

$$V = E - Ir \qquad \text{...(ii)}$$ **(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) $r = \dfrac{r_1 r_2}{r_1 + r_2}$

This is equivalent resistance of the combination.

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

$$V = E - Ir$$ **(1)**

37. No current flows through 4 Ω resistor as capacitor offers infinite resistance in DC circuits.

Also, 2Ω and 3Ω 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.

$$-1.2I - 2.8I + 6 = 0 \Rightarrow 4I = 6 \Rightarrow I = \frac{3}{2}\text{ A}$$ **(1½)**

$\therefore$ Potential difference across AB,

$$V_{AB} = IR_{AB} = \frac{3}{2}\times 1.2 = 1.8\text{ V}$$

$\therefore$ 3Ω and 2Ω are in parallel combination.

$\therefore$ Potential difference across 2Ω resistor is 1.8 V.

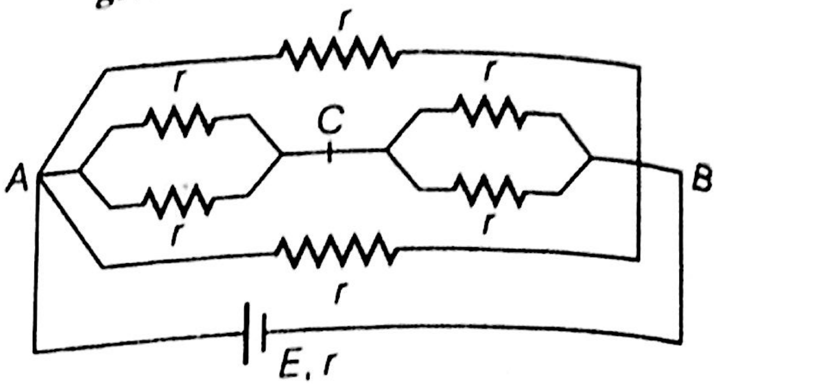
$\therefore$ Current I' through 2Ω resistor is given by

$$I' = \frac{V}{R} = \frac{1.8}{2} = 0.9\text{ A}$$

$$\Rightarrow \quad I' = 0.9\text{ A}$$ **(1½)**

38. (i) **For kirchhoff's rules** Refer to Sol. 31 on

(ii) (a) The circuit diagram can be redrawn as given below. **(2)**



(Equivalent circuit)

$$R_{AC} = \frac{r}{2};\ R_{CB} = \frac{r}{2}$$

$$\Rightarrow \quad \frac{1}{R_{AB}} = \frac{1}{r} + \frac{1}{r} + \frac{1}{r} = \frac{3}{r}$$

$$\Rightarrow \quad R_{AB} = \frac{r}{3}$$

Total resistance of circuit, $r = r + \dfrac{r}{3} = \dfrac{4r}{3}$

Current drawn from cell,

$$I = \frac{E}{4r/3} = \frac{3E}{4r}$$

(b) Power consumed $= I^2 r = \left(\dfrac{3E}{4r}\right)^2 r = \dfrac{9E^2}{16r^2}.r$

$$= \frac{9E^2}{16r}$$ **(3)**

Explanations

1. For same length and same radius, resistance of wire

$$R \propto \rho \quad [\text{where, } \rho = \text{resistivity}]$$

As, $\rho_{nichrome} > \rho_{copper}$

Hence, resistance of nichrome section is more. In series, same current flows through both sections and heat produced $= I^2Rt$. So, more heat is produced in nichrome section of wire. **(1)**

2. The potentiometer works on the principle that potential difference across any two points of a uniform current carrying conductor is directly proportional to the length between those two points. **(1)**

3. Given that, $P = 630$ W and $V = 210$ V, power

In DC source, $P = VI$

Therefore, $I = \frac{P}{V} = \frac{630}{210} = 3$ A **(1)**

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

where, signs are as usual. **(1)**

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

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

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

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)**

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

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

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

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)**

7. The resistance P_1 is $R_1 = \frac{V^2}{P_1}$

and that P_2 is $R_2 = \frac{V^2}{P_2}$

(i) In series, $R = R_1 + R_2$

$$\Rightarrow \quad I = \frac{V}{R} = \frac{V}{R_1 + R_2}$$

and $P = I^2 (R_1 + R_2)$

$$= \frac{V^2}{(R_1 + R_2)^2}(R_1 + R_2)$$

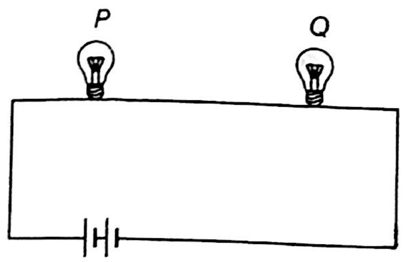
$$= \left(\frac{1}{\frac{R_1}{V^2} + \frac{R_2}{V^2}}\right) = \frac{1}{\frac{1}{P_1} + \frac{1}{P_2}} = \frac{P_1P_2}{P_1 + P_2}$$ **(1)**

(ii) In parallel, $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \Rightarrow \frac{V^2}{R} = \frac{V^2}{R_1} + \frac{V^2}{R_2}$ **(1)**

$$P = P_1 + P_2$$

8. Given, $\frac{R_P}{R_Q} = \frac{1}{2}$

$\therefore \quad R_Q = 2R_P \quad \dots \text{(i)}$



In series, power dissipated is given by the relation

$$P = I^2R$$

or $\quad P \propto R$ **(1)**

$\therefore \quad \frac{P_P}{P_Q} = \frac{R_P}{R_Q} \quad \dots \text{(ii)}$

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

$\therefore \quad \frac{P_P}{P_Q} = \frac{R_P}{2R_P} = \frac{1}{2}$ **(1)**

9. Given, $l_1 = 350 \text{ cm}, R = 9\,\Omega,$

$l_2 = 300 \text{ cm}, r = ?$

As we know that, internal resistance of a cell,

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

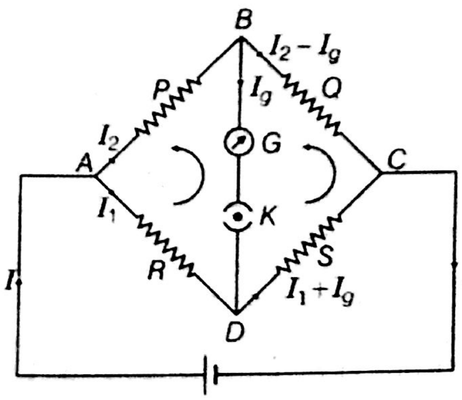
$$= \left(\frac{l_1}{l_2} - 1\right)R \qquad \left(\because \frac{\varepsilon}{V} = \frac{l_1}{l_2}\right)$$ **(1)**

$\therefore \quad r = \left(\frac{350}{300} - 1\right)9 = \frac{1}{6} \times 9 = \frac{3}{2}$

$\therefore \quad r = 1.5\,\Omega$ **(1)**

10. Applying Kirchhoff's loop law to close loop $ABDA$, we get $\quad I_1R - I_gG - I_2P \quad \dots \text{(i)}$

Consider the diagram



Here, G is the resistance of the galvanometer. **(1)**

Applying Kirchhoff's loop law in the closed loop $BDCB$, we get

$$I_gG + (I_1 + I_g)S - (I_2 - I_g)Q = 0 \quad \dots \text{(ii)}$$

When the Wheatstone bridge is balanced, no current flows through the galvanometer,

i.e. $\quad I_g = 0$

$\therefore$ From Eq. (i), we get

$$I_1R - I_2P = 0 \Rightarrow I_1R = I_2P$$

$$\Rightarrow \quad \frac{I_1}{I_2} = \frac{P}{R} \quad \dots \text{(iii)}$$

Similarly, from Eq. (ii), we get

$$I_1S - I_2Q = 0$$

$$\Rightarrow \quad I_1S = I_2Q \Rightarrow I_1/I_2 = Q/S \quad \dots \text{(iv)}$$

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

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

This is the required balance condition in a Wheatstone bridge arrangement. **(1)**

11. (i) Refer to Sol. 2 **(1)**

(ii) Here, $AB = 1\text{m}, R_{AB} = 10\Omega,$

Potential gradient, $k = ?, AO = l = ?$

Current passing through AB,

$$I = \frac{2}{15 + R_{AB}} = \frac{2}{15+10} = \frac{2}{25}\text{A}$$

$$\therefore V_{AB} = I \times R_{AB} = \frac{2}{25} \times 10 = \frac{4}{5}\text{V}$$

$$\therefore \quad k = \frac{V_{AB}}{AB} = \frac{4}{5}\text{Vm}^{-1}$$

Current in the external circuit,

$$I' = \frac{1.5}{1.2 + 0.3} = \frac{1.5}{1.5} = 1\text{ A}$$

For no deflection in galvanometer,

Potential difference across $AO = 1.5 - 1.2I'$

$$\Rightarrow \quad k(l) = 1.5 - 1.2 \times I' \Rightarrow \frac{4}{5}l = 0.3$$

or $\quad l = \frac{0.3 \times 5}{4} = 0.375\text{m}$

$\therefore \quad l = 37.5\text{cm}$ **(1)**

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

Resistance, $R = 10\,\Omega$

emf of a battery, $\quad E_1 = 6 \text{ V},$

$R_1 = 5\,\Omega$ and $x = 40$ cm

$$\therefore \text{Current, } I = \frac{E_1}{R + R_1} = \frac{6}{10+5} = \frac{6}{15}\text{ A}$$ **(1/2)**

$$V_{AB} = IR = \frac{6}{15} \times 10 = \frac{60}{15} = 4\text{ V}$$ **(1/2)**

$\therefore$ emf of the primary cell

$$= \frac{V_{AB}}{l} \times x = \frac{4}{100} \times 40$$

$$= 1.6 \text{ V} \quad \textbf{(1)}$$

Or **Ans.** 1.2V. **(2)**

Or **Ans.** 2.25 V. **(2)**

13. In closed mesh $ABCDA$.

$$I_1 r_1 + (I_1 + I_2) R = 12 \Rightarrow 2I_1 + 4(I_1 + I_2) = 12$$

$$2I_1 + 4I_1 + 4I_2 = 12 \Rightarrow 6I_1 + 4I_2 = 12$$

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

In closed mesh $BCFEB$,

$$(I_1 + I_2)R = 6 \Rightarrow (I_1 + I_2)4 = 6$$

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

On solving Eqs. (i) and (ii), we get, $I_1 = 3\text{A}$

$\therefore$ Putting the value of I_1 in Eq. (i), we get

$$3 \times 3 + 2I_2 = 6$$

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

$\therefore$ Net current in arm BC

$$= I_1 + I_2 = 3 - 1.5 = +1.5\text{A}$$

$\therefore$ Power consumed by 4Ω resistance

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

$$= 225 \times 4 = 9 \text{ W} \quad \textbf{(2)}$$

14. (i) To measure current upto 5A, the shunt S should have a value, such that for 5A input current through system, 4A should pass through shunt S and 1 A should pass through given ammeter.

$$1 \times R_A = 4S$$

$$\Rightarrow \quad 1 \times 0.8 = 4S$$

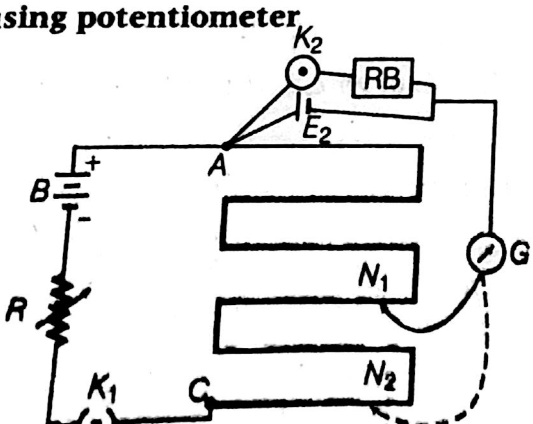
$$\Rightarrow \quad S = 0.2\,\Omega$$

Thus, the shunt resistance is $0.2\,\Omega$. **(1)**

(ii) Combined resistance of the ammeter and the shunt,

$$R = \frac{0.8S}{0.5 + S} = \frac{0.8 \times 0.2}{0.8 + 0.2} = \frac{0.16}{1} = 0.16\Omega. \quad \textbf{(1)}$$

15. 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.

$$E = \phi\, l_1 \quad \text{...(i)}$$

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

$$V = \phi\, l_2$$

$\therefore$ ...(ii)

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

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

$$E = I(r + R) \text{ and } V = IR$$

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

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

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

$$\Rightarrow \quad \frac{r}{R} = \frac{l_1}{l_2} - 1$$

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

We known l_1, l_2 and R, so we can calculate r. **(1)**

16. (i) The balancing condition states that

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

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

When both X and R 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 will continued to be balanced and hence no change occur in the balance point. **(1)**

17. End errors The end error in meter bridge arises due to the following reasons

(a) The zero mark of the scale provided along the bridge wire may not start from the position where the bridge wire leaves the will copper strip and 100cm mark of the scale may not be at position, where the bridge wire just touches the other copper strip.

(b) The resistances of connecting wire and copper strips of meter bridge have not been taken into account. It can be removed by repeating the experiment by interchanging the known and unknown resistances and by taking the mean of resistances determined. **(1½)**

In first case,

$$\frac{5}{l_1} = \frac{S}{100 - l_1} \quad ...(i)$$

In second case,

new resistance becomes, $S' = \frac{S}{2}$ (parallel)

$$\frac{5}{1.5 l_1} = \frac{\frac{S}{2}}{(100 - 1.5 l_1)} \quad ...(ii)$$

Divide Eq. (i) by Eq. (ii), we get

$$1.5 = \frac{2(100 - 1.5 l_1)}{(100 - l_1)}$$

$$\Rightarrow \quad 150 - 1.5 l_1 = 200 - 3 l_1$$

$$\Rightarrow \quad l_1 = \frac{50}{1.5} = \frac{100}{3} \text{ m}$$

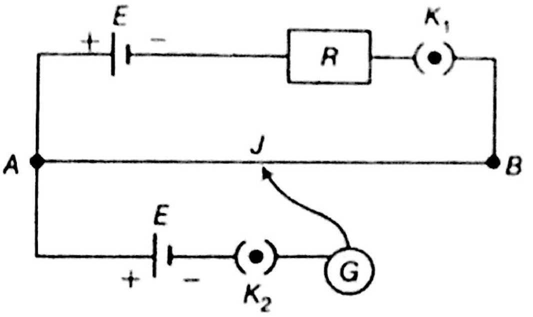
From Eq. (i), we get

$$S = \frac{5(100 - l_1)}{l_1} = \frac{5\left(100 - \frac{100}{3}\right)}{\frac{100}{3}} = 10\ \Omega$$

(1½)

18. 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,

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

where, R = resistance

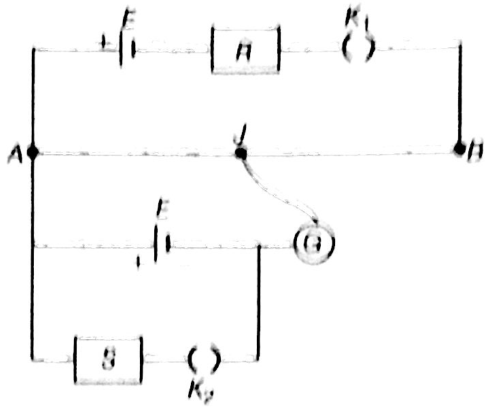
$$E = IR$$

$$\Rightarrow \quad I = E/R$$

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. **(1½)**

(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), we get

$$E = RI \Rightarrow I = E/R$$

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. **(1½)**

19. Total resistance of the circuit $= \frac{R_0}{2} + R_{eq}$

$$\frac{1}{R_{eq}} = \frac{1}{R} + \frac{2}{R_0} = \frac{R_0 + 2R}{RR_0} \Rightarrow R_{eq} = \frac{RR_0}{R_0 + 2R} \quad \textbf{(1)}$$

Total resistance

$$= \frac{R_0}{2} + \frac{RR_0}{R_0 + 2R} = \frac{R_0^2 + 2RR_0 + 2RR_0}{2(R_0 + 2R)} = \frac{R_0^2 + 4RR_0}{2(R_0 + 2R)}$$

Current in the circuit $I = \dfrac{V}{\dfrac{R_0^2 + 4RR_0}{2(R_0 + 2R)}} = \dfrac{2V(R_0 + 2R)}{R_0^2 + 4RR_0}$ **(1)**

Current in $RI = \dfrac{2V(R_0 + 2R)}{(R_0^2 + 4RR_0)} \times \dfrac{R_0/2}{(R + R_0/2)}$

$$= \frac{V(R_0 + 2R)}{(R_0^2 + 4RR_0)} \times \frac{2R_0}{(2R + R_0)} = \frac{2VR_0}{(R_0^2 + 4RR_0)}$$

Potential difference across R,

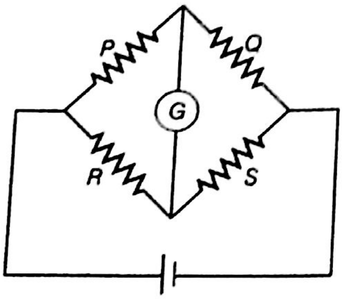
$$V_R = \frac{2V R_0 R}{(R_0^2 + 4RR_0)} = \frac{2VR}{(R_0 + 4R)} \quad \textbf{(1)}$$

20. (i) Heat produced per second $= I^2R = V^2/R$
So, when voltage is made three times, heat produced increase nine times for same R. **(1½)**

(ii) Current in the circuit is $I = \dfrac{E}{R + r} = \dfrac{12}{4 + 2} = 2\text{ A}$

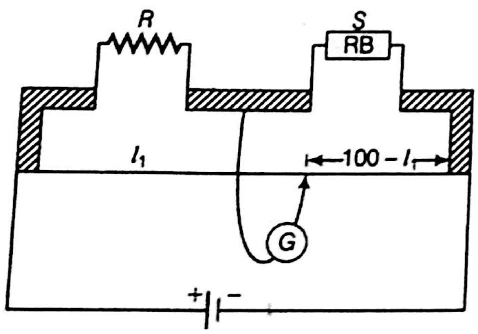
Also, terminal voltage across the cell,
$V = E - Ir = 12 - 2 \times 2 = 8\text{ V}$
So, ammeter reading = 2 A
and voltmeter reading = 8 V **(1½)**

21. (i) A meter bridge is based upon principle of Wheatstone's bridge.



Under balance ($I_g = 0$) condition, $\frac{P}{Q} = \frac{R}{S}$

In case of a metre bridge, resistance R and S are taken in form of a wire.



In balance condition, $\frac{R}{l_1} = \frac{S}{100 - l_1}$ **(1½)**

(ii) In given metre bridge, initially

$$R/l_1 = S/100 - l_1 \quad \ldots(i)$$

When a resistance X is placed in parallel with S, then net resistance in gap = $SX/S + X$

So, in balance (with S and X are in parallel),

$$\frac{R}{l_2} = \frac{(SX/S+X)}{100 - l_2} \quad \ldots(ii)$$

Substitute the value of R from Eq. (i) to Eq. (ii), we get

$$\frac{l_1}{l_2(100 - l_1)} = \frac{X}{(S+X)(100 - l_2)}$$

$$\Rightarrow \quad S + X = X\left\{\frac{l_2(100 - l_1)}{l_1(100 - l_2)}\right\}$$

$$\Rightarrow \quad \frac{S}{X} + 1 = \frac{l_2(100 - l_1)}{l_1(100 - l_2)}$$

$$\Rightarrow \quad \frac{S}{X} = \frac{l_2(100 - l_1) - l_1(100 - l_2)}{l_1(100 - l_2)}$$

$$\Rightarrow \quad X = \frac{Sl_1(100 - l_2)}{100(l_2 - l_1)}\ \Omega$$ **(1½)**

22. (i) The connections between the resistors in a meter bridge are made of thick copper strips because of their negligible resistance. **(1)**

(ii) It is 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. **(1)**

(iii) Alloy, manganin or constantan are used for making meter bridge wire due to low temperature coefficient of resistance and high resistivity. **(1)**

23. (i) **Principle of Potentiometer** Refer to Sol. 2 **(1)**

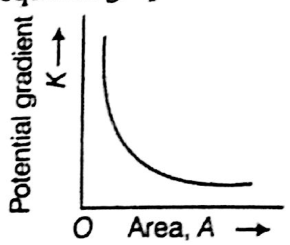
(a) We use a long wire to have a lower value of potential gradient (i.e a lower "least count" or greater sensitivity of the potentiometer.

(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. **(1)**

(ii) Potential gradient, $K = V/L = IR/L = I\rho/A$

$\therefore$ The required graph is as shown below



(1)

24. (i) Let potential gradient be K.

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

(cells are connected in opposite order)

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

(cells are connected in supporting order) **(1)**

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

Now, apply componendo and dividendo

$$\frac{(E_1 + E_2) + (E_1 - E_2)}{(E_1 + E_2) - (E_1 - E_2)} = \frac{5+2}{5-2} \Rightarrow \frac{E_1}{E_2} = \frac{7}{3}$$ **(1/2)**

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

From Eq. (i), we get

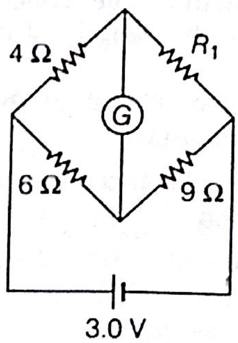
$$E_1 - \frac{3}{7}E_1 = K \times 120, \quad \frac{4}{7}E_1 = K \times 120$$

$$E_1 = K \times 120 \times \frac{7}{4} \Rightarrow E_1 = K \times 210$$

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)**

25. Current sensitivity of a galvanometer is defined as the deflection produced in galvanometer per unit current flowing through it. Its SI unit is rad/amp.

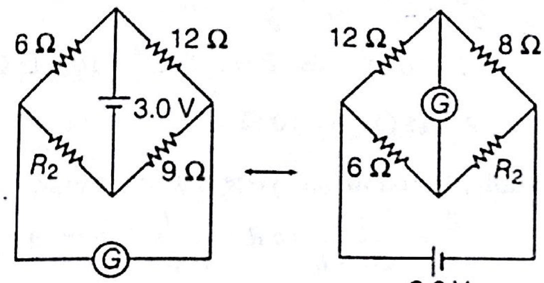


(1)

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

$$\frac{4}{R_1} = \frac{6}{9}$$

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



(1)

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

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

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

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

(1)

26. For principle, Refer to Sol. 2 (1)

The two factors on which the sensitivity of a potentiometer depends are

(a) the value of potential gradient (K). (1/2)

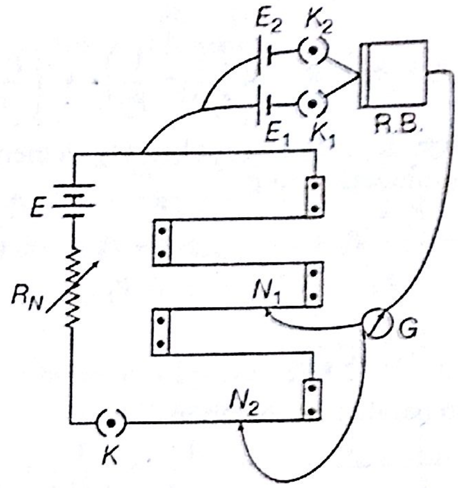
(b) by increasing the length of potentiometer wire.

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. (1)

(ii) if S is increased, keeping R constant, the position of J will shift towards A. (1/2)

27. 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, $$\frac{E_1}{E_2} = \frac{kl_1}{kl_2} = \frac{l_1}{l_2}$$

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

(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.

28.

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

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

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

(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.

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

$$P_s = \frac{P_1 P_2}{P_1 + P_2}$$ (1)

(ii) In parallel combination,

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

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

Now, power consumption in parallel combination

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

$$P_p = P_1 + P_2$$ (1)

29. 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,

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

$$R/S = 2/3$$ ...(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

$$\frac{R}{(12S/12 + S)} = \frac{50}{50} = 1$$ (1/2)

$$\Rightarrow \quad R = \frac{12S}{12 + S}$$ ...(ii)

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

$$\frac{2}{3}S = \frac{12S}{12 + S}$$

$$12 + S = 18 \Rightarrow S = 6\Omega$$

$$R = \frac{2}{3}S = \frac{2}{3} \times 6 = 4\Omega$$

$$R = 4\Omega$$ (1)

30. Refer to Sol. 15 (1½)

The sensitivity of a potentiometer can be increased by reducing the potential gradient. The potential gradient can be reduced by

(i) increasing the length of the potentiometer wire

(ii) reducing the current in the circuit with the help of a rheostat. (1½)

31. The condition of balanced meter bridge

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

$$\frac{R}{S} = \frac{3}{2}$$ ...(i) (1)

Again, applying the condition, when S and 5Ω are connected in series

$$\frac{R}{S + 5} = \frac{50}{50} \Rightarrow \frac{R}{S + 5} = 1$$ ...(ii) (1)

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

$$\frac{3}{2}S = S + 5 \Rightarrow \frac{3}{2}S - S = 5$$

$$S = 10\,\Omega \Rightarrow R = \frac{3}{2}S = \frac{3}{2} \times 10 = 15\,\Omega$$

$$R = 15\,\Omega, \; S = 10\,\Omega$$ (1)

32. Initially, for balanced Wheatstone bridge,

$$\frac{R}{S} = \frac{l_1}{100 - l_1} \Rightarrow R = \frac{l_1}{100 - l_1}S$$ ...(i) (1)

When X is connected in parallel with S, then

$$\left(\frac{R}{SX/S + X}\right) = \frac{l_2}{(100 - l_2)}$$ (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)]

$$\frac{X}{S + X} = \left(\frac{l_1}{l_2}\right)\left(\frac{100 - l_2}{100 - l_1}\right)$$

$$\frac{S + X}{X} = \left(\frac{l_2}{l_1}\right)\left(\frac{100 - l_1}{100 - l_2}\right)$$

$$\frac{S}{X} + 1 = \frac{l_2(100 - l_1)}{l_1(100 - l_2)}$$

$$\Rightarrow \quad \frac{S}{X} = \frac{l_2}{l_1}\left(\frac{100 - l_1}{100 - l_2}\right) - 1$$

$$\frac{S}{X} = \frac{100(l_2 - l_1)}{l_1(100 - l_2)} \Rightarrow X = \frac{l_1(100 - l_2)}{100(l_2 - l_1)}S$$ (1)

33. (a) Refer to Sol. 15 **(2)**
(To Measure Internal Resistance of a Cell)
(b) Refer to Sol. 35 (ii) **(1)**
(c) $I_{AB} = \frac{5}{450+50} = \frac{5}{500} = \frac{1}{100}$ A

$$V_{AB} = I_{AB}R_{AB} = \frac{1}{100} \times 50 = \frac{1}{2} = 0.5\text{V}$$

Potential gradient,

$$K = \frac{V_{AB}}{L} = \frac{0.5}{10}$$

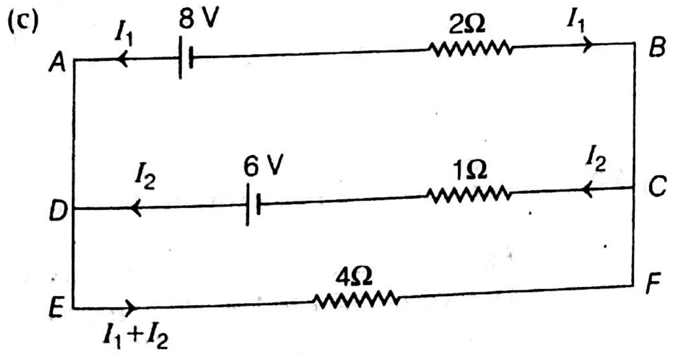
Balancing length,

$$l = \frac{\text{Potential difference}}{\text{Potential gradient}}$$

$$= \frac{300 \times 10^{-3} \times 10}{0.5} = 6\text{ m}$$

If the driver cell of emf 5V is replaced by a cell of 2V keeping all other factor constant, then potential drop across AB is 0.2 V.
The balancing point cannot be obtained on the potentiometer, if the fall of potential along the potentiometer wire due to the auxiliary battery is less than the emf of the cell to be measured. **(2)**

34. (a) Refer to Sol. 21 (i)
(Principle of Meter Bridge) **(2)**
(b) (i) and (ii) Refer to Sol. 22 (i) and (ii) on page 116. **(1)**
(c)



For loop $ADCBA$,

$$-2I_1 + 8 - 6 + I_2 = 0$$

$$I_2 - 2I_1 = -2 \quad \text{...(i)}$$

For loop $DEFCD$,

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

$$\Rightarrow \quad -4I_1 - 5I_2 = -6$$

or $$4I_1 + 5I_2 = 6 \quad \text{...(ii)}$$

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

$$7I_2 = 2$$

$$\Rightarrow \quad I_2 = \frac{2}{7}\text{ A}$$

By Eq. (i)

$$I_1 = \frac{8}{7}\text{ A}$$

Current through 4 Ω resistor,

$$I_1 + I_2 = \frac{10}{7}$$

∴ Potential difference,

$$V = IR = \frac{10}{7} \times 4 = \frac{40}{7}\text{ V}$$ **(2)**

35. (i) As per the figure, total current through the wire AB is given by, $I = E/R+r = 2/R+15$

The potential gradient of the wire is given by

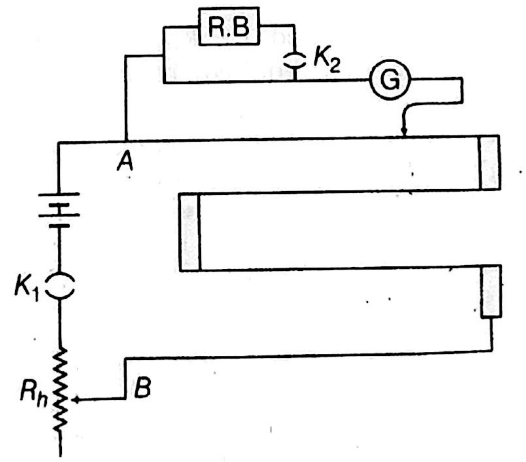
$$K = I \times \frac{15}{100} = \frac{2}{R+15} \times \frac{15}{100}$$

As, the balance point with cell E_2 of emf 75 mV is found at 30 cm from end A

$$\frac{2}{R+15} \times 0.15 \times 30 = 75 \times 10^{-3}$$

$$\left(\frac{2}{75 \times 10^{-3}} \times 0.15 \times 30\right) - 15 = R \Rightarrow R = 105\Omega$$ **(2)**

(ii) Potentiometer is preferred over a voltmeter for comparison of emf of cells because at null point, it does not draw any current from the cell and thus there is no potential drop due to the internal resistance of the cell. It measures the potential difference in an open circuit which is equal to the actual emf of the cell.
(iii) Measuring internal resistance of a cell in the laboratory.

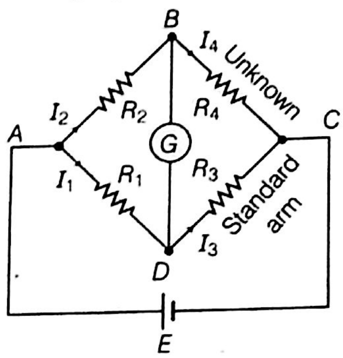


(3)

36. (i) **Working principle of potentiometer**
Refer to Sol. 2
For derivation Refer to Sol. 27 **(3)**
(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. **(1)**
(b) The positive ends of all cells are not connected to the same end of the wire. **(1)**

37. (i) Refer to Sol. 31

Wheatstone Bridge The Wheatstone bridge is an arrangement of four resistances as shown in the following figure.



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, $I_2 = I_4$

Applying junction rule at D, $I_1 = I_3$

Applying loop rule to closed loop $ADBA$,

$$-I_1 R_1 + 0 + I_2 R_2 = 0$$

$$\therefore \quad I_1/I_2 = R_2/R_1 \quad \text{...(i)}$$

Applying loop rule to closed loop $CBDC$,

$$I_2 R_4 + 0 - I_1 R_3 = 0$$

$$\because \quad I_3 = I_1 \Rightarrow I_4 = I_2$$

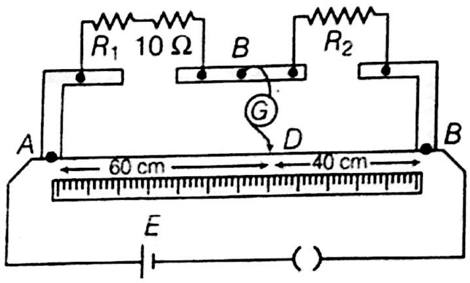
$$\therefore \quad I_1/I_2 = R_4/R_3 \quad \text{...(ii)}$$

From Eqs. (i) and (ii), $R_2/R_1 = R_4/R_3$

This is the required balanced condition of Wheatstone bridge. **(2½)**

(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), we get

$$\frac{2}{3} + \frac{10}{R_2} = \frac{3}{2}$$

$$\Rightarrow \quad R_2 = 12\,\Omega$$

Recalling Eq. (i) again,

$$\frac{R_1}{12} = \frac{2}{3} \Rightarrow R_1 = 8\,\Omega$$ **(2½)**

38. (i) The balance condition is for details refer to Sol. 37(i)

$$P/Q = R/S \Rightarrow P/R = Q/S$$ **(1)**

(ii) Let a carbon resistor S is given to the bridge

$$\Rightarrow \quad R/S = 1 \Rightarrow R = S = 22 \times 10^3\,\Omega$$ **(1)**

(iii) After interchanging the resistances the balanced bridge would be

$$\frac{2R}{X} = \frac{2 \times 10^3}{2 \times 22 \times 10^3} = \frac{1}{2}$$

$$\Rightarrow \quad X = 4R = 4 \times 22 \times 10^3 = 88\,\text{k}\Omega$$ **(1)**

Thus, equivalent resistances of Wheatstone bridge

$$\frac{1}{R_{eq}} = \frac{1}{3R} + \frac{1}{6R} = \frac{3}{6R} \Rightarrow R_{eq} = 2R$$ **(1)**

$\therefore$ Current through it $I = \frac{1}{3} \times \frac{V}{2R} = \frac{V}{6R}$ A **(1)**

39. (i) **For working principle of potentiometer** Refer to Sol. 2 **(1½)**

For circuit diagram to compare emf of two cells Refer to Sol. 27 **(1½)**

(ii) Constantan or manganin (alloy) as they have low temperature coefficient of resistance. **(1)**

(iii) The sensitivity of potentiometer can be increased by increasing the number of wires of potentiometer and hence, decreasing the value of potential gradient. **(1)**

40. (i) Refer to Sol. 21 **(3)**

(ii) Refer to Sol. 16 (ii) **(1)**

(iii) It is because of the fact that meter bridge is most sensitive when null point occur near the mid-point of wire and all the four resistances are of same order. **(1)**

33. (a) Refer to Sol. 15
(To Measure Internal Resistance of a Cell) **(2)**

(b) Refer to Sol. 35 (ii) on page 119. **(1)**

(c) $I_{AB} = \frac{5}{450 + 50} = \frac{5}{500} = \frac{1}{100}$ A

$V_{AB} = I_{AB}R_{AB} = \frac{1}{100} \times 50 = \frac{1}{2} = 0.5$ V

Potential gradient,

$$K = \frac{V_{AB}}{L} = \frac{0.5}{10}$$

Balancing length,

$$l = \frac{\text{Potential difference}}{\text{Potential gradient}}$$

$$= \frac{300 \times 10^{-3} \times 10}{0.5} = 6\text{ m}$$

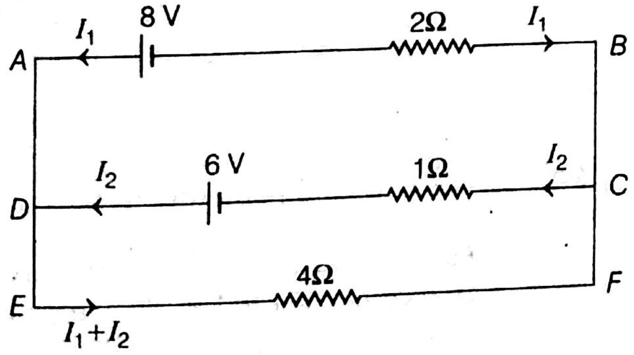
If the driver cell of emf 5V is replaced by a cell of 2V keeping all other factor constant, then potential drop across AB is 0.2 V.

The balancing point cannot be obtained on the potentiometer, if the fall of potential along the potentiometer wire due to the auxiliary battery is less than the emf of the cell to be measured. **(2)**

34. (a) Refer to Sol. 21 (i)
(Principle of Meter Bridge) **(2)**

(b) (i) and (ii) Refer to Sol. 22 (i) and (ii) on page 116. **(1)**

(c)



For loop $ADCBA$,

$$-2I_1 + 8 - 6 + I_2 = 0$$

$$I_2 - 2I_1 = -2 \quad \text{...(i)}$$

For loop $DEFCD$,

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

$\Rightarrow$ $$-4I_1 - 5I_2 = -6$$

or $$4I_1 + 5I_2 = 6 \quad \text{...(ii)}$$

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

$$7I_2 = 2$$

$\Rightarrow$ $$I_2 = \frac{2}{7}\text{ A}$$

By Eq. (i)

$$I_1 = \frac{8}{7}\text{ A}$$

Current through 4 Ω resistor,

$$I_1 + I_2 = \frac{10}{7}$$

$\therefore$ Potential difference,

$$V = IR = \frac{10}{7} \times 4 = \frac{40}{7}\text{ V}$$ **(2)**

35. (i) As per the figure, total current through the wire AB is given by, $I = E/R + r = 2/R+15$

The potential gradient of the wire is given by

$$K = I \times \frac{15}{100} = \frac{2}{R+15} \times \frac{15}{100}$$

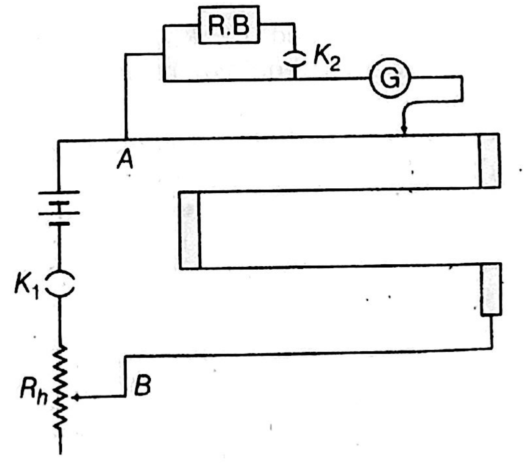
As, the balance point with cell E_2 of emf 75 mV is found at 30 cm from end A

$$\frac{2}{R+15} \times 0.15 \times 30 = 75 \times 10^{-3}$$

$$\left(\frac{2}{75 \times 10^{-3}} \times 0.15 \times 30\right) - 15 = R \Rightarrow R = 105\Omega$$ **(2)**

(ii) Potentiometer is preferred over a voltmeter for comparison of emf of cells because at null point, it does not draw any current from the cell and thus there is no potential drop due to the internal resistance of the cell. It measures the potential difference in an open circuit which is equal to the actual emf of the cell.

(iii) Measuring internal resistance of a cell in the laboratory.



(3)

36. (i) **Working principle of potentiometer**
Refer to Sol. 2
For derivation Refer to Sol. 27 **(3)**

(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. **(1)**

(b) The positive ends of all cells are not connected to the same end of the wire. **(1)**