Explanations

1. current **(1)**

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

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

where, e = charge on electron, m = mass of electron 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)**

3. Average drift velocity is given by

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

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

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

where, τ = relaxation time.

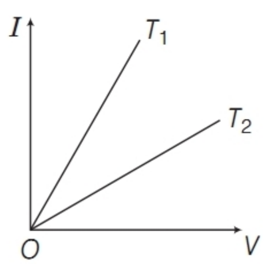
The relaxation time is directly proportional to the temperature of conductor i.e.

$$\tau \propto T$$

$$\therefore \quad v_d \propto T$$

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

5. Consider the figure,



Since, slope of 1 > slope of 2.

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

$$\therefore \quad R_2 > R_1$$

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

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

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

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

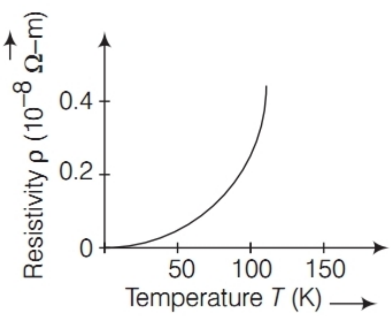
(ii) BC is the region where Ohm's law is obeyed, because in this part the current varies linearly with the voltage. **(1/2)**

7. 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.

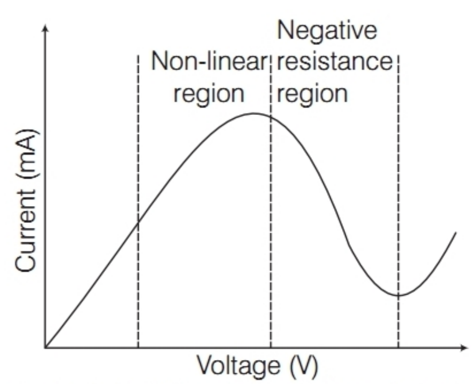
From the above relation, we can say that the graph between resistivity of a conductor with temperature is straight line. But, at temperatures much lower than 273 K (i.e. 0°C) the graph deviates considerably from a straight line as shown in the figure.



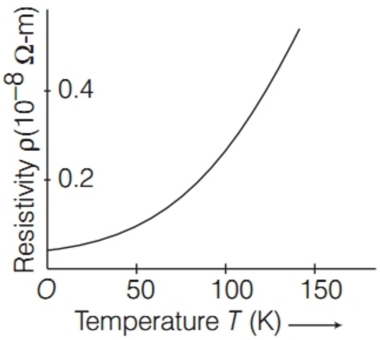
(1)

8. 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 i.e. a potential difference is applied across its ends, then 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)**

9. Variation of current *versus* voltage for the material GaAs is as follows **(1)**



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



11. **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)**

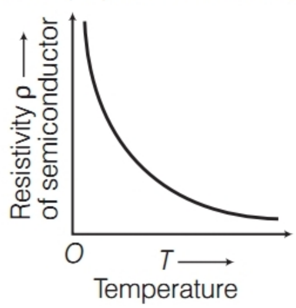
Its **relationship is expressed** as $v_d = \frac{I}{neA}$

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

12. The electrical conductivity (σ) of a metallic wire is defined as the ratio of the current density to the electric field that it creates. Its SI unit is mho per metre $(\Omega\text{-m})^{-1}$. **(1)**

13. The resistivity of a semiconductor decreases exponentially with the temperature.

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



14. 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 $ms^{-1}\ N^{-1}\ C^{-1}$. **(1/2)**

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

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

$$I = Anev_d \Rightarrow V/R = Anev_d$$

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

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 the resistance increases and hence, drift velocity decreases. **(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. 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, $l' = 3l$

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)**

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

20. Refer to Sol. 7 on page 87. **(1)**

21. The resistivity of the material of a 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. As we know that, $I = neAv_d$

Also, current density J is given by

$$J = I/A \quad \textbf{(1)}$$

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

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

(1)

23. 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)**

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

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

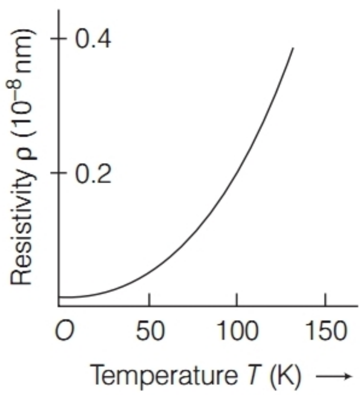
Or

Ans. $= 5 \times 10^{-4} \text{m/s}$ **(2)**

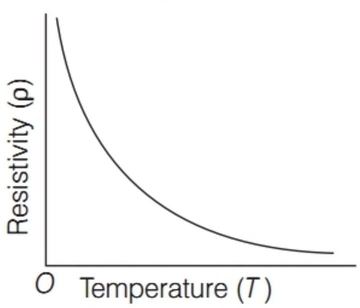
Or

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

24. (i) **For conductor**



(ii) **For semiconductor**



(1)

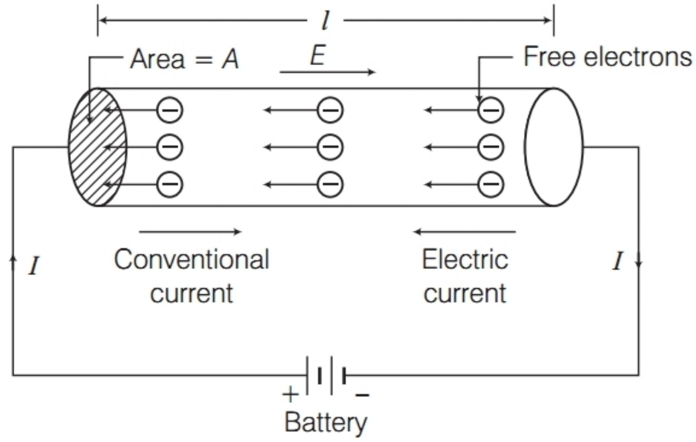
The relation between resistivity and relaxation time, $\rho = \dfrac{m}{ne^2\tau}$

In conductors the 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, resulting in a decrease in resistivity. **(1)**

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

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



Let n = number density of free electrons

A = cross-sectional area of conductor

e = electronic charge.

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

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

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

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

$$t = l / v_d \quad \text{...(ii)}$$ **(1/2)**

where, v_d = drift speed of electron.

$\therefore$ Current through the conductor [from Eqs. (i) and (ii)]

$$I = q/t$$

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

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

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

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

26. 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.

$$\therefore \quad \mu = v_d / E \quad \text{...(i)}$$

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

Drift velocity in term of relaxation time is

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

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

$$\mu = \frac{e\tau}{m} \quad \text{[From Eq. (i)]}$$ **(1)**

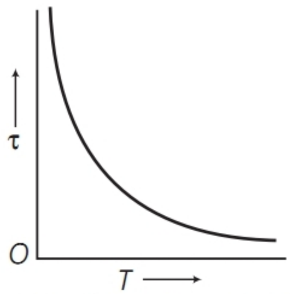
27. To plot the graph between the two quantities, first of all identify the relation between them.

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

where, n = number density of electrons

and τ = relaxation time.

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



Resistivity of a semiconductor decreases rapidly with temperature **(1)**

28. Refer to Sol. 24 on page 89. **(3)**

29. (i) **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)**

(ii) We know that, the drift velocity is given by

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

where, e = electronic charge,

E = applied electric field,

τ = relaxation time

and m = mass of electron.

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

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

From the relation between current and drift velocity,

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

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

But according to Ohm's law,

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

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

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

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

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 the current density, $J = \frac{I}{A}$

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

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

30. (i) **Drift velocity** Refer to Sol. 11 on page 88. **(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 $R = \rho(l/A)$

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

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, $\rho = (ml/ne^2 A\tau)\cdot(A/l)$

$\therefore$ 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 materials. So, resistivity of a conductor depends on the nature of the materials.

(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 i.e. temperature increases τ decreases and 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)**

31. When a conductor is subjected to an electric field $\mathbf{E}$, then each electron experiences a force

$\mathbf{F} = -e\mathbf{E}$ 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 $\mathbf{E}$ = 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

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

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

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

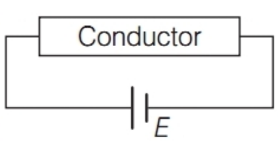
$$\mathbf{v}_d = \frac{(\mathbf{u}_1 + \mathbf{u}_2 + ... + \mathbf{u}_n)}{n} + \frac{\mathbf{a}(\tau_1 + \tau_2 + ... + \tau_n)}{n}$$

$\mathbf{v}_d = 0 + \mathbf{a}\tau$ [$\because$ 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)**

32. 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)**

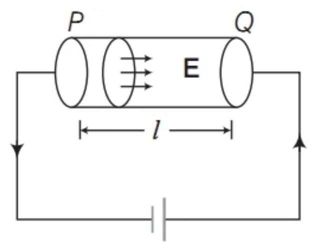
(i) Relationship between current (I) and velocity (v_d) is, $I = neAv_d$

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 gives charge flowing through the conductor

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

33. **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 are related by

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

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

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

$$\therefore \quad R = \rho\frac{l}{A} \quad \left[\because \frac{V}{I} = R\right]$$

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

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

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

$$I = neAv_d \quad \ldots(i)$$

Electric field inside the wire is given by

$$E = V/l \quad \ldots(ii)$$

If relaxation time is τ, the drift speed is

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

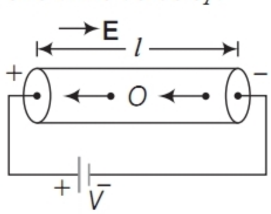
$$\Rightarrow \quad I = \frac{ne^2\tau}{m}AE \quad \ldots(iii)$$

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

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

(ii) Refer to Sol. 23 on page 89. **[1]**

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



Electric field produced inside the wire is

$$E = V/l \quad \ldots(i)$$

Force on an electron, $F = -Ee$ **(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.

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

We know that current in the conductor

$i = neAv_d$ (where, n is number of free electrons in a conductor per unit volume)

$$i = neA \times \frac{e}{m}\tau\frac{V}{l}$$

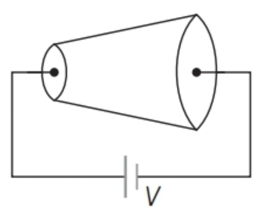
$$\Rightarrow \quad i = \frac{ne^2A\tau V}{ml}$$

$$\Rightarrow \quad i = V/R \quad [\because R = ml/ne^2A\tau]$$

$$i \propto V.$$

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 changes. **(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, $3E = 6\text{ V}$

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

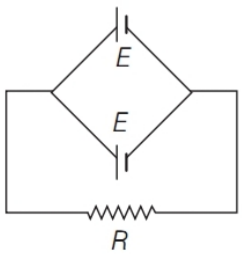
Internal resistance of three cells each of resistance r can be calculated as

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

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

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

2. The cells are arranged as shown in the circuit diagram given below.



As, the internal resistance of cells is negligible.
So, total resistance of the circuit = R
Hence, current through the resistance, $I = E/R$
(In parallel combination the 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

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

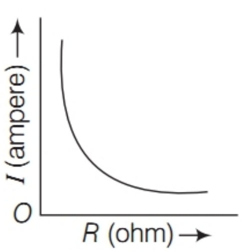
Hence, the current in the circuit is given by

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

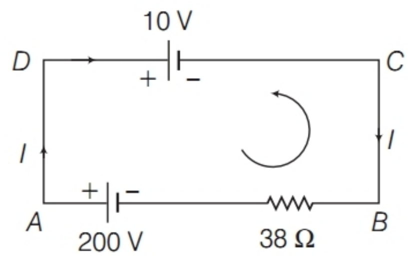
$= r_1 + r_2 + r_3 + R$

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

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

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

7. Given, $E_1 = 10\text{ V}$, $E_2 = 200\text{ V}$, $r = 38\ \Omega$



(1)

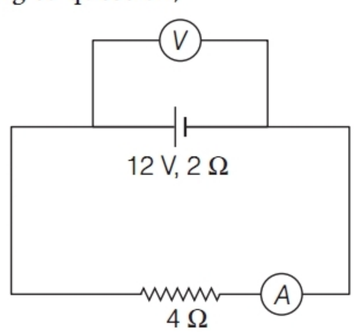
Now, using Kirchhoff's loop law in loop $ABCDA$,

$200 - 38I - 10 = 0$

$190 = 38I$

$\therefore$ $I = \frac{190}{38} = 5\text{ A}$ **(1)**

8. According to question,



$R = 2 + 4 = 6\Omega$

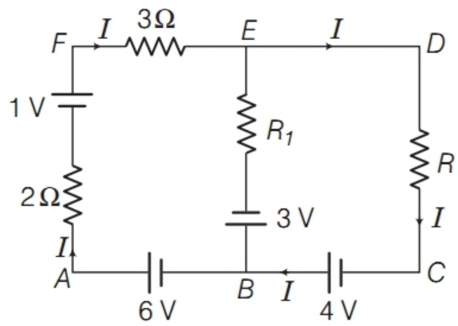
(i) Net current in the circuit $= \frac{12}{6} = 2\text{A}$

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. So, connecting in parallel with the circuit would cause a short-circuit and 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)

$$5I = 7$$

$$\Rightarrow \quad I = \frac{7}{5} \text{A} \quad \ldots \text{(i)}$$

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

$$3I + RI - 4 - 6 + 2I - 1 = 0$$

$$5I + RI = 11 \quad \ldots \text{(ii)}$$

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,

$$V_A - \frac{7}{5} \times 2 + 1 - 3 \times \frac{7}{5} = V_D \Rightarrow V_A - \frac{14}{5} + 1 - \frac{21}{5} = V_D$$

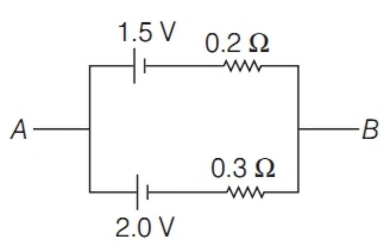
$$\Rightarrow V_A - V_D = \frac{14}{5} + \frac{21}{5} - 1 \Rightarrow (V_A - V_D) = 7 - 1 = 6 \text{ V}$$ **(1)**

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 is

$$E_{eq} = (E_1 r_2 + E_2 r_1) / (r_1 + r_2)$$

Equivalent resistance, $r_{eq} = r_1 r_2 / (r_1 + r_2)$

According to question,



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

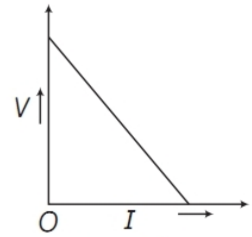
i.e. $= \frac{(1.5 \times 0.3) + (2 \times 0.2)}{0.2 + 0.3} = \frac{0.45 + 0.4}{0.5} = \frac{0.85}{0.5} = 1.7 \text{ V}$ **(1)**

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)**

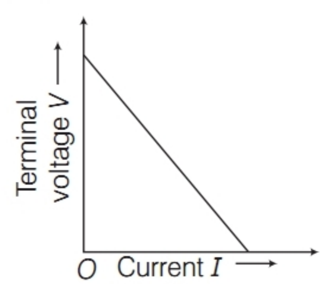
(ii) Maximum current is drawn when terminal voltage is zero. So, $V = E - Ir$

$\Rightarrow 0 = E - I_{max} r \Rightarrow r = E / I_{max}$ **(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 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



(1)

Note Negative slope gives internal resistance.

13. In closed loop $ABEFCDA$,

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

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

In closed loop $BEFCB$,

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

$$20I_2 + 20I_1 = 100 \quad \ldots \text{(ii)}$$ **(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

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

Now, for the 2nd case

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

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

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

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

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

$$E = \frac{1.625}{0.25} \Rightarrow E = 6.5\text{V}$$ **(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 the 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 the effective resistance of circuit is more than situations (i) and (iv), but less than (iii) 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 the 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, $E = 10\text{V}$, $r = 3\Omega$, $I = 0.5\text{A}$

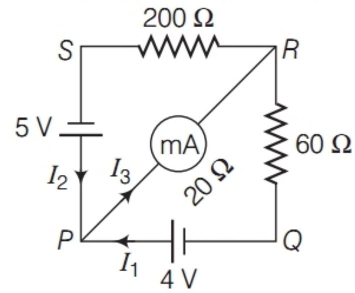
Total resistance of circuit,

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

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

(ii) Terminal voltage, $V = IR = 0.5 \times 17 = 8.5\text{V}$ **(1)**

17. The given diagram is shown below



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

$$-I_3 \times 20 - I_2 \times 200 + 5 = 0$$

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

For loop *PRQP*, **(1)**

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

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

Applying Kirchhoff's first law,

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

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

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

On solving, we get

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

$$I_2 = \frac{4000}{215}\text{mA},\ I_1 = \frac{39000}{860}\text{mA}$$

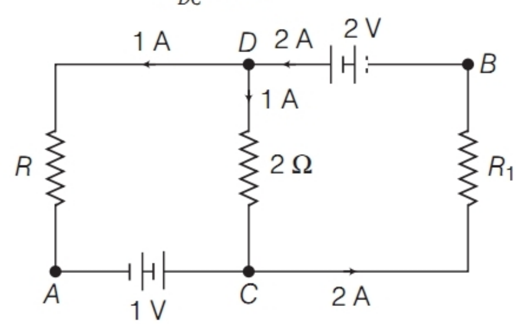
$\therefore$ The reading in the milliammeter will be

$$I_3 = \frac{11000}{172}\text{mA}$$ **(1)**

18. By Kirchhoff's first law at D,

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

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



(1)

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

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

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

19. (i) Applying Kirchhoff's second rule in the closed mesh *ABFEA*,

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

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

$\therefore$ Potential across AB = potential across EF

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

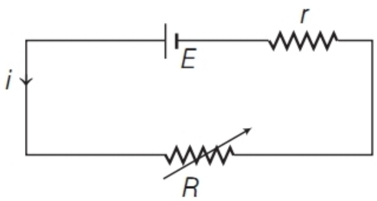
$$2I_2 = 2\text{ A} \Rightarrow I_2 = 1\text{ A}$$ **(1)**

(ii) Potential across R = potential across AB

= potential across EF

$= 3 - 2 \times 0.5 = 2\text{V}$ **(1)**

20. 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.

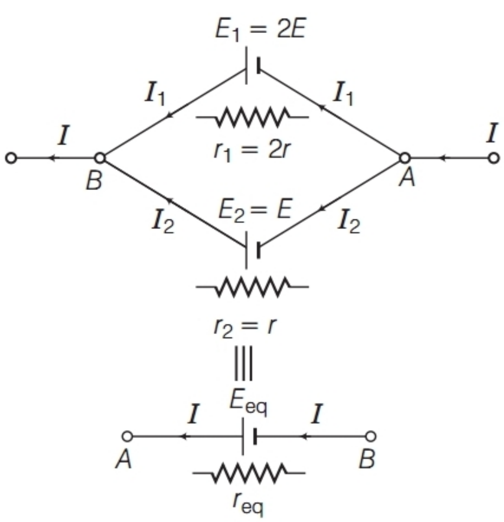
$$\therefore \quad r = \frac{E}{I} = \frac{1.4}{0.28}\,\Omega;\ r = 5\,\Omega.$$ **(1)**

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



For cell I, $\quad V = V_A - V_B = 2E - I_1(2r)$

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

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

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

$\because$ 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

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

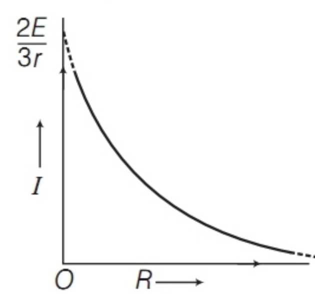
22. In these type of questions we have to look out the connections of different cells. If the opposite terminals of all the cells are connected, then they support each other, i.e. these individual emfs are added up. If the same terminals of the cells are connected, then the equivalent emf is obtained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

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

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

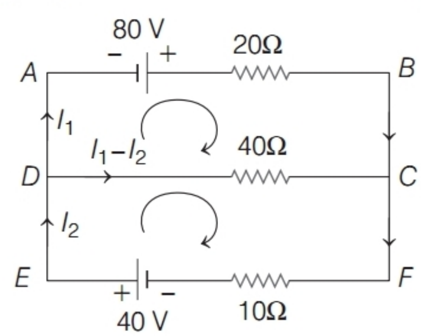
$\therefore$ Current, $I = \frac{V}{R}$ [from Ohm's law]

$$I = \frac{4E}{6r + R}$$ **(1)**



(1)

23. 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 $\quad I_2 = 4\text{ A}$

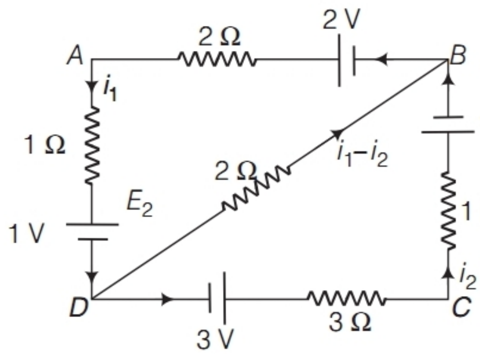
Thus, $\quad I_{40} = I_1 - I_2 = 0\text{ A}$

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

24. Refer to Sol. 21 on page 103. **(3)**

25. Applying Kirchhoff's second law in loop *BADB*,

$$2 - 2i_1 - i_1 - 1 - 2(i_1 - i_2) = 0 \qquad \ldots\text{(i)}$$



(1)

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

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

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

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

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

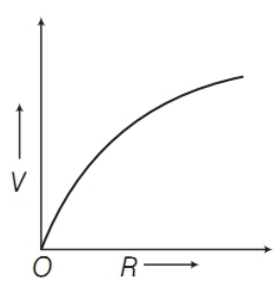
Potential difference between *B* and *D*,

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

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

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

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



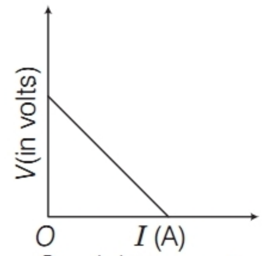
(1)

When $R = 4\,\Omega$ and $I = 1\text{ A}$.

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

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

$\Rightarrow \quad E - r = 4 \qquad \ldots\text{(i)}$ **(1)**



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

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

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

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

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

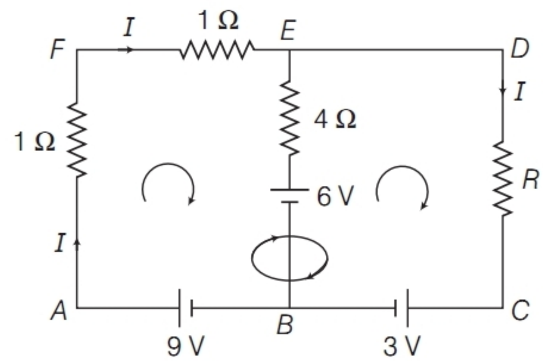
$$r = 1\,\Omega \text{ and } E = 5\text{ V}$$ **(1)**

27. Applying Kirchhoff's second law in mesh *AFEBA*,

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

$$-2I + 3 = 0$$

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



(1/2)

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

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

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

$$2I + IR = 6 \qquad \ldots\text{(ii)}$$ **(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)**

28. For *BCD*, equivalent resistance

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

Across *BA*, equivalent resistance R_2,

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

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

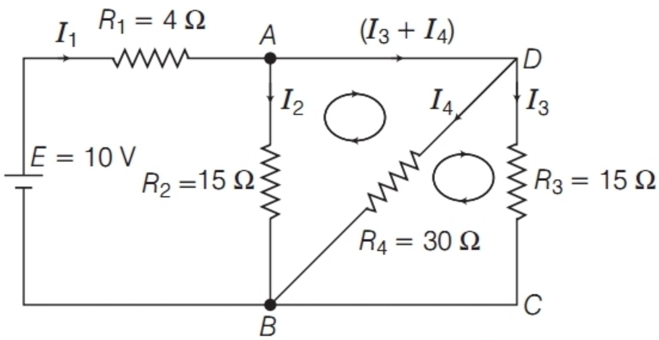
$\Rightarrow \quad R_2 = 5\,\Omega$

Potential difference between points A and B,

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

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

29.



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,

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

Applying Kirchhoff's second rule

(i) In mesh ADB,

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

$$I_2 = 2I_4$$

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

(ii) In mesh BDC,

$$30I_4 - 15I_3 = 0$$

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

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

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

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

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

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

$$I_1 = I_2 + I_2 + \frac{I_2}{2} \quad \Rightarrow I_1 = \frac{5}{2}I_2 \quad \textbf{(1/2)}$$

From Eq. (ii), we get

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

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

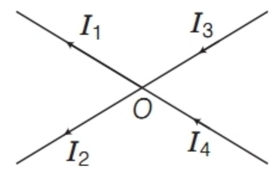
$$\Rightarrow \quad I_2 = I_3 = \frac{2}{5}\text{ A}$$

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

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

30. **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,

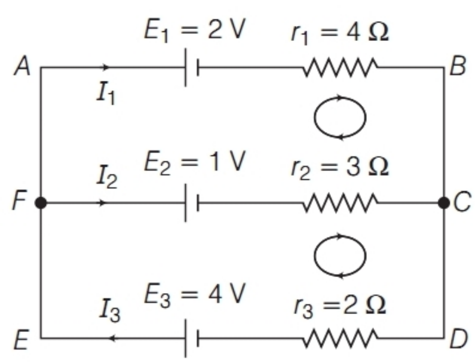
$$I_1 + I_2 = I_3 + I_4 \quad \textbf{(1)}$$

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

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

For given circuit,



At F, applying junction rule,

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

In mesh $ABCFA$,

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

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

In mesh $FCDEF$,

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

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

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

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

and $\quad I_3 = \dfrac{9}{13}\text{ A} \quad$ **(2)**

31. For Kirchhoff's rules Refer to Sol. 30 on page 105.

From given diagram in question, **(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

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

32. For statements of Kirchhoff's rules Refer to Sol. 30 on page 105.

From given diagram in question. **(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)**

33. 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 $5\,\Omega$ 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)**

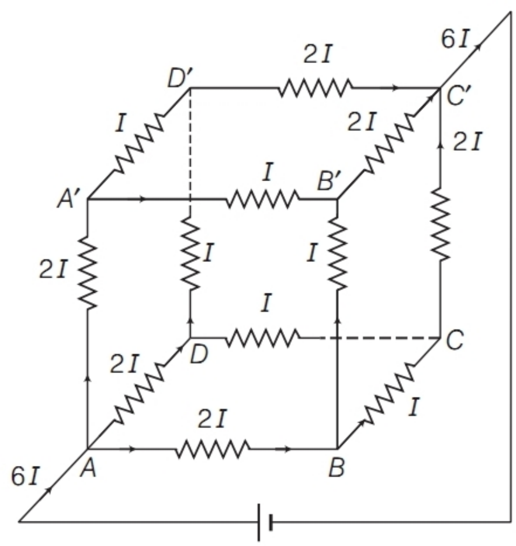
$$\therefore \; r = 5\left(\frac{2.2}{1.8} - 1\right) = 5 \times \frac{0.4}{1.8} = \frac{2}{1.8} = \frac{10}{9}\,\Omega$$

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

34. (i) **For Kirchhoff's rules** Refer to Sol. 30 on page 105. **(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*.

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

$\Rightarrow \; 6IR = 10$ [given $E = 10$ V] ...(i)

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

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

$$\Rightarrow \; 5I = 10$$

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

Total current in the network = $6I$

$$= 6 \times 2 = 12\text{ A}$$

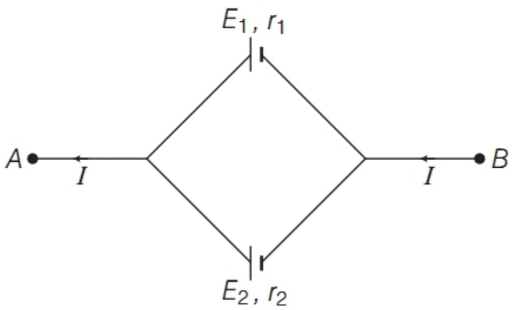
From Eq. (i), we get

$$6I\,R = 10 \Rightarrow 6 \times 2 \times R = 10$$

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

(b) The total current in the network = $6I = 12$A **(1)**

35. 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.

Potential difference across first cell,

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

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

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

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

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

36. 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)**

∴ Potential difference across AB,

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

∴ Potential difference across 2Ω resistor is 1.8 V.

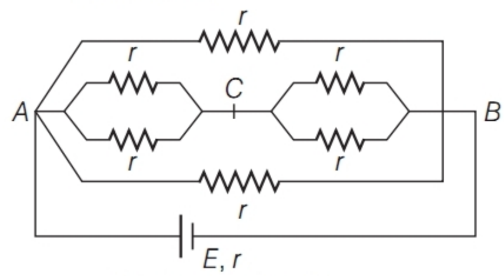
∴ Current I' through 2Ω resistor is given by

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

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

37. (i) **For Kirchhoff's rules** Refer to Sol. 30 on page 105. **(2)**

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



(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, $r = r + \frac{r}{3} = \frac{4r}{3}$

Current drawn from cell,

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

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

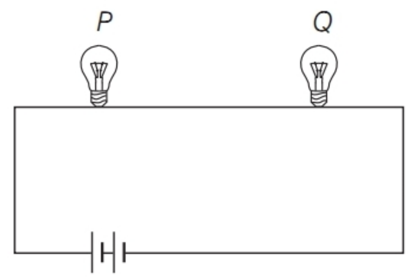
$$= \frac{9E^2}{16r}$$ **(3)**

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

$$P = P_1 + P_2$$

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

$\therefore R_Q = 2R_P$ ... (i)



In series, power dissipated is given by the relation

$$P = I^2R$$

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

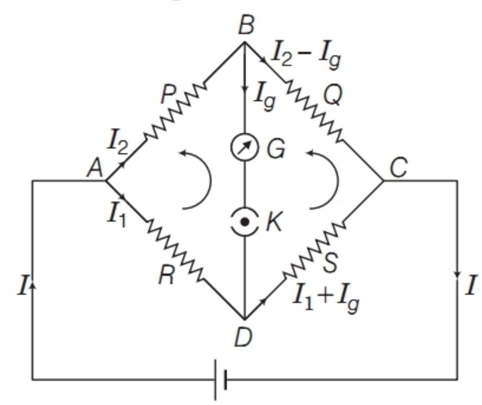
$\therefore$ $\frac{P_P}{P_Q} = \frac{R_P}{R_Q}$ ... (ii)

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

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

5. Applying Kirchhoff's loop law to close loop *ABDA*, we get $I_1 R - I_g G - I_2 P = 0$ ...(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

$$I_g G + (I_1 + I_g)S - (I_2 - I_g) Q = 0 \quad ...(ii)$$

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

i.e. $I_g = 0$

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

$$I_1 R - I_2 P = 0 \Rightarrow I_1 R = I_2 P$$

Explanations

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

$$R \propto \rho$$

[where, ρ = resistivity]

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

$\therefore$ $R_{nichrome} > R_{copper}$

Hence, resistance of nichrome section is more than copper.

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. 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)**

3. The resistance of bulb P_1 is $R_1 = \frac{V^2}{P_1}$

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

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

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

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

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

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

(ii) In parallel, $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$

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

Similarly, from Eq. (ii), we get

$$I_1 S - I_2 Q = 0$$

$$\Rightarrow \quad I_1 S = I_2 Q \Rightarrow I_1/I_2 = Q/S \quad ...(iv)$$

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)**

6. In closed mesh *ABCDA*.

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

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

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

In closed mesh *BCFEB*,

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

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

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*

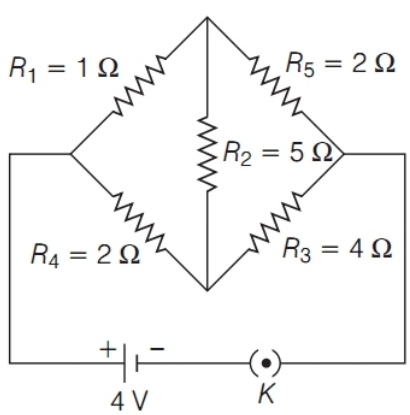
$$= I_1 + I_2 = 3 - 1.5 = +1.5\,\text{A}$$

$\therefore$ Power consumed by 4Ω resistance

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

$$= 225 \times 4 = 9\,\text{W}$$ **(2)**

7. The given circuit can be redrawn as given below



$$\therefore \quad \frac{R_1}{R_5} = \frac{1}{2}$$

$$\frac{R_4}{R_3} = \frac{2}{4} = \frac{1}{2}$$

$$\therefore \quad \frac{R_1}{R_5} = \frac{R_4}{R_3}$$

So, wheatstone bridge is balanced. Hence, there will be 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)**

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

8. (i) Heat produced per second $= I^2 R = V^2/R$

$$\therefore \quad H \propto V^2$$

$$\Rightarrow \quad \frac{H_2}{H_1} = \left(\frac{V_2}{V_1}\right)^2$$

$$\Rightarrow \quad \frac{9H_1}{H_1} = \left(\frac{V_2}{V_1}\right)^2$$

$$\therefore \quad V_2 = 3V_1$$

So, when potential difference is made three times, heat produced increase nine times for same *R*. **(1½)**

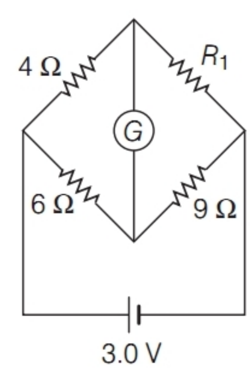
(ii) Current in the circuit is $I = \frac{E}{R+r} = \frac{12}{4+2} = 2\,\text{A}$

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)**

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

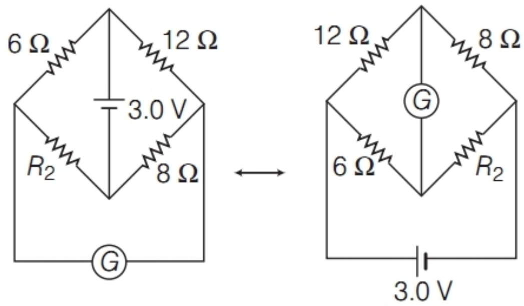


(1)

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)

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

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

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

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

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

(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.

$$\therefore \quad P_s = \frac{V^2}{R_1 + R_2}$$

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

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

(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)