Current Electricity

CHAPTER 3

EXAM DRILL

ANSWERS

1. **(b) :** The internal resistance of a cell is the resistance of electrolyte used in cell because it is the electrolyte which is responsible for conduction of electricity inside the cell.

2. **(a) :** We know that power $P = \frac{V^2}{R}$

$$H = \frac{(110)^2}{10} = 1210\text{ W}$$

3. **(b) :** Bulbs are arranged in series so current through each bulb is same.

$P = I^2R \;\therefore\; P \propto R$

Hence lower is the power, lower is the resistance.

4. **(b) :** $R = \frac{1\text{ volt}}{1\text{ ampere}} = \frac{10^8\text{ emu potential}}{10^{-1}\text{ emu current}}$

$R = 10^9$ emu

5. **(b) :** I^st^ law states that the algebraic sum of charges at the junction is zero, hence it is based on conservation of charge. II^nd^ law states that algebraic sum of the potential in closed path is zero, hence it is based on conservation of energy.

6. **(c) :** Here, Current, $I = 2$ A

Area of cross-section, $A = 2 \times 10^{-6}\text{ m}^2$

Number density of free electrons,

$n = 5 \times 10^{26}\text{ m}^{-3}$

The drift speed of electrons is

$$v_d = \frac{I}{nAe} = \frac{2\text{ A}}{(5\times10^{26}\text{ m}^{-3})(2\times10^{-6}\text{ m}^2)(1.6\times10^{-19}\text{ C})}$$

$$= \frac{1}{80}\text{ ms}^{-1}$$

7. **(d) :** $R = 100\ \Omega$; $I = 1$ A ; $t = 5$ min. $= 5 \times 60 = 300$ s

change in internal energy = heat generated in coil

$= I^2Rt = ((1)^2 \times 100 \times 300)$ J

$= 30000$ J $= 30$ kJ

8. **(d) :** $R = \frac{V^2}{P}$

Using the value of $P = 1200$ W and $V = 60$ V, we get

$$R = \frac{60\times60}{1200}$$

$R = 3\ \Omega$

9. **(a) :** For the given circuit,

$$\varepsilon_{eq} = \frac{\varepsilon_1 r_2 + \varepsilon_2 r_1}{r_1 + r_2}$$

Since $\varepsilon_2 > \varepsilon_1$, ε_{eq} lies between ε_1 and ε_2,

i.e. $\varepsilon_1 < \varepsilon_{eq} < \varepsilon_2$.

10. **(a) :** $H = I^2Rt$

$R = H/I^2t = 80/(4 \times 10) = 2\ \Omega$

11. **(b) :** The resistance , $R = \frac{V^2}{P}$, *i.e.*, $R \propto 1/P$

i.e., higher is the wattage of a bulb, lesser is the resistance and so it will glow bright.

12. **(d) :** Actually the bulbs fuse when they are switched on. As the bulb is switched on, it lights up. Its temperature increases. Due to which the resistance of the filament of the bulbs increases. This happens very quickly. After many cycles, the filament of the bulb become thin and the bulb is at the verge of burning out. When such a bulb is switched on, its initial resistance being low, there will be a sudden, rush of current as a result of which the filament burns out.

13. **(i) (d) :** Using, $R_T = R_0(1 + \alpha T)$

$$\therefore \frac{R_{T_2}}{R_{T_1}} = \frac{R_0(1+\alpha T_2)}{R_0(1+\alpha T_1)} = \frac{2}{1} = \frac{(1+\alpha T_2)}{(1+\alpha\times300)}$$

$\Rightarrow 2 + \alpha \times 600 = 1 + \alpha T_2$

$\Rightarrow 1 = \alpha(T_2 - 600) \Rightarrow \frac{1}{0.00125} = (T_2 - 600)$

$\Rightarrow 800°\text{C} = T_2 - 600$

$T_2 = 800 - 273 + 600$

$T_2 = 1127$ K

(ii) (a) : The temperature coefficient of resistance of an alloy used for making resistors is small and positive.

(iii) (b) : The resistance of a metallic wire at temperature t°C is given by

$R_t = R_0(1 + \alpha t)$, where α is the temperature coefficient of resistance and R_0 is the resistance of a wire at 0°C.

For metals, α is positive. Hence, resistance of a wire increases with increase in temperature.

Also, from Ohm's law

$$\frac{V}{I} = R$$

Hence on increasing the temperature, the ratio $\frac{V}{I}$ increases.

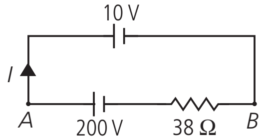
14. Current

15. In an open circuit, terminal voltage across a secondary cell is equal to its emf.

OR

The product of resistivity and conductivity remains constant and equal to 1 at all temperature.

16. As cells are connected in parallel so potential difference across terminals of each cell is same.



$200 - 38I = 10$

$38I = 200 - 10 = 190$

$I = \frac{190}{38} = 5\text{ A}$

17. Resistivity ρ of manganin is much greater than that of copper, therefore, to keep same resistance R, for same length of wire, the manganin wire must be thicker.

18. No, when an electron approaches a junction, in addition to the uniform $\vec{E}$ that it normally faces (which keep the drift velocity v_d fixed), there are accumulation of charges on the surface of wires at the junction. These produce electric field. These fields alter direction of momentum.

19. Here, $n = 8.5 \times 10^{28}\text{ m}^{-3}$; $l = 3$ m

$A = 2 \times 10^{-6}\text{ m}^2$; $I = 3$ A

As, $I = nAev_d$

$\therefore\ v_d = \frac{I}{nAe}$

Now, $t = \frac{l}{v_d} = \frac{lnAe}{I}$

$$t = \frac{3 \times 8.5 \times 10^{28} \times 2 \times 10^{-6} \times 1.6 \times 10^{-19}}{3}$$

$t = 2.72 \times 10^4$ sec

20. (i) When no current is drawn from a cell, potential difference across terminals of the cell is equal to its emf.

From the graph, it is clear that emf = 1.4 V

(ii) As $V = \varepsilon - Ir$ or $r = \frac{\varepsilon - V}{I}$; $\varepsilon = 1.4$ V

Consider any given value of potential difference from graph say $V = 1.2$ V

Current corresponding to this potential difference is $I = 0.04$ A

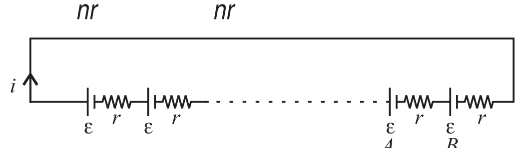
Thus, $r = \frac{1.4 - 1.3}{0.04} = 5\,\Omega$

21. Mobility, $\mu = \frac{\text{Drift velocity}}{\text{Electric field}} = \frac{v_d}{E}$

(i) The charge carriers in an electrolyte are positively and negatively charged ions.

(ii) The charge carriers in an ionised gas are electrons and positively charged ions.

22. $i = \frac{(n-2)\varepsilon - 2\varepsilon}{nr} = \frac{(n-4)\varepsilon}{nr}$



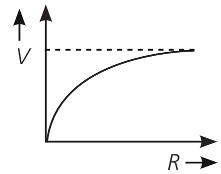
Potential difference across A or B

$= \varepsilon + iR = \varepsilon + \frac{(n-4)\varepsilon r}{nr} = \frac{2\varepsilon(n-2)}{n}$

23. As $V = \varepsilon - Ir = \frac{\varepsilon - Vr}{R}$ $\left(\because\ I = \frac{V}{R}\right)$

or $V\left[1 + \frac{r}{R}\right] = \varepsilon$

or $V = \frac{\varepsilon}{\left(1 + \frac{\varepsilon}{R}\right)}$



A graph between V and R is as shown in figure.

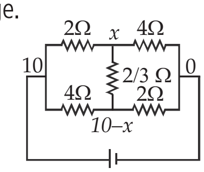
When $R = \infty$, then

$V = \frac{\varepsilon}{1+0} = \varepsilon$

So, V becomes equal to ε, when $R = \infty$ *i.e.*, the graph becomes parallel to resistance axis.

24. This is an unbalanced Wheatstone's bridge.

Submission of current at the Node 'x' is



$\frac{x-10}{2} + \frac{x-0}{4} + 3\left(\frac{2x-10}{2}\right) = 0 \Rightarrow x = \frac{80}{15}$

Current $= \frac{\Delta V}{R} = \left[\frac{10}{15} \times \frac{3}{2}\right] = 1$ A

OR

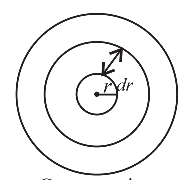
Here, $R_0 = 5\,\Omega$; $R_{100} = 5.25\,\Omega$; $R_t = 5.795\,\Omega$

Let t be temperature of hot bath,

$\therefore\ t = \frac{R_t - R_0}{R_{100}} \times 100$

$t = \frac{5.795 - 5}{5.25} \times 100 = 15.14°\text{C}$

25. Let us take a cylinder of radius r and thickness dr.



Cross-section

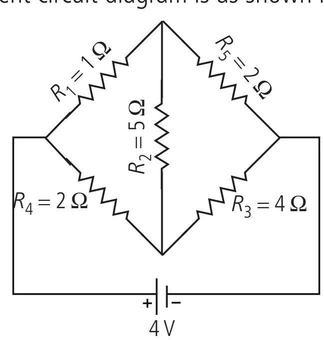
The current crossing the area

$dA = 2\pi r dr$ will be $di = JdA$

$\therefore\ \int di = \int (kr)(2\pi r dr)$

$\Rightarrow\ i = 2\pi k \int_0^R r^2 dr = 2\pi k \frac{R^3}{3}\ \Rightarrow\ i = \frac{2}{3}\pi k R^3$

26. The equivalent circuit diagram is as shown in figure.



It is balanced Wheatstone bridge.

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

Hence no current through arm CD. So resistance R_2 is ineffective.

As R_1 and R_5 are in series, so their equivalent resistance is

$R' = R_1 + R_5$

$= 1 + 2 = 3\ \Omega$

As R_4 and R_3 are in series, so their equivalent resistance is

$R = R_4 + R_3$

$= 2 + 4 = 6\ \Omega$

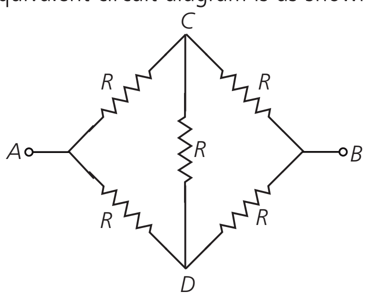
So, net resistance of the network is

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

$R = 2\ \Omega$

So, current drawn from the battery is $I = \frac{V}{R} = \frac{4}{2} = 2\text{ A}$

27. (i) The equivalent circuit diagram is as shown in figure.



It is balanced Wheatstone bridge. Therefore, the resistance of arm *CD* is ineffective.

$\therefore$ Resistance of upper arm *ACB*, $R_1 = R + R = 2R$

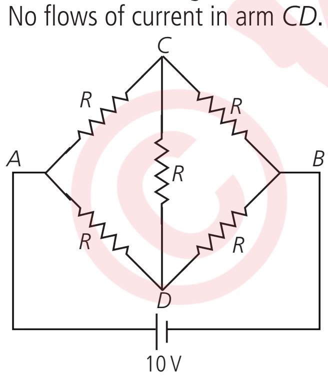
and resistance of lower arm, $R_2 = R + R = 2R$

$\therefore$ Equivalent resistance between *A* and *B* is

$$\frac{1}{R_{AB}} = \frac{1}{2R} + \frac{1}{2R} \Rightarrow \frac{1}{R_{AB}} = \frac{2}{2R}$$

$\therefore$ $R_{AB} = R$

(ii) It is balanced Wheatstone bridge. Therefore, resistance of arm CD is ineffective. No flows of current in arm *CD*.



Resistance of arm $ACB = 2R = 2 \times 2 = 4$

$\therefore$ Current through *ACB*, $I = \frac{10}{4} = 2.5\text{ A}$

28. The batteries are in parallel combination

$$\varepsilon_{eq} = \frac{\frac{\varepsilon_1}{r_1} + \frac{\varepsilon_2}{r_2} + \frac{\varepsilon_3}{r_3}}{\frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}} = \frac{\frac{3}{1} + \frac{2}{1} + \frac{1}{1}}{\frac{1}{1} + \frac{1}{1} + \frac{1}{1}} = \frac{6}{3} = 2\text{V} \Rightarrow V_A - V_B = 2\text{ V}$$

Solving for each branch

$2 = \varepsilon_1 - I_1 r_1 = 3 - I_1(1)$ or $I_1 = 1\text{ A}$

$2 = \varepsilon_2 - I_2 r_2 = 2 - I_2(1)$ or $I_2 = 0\text{ A}$

$2 = \varepsilon_1 - I_3 r_3 = 1 - I_3(1)$ or $I_3 = -1\text{ A}$

OR

Consider a conductor of length *l* and of uniform area of cross-section *A*.

Volume of the conductor = *Al*

If '*n*' is the number density of electrons of the conductor.

Then,

Total number of free electrons in the conductor = *Aln*.

Total charge on all the free electrons in the conductor, $q = Alne$

Let a potential difference *V* be applied across the ends of the conductor.

The electric field set up across the conductor is given by, $E = \frac{V}{l}$ (in magnitude)

$\therefore$ Time taken by the free electrons to cross the conductor,

$$t = \frac{l}{v_d}$$

where v_d is the drift speed of an electron.

Current, $i = \frac{q}{t} = \frac{A\,lne}{(\mu/v_d)}$

or $i = Anev_d$

Current density, $J = \frac{i}{A} = nev_d$

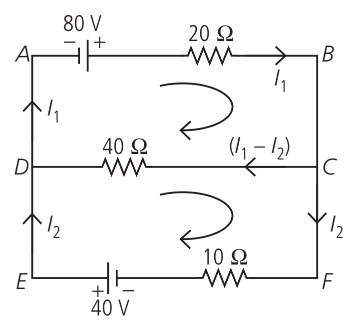
Hence $J \propto v_d$

29. Applying KVL in closed loop *ABCDA*

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

$20I_1 + 40I_1 - 40I_2 = 80$

$60I_1 - 40I_2 = 80$



$3I_1 - 2I_2 = 4$ ...(i)

Applying KVL in closed loop *DCFED*

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

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

$-40I_1 + 50I_2 = 40$

or $-4I_1 + 5I_2 = 4$ ...(ii)

From (i) and (ii)

$I_2 = 4\text{ A}$ and $I_1 = 4\text{ A}$

$\therefore$ Current flows through $40\ \Omega = I_1 - I_2 = 0\text{ A}$

Current flows through $20\ \Omega = 4\text{ A}$

30. Here, number of cells (n) = 6

Emf of each cell, $\varepsilon = 2.0$ V

Internal resistance of each cell, $r = 0.5\ \Omega$

Charging voltage, $V = 100$ V

Charging current, $I = 8$ A

Let R be resistance used in the series. Then

$$I = \frac{V - n\varepsilon}{R + nr}$$

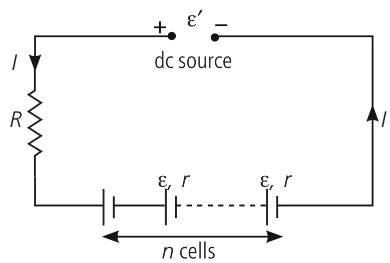
$$\therefore \quad 8 = \frac{100 - 6\times 2}{R + 6\times 0.5}$$

$$R = \frac{64}{8}\,\Omega = 8\,\Omega$$

(i) Power supplied by dc source = VI
= 100 × 8 = 800 Ω

(ii) Power dissipated as heat = $I^2(R + r)$
= $8^2(8 + 6 \times 0.5) = 704$ W

31. (i)



(ii) (a) Net emf of cells = $n\varepsilon$

Net internal resistance = nr

So, charging current in the circuit is

$$I = \frac{\varepsilon' - n\varepsilon}{R - nr}$$

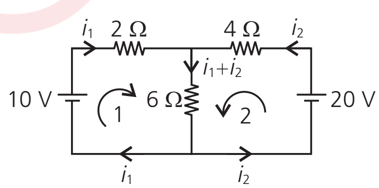
(b) Potential difference across the combination of cells is $V = n\varepsilon + Inr$

$$\text{or} \quad V = n\varepsilon + \left(\frac{\varepsilon' - n\varepsilon}{R + nr}\right)nr$$

$$= \frac{n\varepsilon(R + nr) + (\varepsilon' - n\varepsilon)nr}{R + nr}$$

$$V = \frac{n\varepsilon R + n^2\varepsilon r + n\varepsilon' r - n^2\varepsilon r}{R + nr}$$

32. Say the current flowing through 10V and 20V battery is i_1 and i_2. Applying junction rule, the current in 6 Ω resistor is $i_1 + i_2$



Applying loop rule in loop 1 : $10 - 2i_1 - 6(i_1 + i_2) = 0$

$4i_1 + 3i_2 = 5$ ...(i)

For loop 2 : $20 - 4i_2 - 6\,(i_1 + i_2) = 0$

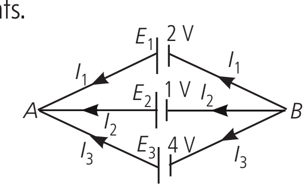
$5i_2 + 3i_1 = 10$ ...(ii)

Solving (i) and (ii), $i_2 = \frac{25}{11}$ A and $i_1 = -\frac{5}{11}$ A

Current through 6Ω resistor $= i_2 + i_1 = \frac{25}{11} - \frac{5}{11} = \frac{20}{11}$ A

33. The scheme of connections is shown in figure.

Let I_1, I_2 and I_3 be the currents flowing through the three cells E_1, E_2 and E_3 are emfs.



Applying Kirchhoff's junction law at the junction A, we get,

$I_1 + I_2 + I_3 = 0$

or $I_3 = -(I_1 + I_2)$ ...(i)

Applying Kirchhoff's loop law to the closed loop BE_1AE_2B and we get

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

pr $4I_1 - 3I_2 = 2 - 1 = 1$ ...(ii)

Applying the Kirchhoff's loop law to the closed loop BE_1AE_3B, we get

$4I_1 - 2 - 2I_3 + 4 = 0$

or $4I_1 - 2I_3 = 2 - 4 = -2$

or $4I_1 + 2 \times (I_1 + I_2) = -2$ (using (i))

or $6I_1 + 2I_2 = -2$

or $3I_1 + I_2 = -1$ ...(iii)

Multiplying eqn. (iii) by 3 and adding to (ii), we get

$(6 + 4)I_1 = 1 - 3 - 2$

or $I_1 = \frac{-2}{13}$ A

From eqn. (iii),

$$I_2 = -1 - 3I_1 = -1 - 3\left(\frac{-2}{13}\right) = \frac{-7}{13}\text{ A}$$

From eqn. (i)

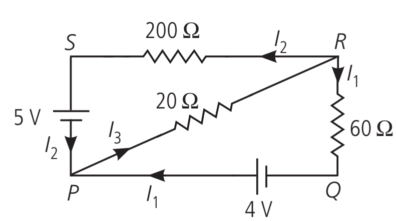
$$I_3 = -\left[\frac{-2}{13} - \frac{7}{13}\right] = \frac{+9}{13}\text{ A}$$

OR

Two rules which are used to find the current in different branches of electric circuit are :

(i) Kirchhoff's junction rule: It states that any junction in an electrical circuit, sum of incoming currents is equal to sum of outgoing currents.

(ii) Kirchhoff's loop rule : It states that in any closed loop in a circuit, algebraic sum of applied emf's and potential drops across the resistors is equal to zero.



Applying Kirchhoff's loop rule to the closed loop $PRSP$, we get

$$20I_3 + 200I_2 - 5 = 0 \quad ...(i)$$

Applying Kirchhoff's loop rule to the closed loop *PRQP*, we get

$$20I_3 + 60I_1 - 4 = 0 \quad ...(ii)$$

Applying Kirchhoff's first rule to the junction,

$$I_3 - (I_1 + I_2) = 0 \quad ...(iii)$$

Substituting the values of I_3 in (i) and (ii), we get

$$20I_1 + 220I_2 - 5 = 0 \quad ...(iv)$$

$$80I_1 + 20I_2 - 4 = 0 \quad ...(v)$$

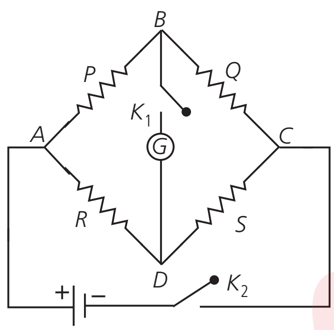
Solving eqn. (iv) and (v), we get

$$I_1 = \frac{39}{860}\text{ A};\ I_2 = \frac{16}{860}\text{ A} = \frac{4}{215}\text{ A}$$

From eqn. (ii)

$$I_3 = I_1 + I_2 = \frac{55}{860}\text{ A} = \frac{11}{172}\text{ A}$$

34. Wheatstone bridge is an arrangement of four resistance which can be used to measure one of them in terms of rest. Here arms *AB* and *BC* are called ratio arm and arm *AC* and *BD* are called conjugate arms.

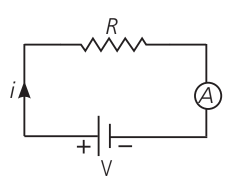


(i) Balanced bridge : The bridge is said to be balanced when deflection in galvanometer is zero *i.e.*, no current flows through the galvanometer or in other words $V_B = V_D$. In the balanced condition $\frac{P}{Q} = \frac{R}{S}$, on mutually changing the position of cell and galvanometer this condition will not change.

Unbalanced bridge : If the bridge is not balanced current will flow from *D* to *B* if $V_D > V_B$ *i.e.* $(V_A - V_D) < (V_A - V_B)$ which gives

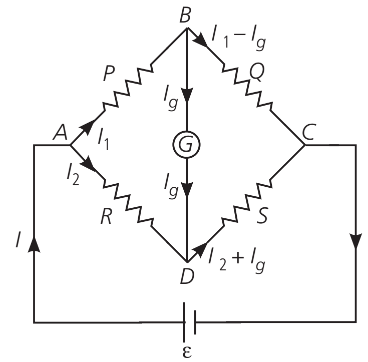
$$PS > RQ$$

Applications of Wheatstone bridge



Meter bridge, post office box and carry foster bridge are instruments based on the principle of Wheatstone bridge and are used to measure unknown resistance.

Derivation of balance condition from Kirchhoff's laws : In accordance with Kirchhoff's first law, the currents through various branches are as shown in figure.



Applying Kirchhoff's second law to the loop *ABDA*, we get

$$I_p + I_g G - I_2 R = 0$$

where *G* is the resistance of the galvanometer.

Again applying Kirchhoff's second law to the loop *BCDB*, we get

$$(I_1 - I_g)Q - (I_2 + I_g)S - GI_g = 0$$

In the balanced condition of the bridge.

$$I_g = 0$$

The above equation becomes

$$I_1 p - I_2 R = 0$$

or $\quad I_1 p = I_2 R \quad ...(i)$

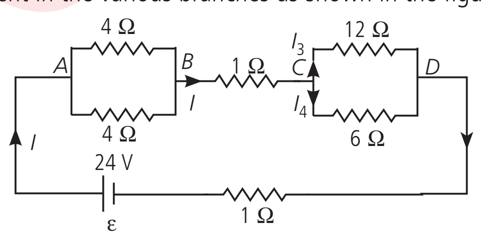
and $\quad I_1 Q = I_2 S \quad ...(ii)$

On dividing equation (i) by (ii), we get

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

OR

The current in the various branches as shown in the figure.



In the given circuit 4 Ω and 4 Ω are in parallel, 12 Ω and 6 Ω are in parallel. These two combination of resistances are in series of the circuit.

∴ Total resistance of circuit between *A* and *D* is,

$$R = R_{AB} + R_{BC} + R_{CD}$$

$$R = \frac{4 \times 4}{4 + 4} + 1 + \frac{12 \times 6}{12 + 6} = 2 + 1 + 4 = 7\,\Omega$$

Total current, $I = \frac{\varepsilon}{(R + r)} = \frac{24}{(7 + 1)} = 3\text{ A}$

Current at *A* is divided equally in each of 4 Ω resistances in parallel.

So, $I = I_2 = 1.5$ A

Potential difference across *C* and *D*,

$$V_{CD} = I \times R_{CD} = 3 \times 4 = 12\text{ V}$$

$$I_3 = \frac{V_{CD}}{12} = \frac{12}{12} = 1\text{ A};\ I_4 = \frac{V_{CD}}{6} = \frac{12}{6} = 2\text{ A}$$

$$V_{AB} = I \times R_{AB} = 3 \times 2 = 6\text{ V}$$

$$V_{BC} = I \times R_{BC} = 3 \times 1 = 3\text{ V}$$

$V_{CD} = I \times R_{CB} = 3 \times 4 = 12\ \text{V}$

35. (a) Current in the circuit,

$$I = \frac{V}{R} = \frac{6\ \text{V}}{6\ \Omega} = 1\ \text{A}$$

As, $I = neAv_d$,

$$v_d = \frac{I}{neA} = \frac{1\ \text{A}}{(10^{29}\ \text{m}^{-3})(1.6\times10^{-19}\ \text{C})(10^{-3}\ \text{m})^2}$$

$= 0.625 \times 10^{-4}\ \text{m s}^{-1}$

Energy absorbed by all the electrons

= number of electrons × KE of an electron

$$= [n(\text{Al})]\left[\frac{1}{2}mv_d^2\right] = \frac{1}{2}[mv_d^2 n\ \text{Al}]$$

$$= \frac{1}{2}[9.1\times10^{-31}\text{kg}]\ (0.625\times10^{-4}\ \text{m s}^{-1})^2$$

$(10^{29}\ \text{m}^{-3})\ (10^{-6}\ \text{m}^2)(10^{-1}\ \text{m})$

$= 1.78 \times 10^{-17}\ \text{J}$

(b) Ohmic loss $= I^2R = (1\ \text{A})^2\ (6\ \Omega) = 6\ \text{Js}^{-1}$

Time taken by all the electrons to lose their kinetic energy, *i.e.*,

$$t = \frac{1.78\times10^{-17}\ \text{J}}{6\ \text{J s}^{-1}} = 0.30 \times 10^{-17}\ \text{s} \approx 10^{-17}\ \text{s}$$

OR

(i) Let h be the resistance of ammeter (*i.e.* galvanometer).

Then current in the circuit, $I = \frac{V}{R+G} = \frac{3}{3+60} = 0.048\ \text{A}$

(ii) When the ammeter (*i.e.*, galvanometer) is shunted with resistance S, its effective resistance,

$$R_p = \frac{GS}{G+S}$$

$$= \frac{60\times0.02}{60+0.02} \simeq 0.02\ \Omega$$

Current in the circuit, $I = \frac{V}{R+R_p} = \frac{3}{3+0.02} = 0.99\ \text{A}$

(iii) For the ideal ammeter with zero resistance current,

$$I = \frac{3}{3} = 1\ \text{A}$$