CURRENT ELECTRICITY

CBSE NCERT Solutions for Class 12 Physics Chapter 3

Back of Chapter Questions

3.1. The storage battery of a car has an emf of 12 V. If the internal resistance of the battery is 0.4 Ω, what is the maximum current that can be drawn from the battery?

Solution:

Given:

emf of the battery $(E) = 12$ V

Internal resistance of the battery $(r) = 0.4\ \Omega$

Let the maximum current drawn from the battery is I

By Ohm's law,

$E = Ir$

$I = \frac{E}{r}$

$I = \frac{12}{0.4} = 30$ A

∴ 30 A is the maximum current drawn from the battery.

3.2. A battery of emf 10 V and internal resistance 3 Ω is connected to a resistor. If the current in the circuit is 0.5 A, what is the resistance of the resistor? What is the terminal voltage of the battery when the circuit is closed?

Solution:

Given:

emf of the battery, E, is 10 V

Internal resistance of the battery, $r, = 3\ \Omega$,

Current in the circuit, $I, = 0.5$ A,

Resistance of the resistor $is\ R$.

According to Ohm's law,

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

$\Rightarrow R + r = \frac{E}{I}$

$= \frac{10}{0.5} = 20\ \Omega$

$\therefore R = 20 - 3 = 17\ \Omega$

The terminal voltage of the resistor $= V$

According to Ohm's law,

$V = IR$

$= 0.5 \times 17$

$= 8.5$ V.

$\therefore$ The terminal voltage is 8.5, V and the resistance of the resistor is 17 Ω.

3.3. (a) Three resistors 1 Ω, 2 Ω, and 3 Ω, are combined in series. What is the total resistance of the combination?

(b) If the combination is connected to a battery of emf 12 V and negligible internal resistance, obtain the potential drop across each resistor.

Solution:

(a) The resistors 1 Ω, 2 Ω, and 3 Ω are combined in series.

Hence, total resistance $= 1 + 2 + 3 = 6\ \Omega$

(b) Current flowing through the circuit $= I$

Emf of the battery, $E\ is$ 12 V

The total resistance of the circuit in series combination, $R\ is\ 6\ \Omega$

According to Ohm's law

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

$= \frac{12}{6} = 2$ A

Let the potential drop across 1Ω resistor $is\ V_1$

The value of V_1 obtained by Ohm's law is:

$V_1 = 2 \times 1 = 2$ V ... (i)

Let the potential drop across 2 Ω resistor $is\ V_2$

Again, from Ohm's law, the value of V_2 can be obtained as

$V_2 = 2 \times 2 = 4$ V ... (ii)

Let the potential drop across 3 Ω resistor $is\ V_3$

Again, from Ohm's law, the value of V_3 can be obtained as

$V_3 = 2 \times 3 = 6\ \text{V} \ldots (iii)$

$\therefore$ The potential drop across $1\ \Omega$ is $2\ \text{V}$, $2\ \Omega$ is $4\ \text{V}$, and $3\ \Omega$ is $6\ \text{V}$.

3.4. (a) Three resistors $2\ \Omega$, $4\ \Omega$ and $5\ \Omega$, are combined in parallel. What is the total resistance of the combination?

(b) If the combination is connected to a battery of emf 20 V and negligible internal resistor, and the total current drawn from the battery.

Solution:

Given:

(a) Given:

$R_1 = 2\ \Omega, R_2 = 4\ \Omega$, and $R_3 = 5\ \Omega$

The total resistance (R) of the parallel combination is given by.

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

$$= \frac{1}{2} + \frac{1}{4} + \frac{1}{5} = \frac{10 + 5 + 4}{20} = \frac{19}{20}$$

$$\therefore R = \frac{20}{19}\ \Omega$$

The total resistance of the combination is $\frac{20}{19}\ \Omega$

(b) Emf of the battery, $V = 20\ \text{V}$

Current flowing through the resistor R_1 is given by,

$$I_1 = \frac{V}{R_1}$$

$$= \frac{20}{2} = 10\ \text{A}$$

Current flowing through the resistor R_2 is given by,

$$I_2 = \frac{V}{R_2}$$

$$= \frac{20}{4} = 5\ \text{A}$$

Current flowing through the resistor R_3 is given by,

$$I_3 = \frac{V}{R_3}$$

$$= \frac{20}{5} = 4 \text{ A}$$

Total Current, $I = I_1 + I_2 + I_3 = 10 + 5 + 4 = 19$ A

∴ The current through each resistor R_1, R_2, and R_3 are 10 A, 5 A, and 4 A respectively and the total current is 19 A.

3.5. At room temperature $(27.0^o$ C) the resistance of a heating element is 100 Ω. What is the temperature of the element if the resistance is found to be 117 Ω, given that the temperature coefficient of the material of the resistor is $1.70 \times 10^{-4}\,^o\text{C}^{-1}$

Solution:

Given:

Room temperature, T *is* 27 ^{o}C

The resistance of the heating element at T, R *is* 100 Ω

Suppose, T_1 is the increased temperature of the filament.

The resistance of the heating element at T_1, R_1 *is* 117 Ω

Temperature Coefficient of filament material is, α *is* $1.70 \times 10^{-4}\,^o\text{C}^{-1}$

α is given by the relation,

$$\alpha = \frac{R_1 - R}{R(T_1 - T)}$$

$$T_1 - T = \frac{R_1 - R}{R\alpha}$$

$$T_1 - 27 = \frac{117 - 100}{100(1.7 \times 10^{-4})}$$

$$T_1 - 27 = 1000$$

$$T_1 = 1027^o\text{C}$$

∴ At 1027^oC, the resistance of the element is 117 Ω.

3.6. A negligibly small current is passed through a wire of length 15 m and uniform cross-section 6.0×10^{-7} m^2, and its resistance is measured to be 5.0 Ω. What is the resistivity of the material at the temperature of the experiment?

Solution:

Given:

Length of the wire, l *is* 15 m

Area of a cross-section of the wire, a *is* 6.0×10^{-7} m^2

The resistance of the wire's material, R *is* 5.0 Ω

ρ is the resistivity of the material/

Resistance is related to the resistivity as

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

$$\rho = \frac{RA}{l}$$

$$= \frac{5 \times 6 \times 10^{-7}}{15} = 2 \times 10^{-7}\ \Omega\, m$$

∴ The resistivity of the material is $2 \times 10^{-7}\ \Omega$ m.

3.7. A silver wire has a resistance of $2.1\ \Omega$ at $27.5\ ^oC$, and a resistance of $2.7\ \Omega$ at $100\ ^oC$. Determine the temperature coefficient of resistivity of silver.

Solution:

Given:

Temperature, $T_1\ is\ 27.5\ ^{\text{o}}\text{C}$

The Resistance of the silver wire at $T_1, R_1\ is\ 2.1\ \Omega$

Temperature, $T_2\ = 100\ ^{\text{o}}\text{C}$

The Resistance of the silver wire at $T_2, R_2\ is\ 2.7\ \Omega$.

Temperature coefficient of silver $is\ \alpha$

It is related to the temperature and resistance as

$$\alpha = \frac{R_2 - R_1}{R_1(T_2 - T_1)}$$

$$= \frac{2.7 - 2.1}{2.1(100 - 27.5)} = 0.0039\ ^{\text{o}}\text{C}^{-1}$$

Temperature coefficient of silver is $0.0039\ ^{\text{o}}\text{C}^{-1}$.

3.8. A heating element using nichrome connected to a 230 V supply draws an initial current of 3.2 A which settles after a few seconds to a steady state value of 2.8 A. What is the steady temperature of the heating element if the room temperature is $27.0\ ^oC$? Temperature coefficient of resistance of nichrome averaged over the temperature range involved is $1.70 \times 10^{-4}\ ^oC^{\ -1}$.

Solution:

Given:

Supply voltage, $V\ is$ 230 V

The Initial current drawn, $I_1\ is$ 3.2 A

Initial resistance = R_1, which is given by the relation,

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

$$= \frac{230}{3.2} = 71.87\ \Omega$$

Steady state value of the current, I_2 *is* 2.8 A

Resistance at the steady state = R_2, which is given as

$$R_2 = \frac{230}{2.8} = 82.14\ \Omega$$

Temperature coefficient of nichrome, α *is* $1.70 \times 10^{-4}\ ^{o}C^{-1}$

The Initial temperature of nichrome, T_1 *is* $27.0\ ^{o}C$

Study state temperature reached by nichrome *is* T_2

T_2 can be obtained by the relation for α,

$$\alpha = \frac{R_2 - R_1}{R_1(T_2 - T_1)}$$

$$T_2 - 27^{o}C = \frac{82.14 - 71.87}{71.87 \times 1.7 \times 10^{-4}} = 840.5$$

$$T_2 = 840.5 + 27 = 867.5\ ^{o}C$$

The steady state temperature of the heating element is $867.5\ ^{o}C$

3.9. Determine the current in each branch of the network shown in fig 3.30:

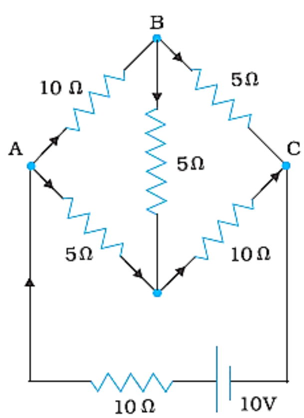
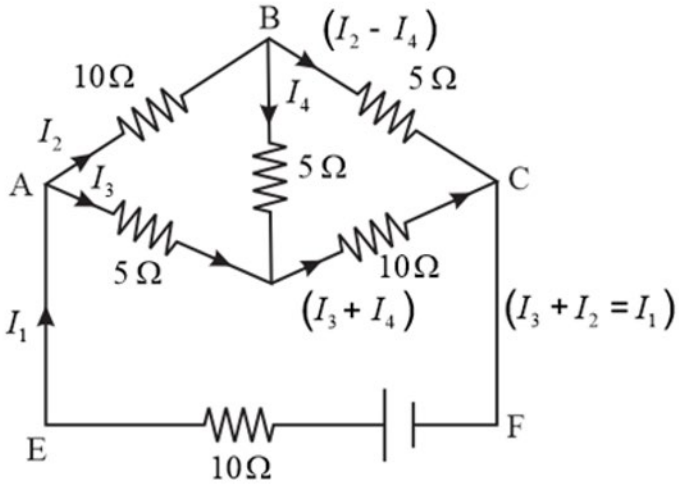


FIGURE 3.30

Solution:

The current flowing through different branches of the circuit is shown in the figure Provided



I_1 = Current flowing through the outer circuit

I_2 = Current flowing through branch AB

I_3 = Current flowing through branch AD

$I_2 - I_4$ = Current flowing through branch BC

$I_3 + I_4$ = Current flowing through branch DC

I_4 = Current flowing through branch BD

For the closed circuit ABDA, the potential drop is zero, i.e.,

$10I_2 + 5I_4 - 5I_3 = 0$

$\Rightarrow 2I_2 + I_4 - I_3 = 0$

$\Rightarrow I_3 = 2I_2 + I_4 \ldots (1)$

For the closed circuit BCDB, the potential drop is zero, i.e.,

$5(I_2 - I_4) - 10(I_3 + I_4) - 5I_4 = 0$

$\Rightarrow 5I_2 + 5I_4 - 10I_3 - 10I_4 - 5I_4 = 0$

$\Rightarrow 5I_2 - 10I_3 - 20I_4 = 0$

$\Rightarrow I_2 = 2I_3 + 4I_4 \ldots (2)$

For the closed circuit ABCFEA, the potential drop is zero, i.e.,

$-10 + 10(I_1) + 10(I_2) + 5(I_2 - I_4) = 0$

$\Rightarrow 10 = 15I_2 + 10I_1 - 5I_4$

$\Rightarrow 3I_2 + 2I_1 - I_4 = 2 \ldots (3)$

From equations (1) and (2), we obtain

$I_3 = 2(2I_3 + 4I_4) + I_4$

$\Rightarrow I_3 = 4I_3 + 8I_4 + I_4$

$-3I_3 = 9I_4$

$-3I_4 = +I_3 \ldots (4)$

Putting equation (4) in equation (1), we can obtain

$I_3 = 2I_2 + I_4$

$\Rightarrow -4I_4 = 2I_2$

$\Rightarrow I_2 = -2I_4 \ldots (5)$

From the given figure,

$I_1 = I_3 + I_2 \ldots (6)$

From equation (6) and equation (1), we obtain

$3I_2 + 2(I_3 + I_2) - I_4 = 2$

$\Rightarrow 5I_2 + 2I_3 - I_4 = 2 \ldots (7)$

$\Rightarrow 5(-2\,I_4) + 2(-3\,I_4) - I_4 = 2$

$\Rightarrow -10I_4 - 6I_4 - I_4 = 2$

$17I_4 = -2$

$$I_4 = \frac{-2}{17}\ A$$

Equation (4) reduces to

$I_3 = -3(I_4)$

$$= -3\left(\frac{-2}{17}\right) = \frac{6}{17}\ \text{A}$$

$I_2 = -2(I_4)$

$$= -2\left(\frac{-2}{17}\right) = \frac{4}{17}\ A$$

$$I_2 - I_4 = \frac{4}{17} - \left(\frac{-2}{17}\right) = \frac{6}{17}\ \text{A}$$

$$I_3 + I_4 = \frac{6}{17} + \left(\frac{-2}{17}\right) = \frac{4}{17}\ \text{A}$$

$I_1 = I_3 + I_2$

$= \frac{6}{17} + \frac{4}{17} = \frac{10}{17}$ A

Therefore, current in branch $AB = \frac{4}{17}$ A

In branch $BC = \frac{6}{17}$ A

In branch $CD = \frac{-4}{17}$ A

In branch $AD = \frac{6}{17}$ A

In branch $BD = \frac{-2}{17}$ A

Total current $= \frac{4}{17} + \frac{6}{17} + \frac{-4}{17} + \frac{6}{17} + \frac{-2}{17} = \frac{10}{17}$ A

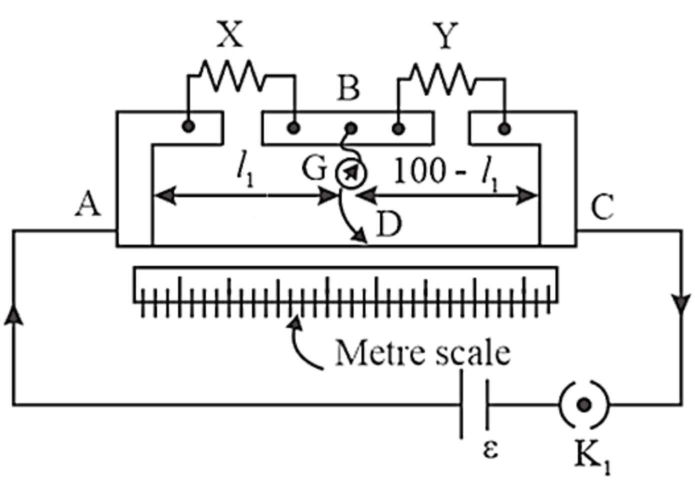
3.10. (a) In a meter bridge [Fig. 3.27], the balance point is found to be at 39.5 cm from the end A when the resistor Y is of 12.5 Ω. Determine the resistance of X. Why are the connections between resistors in a Wheatstone or meter bridge made of thick copper strips?

(b) Determine the balance point of the bridge above if X and Y are interchanged.

(c) What happens if the galvanometer and cell are interchanged at the balance point of the bridge? Would the galvanometer show any current?

Solution:

The figure shows a meter bridge with resistors X and Y.



(a) Balance point from end A, l_1 is 39.5 cm

The Resistance of the resistor Y is 12.5 Ω

Condition for the balance is given as,

$$\frac{X}{Y} = \frac{100 - l_1}{l_1}$$

$$X = \frac{100 - 39.5}{39.5} \times 12.5 = 8.2\ \Omega$$

The resistance of resistor X is $8.2\ \Omega$.

The thick copper strips which are used in a Wheat stone bridge is used to minimize the resistance of connecting wires

(b) If X and Y are interchanged, then l_1 and $100 - l_1$ get interchanged.

The balance point of the bridge is $100 - l_1$ from A.

$100 - l_1 = 100 - 39.5 = 60.5$ cm

The balance point is 60.5 cm from A.

(c) The galvanometer will show no deflection when the galvanometer and cell are interchanged at the balance point. Therefore, no current would flow through the galvanometer.

3.11. A storage battery of emf 8.0 V and internal resistance $0.5\ \Omega$ is being charged by a 120 V DC supply using a series resistor of $15.5\ \Omega$. What is the terminal voltage of the battery during charging? What is the purpose of having a series resistor in the charging circuit?

Solution:

Given:

Emf of the storage battery, E, is 8.0 V

The Internal resistance of the battery, r, is $0.5\ \Omega$

DC supply voltage, $V\ is$ 120 V

The Resistance of the resistor, R, is $15.5\ \Omega$

Effective voltage in the circuit $= V'$

R is connected in series to the storage battery. It can therefore be written as

$V' = V - E$

$\Rightarrow V' = 120 - 8 = 112$ V

Current flowing in the circuit $= I$, which is given by the relation, Reference the sentence

$$I = \frac{V'}{R + r}$$

$$= \frac{112}{15.5 + 5} = \frac{112}{16} = 7 \text{ A}$$

The Voltage across resistor R given by the product, $IR = 7 \times 15.5 = 108.5\ V$

DC voltage supply = Voltage drop across R+Terminal voltage of the battery

The terminal voltage of battery = $120 - 108.5 = 11.5$ V

The Current will be very large in the absence of a series resistor in a charging circuit. The Work of a series resistor in a charging circuit is to reduce the amount of current drawn from the external circuit.

3.12. In a potentiometer arrangement, a cell of emf 1.25 V gives a balance point at 35.0 cm length of the wire. If the cell is replaced by another cell and the balance point shifts to 63.0 cm, what is the emf of the second cell?

Solution:

Given:

Emf of the cell, $E_1 is$ 1.25 V

The Balance point of the potentiometer, l_1 *is* 35 cm

The cell is substituted by another cell of emf E_2

The new balance point of the potentiometer, l_2 *is* 63 cm

The balance condition is given by the relationship,

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

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

$$= 1.25 \times \frac{63}{35} = 2.25 \text{ V}$$

Emf of the second cell is 2.25 V.

3.13. The number density of free electrons in a copper conductor estimated in Example 3.1 is $8.5 \times 10^{28}\ \text{m}^{-3}$. How long does an electron take to drift from one end of a wire 3.0 m long to its other end? The area of cross-section of the wire is $2.0 \times 10^{-6}\ \text{m}^2$ and it is carrying a current of 3.0 A.

Solution:

Given:

The number density in a copper conductor of free electrons, n *is* $8.5 \times 10^{28}\ \text{m}^{-3}$

Length of the copper wire, I *is* 3.0 m

Area of a cross-section of the wire, A is 2.0×10^{-6} m^2

The Current carried by the wire, $I = 3.0$ A,

$I = nAeV_d$

Where,

e = Electric charge $= 1.6 \times 10^{-19}$ C

$V_d = \text{Drift velocity} = \dfrac{\text{Length of the wire }(l)}{\text{Time taken to cover (t)}}$

$I = n\,Ae\,\dfrac{l}{t}$

$t = \dfrac{nAel}{I}$

$= \frac{3 \times 8.5 \times 10^{28} \times 2 \times 10^{-6} \times 1.6 \times 10^{-19}}{3.0}$

$= 2.7 \times 10^4$ s

The Time taken by an electron to drift from one end of the wire to the other is given by 2.7×10^4 s.

3.14. The earth's surface has a negative surface charge density of 10^{-9} C m^{-2}. The potential difference of 400 kV between the top of the atmosphere and the surface results (due to the low conductivity of the lower atmosphere) in a current of only 1800 A over the entire globe. If there were no mechanism of sustaining atmospheric electric field, how much time (roughly) would be required to neutralise the earth's surface? (This never happens in practice because there is a mechanism to replenish electric charges, namely the continual thunderstorms and lightning in different parts of the globe). (Radius of earth $= 6.37 \times 10^6$ m.)

Solution:

Given:

The Surface charge density of the earth (σ) is 10^{-9} C m^{-2}

The Current over the entire globe (I) is 1800 A

The Radius of the earth (r) is 6.37×10^6 m

The Surface area of the earth,

$A = 4nr^2$

$= 4 \sqcap \times (6.37 \times 10^6)^2$

$= 5.09 \times 10^{14}$ m^2

Charge on the earth surface,

$q = \sigma \times A$

$= 10^{-9} \times 5.09 \times 10^{14}$

$= 5.09 \times 10^{5}$ C

Time taken to neutralize the earth's surface $= t$

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

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

$= \frac{5.09 \times 10^{5}}{1800} = 282.77$ s

The Time taken to neutralize the earth's surface is 282.77 s.

3.15. (a) Six lead-acid type of secondary cells each of emf 2.0 V and internal resistance 0.015 Ω are joined in series to provide a supply to the resistance of 8.5 Ω. What is the current drawn from the supply and its terminal voltage?

(b) A secondary cell after long use has an emf of 1.9 V and a large internal resistance of 380 Ω.What maximum current can be drawn from the cell? Could the cell drive the starting motor of a car?

Solution:

Given**:**

(a) Number of secondary cells, $n\ is$ 6

Emf of each secondary cell, $E\ is$ 2.0 V

The internal resistance of each cell, $r\ is$ 0.015 Ω

The Series resistor is connected to the combination of cells.

The Resistance of the resistor, $R\ is$ 8.5 Ω

Current drawn from the supply $= I$, which is given by the relation,

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

$= \frac{6 \times 2}{8.5 + 6 \times 0.015}$

$= \frac{12}{8.59} = 1.39$ A

Terminal voltage, $V = IR = 1.39 \times 8.5 = 11.87$ A

A current of 1.39 A, is drawn from the supply and the terminal voltage is 11.87 A.

(b) After a long use, emf of the secondary cell, E is 1.9 V

The Internal resistance of the cell, r is 380 Ω

A maximum current of 0.005 A can be drawn from the cell.

Since a large current is required to start the motor of a car, it is not possible to use the cell to start a motor.

3.16. Two wires of equal length, one of aluminium and the other of copper, have the same resistance. Which of the two wires is lighter? Hence explain why aluminium wires are preferred for overhead power cables ($\rho_{\text{Al}} = 2.63 \times 10^{-8}\ \Omega\ \text{m}$, $\rho_{\text{Cu}} = 1.72 \times 10^{-8}\ \Omega\ \text{m}$, Relative density of Al = 2.7, of Cu = 8.9)

Solution:

Given**:**

Resistivity of aluminium ρ_{Al} is $2.63 \times 10^{-8}\ \Omega\ \text{m}$

The Relative density of aluminium, $d_{1,}$ is 2.7

Let l_1 be the length of aluminium wire and m_1 be its mass.

The Resistance of the aluminium wire is R_1

Area of a cross-section of the aluminium wire is A_1

The Resistivity of copper, $\rho_{Cu} = 1.72 \times 10^{-8}\ \Omega\ \text{m}$

The Relative density of copper, d_2, is 8.9

Let l_2 be the length of copper wire and m_2 be its mass.

The Resistance of the copper wire is R_2

Area of the cross-section of the copper wire is A_2

The two relations can be written as

$R_1 = \rho_1 \frac{l_1}{A_1}$ …(1)

$R_2 = \rho_2 \frac{l_2}{A_2}$ …(2)

It is given that $R_1 = R_2 \Rightarrow \rho_1 \frac{l_1}{A_1} = \rho_2 \frac{l_2}{A_2}$

$\Rightarrow \frac{A_1}{A_2} = \frac{\rho_1}{\rho_2} = \frac{2.63 \times 10^{-8}}{1.72 \times 10^{-8}} = \frac{2.63}{1.72}$

Mass of the aluminium wire, m_1 = volume × Density

$A_1 l_1 \times d_1 = A_1 l_1 d_1$ (3)

Mass of the copper wire, m_2 = volume × Density

$A_2 l_2 \times d_2 = A_2 l_2 d_2$ (4)

By Dividing equation (3) by equation (4), we obtain

$\frac{m_1}{m_2} = \frac{A_1 l_1 d_1}{A_2 l_2 d_2}$

For $l_1 = l_2$

$\frac{m_1}{m_2} = \frac{A_1 d_1}{A_2 d_2}$

For $\frac{A_1}{A_2} = \frac{2.63}{1.72}$,

$\frac{m_1}{m_2} = \frac{2.63}{1.72} \times \frac{2.7}{8.9} = 0.46$

It can be inferred from this ratio that m_1 is less than m_2. Hence, aluminium is lighter than copper. Because aluminium is lighter, it is preferred for overhead power cables over copper.

3.17. What conclusion can you draw from the following observations on a resistor made of alloy manganin?

Current A	**Voltage V**	**Current A**	**Voltage V**
0.2	3.94	3.0	59.2
0.4	7.87	4.0	78.8
0.6	11.8	5.0	98.6
0.8	15.7	6.0	118.5
1.0	19.7	7.0	138.2
2.0	39.4	8.0	158.0

Solution:

From the given table, it can be inferred that the voltage-to-current ratio is a constant equal to 19.7. Therefore, manganin is an ohmic conductor, i.e., the alloy obeys Ohm's law. According to Ohm's law, the conductor's resistance is the voltage proportion with the current. Therefore, manganin's resistance is 19.7 Ω.

3.18. Answer the following questions:

(a) A steady current flow in a metallic conductor of non - uniform cross-section. Which of these qualities is constant along the conductor: Current, Current density, electric field, drift speed?

(b) Is Ohm’s law is universally applicable for all conducting elements?

(c) A low voltage supply from which one needs high currents must have very low internal resistance. Why?

(d) A high tension (HT) Supply of, say, 6 KV must have a very large internal resistance. Why?

Solution:

(a) Current density, drift speed and electric field are inversely proportional to the area of cross section, and hence, they are not constant. The current flowing through the conductor is constant when a steady current flow in a metallic conductor of the non-uniform cross-section.

(b) Ohm's law cannot be applied universally to all conducting elements. Ohm's law is not applicable for Vacuum diode semiconductor.

(c) By Ohm's law, the relation for the potential is $V = IR$

Voltage (V) is directly proportional to the Current (I).

R is the internal resistance of the source.

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

If V is low, then R must be very low, so that high current can be drawn from the source.

(d) To prevent the electrical current from exceeding the safety threshold, a high tension supply must have a very high internal resistance. If the internal resistance is not high, the current drawn may exceed the safety limits in the case of a short circuit.

3.19. Choose the correct alternative:

(a) Alloys of metals usually have (greater/less) resistivity than that of their constituent metals.

(b) Alloys usually have much (lower/higher) temperature coefficients of resistance than pure metals.

(c) The resistivity of the alloy manganin is nearly independent of/increases rapidly with the increase of temperature.

(d) The resistivity of a typical insulator (e.g., amber) is greater than that of a metal by a factor of the order of $(10^{22}/10^{33})$.

Solution:

(a) Alloys of metals usually have greater resistivity than that of their constituent metals.

(b) Alloys usually have lower temperature coefficients of resistance than pure metals.

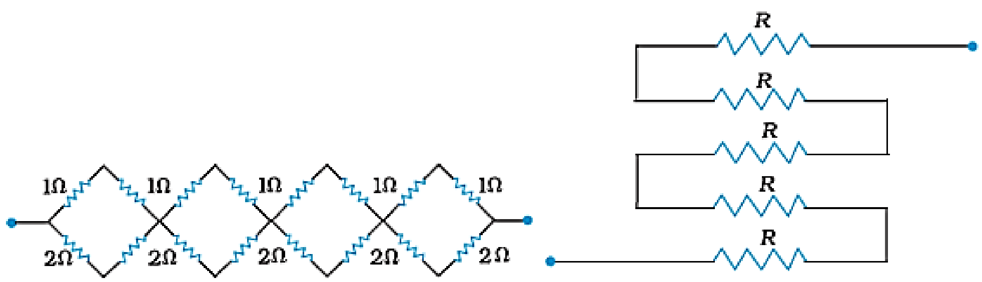
(c) The resistivity of the alloy, manganin is nearly independent of increase of temperature.

(d) The resistivity of a typical insulator is greater than that of a metal by a factor of the order of 10^{22}.

3.20. (a) Given n resistors each of resistance R, how will you combine them to get the (i) maximum (ii) minimum effective resistance? What is the ratio of the maximum to minimum resistance?

(b) Given the resistances of 1 Ω, 2 Ω, 3 Ω, how will you combine them to get an equivalent resistance of (i) $(11/3)\ \Omega$ (ii) $(11/5)\ \Omega$, (iii) $6\ \Omega$, (iv) $(6/11)\ \Omega$?

(c) Determine the equivalent resistance of networks shown in Fig.



(a) (b)

Solution:

Given**:**

(a) Total number of resistors $= n$

The resistance of each resistor $= R$

(i) The effective resistance R_1 maximum when n resistors are connected in series, given by the product nR.

Hence, maximum resistance of the combination, $R_1 = nR$

(ii) When n resistors are connected in parallel, the effective resistance (R_2) is the minimum, given by the ratio $\frac{R}{n}$.

Hence, minimum resistance of the combination, $R_2 = \frac{R}{n}$

(iii) The ratio of the maximum to the minimum resistance is,

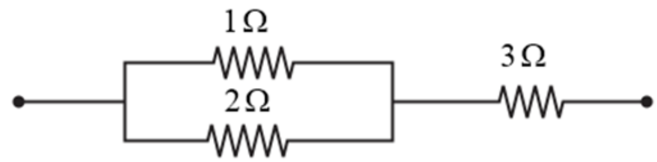
$\frac{R_1}{R_2} = \frac{nR}{\frac{R}{n}} = n^2$

(b) The resistance of the given resistors is,

$R_1 = 1\ \Omega, R_2 = 2\ \Omega, R_3 = 3\ \Omega$

(i) Equivalent resistance, $R' = \frac{11}{3}\ \Omega$

Considering the following combination of the resistors.

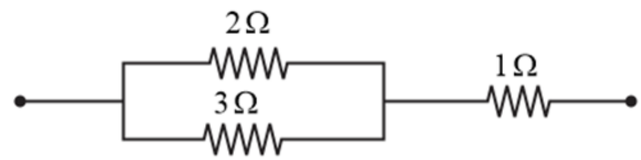


The Equivalent resistance of the circuit is given by,

$R' = \frac{2\times1}{2+1} + 3 = \frac{2}{3} + 3 = \frac{11}{3}\ \Omega$

(ii) Equivalent resistance, $R' = \frac{11}{5}\ \Omega$

Considering the following combination of the resistors.

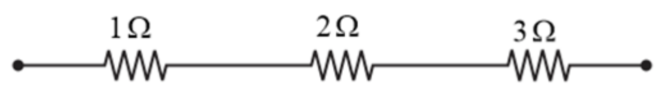


The Equivalent resistance of the circuit is given by,

$R' = \frac{2\times3}{2+3} + 1 = \frac{6}{5} + 1 = \frac{11}{5}\ \Omega$

(iii) Equivalent resistance, $R' = \ 6\ \Omega$

The series combination of the resistors is as shown in the given circuit.

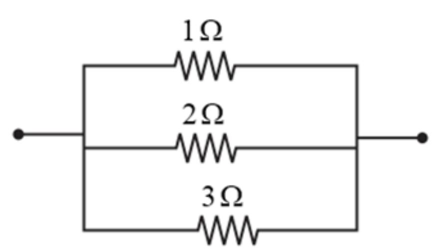


The Equivalent resistance of the circuit is given by the sum,

$R' = 1 + 2 + 3 = 6\ \Omega$

(iv) Equivalent resistance, $R' = \frac{6}{11}\ \Omega$

Considering the series combination of the resistors, as shown in the given circuit.



The Equivalent resistance of the circuit is given by,

$R' = \frac{1\times2\times3}{1\times+2\times3+3\times1} = \frac{6}{11}\ \Omega$

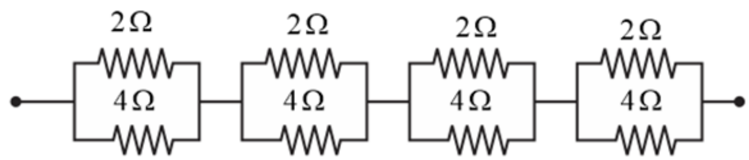
(c) It can be observed from the given circuit that in the first small loop, two resistors of resistance 1 Ω each are connected in series.

Hence, their equivalent resistance $= (1 + 1) = 2\ \Omega$

It can also be observed that two resistors of resistance $2\ \Omega$ each are connected in series.

Hence, their equivalent resistance $= (2 + 2) = 4\ \Omega$.

Therefore, the circuit can be redrawn as

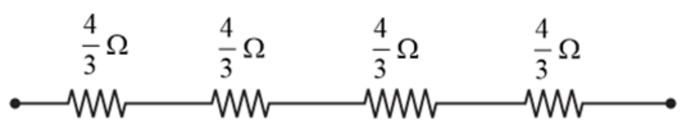


It can be observed that 2 Ω and 4 Ω resistors are connected in parallel in all the four loops.

Hence, the equivalent resistance (R') of each loop is given by,

$$R' = \frac{2\times 4}{2+4} = \frac{8}{6} = \frac{4}{3}\ \Omega$$

The circuit reduces to,

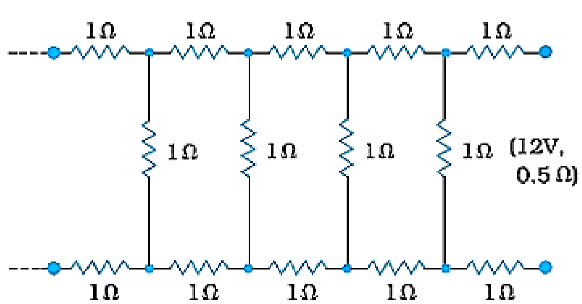


All the four resistors are connected in series.

Hence, the equivalent resistance of the given circuit is $\frac{4}{3} \times 4 = \frac{16}{3}\ \Omega$

(b) The five resistors of resistance R each are connected in series hence, the equivalent resistance of the circuit $= R + R + R + R + R = 5R$

3.21. Determine the current drawn from a 12 V supply with internal resistance 0.5 Ω by the infinite network shown in Fig. Each resistor has 1 Ω resistance.



Solution:

Given:

The resistance of each resistor connected in the circuit, $R\ is\ 1\ \Omega$

Let the equivalent resistance of the given circuit is $R'$and the network is infinite.

Hence, the equivalent resistance is given by the relation,

$R' = 2 + \frac{R'}{(R'+1)}$

$\Rightarrow (R')^2 - 2R' - 2 = 0$

$R' = \frac{2 \pm \sqrt{4+8}}{2}\ \Omega$

$= \frac{2 \pm \sqrt{12}}{2} = \left(1 \pm \sqrt{3}\right)\Omega$

Negative value of R' cannot be accepted.

Hence, equivalent resistance,

$R' = \left(1 + \sqrt{3}\right)\Omega = (1 + 1.73)\ \Omega = 2.73\ \Omega$

The Internal resistance of the circuit,

$r = 0.5\ \Omega$

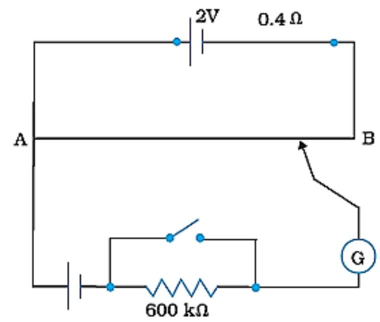
The total resistance of the given circuit is given by

$= 2.73 + 0.5 = 3.23\ \Omega$

Supply voltage, $\mathrm{V} = 12\ \mathrm{V}$

Current drawn from the source is given according, to Ohm's law by $\frac{12}{3.23} = 3.72\ \mathrm{A}$

3.22. The figure shows a potentiometer with a cell of 2.0 V and internal resistance 0.40 Ω maintaining a potential drop across the resistor wire AB. A standard cell which maintains a constant emf of 1.02 V (for very moderate currents up to a few mA) gives a balance point at 67.3 cm length of the wire. To ensure very low currents drawn from the standard cell, very high resistance of 600 kΩ is put in series with it, which is shorted close to the balance point. The standard cell is then replaced by a cell of unknown emf ε, and the balance point found similarly, turns out to be at 82.3 cm length of the wire.



(a) What is the value ε?

(b) What purpose does the high resistance of 600 kΩ have?

(c) Is the balance point affected by this high resistance?

(d) Is the balance point affected by the internal resistance of the driver cell?

(e) Would the method work in the above situation if the driver cell of the potentiometer had an emf of 1.0 V instead of 2.0 V?

(f) Would the circuit work well for determining an extremely small emf, say of the order of a few mV (such as the typical emf of a thermocouple)? If not, how will you modify the circuit?

Solution:

Given:

(a) A Constant emf of the given standard cell, E_1 is 1.02 V

The Balance point on the wire, l_1 is 67.3 cm

The standard cell is replaced by a cell of unknown emf, ε

∴ The new balance point on the wire, l is 82.3 cm

The relation connecting balance point and emf is,

$$\frac{E_1}{l_1} = \frac{\varepsilon}{l}$$

$$\varepsilon = \frac{l}{l_1} \times E_1$$

$$= \frac{82.3}{67.3} \times 1.02 = 1.247 \text{ V}$$

The value of the unknown emf is 1.247 V.

(b) High resistance of 600 kΩ is used to lower the current flow through the galvanometer when the movable contact is far from the balance point.

(c) The presence of high resistance does not affect the balance point.

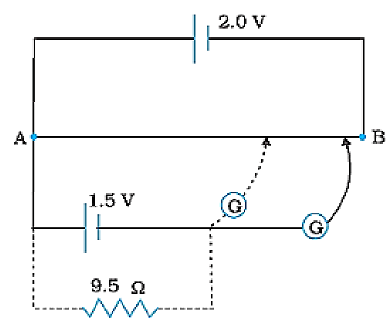
(d) The internal resistance of the driver cell does not affect the balance point.

(e) If the potentiometer's driver cell emf is less than the other cell's emf, then there would be no balance point on the wire, so the method won't operate, if the potentiometer's driver cell has an emf of 1 V instead of 2 V.

(f) The circuit cannot work well for determining an extremely small emf as there will be a very high percentage of error. This is because the circuit would be unstable; the balance point would be close to end A.

If a series resistance is connected to the wire AB, the given circuit can be modified. AB's potential drop is slightly higher than the measured emf. It would be a small percentage error.

3.23. The figure shows a 2.0 V potentiometer used for the determination of internal resistance of a 1.5 V cell. The balance point of the cell in open circuit is 76.3 cm. When a resistor of 9.5 Ω is used in the external circuit of the cell, the balance point shifts to 64.8 cm length of the potentiometer wire. Determine the internal resistance of the cell.



Solution:

Given**:**

The internal resistance of the cell is r

The balance point of the cell in the open circuit, l_1 is 76.3 cm

An external resistance of resistance R = 9.5 Ω is connected to the circuit.

The new balance point of the circuit, l_2 *is* 64.8 cm

The current (I) flowing through the circuit is

The relation between emf and resistance is,

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

$$= \frac{76.3\text{ cm} - 64.8\text{ cm}}{64.8\text{ cm}} \times 9.5\ \Omega = 1.68\ \Omega$$

The internal resistance of the cell is 1.68 Ω .

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