Physics

(Chapter – 3) (Current Electricity)

(Class – XII)

EXERCISES

Question 3.1:

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

Answer 3.1:

Emf of the battery, E = 12 V

Internal resistance of the battery, r = 0.4 Ω

Maximum current drawn from the battery = I

According to Ohm's law, $E = Ir \quad \Rightarrow I = \frac{E}{r} = \frac{12}{0.4} = 30\text{A}$

The maximum current drawn from the given battery is 30 A.

Question 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?

Answer 3.2:

Emf of the battery, E = 10 V and Internal resistance of the battery, r = 3 Ω

Current in the circuit, I = 0.5 A

Resistance of the resistor = R

The relation for current using Ohm's law is,

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

∴ R = 20 – 3 = 17 Ω

Terminal voltage of the resistor = V

According to Ohm's law, V = IR = 0.5 × 17 = 8.5 V

Therefore, the resistance of the resistor is 17 Ω and the terminal voltage is 8.5 V.

Question 3.3:

At room temperature (27.0 °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 $1.70 \times 10^{-4}{}^{\circ}\text{C}^{-1}$.

Answer 3.3:

Room temperature, T = 27°C

Resistance of the heating element at T, R = 100 Ω

Let T_1 is the increased temperature of the filament.

Resistance of the heating element at T_1, R_1 = 117 Ω

Temperature co-efficient of the material of the filament, $\alpha = 1.70\times10^{-4}\ {}^{0}\text{C}^{-1}$

α is given by relation,

$$\alpha = \frac{R_1 - R}{R\,(T_1 - T)} \Rightarrow T_1 - T = \frac{R_1 - R}{R\alpha} \Rightarrow T_1 - 27 = \frac{117 - 100}{100(1.7 \times 10^{-4})} \Rightarrow T_1 - 27 = 1000$$

$\Rightarrow T_1 = 1027\ {}^{0}\text{C}$

Therefore, at 1027°C, the resistance of the element is 117Ω.

Question 3.4:

A negligibly small current is passed through a wire of length 15 m and uniform cross section 6.0×10^{-7} m², and its resistance is measured to be 5.0 Ω. What is the resistivity of the material at the temperature of the experiment?

Answer 3.4:

Length of the wire, l =15 m

Area of cross-section of the wire, a = 6.0×10^{-7} m², Resistance of the material of the wire, R = 5.0 Ω

Resistivity of the material of the wire = ρ, Resistance is related with the resistivity as

$$R = \rho\frac{1}{A} \Rightarrow \rho = \frac{RA}{l} = \frac{5 \times 6 \times 10^{-7}}{15}$$

$= 2\times10^{-7}\ \Omega\ m$

Therefore, the resistivity of the material is 2×10^{-7} Ω m.

Question 3.5:

A silver wire has a resistance of 2.1 Ω at 27.5 °C, and a resistance of 2.7 Ω at 100 °C. Determine the temperature coefficient of resistivity of silver.

Answer 3.5:

Temperature, T_1 = 27.5°C

Resistance of the silver wire at T_1, R_1 = 2.1 Ω

Temperature, T_2 = 100°C

Resistance of the silver wire at T_2, R_2 = 2.7 Ω

Temperature coefficient of silver = α

It is related with temperature and resistance as

$$\alpha = \frac{R_2 - R_1}{R\,(T_2 - T_1)} = \frac{2.7 - 2.1}{2.1\,(100 - 27.5)} = 0.0039\ °C^{-1}$$

Therefore, the temperature coefficient of silver is $0.0039°C^{-1}$.

Question 3.6:

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 value of 2.8 A. What is the steady temperature of the heating element if the room temperature is 27.0 °C? Temperature coefficient of resistance of nichrome averaged over the temperature range involved is $1.70 \times 10^{-4}\ °C^{-1}$.

Answer 3.6:

Supply voltage, V = 230 V and Initial current drawn, I_1 = 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 = 2.8 A

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

$$R_1 = \frac{230}{2.8} = 82.14\ \Omega$$

Temperature co-efficient of nichrome, α = $1.70 \times 10^{-4}\ °C^{-1}$

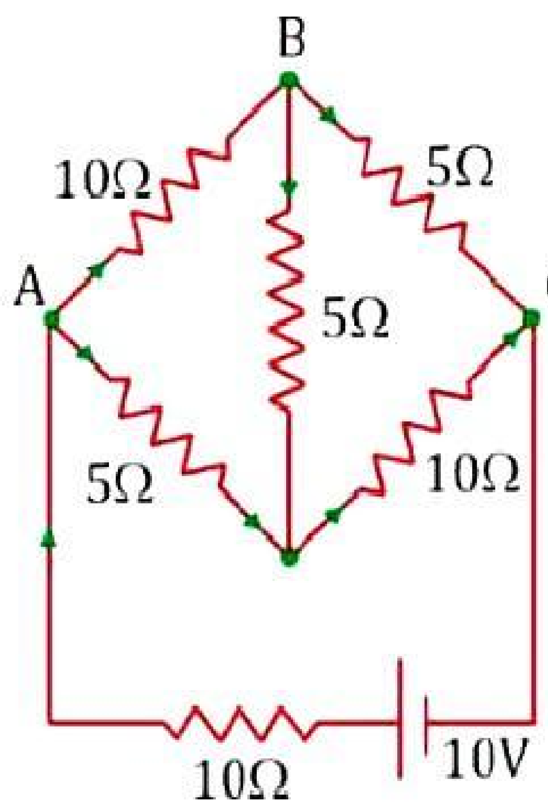
Initial temperature of nichrome, T_1= 27.0°C

Study state temperature reached by nichrome = T_2
T_2 can be obtained by the relation for α, $T_1 = 1027\ ^{0}C$

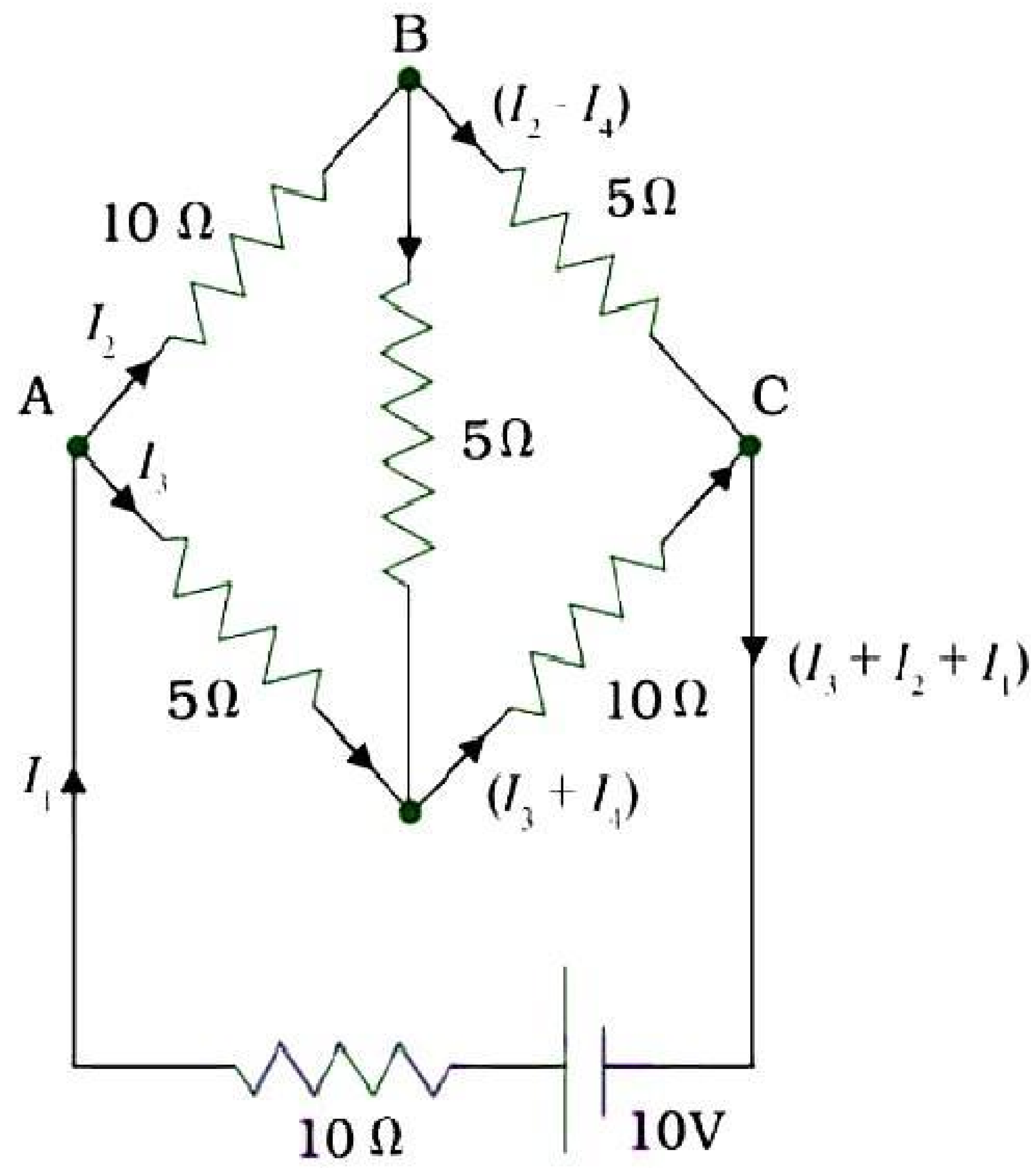
$$\alpha = \frac{R_2 - R_1}{R_1\ (T_2 - T_1)} \Rightarrow T_2 - 27\ ^{\circ}C = \frac{82.14 - 71.87}{71.87 - 1.7 \times 10^{-4}} = 840.5$$

$T_2 = 840.5 + 27 = 867.5\ ^{\circ}C$
Therefore, the steady temperature of the heating element is 867.5°C

Question 3.7:
Determine the current in each branch of the network shown in Figure.



Answer 3.7:
Current flowing through various branches of the circuit is represented in the given figure.
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 CD
I_4 = Current flowing through branch BD



For the closed circuit ABDA, potential is zero *i.e.*,
$10I_2 + 5I_4 - 5I_3 = 0$
$2I_2 + I_4 - I_3 = 0$
$I_3 = 2I_2 + I_4$ ... (1)

For the closed circuit BCDB, potential is zero i.e.,
$5(I_2 - I_4) - 10(I_3 + I_4) - 5I_4 = 0$
$5I_2 + 5I_4 - 10I_3 - 10I_4 - 5I_4 = 0$
$5I_2 - 10I_3 - 20I_4 = 0$
$I_2 = 2I_3 + 4I_4$ ... (2)

For the closed circuit ABCFEA, potential is zero i.e.,
$-10 + 10\ (I_1) + 10(I_2) + 5(I_2 - I_4) = 0$
$10 = 15I_2 + 10I_1 - 5I_4$
$3I_2 + 2I_1 - I_4 = 2$ ... (3)

From equations (1) and (2), we obtain
$I_3 = 2(2I_3 + 4I_4) + I_4$
$I_3 = 4I_3 + 8I_4 + I_4$
$-3I_3 = 9I_4$
$-3I_4 = +I_3$ ... (4)

Putting equation (4) in equation (1), we obtain
$I_3 = 2I_2 + I_4$
$-4I_4 = 2I_2$
$I_2 = -2I_4$ ... (5)
It is evident from the given figure that,
$I_1 = I_3 + I_2$ ... (6)

Putting equation (6) in equation (1), we have

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

$5I_2 + 2I_3 - I_4 = 2$ ... (7)

Putting equations (4) and (5) in equation (7), we have

$5(-2 I_4) + 2(-3 I_4) - I_4 = 2 \Rightarrow -10I_4 - 6I_4 - I_4 = 2 \Rightarrow 17I_4 = -2$

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

Equation (4) reduces to

$$I_3 = -3I_4 = -3\left(-\frac{2}{17}\right) = \frac{6}{17}\ A$$

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

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

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

$$I_1 = I_3 + I_2 = \frac{6}{17} + \frac{4}{17} = \frac{10}{17}\ A$$

Therefore, the current in branch in AB = $I_2 = \frac{4}{17}A$

The current in branch in BC = $I_2 - I_4 = \frac{6}{17}A$

In branch CD = $I_3 + I_4 = \frac{4}{17}A$

In branch AD = $I_3 = \frac{6}{17}A$

In branch BD = $I_4 = -\frac{2}{17}A$

Total current = $I_1 = \frac{10}{17}A$

Question 3.8:

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

Answer 3.8:

Emf of the storage battery, E = 8.0 V and Internal resistance of the battery, r = 0.5 Ω

DC supply voltage, V = 120 V and Resistance of the resistor, R = 15.5 Ω

Effective voltage in the circuit = V^1

R is connected to the storage battery in series. Hence, it can be written as $V^1 = V - E$

$V^1 = 120 - 8 = 112$ V

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

$$I = \frac{V^1}{R + r} = \frac{112}{15.5 + 5} = \frac{112}{16} = 7A$$

Voltage across resistor R given by the product, IR = 7 × 15.5 = 108.5 V

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

Terminal voltage of battery = 120 − 108.5 = 11.5 V

A series resistor in a charging circuit limits the current drawn from the external source.

The current will be extremely high in its absence. This is very dangerous.

Question 3.9:

The number density of free electrons in a copper conductor estimated in Example 3.1 is $8.5 \times 10^{28}\ m^{-3}$. 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 $2.0 \times 10^{-6}\ m^2$ and it is carrying a current of 3.0 A.

Answer 3.9:

Number density of free electrons in a copper conductor, $n = 8.5 \times 10^{28}\ m^{-3}$

Length of the copper wire, $l = 3.0$ m

Area of cross-section of the wire, $A = 2.0 \times 10^{-6}\ m^2$

Current carried by the wire, I = 3.0 A, which is given by the relation, $I = nAeV_d$

Where, e = Electric charge = 1.6×10^{-19} C

V_d = Drift Velocity

$$= \frac{\text{Length of the wire } (l)}{\text{Time taken to cover } l\ (t)}$$

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

$$I = \frac{nAel}{I}$$

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

$= 2.7 \times 10^4$ s

Therefore, the time taken by an electron to drift from one end of the wire to the other is 2.7×10^4 s.