(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,

$$E = Ir$$

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

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

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

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,

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

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

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

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

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:

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.

Answer 3.3:

(a) Three resistors of resistances 1 Ω, 2 Ω, and 3 Ω are combined in series. Total resistance of the combination is given by the algebraic sum of individual resistances.

Total resistance = 1 + 2 + 3 = 6 Ω

(b) Current flowing through the circuit = I

Emf of the battery, E = 12 V

Total resistance of the circuit, R = 6 Ω

The relation for current using Ohm's law is,

$$I = \frac{E}{R}$$
$$= \frac{12}{6} = 2 \text{ A}$$

Potential drop across 1 Ω resistor = V_1

From Ohm's law, the value of V_1 can be obtained as

$V_1 = 2 \times 1 = 2$ V … (i)

Potential drop across 2 Ω resistor = V_2

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

$V_2 = 2 \times 2 = 4$ V … (ii)

Potential drop across 3 Ω resistor = V_3

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

$V_3 = 2 \times 3 = 6$ V … (iii)

Therefore, the potential drop across 1 Ω, 2 Ω, and 3 Ω resistors are 2 V, 4 V, and 6 V respectively.

Question 3.4:

(a) Three resistors 2 Ω, 4 Ω and 5 Ω 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 resistance, determine the current through each resistor, and the total current drawn from the battery.

Answer 3.4:

(a) There are three resistors of resistances,

$R_1 = 2$ Ω, $R_2 = 4$ Ω, and $R_3 = 5$ Ω

They are connected in parallel. Hence, total resistance (R) of the combination is given by,

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$
$$= \frac{1}{2} + \frac{1}{4} + \frac{1}{5} = \frac{10+5+4}{20} = \frac{19}{20}$$
$$\therefore R = \frac{20}{19}\ \Omega$$

Therefore, total resistance of the combination is $\frac{20}{19}\,\Omega$.

(b) Emf of the battery, V = 20 V

Current (I_1) flowing through resistor R_1 is given by,

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

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

Current (I_2) flowing through resistor R_2 is given by,

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

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

Current (I_3) flowing through 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

Therefore, the current through each resister is 10 A, 5 A, and 4 A respectively and the total current is 19 A.

Question 3.5:

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 $1.70\times10^{-4}\,°\text{C}^{-1}$

Answer 3.5:

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,

$\alpha = 1.70 \times 10^{-4}\,°\text{C}^{-1}$

α is given by the relation,

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

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

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

$$T_1 - 27 = 1000$$

$$T_1 = 1027\,°\text{C}$$

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

Question 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?

Answer 3.6:

Length of the wire, l =15 m

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

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

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

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

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

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

Question 3.7:

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 3.7:

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

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

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

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

Question 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 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 $1.70 \times 10^{-4}\ ^\circ\mathrm{C}^{-1}$.

Answer 3.8:

Supply voltage, V = 230 V

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

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

Temperature co-efficient of nichrome, α = 1.70 × 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,

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

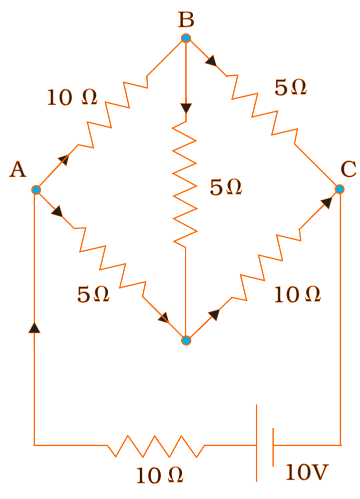
$$T_2 - 27\ °C = \frac{82.14 - 71.87}{71.87 \times 1.7 \times 10^{-4}} = 840.5$$

$$T_2\ =\ 840.5 + 27 = 867.5\ °C$$

Therefore, the steady temperature of the heating element is 867.5°C

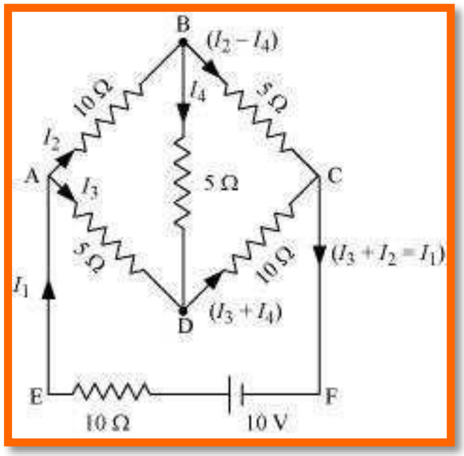
Question 3.9:

Determine the current in each branch of the network shown in figure:



Answer 3.9:

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.,

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

$2I_2 + I_4 - I_3 = 0$

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

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

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

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

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

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

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 obtain

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

$5I_2 + 2I_3 - I_4 = 2$ … (7)

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

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

$- 10I_4 - 6I_4 - I_4 = 2$

$17I_4 = - 2$

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

Equation (4) reduces to

$I_3 = -3(I_4)$

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

$$I_2 = -2(I_4)$$

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

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

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

$$I_1 = I_3 + I_2$$

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

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

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

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

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

In branch BD = $\left(\frac{-2}{17}\right)\text{A}$

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

Question 3.10:

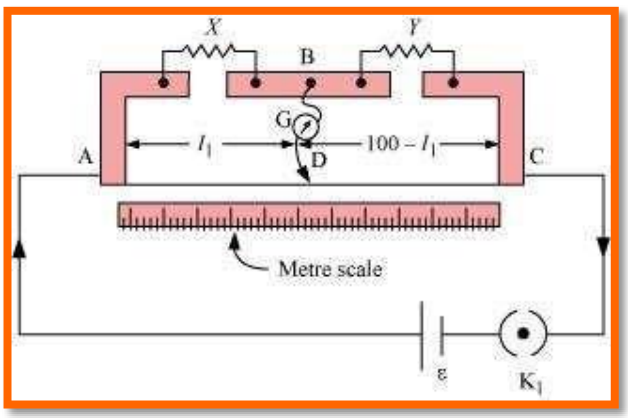
(a) In a metre bridge [Fig. 3.27], the balance point is found to be at 39.5 cm from the end A, when the resistor Y is of 12.5 Ω. Determine the resistance of X. Why are the connections between resistors in a Wheatstone or meter bridge made of thick copper strips?

(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?

Answer 3.10:

A metre bridge with resistors X and Y is represented in the given figure.



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

Resistance of the resistor Y = 12.5 Ω

Condition for the balance is given as,

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

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

Therefore, the resistance of resistor X is 8.2 Ω.

The connection between resistors in a Wheatstone or metre bridge is made of thick copper strips to minimize the resistance, which is not taken into consideration in the bridge formula.

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

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

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

Therefore, the balance point is 60.5 cm from A.

(c) When the galvanometer and cell are interchanged at the balance point of the bridge, the galvanometer will show no deflection. Hence, no current would flow through the galvanometer.

Question 3.11:

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 3.11:

Emf of the storage battery, E = 8.0 V

Internal resistance of the battery, r = 0.5 Ω

DC supply voltage, V = 120 V

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,

$$I = \frac{V^1}{R+r}$$

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

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 3.12:

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?

Answer 3.12:

Emf of the cell, E_1 = 1.25 V

Balance point of the potentiometer, l_1= 35 cm

The cell is replaced by another cell of emf E_2.

New balance point of the potentiometer, l_2 = 63 cm

The balance condition is given by the relation,

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

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

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

Therefore, emf of the second cell is 2.25V.

Question 3.13:

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

Answer 3.13:

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

$$I = nAe\frac{l}{t}$$

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

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

$$= 2.7 \times 10^{4} \text{ s}$$

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