(Chapter – 3) (Current Electricity)
(Class – XII)

Additional Exercises

Question 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 = 6.37×10^6 m.)

Answer 3.14:

Surface charge density of the earth, $\sigma = 10^{-9}$ C m^{-2}

Current over the entire globe, I = 1800 A

Radius of the earth, $r = 6.37 \times 10^6$ m

Surface area of the earth,

$A = 4\pi r^2$

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

$= 5.09 \times 10^{14}$ 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, $I = \frac{q}{t}$

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

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

Therefore, the time taken to neutralize the earth's surface is 282.77 s.

Question 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 a resistance of 8.5 Ω. What are 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?

Answer 3.15:

(a) Number of secondary cells, n = 6

Emf of each secondary cell, E = 2.0 V Internal resistance of each cell, r = 0.015 Ω series resistor is connected to the combination of cells.

Resistance of the resistor, R = 8.5 Ω

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

$$I = \frac{nE}{R + nr}$$
$$= \frac{6 \times 2}{8.5 + 6 \times 0.015}$$
$$= \frac{12}{8.59} = 1.39 \text{ A}$$

Terminal voltage, V = IR = 1.39 × 8.5 = 11.87 A

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

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

Internal resistance of the cell, r = 380 Ω

Hence, maximum current $= \frac{E}{r} = \frac{1.9}{380} = 0.005 \text{ A}$

Therefore, the maximum current drawn from the cell is 0.005 A. Since a large current is required to start the motor of a car, the cell cannot be used to start a motor.

Question 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. (ρ_{Al} = 2.63 × 10^{-8} Ω m, ρ_{Cu} = 1.72 × 10^{-8} Ω m, Relative density of Al = 2.7, of Cu = 8.9.)

Answer 3.16:

Resistivity of aluminium, ρ_{Al} = 2.63 × 10^{-8} Ω m

Relative density of aluminium, d_1 = 2.7

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

Resistance of the aluminium wire = R_1

Area of cross-section of the aluminium wire = A_1

Resistivity of copper, ρ_{Cu} = 1.72 × 10^{-8} Ω m

Relative density of copper, d_2 = 8.9

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

Resistance of the copper wire = R_2

Area of cross-section of the copper wire = A_2

The two relations can be written as

$$R_1 = \rho_1 \frac{l_1}{A_1} \quad \ldots (1)$$

$$R_2 = \rho_2 \frac{l_2}{A_2} \quad \ldots (2)$$

It is given that, $R_1 = R_2$

$$\rho_1 \frac{l_1}{A_1} = \rho_2 \frac{l_2}{A_2}$$

And,

$$l_1 = l_2$$

$$\therefore \frac{\rho_1}{A_1} = \frac{\rho_2}{A_2}$$

$$\frac{A_1}{A_2} = \frac{\rho_1}{\rho_2}$$

$$= \frac{2.63 \times 10^{-8}}{1.72 \times 10^{-8}} = \frac{2.63}{1.72}$$

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)

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.

Since aluminium is lighter, it is preferred for overhead power cables over copper.

Question 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

Answer 3.17:

It can be inferred from the given table that the ratio of voltage with current is a constant, which is equal to 19.7. Hence, manganin is an ohmic conductor i.e., the alloy obeys Ohm's law. According to Ohm's law, the ratio of voltage with current is the resistance of the conductor. Hence, the resistance of manganin is 19.7 Ω.

Question 3.18:

Answer the following questions:

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

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

If not, give examples of elements which do not obey Ohm's law.

(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?

Answer 3.18:

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

(b) No, Ohm's law is not universally applicable for all conducting elements. Vacuum diode semi-conductor is a non-ohmic conductor. Ohm's law is not valid for it.

(c) According to Ohm's law, the relation for the potential is V = IR Voltage (V) is directly proportional to 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) In order to prohibit the current from exceeding the safety limit, a high tension supply must have a very large internal resistance. If the internal resistance is not large, then the current drawn can exceed the safety limits in case of a short circuit.

Question 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 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 ($10^{22}/10^{3}$).

Answer 3.19:

(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.

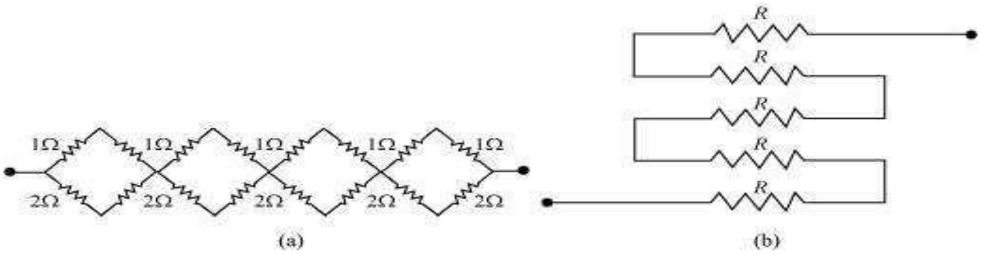
(d) The resistivity of a typical insulator is greater than that of a metal by a factor of the order of 10^{22}.

Question 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 be combine them to get an equivalent resistance of (i) (11/3) Ω (ii) (11/5) Ω, (iii) 6 Ω, (iv) (6/11) Ω?

(c) Determine the equivalent resistance of networks shown in Fig. 3.31.



Answer 3.20:

(a) Total number of resistors = n

Resistance of each resistor = R

(i) When n resistors are connected in series, effective resistance $R_1$is the maximum, 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,

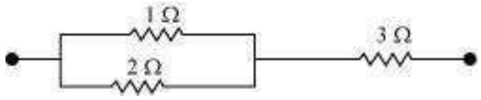
$$\frac{R_1}{R_2} = \frac{nR}{\frac{R}{n}} = n^2$$

(b) The resistance of the given resistors is,

R_1 = 1 Ω, R_2 = 2 Ω, R_3 = 3 Ω2

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

Consider the following combination of the resistors.

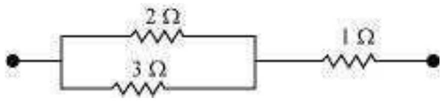


Equivalent resistance of the circuit is given by,

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

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

Consider the following combination of the resistors.

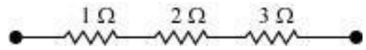


Equivalent resistance of the circuit is given by,

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

(iii) Equivalent resistance, R′ = 6 Ω

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



Equivalent resistance of the circuit is given by the sum,

R′ = 1 + 2 + 3 = 6 Ω

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

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

Equivalent resistance of the circuit is given by,

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

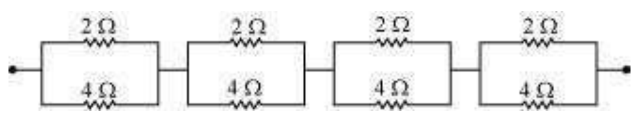
(c) (a) It can be observed from the given circuit that in the first small loop, two resistors of resistance 1 Ω each are connected in series.

Hence, their equivalent resistance = (1+1) = 2 Ω

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

Hence, their equivalent resistance = (2 + 2) = 4 Ω.

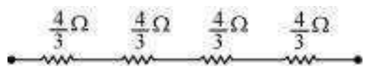
Therefore, the circuit can be redrawn as



It can be observed that 2 Ω and 4 Ω resistors are connected in parallel in all the four loops. Hence, 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, equivalent resistance of the given circuit is $\frac{4}{3}\times 4=\frac{16}{3}\ \Omega$

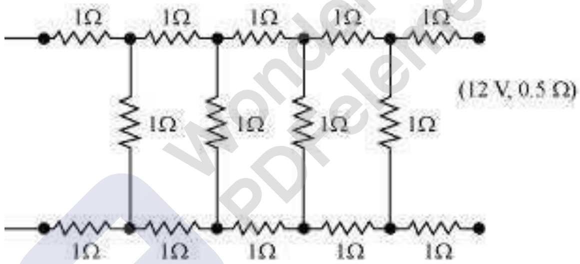
(b) It can be observed from the given circuit that five resistors of resistance R each are connected in series.

Hence, equivalent resistance of the circuit = R + R + R + R + R

= 5 R

Question 3.21:

Determine the current drawn from a 12 V supply with internal resistance 0.5 Ω by the infinite network shown in Fig. 3.32. Each resistor has 1 Ω resistance.



Answer 3.21:

The resistance of each resistor connected in the given circuit, R = 1 Ω

Equivalent resistance of the given circuit = R′

The network is infinite. Hence, equivalent resistance is given by the relation,

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

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

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

$$= \frac{2 \pm \sqrt{12}}{2} = 1 \pm \sqrt{3}$$

Negative value of R′ cannot be accepted. Hence, equivalent resistance,

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

Internal resistance of the circuit, r = 0.5 Ω

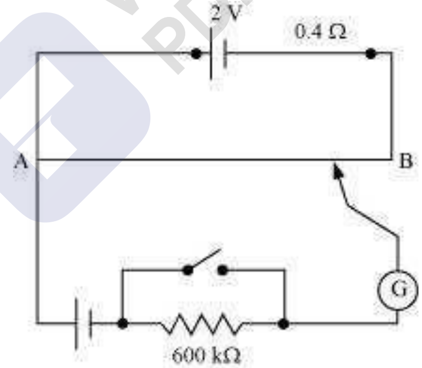
Hence, total resistance of the given circuit = 2.73 + 0.5 = 3.23 Ω

Supply voltage, V = 12 V

According to Ohm's Law, current drawn from the source is given by the ratio, $\frac{12}{3.23}$ = 3.72 A

Question 3.22:

Figure 3.33 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, a 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 thermo-couple)? If not, how will you modify the circuit?

Answer 3.22:

(a) Constant emf of the given standard cell, $E_1 = 1.02$ V

Balance point on the wire, $l_1 = 67.3$ cm

A cell of unknown emf, ε, replaced the standard cell. Therefore, new balance point on the wire, $l = 82.3$ cm

The relation connecting emf and balance point 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 unknown emf is 1.247 V.

(b) The purpose of using the high resistance of 600 kΩ is to reduce the current through the galvanometer when the movable contact is far from the balance point.

(c) The balance point is not affected by the presence of high resistance.

(d) The point is not affected by the internal resistance of the driver cell.

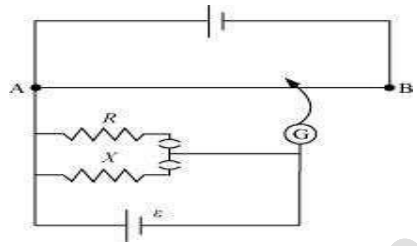
(e) The method would not work if the driver cell of the potentiometer had an emf of 1.0 V instead of 2.0 V. This is because if the emf of the driver cell of the potentiometer is less than the emf of the other cell, then there would be no balance point on the wire.

(f) The circuit would not work well for determining an extremely small emf. As the circuit would be unstable, the balance point would be close to end A. Hence, there would be a large percentage of error.

The given circuit can be modified if a series resistance is connected with the wire AB. The potential drop across AB is slightly greater than the emf measured. The percentage error would be small.

Question 3.23:

Figure 3.34 shows a potentiometer circuit for comparison of two resistances. The balance point with a standard resistor R = 10.0 Ω is found to be 58.3 cm, while that with the unknown resistance X is 68.5 cm. Determine the value of X. What might you do if you failed to find a balance point with the given cell of emf ε?



Answer 3.23:

Resistance of the standard resistor, R = 10.0 Ω

Balance point for this resistance, l_1 = 58.3 cm

Current in the potentiometer wire = i

Hence, potential drop across R, E_1 = iR

Resistance of the unknown resistor = X

Balance point for this resistor, l_2 = 68.5 cm

Hence, potential drop across X, E_2 = iX

The relation connecting emf and balance point is,

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

$$\frac{iR}{iX} = \frac{l_1}{l_2}$$

$$X = \frac{l_1}{l_2} \times R$$

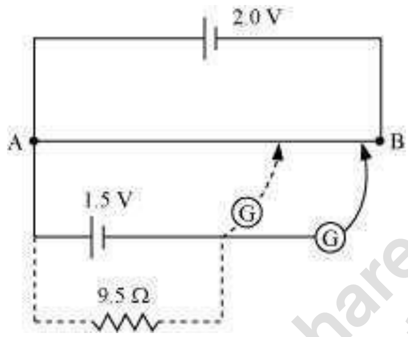
$$= \frac{68.5}{58.3} \times 10 = 11.749\ \Omega$$

Therefore, the value of the unknown resistance, X, is 11.75 Ω.

If we fail to find a balance point with the given cell of emf, ε, then the potential drop across R and X must be reduced by putting a resistance in series with it. Only if the potential drop across R or X is smaller than the potential drop across the potentiometer wire AB, a balance point is obtained.

Question 3.24:

Figure 3.35 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.



Answer 3.24:

Internal resistance of the cell = r

Balance point of the cell in open circuit, l_1 = 76.3 cm

An external resistance (R) is connected to the circuit with R = 9.5 Ω

New balance point of the circuit, l_2 = 64.8 cm

Current flowing through the circuit = I

The relation connecting resistance and emf is,

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

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

Therefore, the internal resistance of the cell is 1.68Ω.