NCERT SOLUTIONS
PHYSICS XII CLASS
CHAPTER - 3
CURRENT ELECTRICITY

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?

Sol. Using V = IR, we get $I = \frac{V}{R}$

Here, R = r = 0.4Ω and V = 12V

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

3.2 A battery of emf 10V and internal resistance 3Ω 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?

Sol. Using E = V + Ir,

$E = IR + Ir$ i.e., $R = \frac{E}{I} - r = \frac{10}{0.5} - 3 = 17\Omega$

$V = IR = 0.5 \times 17 = 8.5V$

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

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

Sol. (a) Using $R_{eq} = R_1 + R_2 + R_3$, we get $R_{eq} = 1 + 2 + 3 = 6\Omega$

(b) Using V = IR, we get $I = \frac{V}{R} = \frac{V}{R_{eq}} = \frac{12}{6} = 2A$

Then voltage drop across R_1 is given by, $V_1 = IR_1 = 2 \times 1 = 2V$

Voltage drop across R_2 is given by, $V_2 = IR_2 = 2 \times 2 = 4V$

Then voltage drop across R_3 is given by, $V_3 = IR_3 = 2 \times 3 = 6V$

3.4 (a) Three resistors 2Ω, 4Ω and 5Ω 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.

Sol. (a) Using $\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

we get, $\frac{1}{R_{eq}} = \frac{1}{2} + \frac{1}{4} + \frac{1}{5} = \frac{10+5+4}{20} = \frac{19}{20}$ or $R_{eq} = \frac{20}{19}\Omega$

(b) Using V = IR, we get $I = \frac{V}{R}$ i.e., $I = \frac{20}{20/19} = 19A$,

Current through 2Ω resistor = $\frac{V}{R_1} = \frac{20}{2} = 10A$

Current through 4Ω resistor = $\frac{V}{R_2} = \frac{20}{4} = 5A$

Current through 5Ω resistor $= \dfrac{V}{R_3} = \dfrac{20}{5} = 4A$

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

Sol. Using, $R_2 = R_1 (1 + \alpha \Delta T)$, we get $\Delta T = \dfrac{R_2 - R_1}{\alpha R_1}$

i.e. $\Delta T = \dfrac{117 - 100}{(1.7 \times 10^{-4}) \times 100} = \dfrac{17 \times 10^2}{1.7} = 1000°C$

i.e., $T_2 - T_1 = 1000°C$ i.e., $T_2 = 1000 + T_1 = 1000 + 27 = 1027°C$

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 5.0Ω. What is the resistivity of the material at the temperature of the experiment?

Sol. $R = \rho \dfrac{\ell}{a}$, we get $\rho = \dfrac{R \times a}{\ell}$ i.e., $\rho = \dfrac{5 \times 6 \times 10^{-7}}{15} = 2 \times 10^{7}\ \Omega\ m$

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

Sol. Using $R_2 = R_1 (1 + \alpha \Delta T)$, we get $\alpha = \dfrac{R_2 - R_1}{R_1 \Delta T} = \dfrac{2.7 - 2.1}{2.1 \times (100 - 27.5)} = \dfrac{0.6}{2.1\,(72.5)} = 0.0039°C^{-1}$

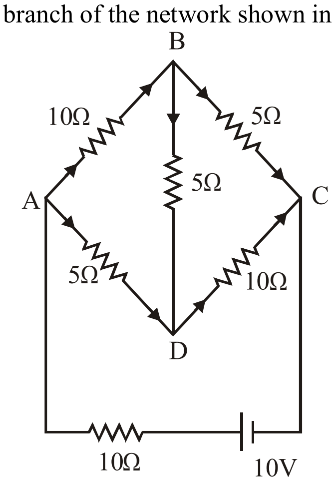
3.8 A heating element using nichrome connected to a 230 V supply draws an initial current of 3.2 A which settles after a few seconds to a steady value of 2.8 A. What is the steady temperature of the heating element if the room temperature is 27.0 °C? Temperature coefficient of resistance of nichrome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

Sol. $R_1 = \dfrac{230}{3.2} = 71.88\Omega$ and $R_2 = \dfrac{230}{2.8} = 82.14\ \Omega$

Using $\alpha = \dfrac{R_2 - R_1}{R_1 \Delta T}$, we get $\Delta T = \dfrac{R_2 - R_1}{R_1 \alpha}$ i.e., $T_2 - T_1 = \dfrac{R_2 - R_1}{R_1 \alpha}$

or $T_2 = \dfrac{R_2 - R_1}{R_1 \alpha} + T_1 = \dfrac{82.14 - 71.88}{71.88 \times 1.7 \times 0^{-4}} + 27 = 840 + 27 = 867°C$

3.9 Determine the current in each branch of the network shown in Figure.



Sol. Applying Kirchhoff's second law to network ABDA, we get

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

i.e., $3I_1 + I_2 - I = 0$ .... (1)

For BCDB,

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

or $3I_1 - 4I_2 - 2I = 0$ .... (2)

For ABCHGA,

$$10I + 10I_1 + 5(I_1 - I_2) = 10$$

or $3I_1 - I_2 + 2I = 2$ .... (3)

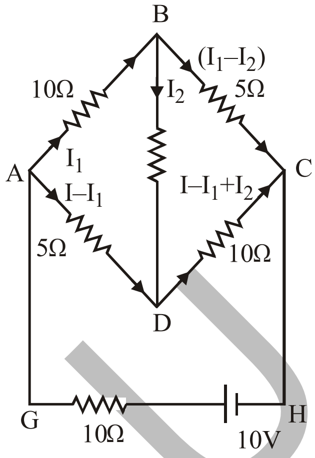
Solving eq. (1), (2) and (3),

$$I_1 = \frac{4}{17}\text{A},\ I_2 = -\frac{2}{17}\text{A},\ I = \frac{10}{17}\text{A}$$

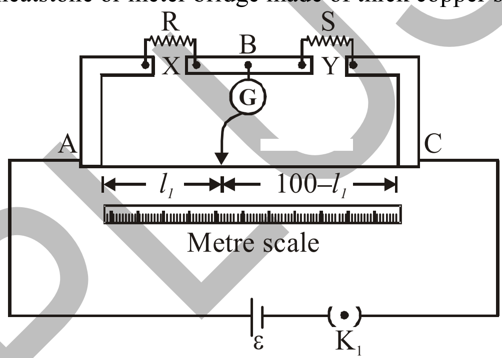
Current in DC $= I - I_1 + I_2 = \frac{4}{17}$A

Current in AD $= I - I_1 = \frac{10}{17} - \frac{4}{17} = \frac{6}{17}$A

Current in BC $= I_1 - I_2 = \frac{4}{17} - \left(-\frac{2}{17}\right) = \frac{6}{17}$A



3.10 (a) In a metrebridge [Fig.], the balance point is found to be at 39.5 cm from the end A, when the resistor Y is of 12.5Ω . 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?

Sol. (a) (i) Using $X = R\frac{\ell}{(100-\ell)}$, we get $X = \frac{12.5\,(39.5)}{(100-39.5)} = \frac{12.5 \times 39.5}{60.5} = 8.2\Omega$

(ii) Thick copper strips are used to reduce their resistance because this resistance is not accounted for in the calculations.

(b) Interchanging R and X, we get

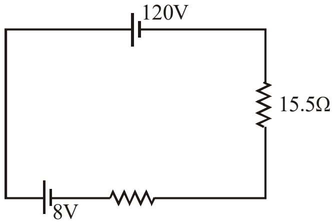
$$R = X\frac{\ell}{(100-\ell)} \quad \text{i.e.,} \quad 100R - R\ell = X\ell$$

i.e., $\ell = \frac{R \times 100}{R + X}$ i.e., $\ell = \frac{12.5 \times 100}{12.5 + 8.2}$ = 60.5 cm from end A.

(c) In this case also the galvanometer will not show current.

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

Sol. During charging, $V = E + I(r + R)$



$$I = \frac{E - V}{r + R} = \frac{120 - 8}{0.5 + 15.5} = \frac{112}{16} = 7A$$

Terminal voltage = 8 + 7 × 0.5 = 11.5V

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?

Sol. Here, $E \propto \ell \quad \therefore \quad \frac{E_1}{E_2} = \frac{\ell_1}{\ell_2}$ i.e., $E_2 = \frac{63}{35} \times 1.25 = 2.25$ V

3.13 The number density of free electrons in a copper conductor 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 3.0A.

Sol. Using $v_d = \frac{I}{neA}$, we get $v_d = \frac{3}{(8.5 \times 10^{28})(1.6 \times 10^{-19})(2 \times 10^{-6})} = 1.1 \times 10^{-4}$ ms^{-1}

Time taken, $t = \frac{\ell}{v_d} = \frac{3}{1.1 \times 10^{-4}} = 2.72 \times 10^4$ s

ADDITIONAL EXERCISES

3.14 The earth's surface has a negative surface charge density of 10^{-9} Cm^{-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.)

Sol. Surface area of earth $A = 4\pi r^2 = 4 \times 3.14 \times 6.37 \times 10^6 \times 6.37 \times 10^6 = 509.64 \times 10^{12}$ m^2
Charge, Q = (Charge density, σ) × (Surface area, A) = $10^{-9} \times 509.64 \times 10^{12} = 509.64 \times 10^3$ C

Time, $t = \frac{Q}{I} = \frac{509.64 \times 10^3}{1800} = 283s$ $\quad \left(\because \; I = \frac{Q}{t}\right)$

3.15 (a) Six lead-acid type of secondary cells each of emf 2.0 V and internal resistance 0.015Ω 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 380Ω. What maximum current can be drawn from the cell? Could the cell drive the starting motor of a car?

Sol. (a) Here, $I = \frac{nE}{R + m} = \frac{6 \times 2}{8.5 + 6 \times 0.015} = 1.397$ A.
Terminal voltage, V = IR = 1.397 × 8.5 = 11.88V

(b) $I_{max} = \frac{E}{r} = \frac{1.9}{380} = 0.005A$. It cannot be used for starting motor of a car.

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.
($\rho_{Al} = 2.63 \times 10^{-8}\ \Omega$m, $\rho_{Cu} = 1.72 \times 10^{-8}\ \Omega$m, Relative density of Al = 2.7, of Cu = 8.9.)

Sol. Aluminium: $R_{Al} = \rho_{Al} \times \dfrac{\ell}{A_{Al}}$; Mass of aluminium wire, $M_{Al} = A_{A\ell}\ell \times \rho_{Al}$

Copper : $R_{Cu} = \rho_{Cu} \times \dfrac{\ell}{A_{Cu}}$; Mass of copper wire, $M_{Cu} = A_{Cu}\ell \times \rho_{Cu}$

Then, $\dfrac{M_{Cu}}{M_{Al}} = \dfrac{A_{Cu}\ell\,(8.9 \times 10^3)}{A_{Al}\ell\,(2.7 \times 10^3)} = \dfrac{8.9\ A_{Cu}}{2.7\ A_{Al}}$.

At resistance R_{Al} and R_{Cu} are equal,

$$\therefore \quad \frac{(2.63 \times 10^{-8})}{A_{Al}}\ell = \frac{1.72 \times 10^{-8}}{A_{Cu}}\ell$$

$$\frac{A_{Cu}}{A_{Al}} = \frac{1.72}{2.63} \quad \therefore \frac{M_{Cu}}{M_{Al}} = \frac{8.9 \times 1.72}{2.7 \times 2.63} = 2.16$$

Aluminium is lightger so it is used for overhead power cables.

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

Sol. 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 19.7Ω.

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?

Sol. (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 tubes, semi-conductor diodes are non-ohmic.
(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 = 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.

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

Sol. (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.

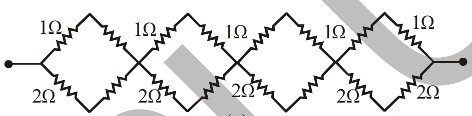
(c) The resistivity of the alloy, manganin, is nearly independent of increase of temperature.

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

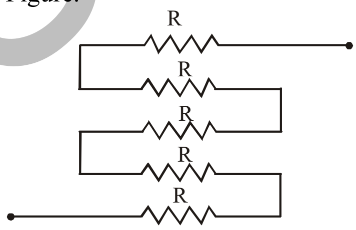
3.20 (a) Given n resistors each of resistance R, how will you combine them to get the (i) maximum (ii) minimum effective resistance? What is the ratio of the maximum to minimum resistance?

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

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



(a)



(b)

Sol. (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, $R_1 = nR$

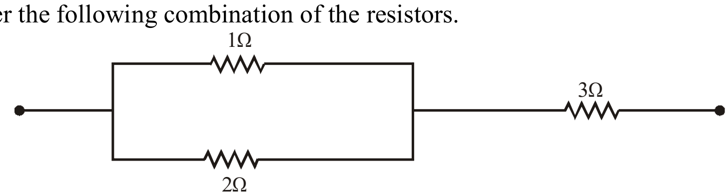
(ii) When n resistors are connected in parallel, the effective resistance (R_2) is the minimum, given by the ratio R/n. Hence, minimum resistance of the combination, $R_2 = R/n$

(iii) The ratio of the maximum to the minimum resistance is, $\dfrac{R_1}{R_2} = \dfrac{nR}{R/n} = n^2$

(b) The resistance of the given resistors is, $R_1 = 1\Omega$, $R_2 = 2\Omega$, $R_3 = 3\Omega$

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

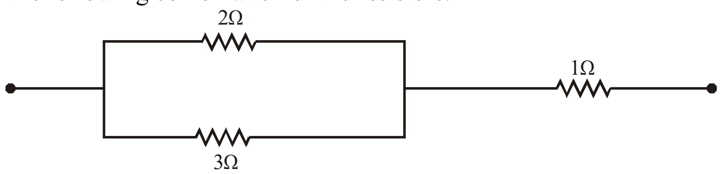
Consider the following combination of the resistors.



Equivalent resistance of the circuit is given by, $R' = \dfrac{2\times 1}{2+1} + 3 = \dfrac{2}{3} + 3 = \dfrac{11}{3}\Omega$

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

Consider the following combination of the resistors.

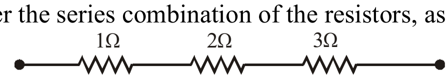


Equivalent resistance of the circuit is given by,

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

(iii) Equivalent resistance, R' = 6

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

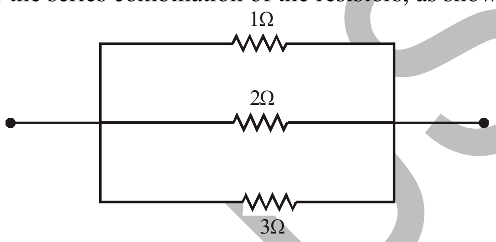


Equivalent resistance of the circuit is given by the sum,

R' = 1 + 2 + 3 = 6

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

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



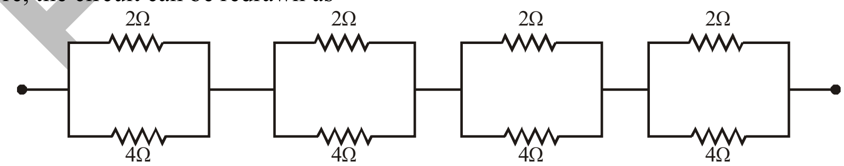
(c) (i) It can be observed from the given circuit that in the first small loop, two resistors of resistance 1Ω each are connected in series.

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

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

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

Therefore, the circuit can be redrawn as

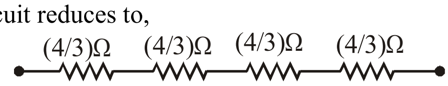


(ii) It can be observed that 2Ω and 4Ω resistors are connected in parallel in all the four loops.

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,



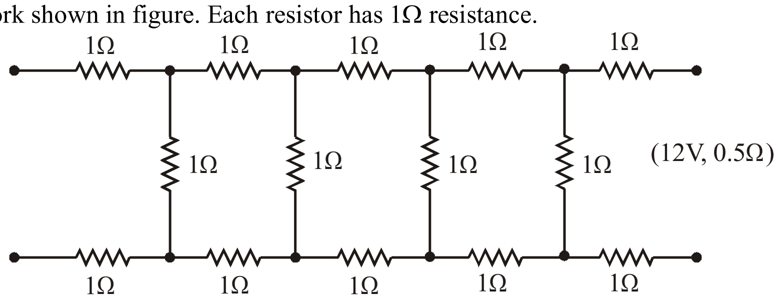
All the four resistors are connected in series.

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

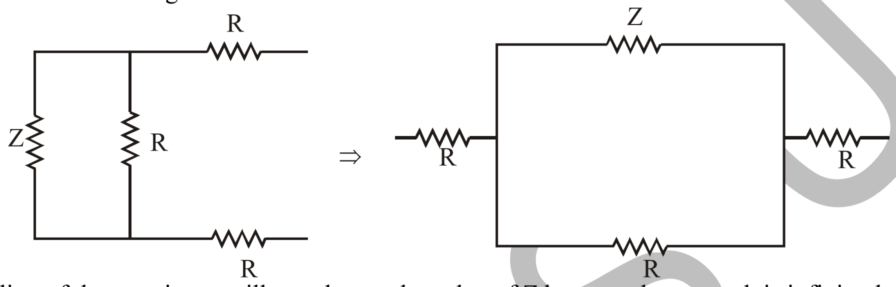
It can be observed from the given circuit that five resistors of resistance R each are connected in series.

Hence, equivalent resistance of the circuit = R + R + R + R + R = 5 R

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



Sol. Let the total resistance of the circuit be Z and a set of three resistors of value R each be connected to it as shown in the figure.



Adding of these resistors will not change the value of Z because the network is infinite then

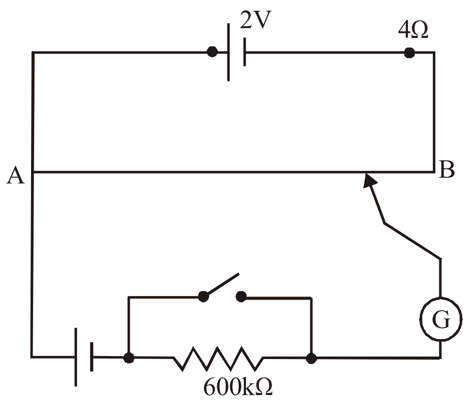
$$Z = R + \frac{ZR}{Z+R} + R = 2R + \frac{ZR}{Z+R}$$

or $\quad Z = 2 + \frac{Z}{1+Z}$ i.e., $Z^2 - 2Z - 2 = 0$ or $Z = 1 \pm \sqrt{3}$

or $\quad Z = 1 \pm \sqrt{3} = 2$ (Value of Z cannot be negative)

Current drawn,

3.22 Figure shows a potentiometer with a cell of 2.0 V and internal resistance 0.40Ω 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 upto a few mA) gives a balance point at 67.3cm 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 1.0V instead of 2.0V?
(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?

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

Balance point on the wire, $\ell_1 = 67.3$ cm

A cell of unknown emf, ε, replaced the standard cell.

Therefore, new balance point on the wire, $\ell = 82.3$ cm

The relation connecting emf and balance point is,

$$\frac{E_1}{\ell_1} = \frac{\varepsilon}{\ell} \; ; \quad \varepsilon = \frac{\ell}{\ell_1} \times E_1 = \frac{82.3}{67.3} \times 1.02 = 1.247\text{V}$$

The value of unknown emf is 1.247 V.

(b) The purpose of using the high resistance of 600 k 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.

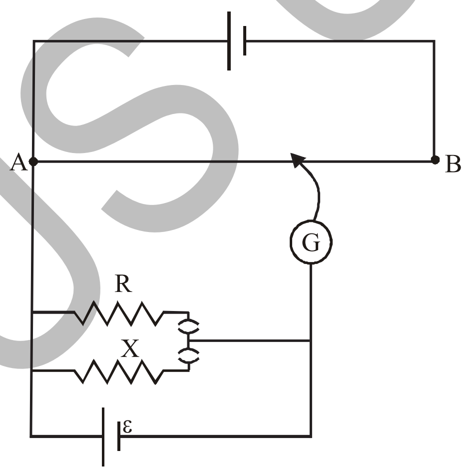
(d) The point is not affected by the internal resistance of the driver cell.

(e) The method would not work if the driver cell of the potentiometer had an emf of 1.0V 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.

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



Sol. 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 = i X

The relation connecting emf and balance point is,

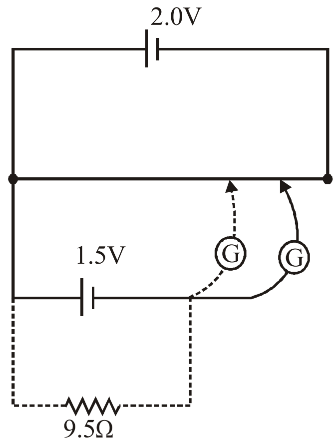
$$\frac{E_1}{E_2} = \frac{\ell_1}{\ell_2} \; ; \quad \frac{iR}{iX} = \frac{\ell_1}{\ell_2}$$

$$X = \frac{\ell_1}{\ell_2} \times R = \frac{68.5}{58.3} \times 10 = 11.749\Omega$$

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

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.

3.24 Figure shows a 2.0V potentiometer used for the determination of internal resistance of a 1.5V cell. The balance point of the cell in open circuit is 76.3 cm. When a resistor of 9.5Ω 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.



Sol. Here, $(\ell_1 - \ell_2)\,R = \ell_2 r$ i.e., $r = (\ell_1 - \ell_2)\dfrac{R}{\ell_2}$,

Where, $\ell_1 = 76.3\text{cm}$, $\ell_2 = 64.8\text{cm.}$ and $R = 8.5\Omega$

$\therefore \quad r = (76.3 - 64.8)\dfrac{9.5}{64.8} = 1.68\Omega$