CHAPTER-3

CURRENT Electricity

Exercise

1) Emf of the battery, $E = 12V$
Internal resistance of the battery, $r = 0.4\Omega$.
Maximum current drawn from the battery $= I$
According to ohm's law,

$$E = Ir$$

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

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

2) Emf of the battery, $E = 10V$.
Internal resistance of the battery, $r = 3\Omega$
Current in the ~~circuit~~ circuit, $I = 0.5A$

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

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

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

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

According to ohm's law

$$V = IR$$

$$= 0.5 \times 17$$

$$= 8.5V$$

Therefore, the resistance of the resistor is 17Ω and the

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terminal voltage is 8.5 V.

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

Total Resistance = $1+2+3 = 6\Omega$

b) Current flowing through the circuit = I
emf of the battery, E = 12 V.

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

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

potential drop across 1Ω resistor = V_1

$V_1 = 2 \times 1 = 2V$. — (i) (By ~~ol~~ ohm's law)

Across 2Ω, $V_2 = 2 \times 2 = 4V$ — (ii)

Across 3Ω, $V_3 = 2 \times 3 = 6V$ — (iii) (By ohm's law)

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

4) a) There are three resistors of resistances $R_1 = 2\Omega$, $R_2 = 4\Omega$ and $R_3 = 5\Omega$.
They are connected in parallel.

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

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

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

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

b) Emf of the battery; $V = 20V$.

$$I_1 = \frac{V}{R_1} = \frac{20}{2} = 10A.$$

$$I_2 = \frac{V}{R_2} = \frac{20}{4} = 5A.$$

$$I_3 = \frac{V}{R_3} = \frac{20}{5} = 4A$$

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

∴ the current through each resistor is 10A, 5A and 4A respectively and the total current is 19A.

(5) Room temperature, $T = 27°C$

Resistance of the heating element at T, $R = 100\,\Omega$

$R_1 = 117\,\Omega$.

Temperature coefficient of the material

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

α is given by the relation.

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

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

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

$$T_1 - 27 = 1000$$

$$T_1 = 1027\,°C$$

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

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(6) Length of wire, $l = 15m$
Area of cross section of the wire, $a = 6.0 \times 10^{-7} m^2$
Resistance of the material, $R = 5.0 \Omega$.
Resistivity $= \rho$

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

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

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

(7) $T_1 = 27.5°C$
$R_1 = 2.1 \Omega$
$R_2 = 2.7 \Omega$
Temperature coefficient of silver $= \alpha$.

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

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

∴ the temperature coefficient is $0.0039 °C^{-1}$

(8) Supply voltage, $V = 230V$
Initial current, $I_1 = 3.2A$.
Initial resistance $= R_1$

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

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

Steady state value of the current, $I_2 = 2.8A$.
~~Read~~ Resistance at the steady state $= R_2$.

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

temperature coefficient of nichrome, α.

$\alpha = 1.70 \times 10^{-4}\ {}^\circ C^{-1}$

Initial temperature of nichrome, $T_1 = 27.0\ ^\circ C$

study state temparature reached by nichrome $= T_2$.

T_2 can be obtained by the relation for α.

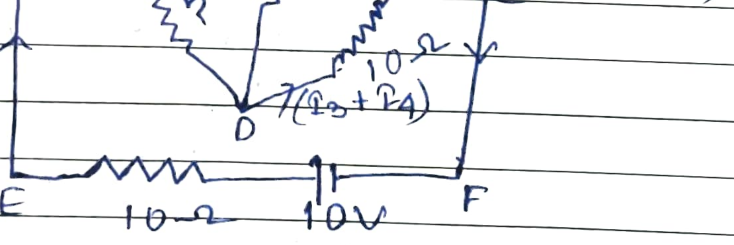
$$\alpha = \frac{R_2 - R_1}{R_1 (T_2 - T_1)}$$

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

$T_2 = 840.5 + 27 = 867.5\ ^\circ C$

$\therefore$ the steady temperature of the heating element is $867.5\ ^\circ C$.

(9)



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

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

$2 I_2 + I_4 - I_3 = 0.$

$I_3 = 2 I_2 + I_4$ — (1)

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

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

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

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

$I_2 = 2I_3 + 4I_4$ —— (ii)

For the closed circuit ABCFEA, potential is zero.

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

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

$3I_2 + 2I_1 - I_4 = 2$ —— (iii)

From equations (1) and (2) we get.

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

$I_3 = 4I_3 + 8I_4 + I_4$

$-3I_3 = 9I_4$

$-3I_4 = I_3$ —— (iv)

Putting eq (4) in eq (i)

$I_3 = 2I_2 + I_4$

$-4I_4 = 2I_2$

$I_2 = -2I_4$ —— (v)

And we know

$I_1 = I_2 + I_3$ —— (vi)

Putting eq (vi) in eq (i) we obtain.

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

$\cancel{-10I_4 - 6I_4 - I_4 = 2}$

$\cancel{17I_4 = 2}$

$5I_2 + 2I_3 - I_4 = 2$ —— (vii)

Putting eq (iv) and (v) in eq (vii)

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

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

$17I_4 = -2$

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

Eq (4) reduces to

$I_3 = -3(I_4)$

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

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

∴ 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 $= \left(\frac{-2}{17}\right)$ A

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

$= \frac{10}{17}$ A.

(10) a) Balance point from end A ; $l_1 = 39.5$ cm

Resistance of the resistor $Y = 12.5\ \Omega$.

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

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

therefore, the resistance of resistor X is 8.2.

The connection between resistors in a wheatstone or metre bridge is made of thick copper strips to minimize the resistance which is not

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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.

(11) Emf, $E = 8.0$ V
Internal resistance, $r = 0.5\ \Omega$
DC supply voltage, $V = 120$ V
Resistance, $R = 15.5\ \Omega$
Effective voltage $= V'$

$V' = V - E$

$V' = 120 - 8 = 112$ V

$$I = \frac{V'}{R+r} = \frac{112}{15.5+5} = \frac{112}{16} = 7\text{A}.$$

$IR = 7 \times 15.5 = 108.5$ V

DC supply voltage = Terminal voltage + voltage drop across R

Terminal voltage $= 120 - 108.5 = 11.5$ V.

(12) Emf, $E_1 = 1.25$ V
$l_1 = 35$ cm
$l_2 = 63$ cm

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Balance condition

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

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

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

(13) $n = 8.5 \times 10^{28} m^{-3}$

$l = 3.0 m$

$A = 2.0 \times 10^{-6} m^2$

$I = 3.0 A.$

$I = nAev_d$

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

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

$= 2.7 \times 10^4 s.$

(14) Surface charge density, $\sigma = 10^{-9} C m^{-2}$

Current, $I = 1800 A.$

Radius, $R = 6.37 \times 10^6 m$

Surface Area

$A = 4\pi R^2$

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

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

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 $= t.$

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

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

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

a) No. of secondary cells, $n = 6$
emf $E = 2.0 V.$
Internal Resistance, $r = 0.015 \Omega$
Resistance of Resistor, $R = 8.5 \Omega.$

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

$= \frac{6 \times 2}{8.5 + 6 \times 0.015} = \frac{12}{8.59} = 1.39A$

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

b) After a long use, emf of the secondary cell, $E = 1.9V$
Internal resistance of each cell, $r_0 = 0380 \Omega.$
maximum current $= \frac{E}{r} = \frac{1.9}{380} = 0.005A$

(16) Resistivity of Aluminium, $\rho_{Al} = 2.63 \times 10^{-8} \Omega m$
Relative density of Aluminium, $d_1 = 2.7$
Resistivity of copper, $\rho_{cu} = 1.72 \times 10^{-8} \Omega m$
Relative density of copper, $d_2 = 8.9$

$R_1 = \rho_1 \frac{l_1}{A_1}$ ——— (i)

$R_2 = \rho_2 \frac{l_1}{A_2}$ ——— (ii)

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;

$$m_1 = \text{volume} \times \text{density}$$

$$= A_1 l_1 \times d_1 = A_1 l_1 d_1 \text{ —— (iii)}$$

$$m_2 = A_2 l_2 \times d_2 = A_2 l_2 d_2 \text{ —— (iv)}$$

Deviding eq (3) by eq (4)

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

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 prefferred for overhead power cables over copper.

(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 obey's 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.

(18) a) when a steady current flows in a mettalic 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 universaley applicable for all conducting elements. Vaccum 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 $V = IR$.

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

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

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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 is not large, then the current drawn can exceed the safety limits in case of a short circuit.

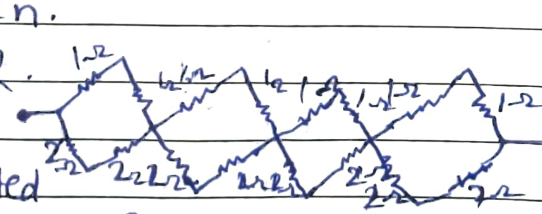
19) a) Alloys ~~of~~ metals usually have greater resistivity than that of their constituent metals.

(b) Alloys usually have lower temperature coefficient 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 of a metal by a factor of the order of 10^{22}

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, max 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 combo, $R_2 = \frac{R}{n}$

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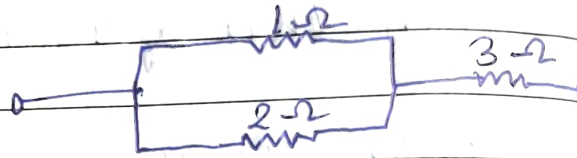
(iii) Ratio of maximum to minimum

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

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

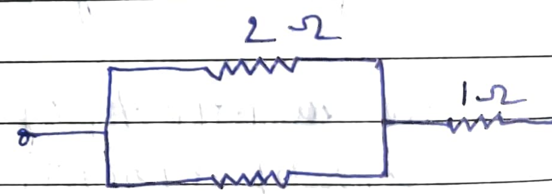
(i) $R' = \frac{11}{3}\,\Omega$



Equivalence Resistance of the circuit.

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

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



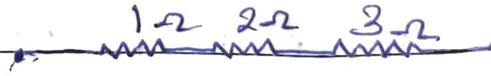
$$R' = \frac{2\times3}{2+3} + 1 = \frac{6}{5} + 1$$

$$= \frac{11}{5}\,\Omega$$

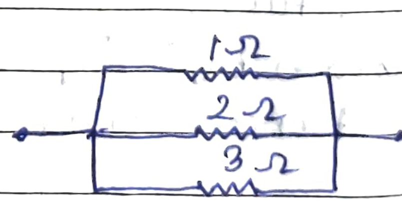
(iii) $R' = 6\,\Omega$.

Equilance resistance

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



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



Equivalance Resistance.

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

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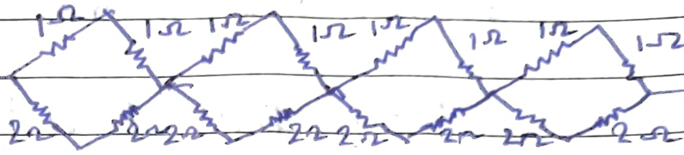
(c) At the first loop, two resistors of resistance 1Ω are connected in series.

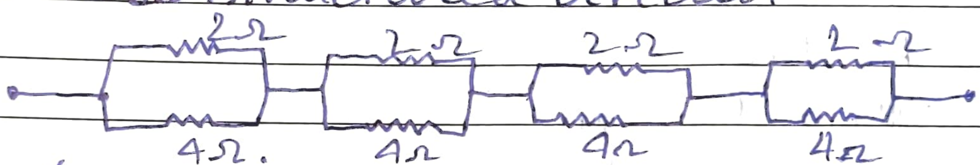


Hence, their equivalence resistance $=(1+1)=2\Omega$

Similarly two 2Ω resistors are connected in series.

$$R_{eq} = 2+2 = 4.$$

$\therefore$ the restructured circuit:



$$R_{eq} \text{ (for each loop) } = \frac{2\times 4}{2+4} = \frac{8}{6} = \frac{4}{3}\,\Omega.$$

Now all the four are connected in series.

Hence, $R_{eq} = 4 \times \frac{4}{3} = \frac{16}{3}\,\Omega.$

D) In the given circuit all five resistors are connected in series.

$$R_{eq} = R+R+R+R+R$$
$$= 5R.$$

(21) Resistance of each resistor, $R = 1\Omega$

The network is infinite..

Hence, $R_{eq} = 2 + \frac{R_{eq}}{(R_{eq}+1)}$

$$R_{eq}^2 - 2R_{eq} - 2 = 0$$

$$R_{eq} = \frac{2 \pm \sqrt{4+8}}{2} = \frac{2 \pm \sqrt{12}}{2} = 1 \pm \sqrt{3}$$

Negative value is not accepted.

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Hence, $R_{eq} = (1+\sqrt{3}) = 1.+1.73 = 2.73\ \Omega$.

Internal Resistance, $r = 0.5\ \Omega$
Hence, total resistance $= 2.73 + 0.5 = 3.23\ \Omega$
Supply voltage; $V = 12V$

According to Ohm's law
$$I = \frac{V}{R} = \frac{12}{3.23} = 3.72\ A.$$

(23) $R = 10\ \Omega$
$l_1 = 58.3$ cm
$l_2 = 68.5$ cm
Resistance of unknown resistor $= x$

Relation connecting emf and balance point.

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

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

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

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

If we fail to find a balance point with the given cell of emf, e, then the potential drop across R and X must be reduced by putting a resistance in series

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.

(24) Balance point, $l_1 = 76.3$ cm (open circuit)
External resistance, $R = 9.5\ \Omega$.
New balance point, $l_2 = 64.8$ cm.

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

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

therefore, the External resistance of the cell is 1.68 Ω.

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